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Can recreational fishers provide an effective means of monitoring artificial reefs?

Submitted by

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This thesis is presented for the Degree of Honours in Marine Science

2015

B.Sc.

Murdoch University

Declaration

I declare that the information contained in this thesis is the result of my own research unless otherwise cited, and has as its main content work which has not previously been submitted for a degree at any university.

James Henry Florisson

Word count 34,250

Signed: …………………………………………………………...

Full Name of Degree: ***Bachelor of Science with Honours in Marine Science***

Thesis Title: ***Can recreational fishers provide an effective means of monitoring artificial reefs?***

Author: ***James FLORISSON***

Year: ***2015***

Figures top to bottom: Samson Fish (*Seriola hippos*) with schooling Sand Trevally (*Pseudocaranx georgianus*), a pair of Western Talma (*Chelmonops curiosus*) and a Pink Snapper (*Chrysophrys auratus*) and Southern Fiddler Ray (*Trygonorrhina fasciata*). All photos were taken with the GoPro fitted Baited Remote Underwater Video system (see Chapter Four).

Acknowledgements

First and foremost I would like to sincerely thank Dr James Tweedley. James has been incredibly supportive and dedicated throughout the project. The input, enthusiasm and sometimes needed discipline James provided were invaluable assets to this project and my sanity. I would also like to thank my other supervisors, Dr Jennifer Chaplin and Dr Howard Gill for their interpretations, suggestions, support and commitment to the study.

A special mention of thanks goes to the staff at Recfishwest for their support and the information they provided. I would also like to thank Andrew Matthews from Ecotone Consulting for the many discussions about artificial reefs and monitoring in WA and around the world. My gratitude is expressed to Paul Lewis and Mark Pagano from the Department of Fisheries for their conversations and meetings. This project would not have been possible without funding from the Recreational Fishing Initiatives Fund and Murdoch University, so thank you.

Big thanks must also go to Daniel Yeoh, Amy Trezona and Helen Florisson for patiently helping with formatting and editing. Thanks to Leyland Campbell and Matt Gillet for your many discussions, ideas and support, and thanks to Tom Bateman, my right hand man in the exploration of artificial reefs.

I would also like to express my gratitude towards the recreational fishers of Geographe Bay, without which this project would not have been possible.

Finally, I would like to thank my parents, brother, friends and family for their tireless encouragement and support. I apologize for being reclusive throughout the year, particularly approaching the due date.

Abstract

Artificial reefs have been constructed and deployed globally to enhance the productivity of aquatic habitats. In April 2013, two artificial reefs were deployed in Geographe Bay, Western Australia for the purpose of enhancing recreational fishing opportunities. These reefs are designed to create varied complex spaces and habitats, as well as to create shallow water upwelling to drive nutrients up into the water column. The deployment of artificial reefs in Australia has recently become the subject of specific focus of policy makers and regulators. Monitoring costs to meet legislative requirements can be prohibitive, however, a potential method to reduce these costs is to utilise volunteers from the general public to collect data (i.e. citizen science). Thus, the overall objective of this project was to determine whether recreational fishers could potentially provide an effective means for monitoring artificial reefs.

A small number of recreational fishers were provided with underwater video cameras and asked to record footage of artificial reefs and nearby natural reefs. Unfortunately, only limited amounts of data were received due to the lack of participation, unseasonal weather and the short timeframe of the project. However, enough videos were received to undertake a preliminary analysis of the differences in the characteristics of the fish faunas of the two types of reef. The results demonstrated that artificial reefs had much higher levels of mean and maximum abundance, number of species and ecological group affinities. However, multivariate statistical analyses did not detect any differences between the fish faunal compositions between artificial and natural reefs. This was due to the dominance of the labrid *Coris auricularis* and the large amount of variability between replicates.

Given the limited data provided by the above citizen science program, a literature review on other similar projects to evaluate the effectiveness of the citizen science components of the pilot project was completed and provided a set of key recommendations. These included enhancing the methods of contacting and recruiting volunteers, providing simplified and consistent instructions and consistent communication and engagement with volunteers.

Finally, Baited Remote Underwater Video (BRUV) systems, constructed from readily available materials, were deployed randomly around the Busselton artificial reef to test the applicability of this method for future use as a citizen science artificial reef monitoring tool. The video footage was analysed to determine whether there was a difference in fish assemblages between artificial reef modules and the surrounding area, *i.e.* videos observing areas in which artificial reef modules were, and were not, observed in the camera's field of view. The results demonstrated that mean number of species and the number of benthic and epibenthic species were greater on footage recorded when the camera faced the modules. There was also a difference in the faunal composition. The footage observing artificial reef modules also exhibited 52.63% more recreational target species than surrounding areas. It was concluded that the BRUV technology employed here could be used, by citizen scientists, to monitor the fish faunas of artificial reefs. However, as this study has also demonstrated that there were significant differences in the characteristics of the fish faunas recorded depending on the direction the camera was facing, consideration is needed to design an unbiased and robust quantitative monitoring regime.

It is concluded that recreational fishers did not provide an effective means for monitoring artificial reefs during this project. This result, however, is a consequence of a lack of data stemming from an absence of volunteer engagement in a limited pilot project with a short time frame and unseasonal weather. This does not exclude the potential for using citizen scientists to monitor artificial reefs, following some changes in the methodology, technology and management of citizen science protocols, and thus it is possible to utilise recreational fishers as an effective means for monitoring artificial reefs. This project was subjected to restrictive and limiting factors but more importantly, discovered ways to overcome these issues by provided key recommendations on technology, methodologies and community engagement that should be followed to increase the effectiveness of using recreational fishers to provide sound scientific information in the future.

Contents

Chapter 1: General Introduction

1.1: Monitoring of marine environments using underwater video systems

With increasing pressures on the marine environment, such as climate change, ocean acidification, overfishing, eutrophication and hypoxia (Breitburg, 2002; Diaz and Rosenburg, 2008), there is an increasing need to effectively monitor the health of these ecosystems (Hoegh-Guildberg *et al*, 2007; Halpern *et al*, 2008). There are many different types of monitoring that are used to inform ecosystem-based management approaches to help conserve biodiversity and functioning (Christensen *et al*, 1996) and these can be broadly categorised in to extractive or non-extractive monitoring approaches. One of the most frequently employed method of non-extractive monitoring in the marine environment involves the use of underwater video systems. The use of underwater video systems for research in the marine environment has become increasingly popular since it was first employed in the 1950s (Brock, 1954). There are many reasons for this popularity including: the limited amount of damage done to the surrounding habitat and target organisms, the fact that footage can be permanently archived and replayed/reused and the increasing quality of the footage and decreasing purchasing costs of the equipment (Willis *et al*, 2000; Tessier *et al*, 2005; Mallet and Pelletier, 2014). This chapter provides a general introduction to these differing systems and their general strengths and weaknesses. This information is relevant to making decisions about exactly what type of system could be used for monitoring different marine habitats.

Underwater video systems vary in structure and purpose, and can be categorised into four main groups, i.e.) Baited Remote Underwater Video systems (BRUVs), ii) Remote Underwater Video systems (RUVs), iii) Diver Operated Video systems (DOVs) and iv) Towed Video (TOWV).

1.1.1: Baited Remote Underwater Video System (BRUVs)

A BRUV is a RUV (see 1.1.2), however, it uses bait as an attractant. The bait is usually extended on a pole, from which a camera sits on a weighted frame or sled attached to a boat or buoy at the surface. BRUVs are used in many types of research, but mainly on analysing spatial and temporal variation in fish assemblages. Some examples of BRUV research areas include: contrasting habitat use of diurnal and nocturnal fish assemblages (Harvey *et al*, 2012), bait effects in sampling specific assemblages (Harvey *et al,* 2007), composition of fish species along depth gradients (Brokovich *et al*, 2008) and many other studies that analyse the effects of fishing and protected areas on fish assemblages (Mallet and Pelletier, 2014).

1.1.2: Remote Underwater Video systems (RUVs)

RUVs are systems that don't use bait, are not towed by vessels and don't require divers for the majority of deployment (see DOVs and TOWVs below). RUVs can vary from simple baitless BRUV-like structures to very complex systems. RUVs are analysed according to their degree of autonomy, i.e. whether it's a linked system or autonomous system. Linked systems are systems that do not operate independently, and Autonomous systems can (for certain amounts of time depending on type) operate independently of human interference (Mallet and Pelletier, 2014). These systems are diverse in structure and purpose and eliminate interaction related bias. RUVs are commonly used to study fish movement and behaviour, the temporal variability of undistributed fish populations, feeding activity, and species interactions (Fedra and Machan, 1979 and Chabanet *et al*, 2012). Many types of RUVs are generally not limited by depth (due to not using divers), allowing research into high pressure deep sea habitats, up to and past the abyssal depths, to study rarely seen environments, ecosystems and scavenger behaviours (Priede and Merret, 1996; Denny *et al*, 2004; Harvey *et al*, 2007).

1.1.3: Diver Operated Video Systems (DOVs)

Diver Operated Video systems are simply video cameras carried by divers. DOVs are essentially similar to Underwater Visual Census (UVC) techniques, which traditionally comprise divers recording on slate or taking photos, while DOVs comprise divers recording video footage (Mallet and Pelletier, 2014). While DOV monitoring methods vary, most originated from the ‘transect count’ developed by Brock (1954), which is now known as the ‘strip transect’ and is the most widely accepted method of obtaining footage by divers (Kulbicki *et al*, 2010). This method is generally used to follow transects to observe fish and sessile organism abundance, diversity and percentage cover (such as monitoring coral reef health), analysing fish energy expenditure and movement variations, and analysing species specific responses to diver interactions (Krohn and Boisclair, 1994; Hall and Hanlon, 2002; Colton and Swearer, 2010). Some limitations of the DOV method include: the behavioural disturbance effects on marine fauna from moving divers (Wartenburg and Booth, 2014) and potential limitation to diurnally active species and permanent resident organisms depending on the temporal and seasonal structure of the study (Sale and Douglas, 1981; Brock, 1982 and Harmelin-Vivien *et al*, 1985). A final limitation is that divers, unlike machines, are limited in the depth, time and frequency of dives that can be undertaken (Langlois *et al*, 2010). Mixed gas technologies can allow divers to use these methods at greater depths (<150m, Pyle, 2000); however, for frequent sampling in long term studies these technologies are normally prohibitive from a cost and health and safety perspective (Langlois *et al*, 2010). Using divers can become very expensive as divers usually go in buddy pairs and must be experienced at a high level to minimise variability due to diver ability (Wartenburg and Booth, 2014). Some strengths of the technique include; that DOVs don’t always have to face one direction which can be advantageous to scan for more species, rare fish and/or to move towards an observation target to compensate for reduced visibility, contrast or cryptic species (Mallet and Pelletier, 2014). DOVs can also survey different fish assemblages at same reef locations when compared to other techniques and often records smaller species such as

Chromis sp. than other methods such as BRUVs (Watson *et al*, 2010). DOVs also potentially present another cost effective option in developing citizen-science capabilities (Katsanevakis *et al*, 2011; Salomidi *et al*, 2013; Bulleri and Benedetti-Cecchi, 2014).

1.1.4: Towed Video Systems (TOWV)

Finally, TOWVs are monitoring video systems that are towed by a vessel that usually film along transects that dimensionally vary. Such methods are used for habitat mapping, analyses of benthic macroflora (for example, seagrass and kelp) and macrofauna (for example, coral cover, scallops and other shellfish), analysis of demersal and epifaunal species, research into trawl fisheries and seafloor geomorphology and general exploratory research (Holmes *et al*, 2008; Mallet and Pelletier, 2014). With the use of bottom-contacting sleds and trawl gear, TOWV limitations include cameras only facing one way with one field of view, gear can easily get snagged and fouled on obstacles and it can also damage sessile biota (sometimes causing mortality making it a destructive monitoring method) (Cappo *et al*, 2004; Rooper, 2008). Other problems include larger fish out-running the sampling gears and the passage (and associated noise in shallower systems) of towing vessels affecting the behaviour of species (Ferno and Olsen, 1994; Morrison and Carbines, 2006). Strengths of TOWVs include that it can cover a large area in a short period of time, thereby increasing the spatial coverage of habitats, and the probability of observing species, including rarer species (Mallet and Pelletier, 2014). Other advantages include cost-effectiveness (of some variations), the lack of human disturbance, straight forward image interpretation and processing, and little or no need for ground-truthing (Grizzle *et al*, 2008).

1.1.5: Stereo-Video Systems

It should be acknowledged that all these methods can also be used in conjunction with stereo-video equipment, i.e. the use of two paired cameras. The cameras (two cameras calibrated together) use a software program, known as Vision Metrology

Systems (VMS, Cappo *et al*, 2007), that creates measurements from digitally captured images and the system is generally fixed to a frame that rests on the sea floor filming parallel to it (Harvey and Shortis, 1995 and Harvey *et al*, 2001). The use of the stereo-video analyses enables the collection of accurate estimates of fish size, as well as assisting to identify individual fish on the recordings, making it an important fisheries management tool (Lines *et al*, 2001 and Cappo *et al*, 2003). Underwater video monitoring techniques are not just limited to research on natural habitats, they can also be employed to survey Habitat Enhancement Structures such as artificial reefs (Lowry *et al*, 2012), the focus of this study.

1.2 Habitat Enhancement Structures

Habitat Enhancement Structures (HES), are a purpose built structure or material placed in the aquatic environment for the purpose of creating, restoring or enhancing a habitat for fish, fishing and recreational activities in general (Department of Fisheries, 2012b). These structures can be broadly categorised into artificial reefs, Fish Aggregation Devices and biological enhancement and rehabilitation methods (Table 1.0).

Table 1.0: Descriptions and different examples for Habitat Enhancement Structures.

Habitat Enhancement Structure	Description	Examples	References
Artificial Reefs	Human-made structures that can mimic some characteristics of natural structures. Intentionally deployed for many purposes, such as enhancing fisheries and tourism as well as surfing and diving.	Materials of opportunity such as sunken vehicles, pipes, rubble and tyres as well as purpose built reefs, often constructed with steel and reinforced concrete to enhance surrounding habitats and some designs aim at specific species.	Sherman et al, 2002; Diplock, 2010; Department of Fisheries, 2012b; Haejoo, 2015
Fish Aggregation Devices (FADs)	Positively buoyant structures that aggregate marine species. Purpose built FADs are designed to enhance fisheries.	Buoys, flotsam, shipping containers, vessel hulls, palm fronds and purpose built FADs.	White et al, 1990; Soria et al, 2009; Department of Fisheries, 2012b
Biological Enhancement and Rehabilitation Methods	The use of natural or artificial materials to have certain benefits on the surrounding ecosystem, such as restoring damaged ecosystems, translocating organisms from areas under threat (i.e. from dredging) and to create new habitat or improve existing habitat.	Artificial and translocated seagrass, translocated coral, bird roosts, algal mats, branches and fallen trees in rivers.	Huusko and Yrjana, 1997; Norkko et al, 2000; Cardoso et al, 2004; Doorn-Groen, 2007; Shahbudin et al, 2011

One of the most common HES are artificial reefs, which have been deployed in more than 50 countries around the globe (Diplock, 2010). Artificial reefs vary greatly in type, structure, purpose and ecological function. There are two types of artificial reefs, 'materials of opportunity' and 'purpose-built artificial reefs'. 'Materials of opportunity' are pre-existing materials prior to designing the artificial reef and can include concrete blocks and rubble, stones, polyvinyl pipe, tyres, derelict ships, car bodies, oil extraction equipment (such as disused oil rigs) and disused armed forces equipment and vehicles, which are deployed to form the reef (Figure 1.0) (Sherman *et al,* 2002). Purpose-built artificial reefs are specifically designed for species, habitats or effects (such as upwelling) having preferred shapes, voids, surfaces and profiles (Department of

Fisheries, 2012b; Haejoo 2015). Purpose-built artificial reefs can be built out of metal framework, steel, steel-reinforced concrete or concrete and can include species specific reefs (such as abalone habitat reefs), larger Offshore Artificial Reefs (OAR) such as the Sydney OAR (a 12m tall metal structure aimed at facilitating the propagation of pelagic species) and concrete fish homes (such as Fish Boxes^{TM} and ReefBalls^{TM}) designed to form habitats for a myriad of different species (Figure 1.1) (Sherman *et al*, 2002, Haejoo 2011; Haejoo 2013).

Fig. 1.0: Materials of opportunity, from left to right; the Tangalooma Wrecks (www.queensland.com), Tyre reef at Moreton Bay, Queensland (www.divingthegoldcoast.com) and disused oil rig (www.nytimes.com).

Fig. 1.1: Purpose-built artificial reefs, from left to right; Abalone habitat reef, a Fish Box^{TM} and the Sydney OAR (pictures all sourced from Haejoo, 2014).

Artificial reefs are usually deployed to increase the abundance and diversity of marine life within an area by creating additional shelter, food sources and a colonising surface for marine organisms. For example, Svane and Peterson (2001) showed that due to providing a range of new habitats for organisms, artificial reefs can 'have a positive ecological effect, often facilitating the development of highly diverse marine communities that reflect those of natural reefs'. Although most often aimed at increasing the abundance and diversity of marine life in an area for the purposes of fishing and diving, artificial reefs are also used for a variety of other purposes. Some of these functions include (but are not limited to): engineering solutions for coastal erosion, wave creation for surfing, increasing local economies through related expenditure, conservation, habitat protection (as offsets for marine protected areas), illegal fishing mitigation (trawling), to displace fishing effort, aquaculture (such as sea ranching) and as ecotourism ventures (Brock, 1994; Baine 2001; Ng *et al*, 2014).

1.3: Development of purpose built artificial reefs in Western Australia

Western Australia has many artificial reefs along its coast, however almost all of these structures comprise 'materials of opportunity' (Pollard, 1989 and Diplock, 2010). Due to the large number of ship wrecks off Western Australia's coast, it is not known when the first non-accidental sinking of a ship occurred. On the other hand, the first tyre reef was likely the 80 tyres deployed by the Underwater Explorers Club of WA near Rottnest Island in 1971 (Pollard, 1989).

Artificial reefs comprising 'materials of opportunity' have become unfavourable in certain locations due to past failures of such reefs because of incorrect design and deployment, lack of management, adverse environmental effects and structures being dislodged by extreme weather and hydrological events (Gregg, 1995 and Chou, 1997). The resultant negative environmental effects can include pollution from leaching zinc and other heavy metals, benzothiazoles and a range of hydrocarbons. These pollutants are toxic to all forms of life, causing a range of health effects on wildlife, depending on the level of exposure and susceptibility (Collins *et al*, 2001; Abha and Singh, 2012). Furthermore, there is usually a high cost for the safe removal of artificial reefs if this required (Sherman and Spieler, 2006; Diplock, 2010). Hence, there has been a shift to designing and implementing purpose-built artificial reefs in Australia in general and Western Australia in particular.

The first and only purpose-built artificial reefs for recreational purposes in Western Australian were deployed in April 2013 on the lower-west coast of Australia. Specifically, one reef was deployed off the coast of Bunbury and another was deployed off the Dunsborough coast. Each reef is made up of six clusters of five modules, each module being three cubic meters and weighing ten tonnes. Each module or Fish Box ™ has cross braces made from re-enforced concrete, the design is aimed to promote upwelling (due to the curvature of the cross braces) and create varied complex spaces and habitats which act as shelter for fish (Haejoo, 2011; Department of Fisheries, 2012b). The reefs were installed by the Department of Fisheries in conjunction with Recfishwest, the Western Australian peak body for recreational fishing, for the purpose of providing new habitats for key recreational species such as Pink Snapper (*Chrysophrys auratus*), Samson Fish (*Seriola hippos*) and Silver Trevally (*Pseudocaranx dentex*).

Fig. 1.2: The Haejoo Fish Box™ artificial reef module, deployed in the South West Artificial Reef Trial (Photo: Recfishwest).

Deploying artificial reefs in Australia has more recently become the subject of dedicated fisheries enhancement management policies, which require costly and time-consuming environmental impact assessments (Diplock, 2010). This can be seen in WA, with the creation of the 'Policy on Habitat Enhancement Structures in Western Australia' that ensures compliance of the reefs with the *Fish Resources Management Act 1994* (FRMA) (Department of Fisheries, 2012b). To establish an artificial reef in WA, a rigorous proposal assessment has to be completed. The aforementioned policy dictates that artificial reefs will not 'diminish effective aquatic resource management as the primary focus is to ensure the long term sustainability of any aquatic resource (including fisheries)'and thus that the reefs are consistent with the FRMA. As part of the policy, a risk assessment methodology must be applied. This includes an environmental monitoring plan that evaluates the structure and its effects on the surrounding ecosystems. The structural integrity, design, materials, surrounding environment, target species, usage and effort, and outcomes must all be considered during design and site selection to ensure that HES objectives are met while minimising risks as set out in the policy. Variables that may require monitoring include (adapted from the policy, Department of Fisheries, 2012b):

- modules are structurally sound, safe for the intended purpose and do not pose risk to other activities in the long term;
- the design is not affected by hydrological effects, tides, currents and storms;
- construction materials do not adversely affect the marine environment;
- the location provides safe and convenient access for intended users;
- the socio-economic impacts/benefits of the structure are outlined;
- the structure does not have a significant, adverse environmental impact;
- the structure remains stable and meet its life span and
- there is no potential to harm or damage a listed critical habitat or threatened species, population or ecological community.

1.4: Monitoring Habitat Enhancement Structures

Monitoring can be classified as 'the gathering of data and information on ecosystems or on those people who use the resource' (Hill and Wilkinson, 2004). This study used volunteers to monitor the fish assemblages on natural and artificial reefs. Studies globally compare the fish assemblages of natural and artificial reefs to detect variation in the fish faunal communities (Bombace *et al*, 1994; Rilov and Benayahu, 2000; Arena *et al*, 2007; Burt *et al*, 2009; Hunter and Sayer, 2009; Koeck *et al*, 2014; Granneman and Steele, 2015). Variation in these communities or assemblages are accurately and statistically shown to be a product of artificial reef enhancement on the surrounding systems in many studies from around the world (Shulman, 1984; Santos and Monteiro, 1997; Charbonnel *et* al, 2002; Sherman *et al*, 2002; Arena *et* al, 2007; Granneman and Steele, 2015). This comparison of fish assemblages is used to help assess the performance of the artificial reef. Monitoring the performance of the artificial reef (a legislative requirement in WA) includes whether it's enhancing surrounding fish faunas and ecosystems as well as how the reef is meeting other specific objectives such as propagating recreational target species. Ongoing monitoring can be expensive and time-consuming if conducted through government organisations or consulting companies employing professional scientists (Conrad and Hilchey, 2011). The effectiveness of monitoring by government organisations have decreased in some countries due to cutbacks in funding and staffing, however the monitoring data is still needed for decision-making processes (Stokes *et al*, 1990; Lawrence and Deagan, 2001; Conrad and Daoust, 2008; Conrad and Hilchey, 2011), given HES are generally deployed for the purposes of community recreation. One mechanism to reduce costs, would be to use citizen science to collect monitoring data.

1.5: Citizen Science

In recent years, there has been a marked increase in the use of members of the general public to assist in scientific research (Silverton, 2009; Baltais, 2013; Lambert, 2014). This type of approach is called 'citizen science' (Kruger and Shannon, 2000). Citizen science potentially provides a cost-effective method for data collection and monitoring, as well as a range of other benefits, although there are also some potentially significant limitations (Silverton, 2009; Dickinson *et al*, 2010; Rotman *et al*, 2012; Baltais, 2013). This thesis investigates the use of a citizen science approach to monitoring the fish assemblages on the Bunbury and Dunsborough artificial reefs. Since this approach is fundamental to the project, a critique of citizen science in general and in relation to this reef project in particular is presented in Chapter 3. Citizen science involves the use of volunteers to conduct research, sampling, data collection and/or analyses or monitoring. Citizen science has the ability to reduce funding and labour costs to research organisations and increase general cost efficiency, whilst also providing social benefits to volunteers and the opportunity for the collection of spatially and temporally large data sets and samples (Dickinson *et al*, 2010: Tulloch *et al*, 2013; Wilson and Godinho, 2013).

There are a range of ecologically/environmentally based citizen science projects being undertaken in WA, varying from terrestrial bird counts (Great Cocky Count – *Calyptorhynchus latirostris* in Perth WA) to logging species observations by fishers and divers in the marine environment (REDMAP). There are many aquatic citizen science projects occurring in WA that utilize participants to; tag marine organisms (such as fish or crabs), give biological donations of caught species (such as fish frames, otoliths and fin clips), keep logbooks and do monitoring studies (such as recording fishing effort) and log observations to identify movement patterns, migration routes and range shifts as well as identify invasive species (PestWatch and Whale Sightings WA). While citizen science monitoring has not been employed on artificial reefs within Western Australia, projects have been run around the world. To date however, this has generally been limited to collecting fish distribution and abundance data using a standardised visual method while diving or snorkelling on artificial reefs (Halusky *et al*, 1994; Pattengill-Semmens and Semmens, 2003). With the development of more robust and higher resolution cameras and their expansion into the domestic market, which has lowered their cost, underwater cameras are now more able to be employed in citizen science projects. One such study in the Mediterranean by Bulleri and Benedetti-Cecchi (2014), gave recreational spear fishers cameras so that they could film while spearfishing to help assess the structure of fish assemblages on shallow rocky reefs. Given legislative requirements to monitor artificial reefs there is no reason why a similar project could not be employed to survey fish communities around HES.

1.6: Thesis objectives

To see if the recent deployment of two artificial reefs in the waters off Bunbury and Dunsborough have achieved their purpose and enhanced the surrounding habitat, there is a need to develop effective monitoring techniques. This need is further reinforced by the legislative requirements to monitor these reefs now and into the future. One such technique could involve utilising citizen scientists. Thus the overall aim of this project was to determine whether volunteer recreational fishers could provide effective monitoring of the fish communities around the artificial reefs in Bunbury and Dunsborough, as well as how this type of citizen science based monitoring can be further developed in the future. To achieve this there were four aims.

1) To evaluate the quality and quantity of data on fish assemblages collected by recreational fishers, on the artificial reefs in the waters off Bunbury and Dunsborough (Chapter Two).

2) To use the data from aim 1 to make preliminary conclusions about the fish assemblages on the Dunsborough and Bunbury reefs in the first 15 months since they were deployed (Chapter Two).

3) To (i) review the literature on citizen science projects, (ii) apply the lessons learned from the review to evaluate the effectiveness of the citizen science components of the current study and (iii) provide a set of recommendations for maximising the success of any future citizen science monitoring of artificial reefs (Chapter Three).

4) To analyse differences in fish assemblages between cameras observing and not observing artificial reef modules in the camera field of view on the Dunsborough artificial reef, for the purpose of testing the applicability of randomised BRUV deployment as a future citizen science method of monitoring artificial reefs (Chapter Four).

Chapter 2: Fish communities on Bunbury and Dunsborough artificial reefs and comparisons to nearby natural reef

2.0 Abstract

In April 2013, two artificial reefs were deployed in Geographe Bay, Western Australia. To comply with environmental assessments, legislative requirements to monitor the development of the artificial reefs were established. There are evidently high costs associated with monitoring the artificial reefs, costing the Australian government $575,000 over a five year period (Department of Fisheries, 2015). A method to decrease the cost of monitoring projects is to use citizen science. This project gave eight local fishers towable cameras to monitor the artificial reefs by collecting footage of the clusters of artificial reef modules and nearby natural reefs. Only 3.1% of the expected data was received due to lack of participation, the short timeframe of the project and unseasonal weather. This lack of data severely limited the hypotheses able to be tested and the range of statistical analyses employed. However, a preliminary assessment of the fish faunas of artificial and natural reefs was able to be undertaken to assess the hypothesis that there would be a difference in the fish assemblages on natural and artificial reefs. These demonstrated that artificial reefs had much higher levels of mean and maximum abundance, number of species and ecological group affinities. Furthermore, multivariate statistical analyses did not detect any differences between the fish faunal compositions between artificial and natural reefs. This was primarily due to the dominance of the labrid *C. auricularis* and the large amount of variability between replicates. Although this study experienced several limitations it's important to recognise that it was a pilot study and first of its type in Western Australia.

2.1 Introduction

In recent years there has been an increase in the number of Habitat Enhancement Structures (HES), *i.e.* purpose built structures or materials placed in the aquatic environment for the purpose of creating, restoring or enhancing a habitat for fish, fishing and recreational activities in general, in coastal waters worldwide (Diplock, 2010; Department of Fisheries, 2012b). Of the many types of HES, artificial reefs are the most common and have been deployed in more than 50 countries around the globe (Diplock, 2010). An artificial reef is an anthropogenically manipulated underwater structure deployed for a range of purposes. While they serve a range of functions *e.g.* engineering solutions for coastal erosion and providing locations for recreational activities, such as surfing and diving (Brock, 1994; Baine, 2001; Ng *et al*, 2014), these reefs are typically employed to increase the abundance and diversity of marine life within an area by creating additional shelter, food sources and a colonising surface for marine organisms (Svane and Peterson, 2001).

In Western Australia, several artificial reefs exist, however these structures have generally been constructed from 'materials of opportunity', such as used tyres and sunken ships rather than purpose built structure (Pollard, 1989 and Diplock, 2010). This changed in April 2013, when two purpose built artificial reefs were deployed off the coasts of Bunbury and Dunsborough, on the lower-west coast of Australia. Each reef is made up of six clusters of five modules, each module being three cubic meters and weighing ten tonnes (see Fig. 2.1.). Each module is designed to promote upwelling (by driving nutrients up the water column) due to the curvature of the cross braces made from re-enforced concrete, as well as provide shelter and variation in environmental effects such as light, temperature and hydrological variables to increase habitat (Haejoo, 2011; Department of Fisheries, 2012b). The primary aim of the artificial reef was to provide additional habitat for key fish species of recreational interest, such as Pink Snapper (*Chrysophrys auratus*), Samson Fish (*Seriola hippos*) and Silver Trevally (*Pseudocaranx dentex*).

To meet legislative requirements, any artificial reef in WA has to have a dedicated monitoring and management plan, to ensure the structural integrity of the structure (Department of Fisheries, 2012b). At the same time, monitoring of the success of the artificial reefs in attracting fish species, and increasing fish biomass (e.g. if fish feed and/or reproduce in association with the reefs) is also being measured by the Department of Fisheries during the structural surveys. Although these structures are very popular with the local community and organisations associated with recreational activities (*e.g.* fishing and scuba diving), there is also interest from the commercial sector in utilising these reefs. The high cost associated with designing/selecting, purchasing, deploying and monitoring, *i.e.* at least $2.38 million in the case of the Bunbury and Dunsborough artificial reefs (Department of Fisheries, 2015), are prohibitive. One mechanism of reducing the cost of artificial reefs would be to use citizen science to collect monitoring data, a method which would also result in increased ownership/stewardship of the structures by the community (Pattengill-Semmens and Semmens, 2003; Conrad and Daoust, 2008).

In light of the above, this study utilised a small suite of keen recreational fishers as citizen scientists to collect underwater video footage from both the artificial reefs, and nearby natural reefs, to help elucidate whether volunteers could effectively monitor the differences in fish assemblages potentially caused by artificial reefs. The initial aim of this chapter was to analyse video footage collected by the recreational fishers to determine whether the fish communities on the artificial reefs were similar to those on nearby natural reefs and thus whether the artificial reefs were fulfilling their objective of enhancing the surrounding habitat. For various reasons, however, very little footage was obtained from the recreational fishers (discussed in Chapter Three). In view of the limited footage, the revised goal was to use the footage that was available to make a preliminary assessment of the fish assemblages of the Dunsborough and Bunbury artificial reefs during the first 15 months of their deployment.

This small pilot study, which is the first of its kind for Australia, and possibly the world, experienced teething problems with the citizen science aspects of the project resulting in lower numbers of videos being recorded than was expected. Thus, the methods associated with volunteer management changed throughout the study. A summary of these various approaches and their advantages, disadvantages and recommendation for the future are provided in Chapter 3, while the current chapter solely focuses on data extracted from the video footage collected from the recreational fishers.

2.2: Materials and Methods

2.2.1: Study Site

Geographe Bay, is located on the lower west coast of Australia and ranges from the Bunbury breakwater (33^o 18'S, 115^o 39'E) in the north to the northwest point of Cape Naturaliste (33^o 32'S, 115^o 00'E) in the south. It covers an area of ~290 nautical miles^2 and has a maximum water depth of 30 m (Bellchambers *et al*, 2006). Having a north facing aspect and being exposed to prevailing south-westerly swell, makes Geographe Bay the southernmost protected embayment on the west coast of south-western Australia (Bellchambers *et al*, 2006). Geographe Bay exhibits an array of different habitats ranging from low profile reefs to large seagrass meadows, with limited areas of sandy habitat. The substratum of the bay is dominated by expansive (approximately 70%) and continuous monospecific seagrass meadows from 2-14 m deep consisting of *Amphibolis griffithi* and *Amphibolis antartica* (Heald, 1976; Walker *et al*, 1987; Laurenson *et al*, 1993; Bellchambers *et al*, 2006). Deeper seagrass meadows (including artificial reef depths) are dominated by *Posidonia sinuosa* (ribbon weed) (Oldham *et al*, 2010). The influence of currents on Geographe Bay vary seasonally, with the poleward flowing Leeuwin Current flowing in winter, while a cool equator-ward flowing coastal counter current, the Capes Current, occurs in summer (Pearce and Pattriachi, 1999). When the Leeuwin Current moves offshore between November and March, initiating the Capes Current, there may be localised upwelling, which influences local fisheries (Gersback *et al*, 1999; Pearce and Pattriachi, 1999). Geographe Bay experiences microtidal conditions, with the mean tidal range being < 1 m resulting in most water movement occurring as a result of winds (McMahon *et al*, 1997). The bay is a key recreational hotspot for people from the towns of Dunsborough and Busselton and the city of Bunbury, as well as tourists from other regions, particularly the state capital, Perth (Varma *et al*, 2010).

Geographe Bay was chosen as a suitable site for the deployment of the artificial reefs primarily due to the passion of local recreational fishers who had promoted the deployment of artificial reefs for many years and that the reef may increase tourism into the area (Mark Pagano, Department of Fisheries WA pers. comm., 2015). Furthermore, the artificial reefs were not able to be deployed north of Bunbury due to large amounts of sediment being flushed from the Leschenault Estuary during winter and the presence of a nearby colony of Little Penguins (*Eudyptula minor*), which could be negatively affected by an increase in boat traffic. Prior to deployment, constraints mapping was employed to analyse any social or experimental limitations on the success of the reefs policy. The design, construction, placement and relationship of artificial reefs with the hydrology, sediment dynamics and surrounding environment were considered throughout the project (Department of Fisheries, 2012b). The Department of Fisheries, together with the South West Artificial Reefs Reference Group, which comprised scientists and environmental and fisheries managers and key stakeholders, identified the following criteria to identify possible sites within Geographe Bay - (i) likely to attract key nearshore recreational species, (ii) in close proximity to boat ramps to allow safe access by small vessels, (iii) situated over predominantly sand substrate to avoid seagrasses, (iv) aware of state and commonwealth marine park zoning - and (v) in water depths of between 20 and 30 m (Department of Fisheries, 2014).

In April 2013, 60 purpose built modules were deployed to create two separate artificial reefs off the coasts of Bunbury and Dunsborough in Geographe Bay, creating the South West Artificial Reef Trial. Each of the modules (FishBox™) is constructed from steel-reinforced concrete, is 3 m^3 and weighs 10 tonnes (Fig. 2.1 Haejoo, 2013). To construct each reef, 30 modules were grouped into six clusters of five modules (Fig 2.2), over an area of four hectares (Haejoo, 2013). The Bunbury artificial reef was deployed around 115° 35.900'E, 33° 18.500'S in a water depth of 17 m depth, while the artificial reef at Dunsborough was deployed around 115° 9.980'E, 33° 3.962'S in a water depth of 27 m (Fig. 2.2; Department of Fisheries, 2013). To ensure that the reefs are easily assessable to recreational fishers both were located within 5 km, as the crow flies, of boat ramps.

Fig. 2.1: Some of the 60 Fishbox modules being constructed to be deployed in the artificial reefs off Bunbury and Dunsborough. Image courtesy of Haejoo.

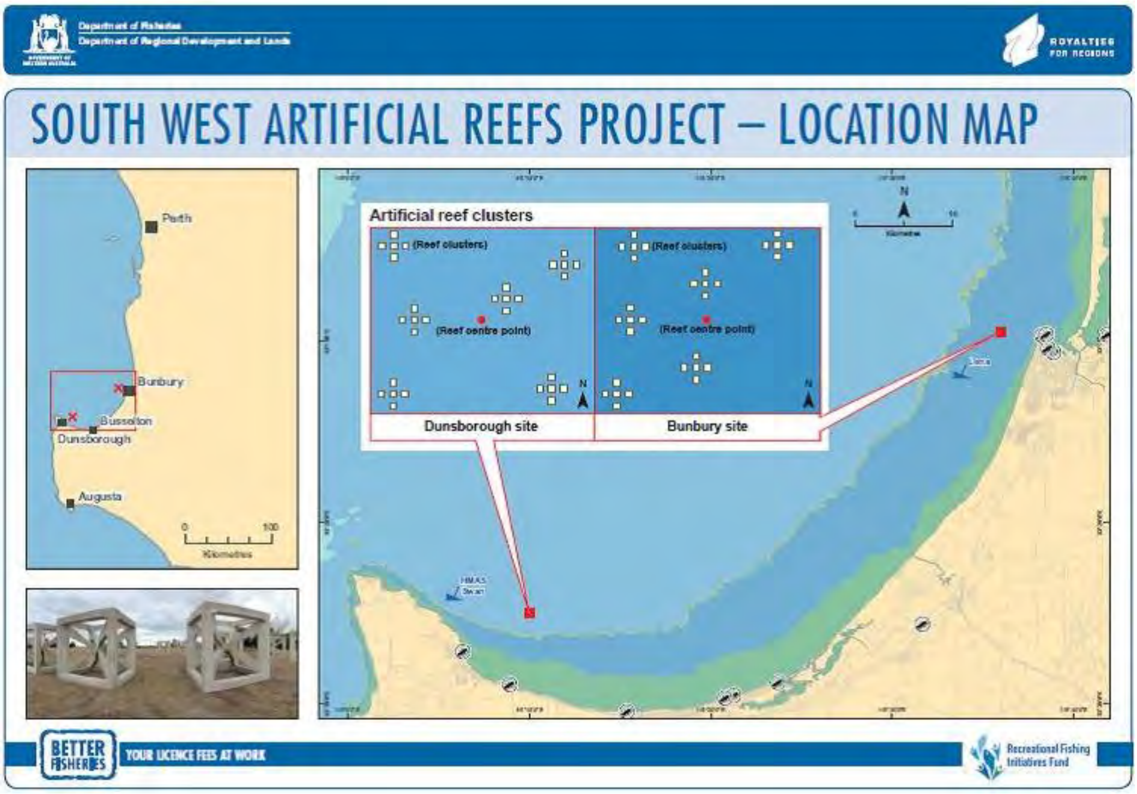


Fig. 2.2: Maps showing the location and spatial arrangement of the two purpose built artificial reefs in Geography Bay, Western Australia. Image courtesy of the Department of Fisheries WA.

2.2.2: Monitoring regime

Full details of the methodology employed to recruit and engage recreational fishers are given in Chapter 3. These methods are summarised briefly here to provide an understanding of what the citizen science aspects of the project entailed.

In order to select the most appropriate underwater cameras for use by the recreational fishers, 12 different models were compared in desktop study and two that were most suitable in terms of their (i) safety and ease of use for fishers (ii) ability to collect footage of adequate quality and (iii) ability to stream live footage back to the fisher on the boat to reduce snagging in the artificial reef modules, were purchased and trialled by the volunteer fishers. Of the two cameras the Sony Charged-Coupled Device (CCD) 700 TVL Underwater Fishing Camera (Fig. 2.3) was deemed the best and the equipment provided to each fisher.

Fig. 2.2: The Sony Charged-Coupled Device (CCD) 700 TVL Underwater Fishing Camera, with 50 m cable and 360° rotating head (picture sourced from Sony CCD 700 TVL Under Water Fishing Camera User Manual).

Each of the eight participants (four per artificial reef) was asked to go to their local artificial reef once a month between November 2014 and April 2015 to collect video footage. Initially, each fisher was asked to record 15 minutes of video on each of the six clusters (90 minutes total) and another 15 minutes on nearby natural reefs. However, this was later reduced to ≥ 15 minutes a month on any artificial reef cluster and 15 minutes on a nearby natural reef. Participants were also asked to record metadata in a logbook (Appendix 2.1). This document collected information on the location and duration of the video recording and any general comments and/or environmental observations. Note that fishers were not prohibited from fishing whilst recording video footage. The logbook data and video footage were then transferred to Murdoch University.

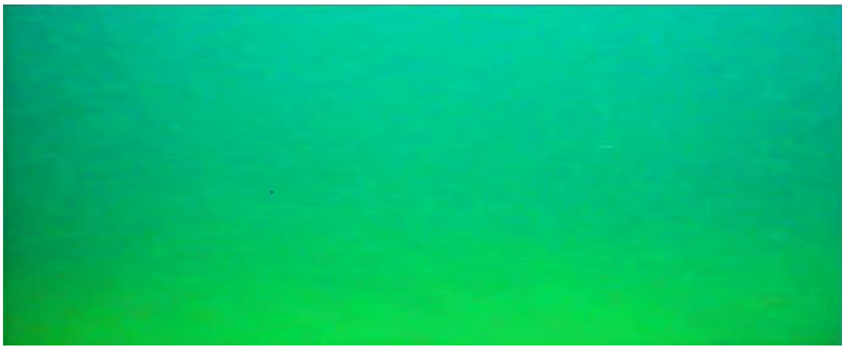
2.2.3: Video metadata

Once received, a suite of metadata were recorded for each video, namely footage code (1-999), footage number (1-999), fisher code (F1-F8), locality (Bunbury or Dunsborough), habitat type (artificial or natural), length of footage (seconds), file size (megabytes) and quality rating. The quality rating was a visual assessment of the clarity of the footage and was assessed across the entire video. The scales ranged from 1 (worst quality) to 10 (best quality) and incorporated factors such as turbidity, water and camera movements, video length and the amount of fish and structures identifiable (Fig. 2.4).

2.2.4: Observation protocols

For each video, the values of two quantitative variables, namely Max-N and Count-N were recorded for each species observed. The first of these variables, Max-N, is the maximum number of individuals of a species observed simultaneously during the video, *i.e.* the largest number in a single video frame (Priede and Merret, 1996 and Willis and Babcock, 2000). This variable is commonly used as an indication of abundance because, by counting the maximum individuals of one species in the field of view at one time, it avoids the possibilities of double counting the same individuals (in a different frame) and gives a conservative estimation of relative fish density (Priede *et al*, 1994; Cappo *et al*, 2004; Watson *et al*, 2005; Gomelyuk, 2012).

The second variable calculated for each species in each video was Count-N, *i.e.* the total number of individuals of a species seen during an observation period (Schobernd *et al*, 2013; Mallet and Pelletier, 2014; Wartenburg and Booth, 2014). Count-N enumerates and identifies all individuals observed in 'digital transects', effectively imitating an *in-situ* slate-transect enumeration. Thus, this variable identifies and counts all individual fish that appear on the screen (Wartenburg and Booth, 2014). Each species recorded was also assigned to an ecological group affinity using the Nakamura (1985) classification. Under the Nakamura classification each species is classified based on their typical spatial position with regard to the reef (Tessier *et al*, 2005; Bortone, 2007). A-type species are found proximate to/or inside holes and crevices on the reef and are thus classified as *benthic*. B-type species are found closely associated with the reef, but not in direct contact are known as *epibenthic* and C-type species are loosely associated with structure, often found schooling above it and distinguished as *pelagic species* (Nakamura, 1985; Bortone, 2007; Wartenburg and Booth, 2014). The number of modules per video was also analysed to analyse whether there was a localised effect on fish assemblages.

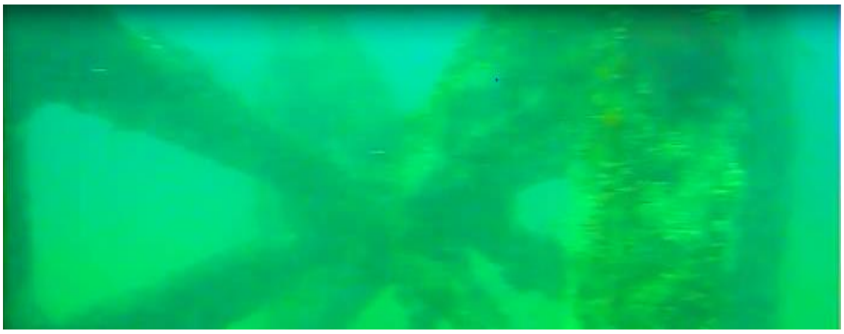


Quality level 1

Very turbid. Screen has grain-like effect. Camera shaking. Video only lasts 10 seconds.

Quality level 3

Quite turbid but fish and modules visible. Small grain effect on screen. Limited shaking. Video lasts over one minute.



Quality level 5

Fish easily identifiable in close proximity to the camera. Reduced shaking and greater clarity. Epiphytic growth observable on modules. Video lasts over two minutes.

Quality level 10

All fish easily identifiable. No shaking and excellent clarity. All fish easily identifiable. Module growth easy to observe. Footage length over 15 minutes.

Fig. 2.4: Examples of different quality levels of footage obtained from the Sony CCD 700 TVL Underwater Fishing Camera. Note that footage at quality level 10 was taken from the video footage used in Chapter 4 from the same artificial reefs and is shown here for comparative purposes. That screen shot is used with permission from Recfishwest.

2.2.5: Multivariate analysis of fish community composition

The count-N data for each species in each video was standardised by dividing that number by the length of that video (in seconds) and multiplying by 60, to give a count per minute for each species in each video. All videos less than one minute were removed from the data set as they were too short to contain any species. Individuals that were unable to be identified were also removed from the data set (Lek *et al*, 2011). The data matrix was then square-root transformed to down-weight the contributions of species with consistently relatively high values and balanced them with the values of rarer species and used to construct a Bray-Curtis similarity matrix. This matrix was then subjected to a one-way Permutational Multivariate Analysis of Variance (PERMANOVA; Anderson, 2001) test to determine whether the fish communities on the two reef types, *i.e.* artificial and natural reefs, differed significantly. This test was chosen as it is robust enough to cope with the unbalanced design of 3 samples from natural reefs *vs* 12 from artificial reefs (see Anderson *et al*, 2008). The above Bray-Curtis similarity matrix was then subjected to non-metric Multi-dimensional Scaling (nMDS; Clarke, 1993) to produce an ordination plot to explore visually any trends among reef types.

A shade plot, derived from the square-root transformed fish fauna data for each video, was used to visualise the trends exhibited by the counts (per minute) of the various fish species across the artificial and natural reefs. This plot is a simple visualisation of the frequency matrix, where a white space for a species demonstrates that the taxon was never collected, while the depth of shading from grey to black is linearly proportional to the density of that taxon (Clarke *et al*, 2014; Tweedley *et al*, 2015).

2.3: Results

2.3.1: Video metadata

Of the eight participants, video footage was successfully obtained from three. Moreover, those three fishers recorded only 17 videos, with a total duration of just over one hour. Video length varied from 10 seconds to 13 minutes 24 seconds, with an average length being 3 minutes 45 seconds per video. The general reef location was not specified for the vast majority of videos from both artificial reefs (85%) and natural reefs (100%) *i.e.* the logbook data were incomplete (Table 2.1). Moreover, only four of the 17 videos (24%) were recorded over natural reef.

Table 2.1: The number (#) and percentage (%) of videos recorded from artificial and natural reef off Bunbury and Dunsborough.

	Artificial Reefs		**Natural Reefs**		**Total**	
	#	%	#	%	#	%
Bunbury	0	0	0	0	0	0
Dunsborough	2	15	0	0	2	12
Unknown	11	85	4	100	15	88
Total	**13**	**100**	**4**	**100**	**17**	**100**

The quality of the footage was generally low and ranged between 1 and 5 on the 1-10 scale (Fig. 2.5). The average quality of artificial reef footage (3.8) was similar to that of the quality of footage obtained over natural reef (3).

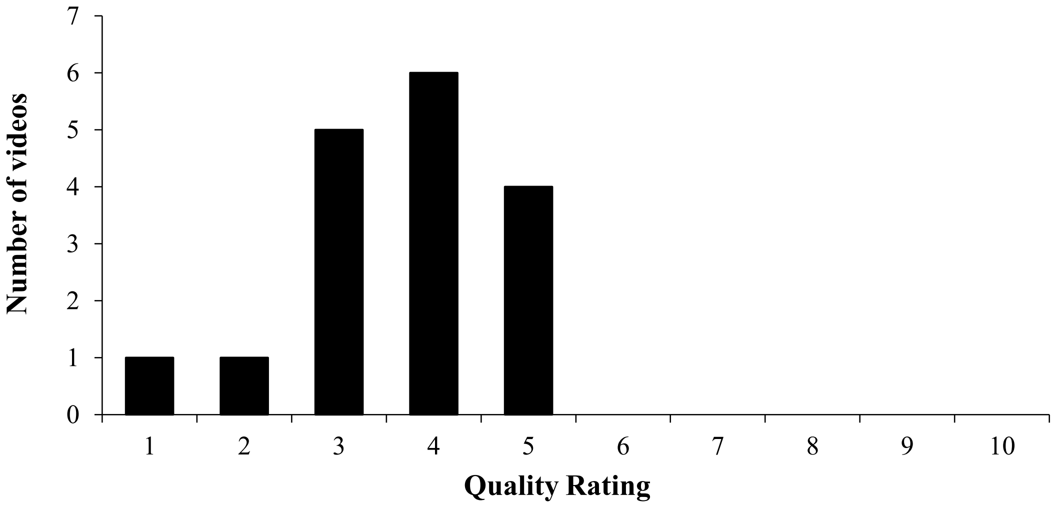


Fig. 2.5: The quality rating of the 17 videos collected on the natural and artificial reefs.

2.3.2: Univariate metrics

Of the thirteen species that were recorded across the 64 minutes of footage from the 17 videos (see Table 2.2), nine (69%) belonged to the 'B Type' ecological group indicating that they were epibenthic (Fig. 2.6). The remaining four species were equally assigned to the A (benthic) and C (pelagic) types.

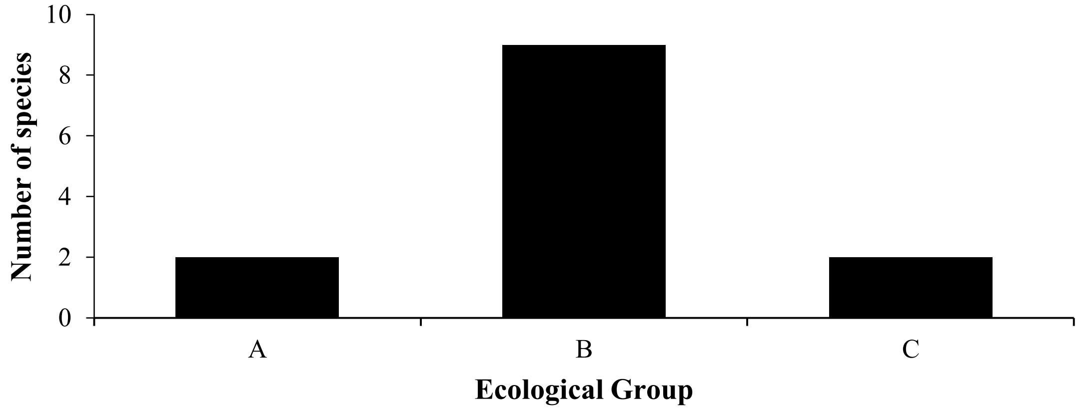


Fig. 2.6: The numbers of species recorded representing each of the three ecological groups defined by Nakamura (1985).

To test whether a larger amount of reef modules observed in the footage, had an effect on the fish assemblages, fish ecological groups as well as average mean abundance and average number of species was tested. In just over half (54%) of the 17 videos two or more of the five artificial reef modules could be sighted, while 23% of videos captured footage of one or two modules and the final 23% of the videos were filmed on natural reef (Fig. 2.7). Videos in which more than two modules were sighted contained larger numbers of mean individuals (numbers of individuals observed per minute of footage) of fish assigned to Type B ecological group (epibenthic species), while natural reefs had more Type A (benthic) and Type C (pelagic) species. The most abundant group overall was Type B, followed by C and A respectively (Fig. 2.8).

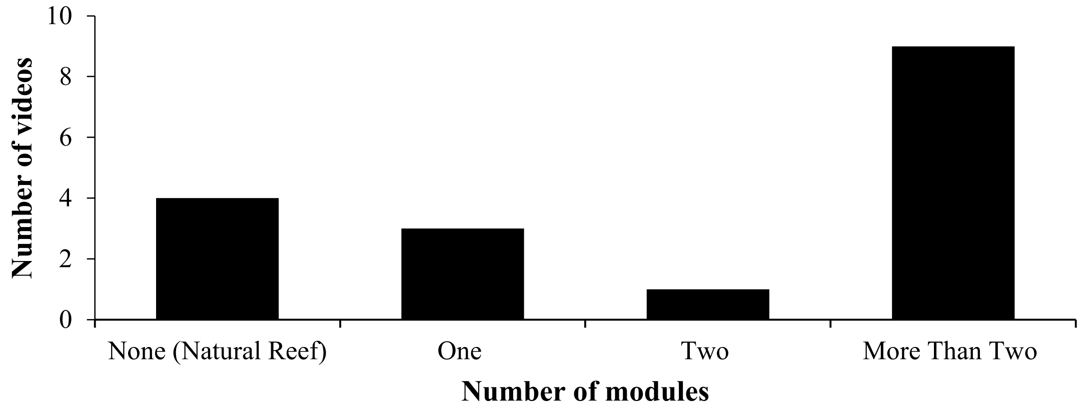


Fig. 2.7: The number of videos in which none, one, two or >2 modules were observed.

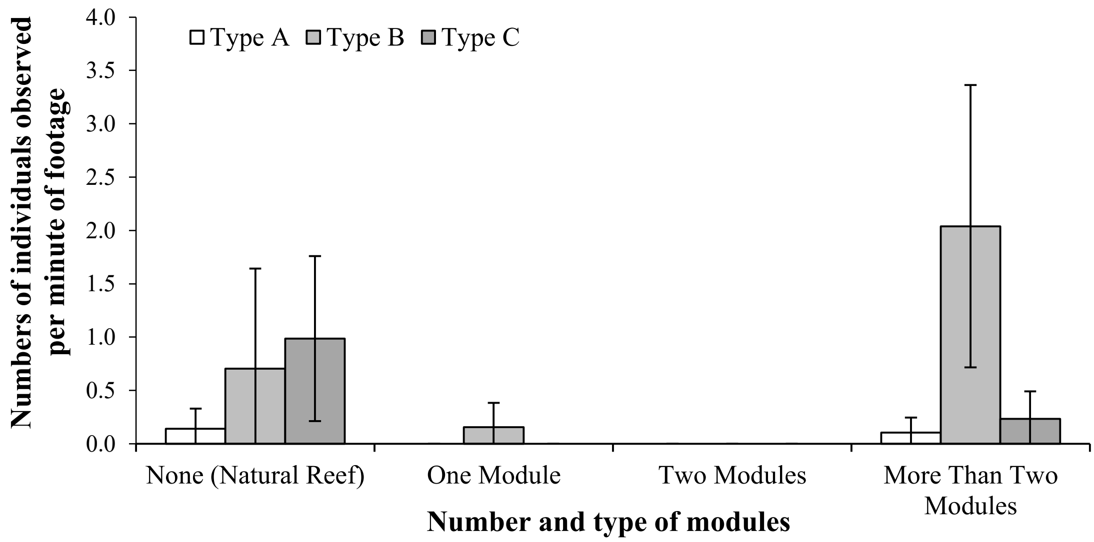


Fig. 2.8: The number of mean individuals (Max-N) from each ecological fish type (Nakamura classification) per minute of footage observing each number and type of modules. There is no data for two modules, as although fish were observed, they were unidentifiable. There error bars show the large variability between fish observed and the differing lengths of footage recorded (for example, there was 6.39 minutes for footage with one module and 38.24 minutes or over half the footage for more than two modules.

Average mean abundance (Max-N – mean abundance averaged to the amount of videos that exhibited each amount of modules) was far greater in videos that sighted more than two modules, rather than those recorded on natural reef or that sighted one module or two modules, *i.e.* ~10 *vs* ~3 and~0.3, mean individuals per video, respectively (Fig. 2.9). Average number of species was slightly higher (1.2) in videos with more than two modules, than those on natural reef or with one modules (both 1, Fig. 2.9).

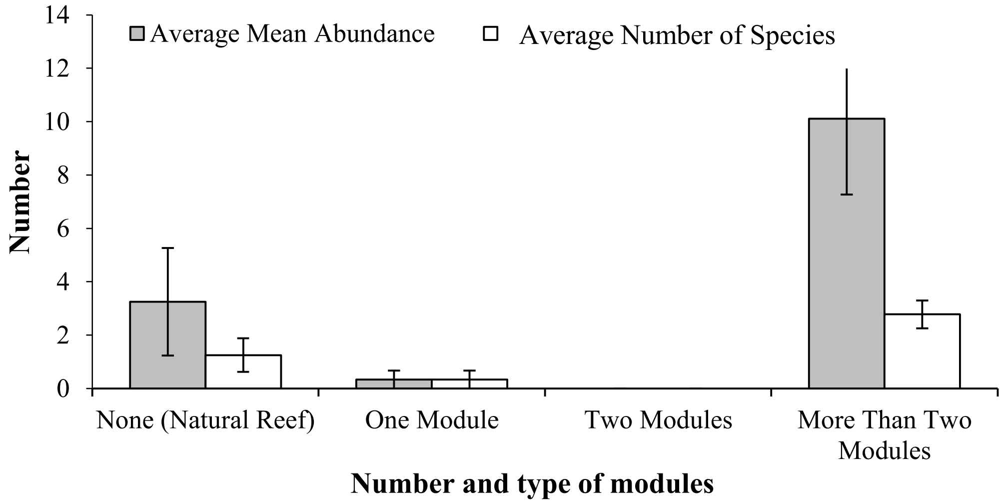


Fig. 2.9: The average mean abundance (Max-N – mean abundance averaged to the amount of videos that exhibited each amount of modules) and average number of species for differing numbers of modules encountered in the videos recorded on the natural and artificial reef. The error bars signify the variability of average mean abundance and average number of species in the differing amounts of modules.

Overall, thirteen identifiable fish species were recorded across the 17 videos and for each species in each video a max-N and count-N were recorded (Table 2.2). The Max-N ranged from 0 - 18, but was almost invariably < 5, while the number of identifiable species in a single video ranged from 0 - 6 and was typically ≤ 3 (Table 2.2a). Four species were recorded over natural reefs and 11 over the artificial modules, however, it should be noted that far fewer videos were recorded over natural reefs.

Among the fish species, the Western King Wrasse *Coris auricularis* was the most abundant, representing ~31% and ~47% of the maximum number of individuals on natural and artificial reefs, respectively (Table 2.2a). While *C. auricularis* represented ≥ 5% of the total fish individuals (based on Max-N) on both reef types, six other species, representing more ≥ 5% of the total fish individuals, occurred almost exclusively on only one or the other of the reefs types. These other species were the Southern Silver Belly *Parequula melbournensis*, Magpie Perch *Cheilodactylus nigripes* and Spinefoot *Siganus fuscescens* on natural reefs and the Footballer Sweep *Neatypus obliquus,* Sand Trevally *P. georgianus* and Rough Bullseye *Pempheris klunzingeri* over artificial reefs (Table 2.2a).

When considering species based on Count-N, far larger numbers of individuals per minute were recorded over artificial than natural reefs, *i.e.* ~10 and ~6, respectively (Table 2.2b). While, the Max-N of *C. auricularis* was largest overall, and species ranked 1st on artificial reefs (representing ~39% of all individuals), it only ranked 3rd over natural reefs, representing ~15% of the fish fauna. The most abundant species recorded over natural reefs was *P. melbournensis*, which although contributed almost 50% to the total number of fish recorded over natural reefs, was recorded on only 1 of the 13 videos over artificial reefs and represented < 4% of the total fish fauna. In contrast, *N. obliquus* contributed 28% to the fish fauna over artificial reefs, but was never recorded over natural reefs (Table 2.2b). Unidentifiable species, *i.e.* those that could be counted but not accurately assigned to a species, made up substantial contributions to the fish fauna of both reef types, representing 31.86% of the individuals observed on natural reefs and 18.81% of the individuals observed on artificial reefs.

Table 2.2: (a) Max-N and (b) Count-N values for each species recorded in each video. Note that Max-N values are for a single frame, while Count-N values are average for 1 minute of video footage. # = the count of values and % the percentage contribution made by that species to the total fauna of that video. Relatively abundant species, *i.e.* those that represented ≥ 5 % are shaded in grey. R = rank based on %. The number of species, individuals and length of each video is also provided.

(a) Max-N	**Natural Reefs**						**Artificial Reefs**															**Total**		
Species Name	1	2	3	4	*#*	*%*	1	2	3	4	5	6	7	8	9	10	11	12	13	*#*	*%*	**#**	**%**	**R**
Coris auricularis		4			***4***	***30.77***	6	1			1		3		14				18	***43***	***46.74***	**51**	**43.22**	**1**
Neatypus obliquus											4	9							5	***18***	***19.57***	**18**	**17.14**	**2**
Parequula melbournensis	3	4			***7***	***53.85***													3	***3***	***3.26***	**17**	**16.19**	**3**
Pseudocaranx georgianus							4	2												***6***	***6.52***	**6**	**5.71**	**4**
Pempheris klunzingeri											5						1			***6***	***6.52***	**6**	**5.71**	**4**
Pentaceropsis recurvirostris									2	2										***4***	***4.35***	**4**	**3.81**	**6**
Anoplocapros amygdaloides							2		1	1										***4***	***4.35***	**4**	**3.81**	**6**
Choerodon rubescens								1					1						1	***3***	***3.26***	**3**	**2.86**	**8**
Anoplocapros lenticularis							1			1										***2***	***2.17***	**2**	**1.9**	**9**
Siganus fuscescens																			2	***2***	***2.17***	**2**	**1.9**	**9**
Cheilodactylus nigripes				1	***1***	***7.69***														***0***	***0***	**2**	**1.9**	**9**
Upeneichthys vlamingii		1			***1***	***7.69***														***0***	***0***	**2**	**1.9**	**9**
Chelmonops curiosus																			1	***1***	***1.09***	**1**	**0.95**	**13**
Number of species	1	3	0	1	***4***		4	3	2	3	3	1	2	0	1	0	1	0	6	***11***			**13**	
Number of individuals	3	9	0	1	***13***		13	4	3	4	10	9	4	0	14	0	1	0	30	***92***			**105**	
Length of footage	2:44	2:18	0:10	1:58	***7:10***		13:24	2:19	11:48	11:31	2:42	1:26	2:02	0:11	1:37	1:17	4:52	1:36	1:47	***8:32***			**63:42**	

Table 2.2 continued: (a) Max-N and (b) Count-N values for each species recorded in each video. Note that Max-N values are for a single frame, while Count-N values are average for 1 minute of video footage. # = the count of values and % the percentage contribution made by that species to the total fauna of that video. Relatively abundant species, *i.e.* those that represented ≥ 5 % are shaded in grey. R = rank based on %. The number of species, individuals and length of each video is also provided.

(b) Count-N	**Natural Reefs**						**Artificial Reefs**															**Total**		
Species Name	1	2	3	4	***X***	*%*	1	2	3	4	5	6	7	8	9	10	11	12	13	***X***	*%*	**X**	**%**	**R**
Coris auricularis		3.91			***0.98***	***15.35***	3.58	0.86			0.75		2.46		21.39				27.48	***4.35***	***38.57***	**3.56**	**35.13**	**1**
Neatypus obliquus											12.22	16.47							12.34	***3.16***	***28***	**2.41**	**23.85**	**2**
Unidentifiable species	0.37	5.22		2.54	***2.31***	***31.86***	3.73	1.29	0.58	0.53	2.96	1.4	0.98		1.24	1.56	0.82	1.25	11.21	***2.12***	***18.81***	**2.1**	**20.75**	**3**
Parequula melbournensis	5.49	6.96			***3.11***	***48.8***													5.47	***0.43***	***3.73***	**1.05**	**10.41**	**4**
Pseudocaranx georgianus							3.73	3.22												***0.53***	***4.74***	**0.41**	**4.04**	**5**
Pempheris klunzingeri							0.52		0.85	0.87										***0.17***	***1.53***	**0.13**	**1.3**	**6**
Pentaceropsis recurvirostris											1.85						0.25			***0.16***	***1.44***	**0.12**	**1.22**	**7**
Anoplocapros amygdaloides								0.43					0.49						0.57	***0.11***	***1.18***	**0.09**	**0.87**	**8**
Choerodon rubescens									0.76	0.35										***0.85***	***0.76***	**0.07**	**0.65**	**9**
Anoplocapros lenticularis							0.75			0.17										***0.78***	***0.63***	**0.05**	**0.53**	**10**
Siganus fuscescens				0.58	***0.15***	***2.29***																**0.03**	**0.34**	**11**
Cheilodactylus nigripes																			0.57	***0.44***	***0.39***	**0.03**	**0.33**	**12**
Upeneichthys vlamingii																			0.57	***0.44***	***0.39***	**0.03**	**0.33**	**12**
Chelmonops curiosus		0.43			***0.19***	***1.75***																**0.03**	**0.25**	**14**
Number of species	2	4	0	2	***5***		5	4	3	4	4	2	3	0	2	1	2	1	7	***12***		**14**		
Number of individuals	16	38	0	6	***6.38***		156	13	16	13	48	25	8	0	36	2	5	2	103	***11.27***		**10.12**		
Length of footage	2:44	2:18	0:10	1:58	***7:10***		13:24	2:19	11:48	11:31	2:42	1:26	2:02	0:11	1:37	1:17	4:52	1:36	1:47	***8:32***		**63:42**		

3.3.3: Multivariate analysis of fish community composition

One-way PERMANOVA demonstrated that there was no significant difference between the fish faunas recorded from video data collected over the two reef types (Table 2.3). This conclusion is supported by the nMDS ordination plot, were the three points representing the natural reefs were intermingled amongst those representing the artificial reefs (Fig. 2.10). Moreover, the shade plot shows that there was no clear division between the fish faunas of the artificial and natural reefs (Fig. 2.11). This was due to some of the few species that were recorded on natural reefs also being present on natural reefs (*i.e. C. auricularis* and *P. melbournensis*), but also the high degree of variability between the fish compositions of the artificial reefs.

Table 2.3. Mean squares (MS), Pseudo-*F* (p*F*) values and significance levels (*P*) for a one-way PERMANOVA test, employing a Bray-Curtis resemblance matrix constructed from the square-root transformed count-N data from the 15 videos recorded over artificial and natural reefs, which were obtained from recreational fishers.

	df	**MS**	**p*F***	**P**
Reef type	1	3233	1.60	0.170
Residual	13	2033		

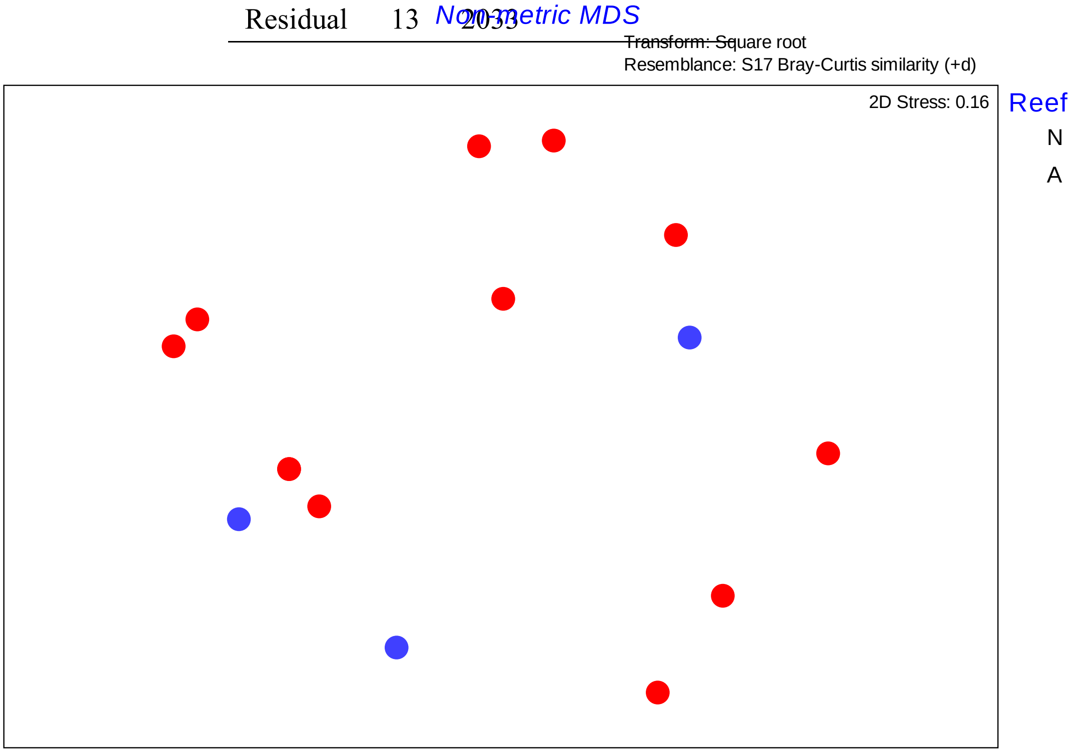


Fig. 2.10: nMDS ordination plot derived from a Bray-Curtis similarity matrix constructed from the square-root transformed count-N data from the 15 videos recorded over artificial and natural reefs, which were obtained from recreational fishers. ● Natural reefs. ● Artificial reefs.

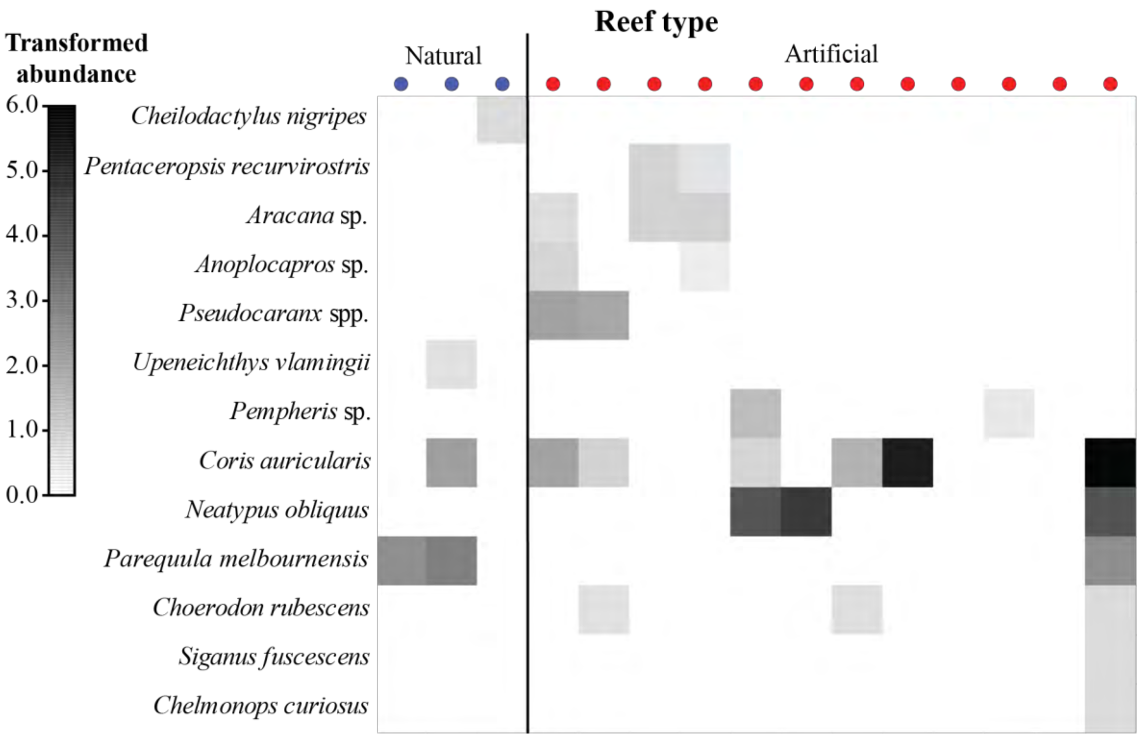


Fig. 2.11: Shade plot of the square-root transformed count-N data from the 15 videos recorded over artificial and natural reefs, which were obtained from recreational fishers. Grey scale represents the square-root transformed counts of each species per minute. ● Natural reefs ● Artificial reefs.

2.4: Discussion

2.4.1: Data quantity and quality

Any discussion of the results of this chapter should consider that the study was severely limited by a lack of data. Reasons for this are considered in detail in Chapter 3, but, in brief, were a lack of volunteer participation, poor quality of the video footage, the short timeframe of the project and unseasonal weather. As a result of these issues, only three of the recreational fishers submitted videos and these had a total duration of ~64 minutes. This limited amount of data is far less than was anticipated. Initially each of the eight fishers was asked to collect 15 minutes of footage on each cluster and 15 minutes on nearby natural reef, at least once a month for a four month period (which was later extended by another two months). This, even without the additional months, would have equated to 4 hours and 20 minutes of footage per fisher, giving a total of 34 hours and 40 minutes. However, the amount of footage received from the citizen scientists was only 3.1% of this initial figure.

Following the feedback that the memory capacity of the camera and SD cards were not sufficient to record the amount of video footage requested, the methodology was changed to ≥ 15 minutes per month on any cluster and 15 minutes on a nearby natural reef. Had this methodology been adopted for the entire data collection period, 16 hours of footage should have been required, which was 16x more footage than was received. In addition, of the 17 videos received, only two were accompanied by location metadata. A critical evaluation and suggestions on how to improve volunteer management of citizen science projects such as this are given in Chapter 3.

In terms of picture quality of the videos received from the fishers, all 17 had a quality rating of ≤ 5 (out of ten). This lack of quality was due to a grain-like effect limiting clarity, a small field of focus, glare and turbidity. For example, one video had approximately 30% of the screen covered by 'pink fuzz' for the entire duration caused by glare. As a result ~20% of all individual fish encountered, when standardised to the maximum abundance per minute of footage, were unable to be identified. These fish were unable to be identified due the quality of the footage as well as the distance from the camera and in some cases, high levels of turbidity. Although some individuals could be identified as far as the Family level, they could not accurately be identified to species level and thus were included as unidentified species. Although it's not rare to observe unidentifiable fish, ~20% is an abnormally large number to encounter (discussed below), and is likely due to the quality of footage, glare and turbidity. A study by Ebner *et al* (2009) looked at whether remote underwater video can be used to investigate in-stream behaviour of small fishes and decapods in Cottie River, Australian Capital Territory. The study found 9.36% of individuals unidentifiable. Another study by Fischer *et al* (2007), assessed the role of habitat complexity for fish using a small, semiportable, 3-D underwater observatory in Lake Constance, Germany. This study classified 10% of individual fish as unidentified because they could not be identified to species level. To fix the issue of identifiability, several studies only include the unidentified fish data in certain parts of the analysis, such as overall abundance measures (Gledhill *et al*, 1996; Ebner *et al*, 2009). A study assessing reef fish populations (Gledhill *et al*, 1996) in the Gulf of Mexico included unidentified fish in estimates of general reef fish abundance, however excluded unidentified fish data from a species table for frequency of fish occurrence 0.5 m or more above the bottom. This aforementioned study didn't divulge the number of unidentified individuals, just that they were observed on the video tapes. It should be noted that univariate and multivariate analyses and results (except Table 2.2) disregarded unidentifiable species as outliers, as they could not contribute to a Max-N or total species values or belong to a specific ecological group, although they could be grouped as unidentifiable individuals in a Count-N analysis. It should be discussed that this is therefore, another limitation to the data that ~ 20% of all individual fish encountered, when standardised to the maximum abundance per minute of footage could not be included in the preliminary results. This large percentage of fish, could have potentially altered the differences between abundance and number of species in footage from artificial and natural reefs.

2.4.2: Comparisons between the fish faunas of artificial and natural reefs

Many studies globally, have compared the fish assemblages of artificial and natural reefs. Of several studies analysed, the large majority of papers found both number of species and abundance to be significantly higher in fish assemblages on artificial reefs rather than natural reefs (Bohnsack *et al*, 1994; Bombace *et al*, 1994; Arena *et al*, 2007; Booth and Fowler, 2013; Folpp *et al*, 2013; Koeck *et al*, 2014) while less papers found the number of species and abundance to be significantly higher on natural reefs (Burchmore *et al*, 1985; Car and Hixon, 1997). Some studies found there is no difference between the structures (Fowler and Booth, 2012) and that natural reefs have a higher number of species but lower abundance (Hackradt *et al*, 2011; Granneman and Steele, 2015). In a general sense, it is a challenge to identify a trend throughout the results of the papers due to the variation in research projects, *i.e.* spatial and temporal variation in fish assemblages and structures, distance to natural reef, dimensions of the artificial and natural reefs being compared and amount of habitat complexity each reef exhibits amongst other factors.

Although limited data were available, preliminary comparisons between the characteristics of the fish faunas of artificial and natural reefs were able to be undertaken. In terms of both Max-N and Count-N, greater numbers of fish were recorded on artificial rather than natural reefs. While there were also seven more species recorded on artificial reefs, it is important to consider that more footage was collected over artificial reef than natural reef and, generally, those videos on the artificial reefs were longer. Thus, further sampling and analysis should be conducted to determine whether this is a *bone fide* finding or a sampling artefact. However, a potential explanation for the greater abundances and number of species recorded on artificial reefs may be due to the upwelling effect, vertical profile, range and complexity of the habitat, and growth on the modules (Bohnsack *et al*, 1994; Kellison and Sedberry, 1998; Rilov and Benayahu, 2000; Svane and Peterson, 2001; Hunter and Sayer, 2009; Department of Fisheries, 2012b; Granneman and Steele, 2014).

Surveys of the substrate of Geographe Bay demonstrate that high profile reefs only represent a small proportion of the benthic habitats in the nearshore waters of the embayment, as the majority of the substrate comprises low profile reefs, sand and seagrass beds (McMahon *et al*, 1997). It is therefore possible that the increased number of species and abundances of fish on the artificial reefs could be due to the relatively large vertical profile (3 m). This is supported by the findings of a study by Kellison and Sedberry (1998) who compared the abundances of fish on low and high vertical profile artificial reefs in Charleston, South Carolina in America. These authors found that the abundance of finfishes were significantly greater on the reefs with higher vertical profile. Moreover, research conducted by Harman *et al* (2003), on natural reefs in Hamelin Bay south-western Australia, found a significant difference between the numbers of species of sites location on high and low vertical profile reefs in the same area, with more species being found on reefs with higher vertical profile.

It is also possible that the combination of the two habitats, *i.e.* the artificial modules and the surrounding natural habitat, predominantly sand and seagrass, could create an ‘edge effect’, possibly resulting in species segregation, potentially driven by predation or competition (Dorenbosch *et al*, 2005). Generally, edge effects are changes in community structure (fish assemblages) that occur at the boundary of two habitats (Harris, 1988). Depending on underlying mechanisms, the transition of different habitats may result in an 'edge effect' where species can potentially increase or decrease in abundance and biodiversity (Ries and Sisk, 2004 and Dorenbosch *et al*, 2005). These increases or decreases of abundance and biodiversity along the boundary of two habitats can be caused by migration of individuals and fish schools between habitats, the presence of predators and the availability of food (Dorenbosch *et al*, 2005).

The presence of sand and seagrass with the relatively high vertical, albeit artificial reef and the natural low profile reef also increases habitat complexity. Moreover, artificial reefs, such as those deployed in Geographe Bay, are designed to provide complex spaces and areas varying in water flow and light shade. These reefs can also provide cryptic spaces and shelter for a range of organisms including fish and invertebrates (Kellison and Sedberry, 1998; Charbonnel *et al*, 2002; Hunter and Sayer, 2009). As a result they can have a positive ecological effect, often facilitating the development of highly diverse marine communities with characteristics (such as the recruitment, colonisation, succession and development of sessile biota) that reflect those of natural reefs (Svane and Peterson, 2001). A study by Hunter and Sayer (2009) tested species diversity and abundance on natural reefs, simple artificial reefs and complex artificial reefs, with the complex artificial reefs harbouring 2-3 times greater number of individuals for most species. This finding led the authors to conclude that 'enhanced habitat availability produced by the increased structural complexity delivered through specifically designed artificial reefs may have the potential to augment faunal abundance while promoting species diversity' (Hunter and Sayer, 2009).

Although the individual artificial reef modules are only three meters high, their unique cross brace design promotes not only shelter for fish habitats, but also potentially increases upwelling (Haejoo, 2011). Such a feature aims to 'force' water currents of colder, more nutrient-rich water from close to the substrate up and into the water column, thus providing a food source for plankton and larval fish, which, in turn, attract larger fish. This theory was tested in Bungo Channel in the Seto Inland Sea, Japan by Yanagi and Nakajima (1991), who deployed an artificial reef with the aim to induce upwelling. Field observations preformed before and after the deployment demonstrated that concentration of nutrients and chlorophyll *a* (the latter a surrogate for phytoplankton biomass) and biomass of zooplankton all increased after deployment.

Having been deployed 15 months before the start of this study, the artificial reef modules had had the opportunity to be colonised by a range of sessile organisms (see Fig. 2.4). The growth of these sessile organisms on artificial structures has been shown by Bailey-Brock, (1989), to provide food for some reef fish and eventually increase cover by adding to the three-dimensional structure of the reef. It is thus relevant that, compared to initial surveys at the deployment sites, after two years, four times more fish species have been recorded on the artificial reefs (Paul Lewis, Department of Fisheries, *pers.* comm.).

From a fish community perspective, PERMANOVA did not detect a significant different in the compositions of the fish fauna recorded over artificial and natural reefs. Shade plot analysis demonstrated that the lack of difference between the two reef types was due to the high levels of variability on the fish compositions within a reef type and the fact that several species were recorded in both environments. This highlights the fact that the above analysis should be approached with caution, due to the limited amount of data available and that more video footage is required to statistically analyse, in a robust quantitative manner, the fish faunas of the two types of reefs.

2.4.3: Future work

Due to the low amounts of footage received from the participants, the results detailed in this chapter should be considered preliminary. This lack of data (particularly the number of videos [samples]) reduced the suite of hypotheses available to test. However, if greater amounts of footage were received from the participants then it would have been possible to compare the fish faunas on the two artificial reefs (*i.e.* Bunbury and Dunsborough) in addition to the artificial *vs* natural reefs comparison.

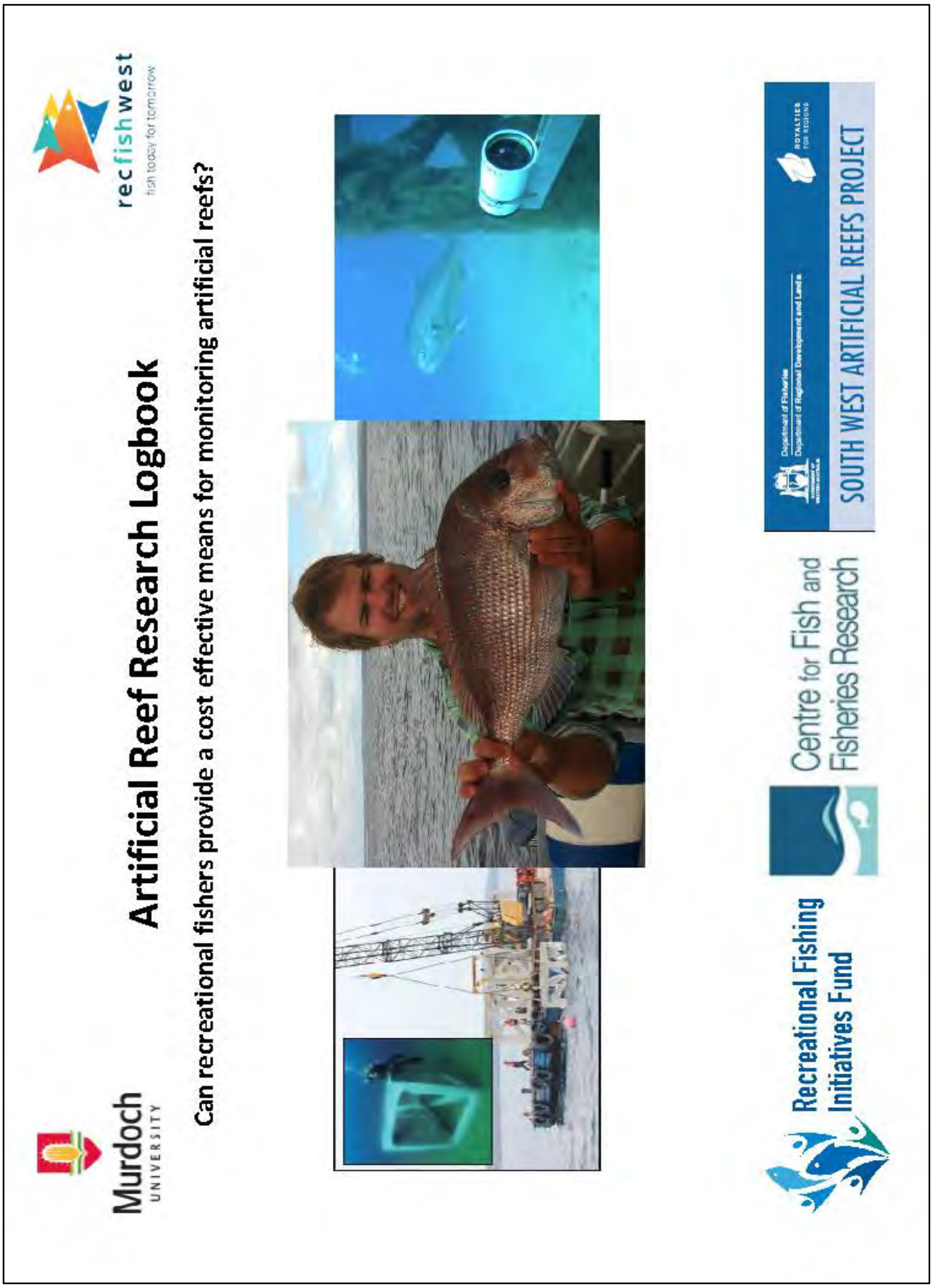
As the fish faunas of natural reefs around the world have been shown to change seasonally (Sale, 1980; Holbrook *et al*, 1994; Felix-Hackradt *et al*, 2013; Henriques *et al*, 2013; Lopez-Perez *et al*, 2013), it would be useful to see whether the fish fauna artificial reef changes temporally and, if so, whether it follows the same pattern of changes as natural reef. This would also identify the species which utilise the reef for large periods of time, *i.e.* resident species, and those more 'transient' species, which may utilise the reefs for shorter periods of time.

2.4.4: Summary

The lack of data received from the participants' severely limited hypothesis able to be tested and the range statistical analyses employed. However, a preliminary assessment of the fish faunas of artificial and natural reefs was undertaken. This included a preliminary assessment of the hypothesis that there is a difference in the fish assemblages on natural and artificial reefs. The results of this preliminary assessment suggest that artificial reefs had much higher levels of mean and maximum abundance, number of species and ecological group affinities. However, multivariate statistical analyses did not detect any differences between the fish faunal compositions between artificial and natural reefs. This was due to the dominance of the labrid *C. auricularis* and the large amount of variability between replicates. Although this study experienced several limitations it's important to recognise that it was a pilot study and first of its type in Western Australia. The management of volunteers and the citizen science component of the project, as well as future recommendations to improve engagement will be discussed, in detail, in Chapter 3.

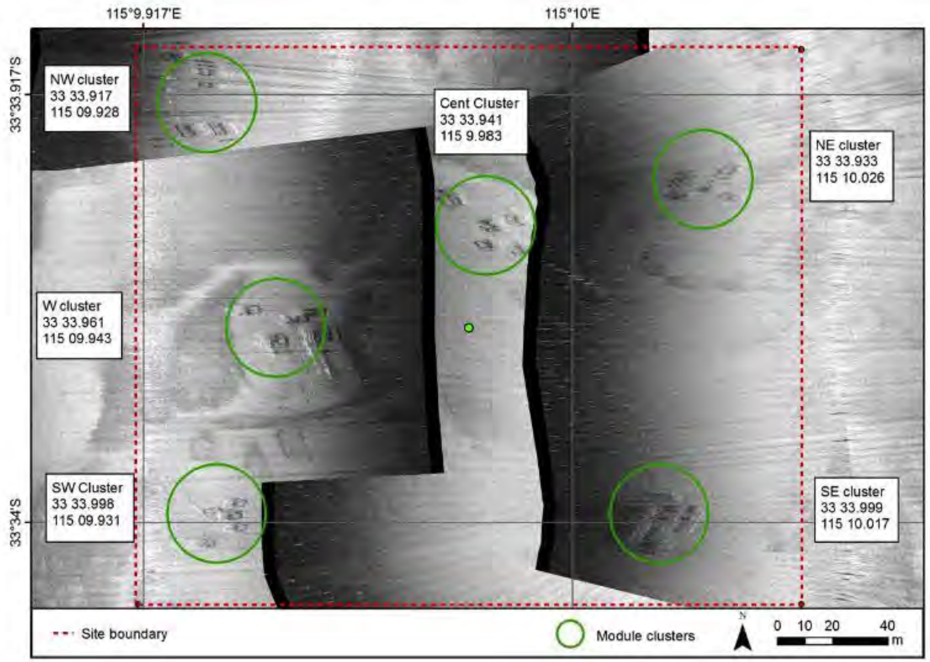
2.5: Appendix

Appendix 2.1: Example pages from the logbook given to participants.



Coordinates and locations for the Dunsborough artificial reefs

Thank you for your participation!



PLEASE NOTE PRIOR TO INITIAL CAMERA DROP: When deploying the cameras over the artificial reefs, it does not matter how long you wish to record for. HOWEVER we ask that you do each individual drop for the same amount of time as your first drop for that day. For example, if you record for 5 minutes on the first drop, please do not go for more or less than 5 minutes on each of the other drops, including on natural reef. Any confusion or questions, please ring (email) Howard Gill on **0406995036** (**h.gill@murdoch.edu.au**) or James Florisson on **0410320663** (James@recfishwest.org.au).

EXAMPLE SHEET (BUNBURY)

Date : November 7 2014

Reef module	Camera in (time: hrs/mins)	Camera out (time: hrs/mins)	Total (time: hrs/mins)	Species caught (cm), other comments:
NW cluster 33 18.454 115 35.859	10:25am	10:30am	5 minutes	No fish, few decent bites.
Cent cluster 33 18.479 115 35.898	10:52am	10:57am	5 minutes	2 pink snapper (35 and 40cms)
NE cluster 33 18.472 115 35.941	11:30am	11:35am	5 minutes	No bites, school of dolphins
W cluster 33 18.499 115 35.853	11:47am	11:52am	5 minutes	Strong gusts, no bites
SW cluster 33 18.545 115 35.857	12:04am	12:09am	5 minutes	1 Baldchin groper (62cm) released
SE cluster 33 18.529 115 35.895	12:31am	12:36am	5 minutes	2 Dhufish, 42 and 53cm, smaller released
Natural reef	01:35am	01:40am	5 minutes	Saw a bronze whaler, hooked 3 pink snapper, released 2 under 40cm. kept one at 76cm.

General comments, e.g., wind, swell current strength and direction etc: Gusty at times, wind changed direction from NE to SW around 10-15knots. Not much swell.

Chapter 3: Citizen science and how it can help provide a cost effective means for monitoring artificial reefs

Abstract

Volunteer recreational fishers were used as citizen scientists to monitor artificial and natural reef fish assemblages in Geographe Bay, Western Australia. This chapter investigated the role of citizen science in this project and how it influenced the hypothesis that fishers can effectively monitor artificial reefs. The resultant data from the initial project period had a low level quality and quantity due to environmental, operational and communicational issues. After a background review of citizen science, an analysis of the citizen science approach to the methodology was undertaken, followed by a critical review of the original citizen science methodology. A set of future recommendations in relation to citizen science approaches was developed to allow a higher level of quality data in higher quantities as well as more efficient volunteer management, engagement and communication in future monitoring programs that use citizen scientists.

3.1. Introduction

The fishers that monitored the Dunsborough and Bunbury artificial reef clusters, as part of the South West Artificial Reef Trial, as well as nearby natural reefs (used as a control site) were volunteers collecting data for a scientific research project. Thus, these fishers are citizen scientists. The use of citizens and the general public in science, is known as citizen science. Citizen science is an increasingly growing area in scientific research, providing benefits such as cost efficiency and effectiveness, social benefits to volunteers and the possible provision of large temporal and spatial data sets - in relevance to certain project purposes (Silverton, 2009; Dickinson *et al*, 2010; Wiersma, 2010; Baltais, 2013; Wilson and Godinho, 2013; Sullivan *et al*, 2014). There are also however, issues in relation to utilising citizen science in research, such as the commonly misconstrued (not applicable to all citizen science projects) stigma around data quality, as the data is not collected by experts and other issues such as volunteer attrition rates, poor management and potential for error and bias due to potential lack of objectivity in volunteers and variations in sampling effort over time and space (Conrad and Daoust, 2008; Dickinson *et al*, 2010; Wiggins and Crowston, 2011; Rotman *et al*, 2012).

This study utilised volunteer recreational fishers to collect footage of fish assemblages on natural and artificial reefs to test the thesis hypothesis that fishers can effectively monitor artificial reefs. Fishers were asked to collect footage by drifting a 360^{o} rotating camera over the artificial and natural reefs, to collect quantitative and qualitative data on the differing fish assemblages, for set periods of time. Fishers were also asked to fill in specific details in a logbook, as well as store data and communicate with researchers. Although some data were collected in this initial phase of the project, the quality and quantity of the resultant data were not high. Only 17 videos, equating to 63 minutes and 42 seconds was collected from only 50% of the fishers. All the videos had a quality rating of 5 or under out of 10, and over 25% of all individual fish encountered over all the footage were unidentifiable. The poor quality and quantity of data was due to a number of communicational, operational and environmental issues.

This chapter commences with a background review of citizen science including issues, benefits, types and aquatic citizen science projects in WA. The purpose of this is to inform the reader of the developments, approaches, strengths, difficulties and techniques associated with citizen science. This then provides the basis for the analyses of the citizen science approach to the methodology utilised in this study, to see whether fishers can monitor artificial reefs. The aim of this chapter is to create a review of citizen science to then informatively analyse the citizen science approach to the project methodology. Another aim is to then critically review the original citizen science methodology to create recommendations for future recreational monitoring programs.

3.2. Citizen Science Background and Review

3.2.1. Introduction

As the human population increases, so does the range and extent of deleterious anthropogenic activities and associated perturbations. As a result, there is a growing need to monitor these influences to ensure ecosystem sustainability. The collection of robust scientific data by government organisations and tertiary educational institutions can be expensive and prohibitive. Thus, for example, the cost of monitoring several fisheries is more than the income the government receives from these fisheries (Leyland Campbell, Recfishwest, pers. comm.). In an effort to reduce costs and engage the general public many organisations are turning to citizen science. Citizen science is defined by Open Scientist (2011) as "*the systematic collection and analysis of data; development of technology; testing of natural phenomena and the dissemination of these activities by amateur scientists, the public or researchers on a primary avocational basis*". This term encompasses a variety of aspects of volunteering in scientific research including community-based monitoring, community science and volunteer monitoring (Sbrocchi, 2013). The different types, research aims, capabilities and opportunities in citizen science are vast and varied, for example: counting numbers of stars in distant galaxies, determining the timing of flowering events, monitoring the health of coral reefs and recording information on bird migrations (Gollan, 2013). The success of many of these projects has resulted in decision makers and non-government organisations increasing their use of citizen volunteers to enhance their ability to monitor and manage natural resources, track species at risk and conserve protected areas (Conrad and Hitchey, 2011).

Citizen science is not a modern facet of science. In the past many scientists have conducted research, with their studies being avocational or unpaid and thus essentially being a form of citizen science. For example, Benjamin Franklin was a printer, diplomat and politician and Charles Darwin sailed on *HMS Beagle* as an unpaid companion to Captain Robert FitzRoy, rather than as a professional naturalist (Silverton, 2009). The restrictions facing modern research (such as costs, funding cuts and collecting large amounts of data across large spatial and temporal ranges) are fuelling exponential growth in the area of citizen science. Silverton (2009) and Baltais (2013) both commented that as of January 2009, the ISI Web of Knowledge database only contained 56 citizen science research articles, with 80% being published in the last 5 years. However, there are hundreds of scientific publications investigating patterns and processes that are based upon data gathered by citizen scientists. As of April 2015, the ISI Web of Science contained 355 citizen science articles, 299 more than in 2009, however it's likely that there are many more articles included in the collection based on data procured through citizen science. Though citizen science can be applied to most scientific disciplines (from drug trials in medicine to observations in astronomy), it is also commonly used in the analyses of ecological patterns and processes. Many ecological processes occur over large spatial and temporal scales, including migration patterns, disease spread and species range changes. Gathering sufficient data on such processes can be difficult using traditional research methods, particularly given limitations in time and funds (Bonney *et al*, 2009; Dickinson *et al*, 2010; Tulloch *et al*, 2013). Recruiting volunteers from the general public into citizen science projects potentially offers a low cost way to expand the reach and frequency of data collection, although this can be dependent on context (Lambert, 2014). This background to citizen science aims to critically review the benefits and limitations resultant of using citizen science for research purposes. It also aims to assess the range of types of citizen science projects, as well as document the citizen science projects that have been or are being conducted in aquatic environments in Western Australia.

3.2.2. Benefits

The number of citizen science projects is expanding both in Australia and throughout the world due to the benefits it provides both to the project managers (such as cost efficiency) and the participants (such as social values). The major benefit of citizen science to the project managers and/or researchers is its cost effectiveness and efficiency and increasing stakeholder capacity (Wiersma, 2010; Sullivan *et al*, 2014).

The use of volunteers helps reduce the overall cost of the research by i) reducing fieldwork and/or data collection costs, ii) reducing staffing costs and iii), by reducing the above costs, and may also reduce the cost of indirect or 'hidden' charges such as oncosts and overheads.

Volunteers can collect data over large spatial scales, creating large longitudinal data sets which have led to new quantitative approaches to emerging questions about the distribution and abundance of organisms across space and time (Dickinson *et al*, 2010). One of the best examples to illustrate the power of citizen science in obtaining large amounts of ecological data is eBird. This project, which was established by the Cornell Lab of Ornithology in 2002, collects information on bird distribution and abundance through the presence or absence of species and through checklist data. Through a combination of community engagement and partnerships, eBird has created a global network of volunteers who submit an average of three million observations per month (Lambert, 2014 and Sullivan *et al*, 2014).

Similarly, in Australia, the Range Extension Database and Mapping Project (REDMAP) was developed and launched in 2009. This is a web-based citizen science initiative where community members submit photographic observations of species found outside of their native range, which are then verified by expert scientists (Pecl *et al*, 2014). REDMAP was created after it was identified that range shifts globally, are one of the most frequently reported impacts of climate change (Pecl *et al,* 2014). Detailed examination of whole assemblages or ecosystems suggest that between 20% and 85% of species are shifting where they live in response to changes in temperature (Chen *et al*, 2011 and Wernberg *et al*, 2011). To date, REDMAP has had over 1,060 reports of species outside of their previously known and recorded ranges, verified by over 80 expert scientists (Pecl *et al*, 2014).

The cost-saving and efficiency of successful citizen science projects can be very large, for example, two studies by Dickinson *et al* (2010) and Sullivan *et al* (2014) both analysed the cost effectiveness of 'Project Feeder Watch', to find it was extremely cost effective at collecting large amounts of data. Dickinson *et al* (2010) suggests that the

Cornell Lab's Project Feeder Watch contributes $3 million per year worth of observer effort, and Sullivan *et al* (2014) noted that the cost per datum on eBird in 2008 was only 3 cents (Wiersma, 2010). It's likely that in most citizen science projects, the value of the project increases with the number of participants and the amount of data provided by those people (depending on the context of the project). It is important to consider that, while citizen science can save financial resources in a number of different facets, they do require initial and continued expenditure.

Many citizen science projects have developed data platforms and portals such as websites and smart-phone applications that are user friendly and easy to input large amounts of data. The design and development of such software can be expensive, however, having the end users enter the data saves costs in the long term by preventing the data being manually entered by researchers and for the ability for large amounts of free data (i.e. numbers, photographs and videos) to be uploaded. Moreover, the development of software (e.g. a smart-phone application) may increase the accuracy of the resultant data over paper recording (e.g. a logbook) by i) promoting the end user to look at potentially erroneous data and, where necessary, modify and ii) by standardising data by forcing the end user to choose from a small list of options and iii) automated data from the device (e.g. location / time data) rather than data entered by the end user (Kerry Trayler, Swan River Trust, pers. comm.).

While the costs of citizen science surveys can be high, Goldstein *et al.* (2014) found that this method was more cost effective and efficient on a per detection basis for the purpose of recording the presence of the species being studied. These authors stated that "*in the face of increasing ecological and economical costs of biological invasions we recommend straight forward citizen science surveys, over indirect field surveys, to managers and researchers seeking to efficiently track progressing invasions of readily observable animals cost-effectively*".

One of the less obvious benefits of citizen science is fostering collaboration between organisations to share data, funding, resources, volunteers and reach a wider audience by promotion through alternative networks. One example of this multi-organisational collaboration is PrawnWatch in WA. PrawnWatch receives shared funding from the Swan River Trust (WA government agency that manages the Swan Canning Riverpark) and Recfishwest (WA peak body for recreational fishing), shares data with Murdoch University, Swan River Trust and Recfishwest and has a large range of alternative networks through Murdoch University, Recfishwest, Department of Fisheries and the Swan River Trust (Leyland Campbell, Recfishwest, pers. comm.). Another active example of this was the creation of the Reef Citizen Science Scoping Study by the Great Barrier Reef Foundation. This enhanced collaboration between citizen science groups across the reef, promoted and raised the credibility of citizen science and optimised the use of citizen science data by scientists, reef managers, conservation groups and communities (Great Barrier Reef Marine Park Authority, 2013). A further benefit is that due to large temporal and spatial ranges combined with observer effort, citizen science appears to be particularly effective at finding disappearing native species, rare organisms, new organisms and invasive organisms. This is demonstrated in many studies, two examples include the Lost Ladybug Project (lostladybug.org) finding extremely rare native ladybugs by the public analysing ladybug species compositions (Dickinson *et al*, 2010) and FeralScan (feralscan.org.au) in which the public map feral animal sightings in their area, which is an Australian initiative that now has over 25,000 community recordings (Lambert 2014).

The major benefit of citizen science from the citizen's perspective is the social values of volunteer involvement. Volunteers, by engaging in the project, are able to become a 'scientist' for a certain period of time helping to contribute and collect data and samples. A citizen science based project in Melbourne, designed to describe the distribution and habitat preferences of bats, found that the benefits to volunteers included i) discussing research and wider conservation issues with scientists, ii) experiencing something unique (e.g. seeing animals and habitats that they didn't know existed in the area), iii) gaining an understanding and appreciation of the issues facing the organisms and their importance in ecosystems as well as mastering new skills and

iv) developing an appreciation of the effort involved in collecting ecological data (Wilson and Godinho, 2013).

Involvement in citizen science programs can promote active engagement, encourage pro-environmental/ecological attitudes and behaviours and increase the public's scientific literacy, awareness of issues and ecological knowledge (Lambert, 2014). The evaluation by Jordan *et al* (2011), of an invasive plant monitoring project determined that volunteers' knowledge of invasive plants increased on average by 24%. Similarly, following engagement into a prawn monitoring project, participants' knowledge of the rules of the recreational fishery increased on average from 50% to 91% (Tweedley *et al,* 2014; Trayler *et al,* 2015). Furthermore, volunteers involved in the 'Monarch Butterfly (*Danaus plexippus*) Larvae Monitoring Program' reported that the project had led them to take an active role in habitat improvement (Oberhauser and Prysby, 2008 and Lambert, 2014). Other social benefits of engagement in citizen science projects include improved communication leading to shared goals between diverse stakeholder groups and increased engagement and participation in local issues and community development, all of which influence policy-makers (Fernandez-Gimenez *et al*, 2008; Conrad and Hilchey, 2011; Lambert, 2014).

3.2.3. Limitations

Although citizen science has many benefits, it also has several limitations. These can be broken into three main groups, namely organisational issues (including volunteer participation issues), data collection issues and data use issues. Conrad and Hilchey (2011) stated that many of the challenges for community based monitoring occur at the organisational level.

Organisational issues include occupational health and safety (Baltais, 2013), funding (Whitelaw *et al*, 2003), information access challenges (Discussed on page 11) (Milne *et al*, 2006) and a lack of volunteer interest (Conrad and Daoust, 2008). As legislation and regulations are consistently changing, especially in relation to occupational health and safety and insurance, the reviewing of policies and insurances needs to be continually undertaken by organisations to ensure adequate compliance. Legislation is an issue as if it's not adhered to, projects can lose funding. The Wildlife Preservation Society of Queensland (a major citizen science organisation) stated that insurance and workplace health and safety are emerging concerns and 'many contributory and collaborative projects offer no insurance to those projects through their own organisations' (Baltais, 2013).

Another major operational issue is funding. Funding issues vary between organisations, projects, locations and funding priorities, however, they can have dire consequences on citizen science projects. This is particularly problematic in relation to the timeframe around funding. For example, long-term projects are more susceptible to funding variations and issues, especially when the projects are funded by multiple short term grants from different organisations. Projects that rely on short term grants can present a barrier to long term sustainability (Crall *et al*, 2010). While corporate sponsorship is an option, active searching for funding opportunities, good communication techniques and enhancing relationships with funding bodies could potentially help alleviate funding issues, instead of depending on corporate sponsorship.

A final organisational issue is generating, managing and maintaining volunteers and volunteer interest. Generating and maintaining volunteer interest is a key challenge of citizen science and it is especially difficult as it's hard to establish clear links between citizen science projects and their influence on participant behaviour and attitudes (Lambert, 2014). Managing volunteers and volunteer interest requires qualified staff, usually a volunteer coordinator and can also be helped by having well established user friendly technology. 'Volunteers motivations are complex, change throughout the project life cycle and are strongly affected by personal interests and are thus an issue for citizen science project management' (Rotman *et al*, 2012).

The second major limitation of citizen science is issues with the collection of data. These issues include error and bias due to variation in observer quality and/or participant objectivity and bias from variation in sampling effort over time and space. Many of the error and bias are due to the fact that the skills of citizen scientists are often, as expected, much lower than those of research staff. Citizen scientists vary in ability, experience and the type of training they have been exposed too (Dickinson *et al*, 2010). These authors reported that, a lack of training can increase the error and bias in the misidentification of species, incorrect reporting and selective data collection. Age is also an important factor to consider. For example, a study undertaken by Delaney *et al* (2008) found that 80% and 90% of students in, respectively, grades 3 (8-9 years old) and 7 (12-13 years old) had the ability to differentiate between two species of invasive crabs, while older volunteers, who had at least two years of university education, were able to correctly identify both species and the age of the crabs with a success rate of 100%. For many projects, most of the variation in observer ability is due to new participants, affecting short and medium term projects. For example, a short term project will likely have a larger variation in observer skill than a long term project as new participants in a short term project do not have a long timeframe in which to learn, whereas, conversely, observers in longer projects have more time to be trained and learn accurate and consistent methods to conducting observations in longer projects. Several studies of volunteer based monitoring programs conducted over many years have documented 'learner' or 'first year' effects, where observers become better data collectors over time (Bas *et al*, 2008; Jiguet, 2009; Shmeller *et al*, 2009; Dickinson *et al*, 2010). An example of this can be seen in the French Breeding Bird Survey, in which the average increase in the detected abundance of bird species between the first and all subsequent years of volunteer participation was 4.3% (Jiguet, 2009).

Bias from variation in sampling effort over time and space is a common issue in citizen science and varies with method, effort, species and environments sampled. Bias caused from variation in spatial and temporal sampling effort usually stems from lack of standardization. To limit bias, most scientific projects have strict standardisation protocols in relation to intervals, repeated tests, guidelines and benchmarks. However, when these protocols are too demanding or strict, there is a chance of loss of volunteer participation and interest. For example, it might be easy to recruit volunteers to record data from wilderness environments during warm, dry summer months, but less so during colder, wetter months or vice versa depending on the climate of the environment. This can be minimised, to some extent, by having a large number of participants and using some of the more experienced volunteers (i.e. champions) to undertake more intensive roles.

The less control that programs have over effort, the greater the potential for bias in the resultant data, however, as specified before, a high level of control and standardisation can severely impact volunteer participation (Dickinson *et al*, 2010). Dickinson *et al*, (2010) considered that the data collected by citizen science programs that have no prerequisites for the minimum level of sampling effort required may be highly biased. For example, in a program where participants are asked to record species they see in a particular area, this can result in the over-reporting of rare species, under-reporting of common species, and failure to report repeated sightings, because they are not deemed as 'interesting' by the observer. Moreover, some volunteers even stop reporting when there are no interesting species recorded, this can lead to analyses and conclusions that reflect variation in effort more than actual biological patterns and processes (Dickinson *et al*, 2010). Thus, projects with no framework for standardizing effort may not necessarily present inaccurate data, but varying numbers of participants, count durations and inclusion of effort measurable, needs to be taken into account in the analyses of the project. The amount of effort expended should be considered an important variable that should be accounted for in analysis (Link and Sauer, 1999).

Spatial biases in sampling effort may also occur when resulting data are not representative of the habitat/location, the sampling method is not standardization and/or when large data sets are not filtered appropriately (Dickinson *et al*, 2010). If the habitat types surrounding sampling sites are not representative of the larger regional landscape, then differences in species occurrences or abundance may reflect spatial sampling bias rather than true geographic differences in population size (Lawler and O'Connor, 2004 and Niemuth *et al*, 2007). This can be accounted for by sampling in more locations, with more replications to try and increase the level of representation to the larger landscape. Irrespective of sampling methods, sampling sites should be representative of the surrounding region to be unbiased, if not, this can also introduce levels of bias to citizen science research. When managing large citizen science data sets (such as lots of recordings, samples or observations from ranging temporal and spatial scales), filters are extremely beneficial. Filters are a tool to select or omit specific data out of a larger data set and can be used in the data entry process to ensure all required protocol information is accurately entered as well as to extract specific data from large general data sets, post data entry (Hochachka *et* al, 2012). An example of filter use is in Project FeederWatch in which automated filters are used to identify potential errors in bird observations submitted by participants by the use of historical data and if a species had not been reported by at least 4% of participants in the last season (Bonter and Cooper, 2012). Some projects like eBird, get people to report for all species, but code birds that aren't targeted as absent, in presence-absence studies, thus just extracting data on the specific target species while still collecting a broad range of data (Bonney *et al*, 2009).

The final category of citizen science issues are those relating to data usage. These issues are centred on the perceived lack of quality and distrust of citizen science data as well as access rights to that data. In light of the issues discussed above, data collected by citizen scientists may not be taken seriously by decision makers and scientists (Conrad and Daoust, 2008 and Wiggins and Crowston, 2011). Thus, many researchers can potentially find that their data is not considered for use in the decision making process or published in scientific peer-reviewed journals, either due to data collection concerns or difficulty getting their data to the appropriate decision-maker or journal (Milne *et al*, 2006; Conrad and Daoust, 2008). The values of certain citizen science groups and volunteers may also impact data use, for example, purposely targeting or avoiding certain species to get a desirable outcome. These concerns led to the US Congress, in 1994, calling for the National Biological Survey to exclude data gathered by volunteers because of the belief that their 'environmentalist agenda' would lead to biased data collection (Root and Alpert, 1994; Conrad and Hilchey, 2011). Citizen science projects may also encounter issues around intellectual property rights and data ownership policies. For example, Only 64% of the invasive species monitoring programs reviewed by Crall *et al* (2010), generated species distribution maps and only 23% made their data publically available, due to concerns about privacy and data sensitivity'(Lambert, 2014). This is likely due to some citizen science initiates not being adequately shared or analysed with other groups, as few projects inform volunteers about intellectual property rights or have clear data ownership policies (European Commission, 2014).

3.2.4. Types of citizen science

There are many different classifications and types of citizen science projects. These projects can vary from small scale localised studies (PrawnWatch) to global research projects (eBird). While citizen science has the potential to contribute to a plethora of research projects, it is best suited to studies where, i) data collection is labour intensive and involves fieldwork, ii) quantitative data are required, iii) the spatial and/or temporal extents are broad, iv) the methodology is well designed, simple and easy to execute, v) guidance material and/or professional assistance are available and vi) data submission can be done electronically (Gommerman and Monroe, 2012).

Citizen science is rapidly becoming more popular with people taking part in projects all over the world. Volunteers can now participate in projects on population ecology, conservation biology, ecological restoration, climate change and various types of monitoring. Throughout the rapid expansion of citizen science's popularity, a single universal classification for different typologies has not yet evolved, instead having various classification systems for project types. Dickinson *et al,* (2010), puts projects into organismal monitoring; classifying projects by taxonomic group, environmental monitoring; classifying projects by environmental variables and non-ecological projects which classify projects by their field of inquiry. Although approaches are diverse, two commonly accepted typologies are those proposed by Bonney *et al*, (2009a) and Wiggins and Crowston (2011). Bonney *et al,* (2009a) proposed a typology that classifies projects according to their degree of public participation, and Wiggins and

Crowston (2011) classifies projects based on their goals (Lambert, 2014). These two typologies are provided in Table 3.1 with examples.

Tables 3.1. Project Typologies, modified from Lambert (2014).

Bonney *et al*. (2009 typology)			
Type	Description	Example Project	Purpose
Contributory	Designed by scientists, volunteers primarily contribute data	ClimateWatch	Monitoring phenology (seasonal life cycles)
Collaborative	Designed by scientists, volunteers contribute data, refine project design, analyse data, disseminate findings	Coastal Walkabout	Monitoring coastal biodiversity
Co-created projects	Co-designed by scientists and volunteers	Streamwatch	Monitoring local stream health
Wiggins and Crowston (2011) typology			
Type	Description	Example Project	Purpose
Action	Citizens collaborate with scientists in action research approaches, often to address local environmental concerns	Sherman's Creek Conservation Association	Protecting local creek
Conservation	Focus on protecting and managing natural resources whilst educating the general public	Invasive Plant Atlas of New England	Mapping invasive plants
Investigation	Focus on testing specific research hypotheses	eBird	Collecting bird observations
Virtual	May have similar goals, but all activities are carried out remotely, using online platforms	Explore the Sea Floor	Classifying marine organisms
Education Projects	Primarily conducted to achieve educational goals (scientific rigour may be less important)	Biodiversity snapshots	Biodiversity surveys

3.2.5. Aquatic citizen science projects in Western Australia

With its ability to provide large data sets on a range of variables cost effectively and inform and engage the public, numerous citizen science projects been employed in a Western Australia. These projects vary from tagging, biological donations, logbooks and monitoring and identifying movements, patterns and range shifts and are covered in the following section.

3.2.5.1. Tagging

There are various citizen science projects that use tagging as a research tool. Tagging fish are part of what is known as the capture-mark-recapture sampling method (CMR). In CMR experiments, animals are captured, marked, released and recaptured many times by repeat sampling (Pradel, 1996), In WA, recreational fishers tag fish as well as submit recapture data, such as location, length and the health of the specimen, usually in logbooks (see 3.2.5.3 *Logbooks and monitoring*). Key species are tagged all over the state for various projects such as Dhufish (*Glaucosoma herbraicum*), Baldchin Groper (*Choerodon rubescens*), Pink Snapper (*Chrysophrys auratus*), Breaksea Cod (*Epinephelides armatus*) and Samson Fish (*Seriola hippos*) by Australian National Sportfishing Association WA, Westag and Infofish Australia. The Department of Fisheries also tags Tailor (*Pomatomus saltatrix*), Pink snapper, Samson Fish and blue swimmer crabs (*Portunus armatus*). Western Australian universities, gamefishing associations and fishing clubs also tag many species. Different species get tagged for varying purposes, for example, pelagic and migrating species such as Southern Bluefin Tuna (*Thunnus maccoyii*) are tagged to discover where the fish migrates to, its varying distributions and its growth if recaptured. All these species and many more are tagged and caught by citizen scientists in WA, with data going towards research on recruitment, movement and migration, stock structure, monitoring and mortality. The Department of Fisheries have created a tagging iPhone application for reporting recaptures which helps citizen science through being a user friendly basic vessel to transport tagging data.

3.2.5.2. Biological donations

Citizen scientists can also assist by helping sampling or donating their catch (or part of it). One of the largest and most successful of these projects in WA is known as Send Us Your Skeleton (SUYS), ran by the Department of Fisheries. SUYS asks recreational fishers to voluntarily donate fish frames belonging to a number of key recreational species such as: Herring (*Arripis georgianus*), Dhufish, Baldchin Groper, Pink Snapper and Bight Redfish (*Centroberyx gerrardi*) from their catch to allow biological data extraction by scientists to produce age structures and conduct stock assessment analyses (Fairclough *et al*, 2014). Some examples of the biological data extractable includes dietary analyses from the fish guts, sexual analyses from the gonads, genetic analyses from tissue samples and ageing from the otoliths (structure in the inner ear) or vertebrae of species (Fairclough *et al*, 2014). A multi-organisational project looking at restocking western school prawns into the Swan River Estuary has a citizen science component known as PrawnWatch. PrawnWatch has 135 volunteer citizen scientists (as of October 2014) that have participated in the broodstock collection events and contributed to the collection of 580 gravid females that produced 12.5 million eggs. A project ran by Murdoch University in the south-west of WA is based on fishers providing squid samples, has had over 3152 samples collected with over 28% coming from recreational fishers. The samples are aged and data being collected will contribute to biological information, as well as a stock assessment on this species. Biological samples are also taken by many recreational fishers when catching game fish such as Tuna and Mackerel (Scombridae), Dolphinfish (Coryphaenidae) and Billfishes (Xiphiidae and Istiophoridae) to help with research. Fin clips and tissue samples (in some cases used when collecting samples but releasing fish after) can be used for DNA and genetic analyses, hard parts such as otoliths and Chondrichthyes (sharks and rays) vertebrae can be used for ageing, guts can be used dietary and internal parasite analyses and gonads can be used to determine sex and sexual maturity (Pepperell, 2010). These differing biological samples can be used in studies to help analyse local and global genetics and distributions, biology, parasite analyses and ecology of these species (Pepperell, 2010).

3.2.5.3. Logbooks and monitoring

Another method for obtaining data from citizen scientists/recreational fishers is through the adoption of survey techniques or a fishing logbook. Surveys involve verbal contact with the participant and asking them a range of questions to collect data, while logbooks involve fishers themselves recording information on their catches to later be submitted to an organisation for analyses. A project by the Western Australian Department of Fisheries on blue swimmer crabs has over 100 recreational fisher volunteers issue logbooks to measure the size, sex and distribution of the crabs in the Swan-Canning, Peel-Harvey and Leschenault estuaries. The Western Australian Department of Fisheries also administers the Research Angler Program which involves anglers filing out logbooks to provide data on a whole range of variables on a large amount of recreational species. These variables can include population structure, movement, growth, mortality, abundance and diversity on species such as Tailor (*Pomatomus saltatrix*), Herring (*Arripis georgianus*), Squid (Order *Teurhoidea*), Dhufish (*Glaucosoma herbraicum*), Baldchin Groper (*Choerodon rubescens*), Pink Snapper (*Chrysophrys auratus*) and many others (Department of Fisheries, 2012c). The Department of Fisheries also conduct a survey known as the isurvey, where volunteers keep a 12 month diary for a biennial survey of recreational catch and effort. One of the main purposes of PrawnWatch (previously discussed) is also monitoring. Prawn catches are monitored and data is collected through a mobile phone application to analyse location information, type and number of prawns, gravidity of the prawns and bycatch information.

One of the more common types of citizen science approaches adopted as a marine research tool is monitoring. Monitoring generally means observing a system or species and recording any variability that is observed in the system or species. There are currently a number of marine based citizen science monitoring projects that use recreational fishers as volunteers. Stocked and tagged fish are monitored to ensure the health of the stock. This is currently being done by many different organisations in different projects such as monitoring tagged Black Bream (*Acanthopagrus butcheri*) in rivers and estuaries such as in the Peel-Harvey and Swan-Canning systems. Restocked bream are also monitored to assess the successfulness of the stocking activity in systems such as the Blackwood River Estuary in south-western WA. Fishers are asked to report the lengths of these restocked species to assess their growth rate as well as the number caught, to assess their size class and their contribution to the overall population. Restocked fish can be differentiated from natural cohorts as they generally have stained otoliths. Staining mediums such as alizarin complexone are used for staining the otoliths, initiated by emerging hatchery-reared juveniles in the stain, the stained otolith is still visible to the naked eye years later (Jenkins *et al*, 2006). Restocked Mulloway (*Argyrosomus japonicus*) and Barramundi (*Lates calcarifer*) are also monitored using the same method in the west coast and Kimberley regions of WA respectively. Monitoring can also be used to analyse the effects and successfulness of habitat enhancement structures such as FADs (Fish Attraction Devices) and artificial reefs.

3.2.5.4. Identifying movements, patterns and range shifts

Citizen scientists also play a key role in identifying movements, patterns and range shifts of migratory, invasive, rare and common species. The Department of Fisheries have the Pestwatch Application, in which hundreds of citizen scientists have reported sightings of invasive marine species such as the Asian date mussel (*Musculista senhousia*), northern pacific sea star (*Asterias amurensis*) and European fan worm (*Sabella spallanzanii*) and freshwater species such as Redfin perch (*Perca fluviatilis*), Carp (*Cyprinus carpio*) and Mosquitofish (*Gambusia holbrooki*) (Department of Fisheries, 2012a). Aquatic pests, aquatic diseases (including fish kills) and illegal fishing activities are all reportable to FISHWATCH on the phone number: 1800 815 507. Citizen scientists can also log species sightings when the species are rare or not usually found in the area to show movements, patterns and distribution shifts such as in the REDMAP project. The Range Extension Database and Mapping Project (REDMAP) is a web-based citizen science initiative where community members submit photographic observations of species found outside of their native range, which are then verified by expert scientists (Pecl *et al*, 2014). To date, REDMAP has had over 1,060 reports of species out of their respective ranges verified by over 80 expert scientists (Pecl *et al*, 2014).

3.2.6. Summary

Citizen science is scientific research or analyses conducted by, or contributed to, from the general public or nonprofessional scientists. Applicable to most scientific disciplines, citizen science is increasing in popularity and is used for many different purposes such as collecting samples, observational monitoring and recording information on specific anomalies. Citizen science can generally be seen as a cost effective way of collecting, and in some cases analysing data, however it does have several more benefits as well as some notable setbacks.

There are many benefits to using citizen science in scientific research. One of the major benefits is its cost effectiveness and efficiency, due to reducing fieldwork and data collection costs, reducing staffing costs and reducing indirect costs such as overheads. Another benefit is that volunteers can collect data over large spatial and temporal ranges. For example, eBird, collects data from over 80 countries, has been for 13 years and as of August 13th, 2012 had 100,333,837 observations (Cornell University, 2012). Other benefits include organisational benefits in relation to sharing data, funding, resources and volunteers, as well as the benefit of enhancing social values attributable to volunteer involvement. There are also several issues with citizen science including organisational, data collection and data usage issues. Organisational issues can include legislation and insurance, funding, and variations in volunteer interest. Data collection issues include error and bias due to variation in observer or sampler quality and/or participant objectivity as well as bias stemming from variation in sampling effort over time and space. Final issues involve those in relation to data usage. These issues are based on the perceived (and in some case, potentially misconstrued) lack of quality in, and distrust of citizen science, as well as issues surrounding data access rights.

Citizen science is used globally to analyse organisms, objects, patterns and phenomena, from logging comets and asteroid showers (Fireball-global) and collecting bird observations (eBird-global) to locating and managing invasive plants (Invaders of Texas-America) and monitoring water, air, soil, biodiversity, bugs and the climate (OPAL-United Kingdom) (Lambert, 2014). In Western Australia, one of the main disciplines citizen science is used in, is biology and ecology (however it’s also used in many others such as medicine and anthropology). Citizen science in WA is used to monitor and sample many different ecosystems from terrestrially locating invasive fauna (FeralScan) to logging marine species observed out of their natural distribution while fishing, snorkelling or diving (REDMAP). Citizen science is used as a research tool in many aquatic projects in WA, including projects that utilize tagging data, biological donations, logbooks and monitoring techniques and those that identify movements, patterns and range shifts.

3.3. Can recreational fishers provide an effective means to monitoring artificial reefs? The Citizen Science approach to the methodology

3.3.1. Introduction

The aim of this thesis was to investigate whether recreational fishers could be used as citizen scientists to collect data on the fish communities of artificial reefs and, if so, are the data robust and is the process effective (see Chapter 1). In brief, a small number of recreational fishers were given underwater video cameras and asked to deploy them monthly on the man-made reefs deployed off Dunsborough and Bunbury as part of the South West Artificial Reef Trial. Fishers were asked to deploy the camera and collect footage for at least 15 minutes on natural and 15 minutes on artificial reefs as well as fill in a logbook. The footage would be transferred to researchers who would then calculate the abundance and diversity of fish utilising the artificial reefs and the difference between artificial and natural reefs. Such a project is classified as an investigation as it focussing on testing a specific research hypothesis, but is also contributory and collaborative as volunteers contributing data and helping to refine project design (Bonney *et al*, 2009; Wiggins and Crowston, 2011).

As this project commenced before the above citizen science literature review was completed, it is possible that some of the methodologies and engagement tools employed during the study (See Chapter 2), were suboptimal. Thus the aim of this component of my thesis is to assess and critically evaluate each stage of the citizen science components of the projects and suggest improvements to that methodology.

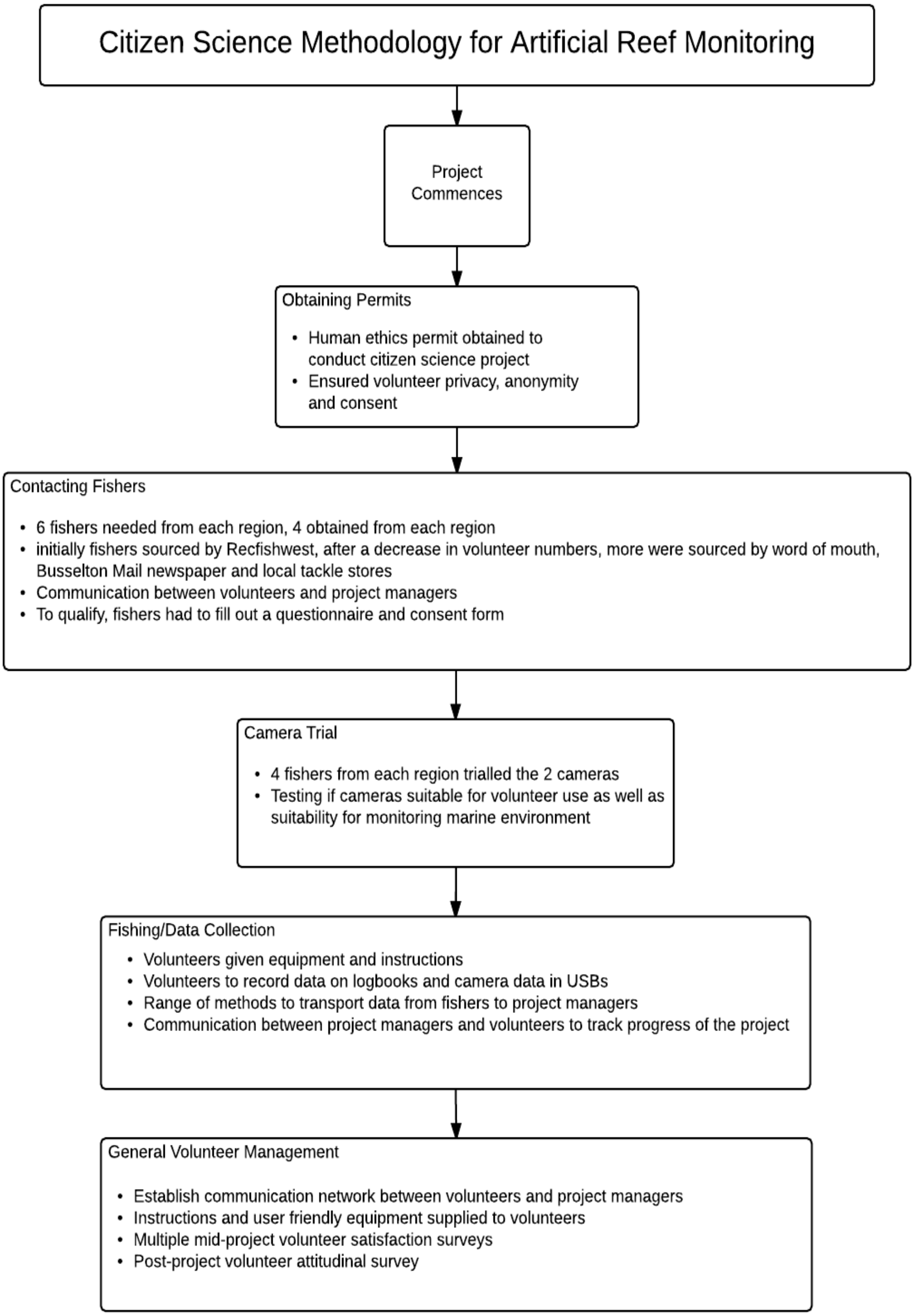


Fig. 3.1. Flowchart detailing the citizen science aspects of the project methodology.

3.3.2. Original methodology

3.3.2.1. Obtaining Permits and Contacting Fishers

Any university project involving human participants must obtain human ethics approval from the Universities Human Research Ethic Committee (HREC). The purpose of this panel is to ensure that the study conforms to the National Statement on Ethical Conduct in Human Research (2007) and that the research is of high quality and integrity and to protect the project participants (recreational fishers) and also the researchers. This project was approved by the HREC (permit number 2014_005) in early 2014, prior to the commencement of any engagement. To maintain volunteer privacy, participants were not to be identifiable by name, only by a volunteer code to ensure anonymity, this information was stored separately to the data. Each participant was also required to fill out and sign a consent form to ensure that they voluntarily committed to the study and understand the circumstances around instructions, responsibility, and the rights of the volunteer and that they will not be personally identified in any publication.

To ensure enough data were collected, the project aimed to recruit twelve recreational fishers, with six living in close vicinity to each of the artificial reefs in Bunbury and Busselton-Dunsborough areas. The selection of twelve was a trade-off between the need to collect sufficient data and the need to cap project costs, given the relatively high cost of the cameras. This number of volunteers was chosen to help account for any volunteer attrition stemming from issues with fishers, such as their boat not working for periods of time or their disengagement and subsequent removal from the project. Thus decreasing the impacts of these issues on the overall outcome of the project. Each of the volunteers, all of whom were avid recreational fishers, were asked to visit the reefs and record video footage using their own vessel at least once a month, notwithstanding of personal circumstances or environmental conditions.

The selection process was initially completed by Recfishwest, the peak body for recreational fishing in Western Australia. Out of the 14 applications from Recfishwest, a total of eight suitable fishers were enlisted, with four living in the vicinity of each of the artificial reef. These initial volunteers were recruited by responding to an advertisement placed in Recfishwest's electronic newsletter. This newsletter is emailed to Recfishwest members every month. Fishers were also recruited through direct contact with staff members at Recfishwest. After recruitment into the study, a project manager from Murdoch University contacted the fishers by phone and email, then travelled to Bunbury and Busselton-Dunsborough to speak, in person, to each of the volunteers. However, after only three months, 50% of the volunteers withdrew from the project, three from Busselton-Dunsborough and one from Bunbury. Reasons for their withdrawal included poor volunteer management by the project manager, personal reasons, attitudinal change and frustration at the long period of inactivity in the project due organisational issues, funding difficulties and delays between ordering and receiving the cameras. In an attempt to recruit more volunteers, the project was promoted via a news article in the Busselton Mail, a popular local newspaper, by holding discussions with tackle shops and by word of mouth from current volunteers. This promotion and advertising campaign led to the project regaining four volunteers at each location.

To participate in the project, each volunteer had to complete a questionnaire, which included details on the participants' recreational boating license, boating experience, type of vessel, availability of safety equipment and contact details. The purpose of the questionnaire was to make sure that the volunteers had a clear understanding of instructions and the project methodology, that they had conformed to all marine licencing requirements, *i.e.* licensed and insured vehicles and vessels complete with the required safety equipment, as specified by the Western Australian Department of Transport. Furthermore, that each volunteer had ample experience as a skipper, that the boat was suitable for use in the project, they knew what location they were asked to monitor.

3.3.2.2. Camera trial

A trial of two cameras, the 50m LCD Underwater Video Fishing Camera Kit with DVR and the Sony CCD 700 TVL (see figures 2.2 an 2.3 in Chapter 2) was undertaken, by the volunteers, in Bunbury and Dunsborough to select which camera was best for monitoring the fish assemblages of the natural and artificial reefs. Volunteers were asked to consider, i) ease of use and ii) potential safety issues. Ease of use is a major facet of citizen science, with user-friendly technology being a contributing factor in overall volunteer satisfaction (Newman *et al*, 2010). Insurance and workplace health and safety are emerging concerns in many contributory and collaborative projects (Baltais, 2013). Thus, the trial ensured that the camera equipment used in the majority of the monitoring was as safe as possible by considering potential issues such as the weight of the equipment and tripping hazards associated with the 50 m of cable required for the camera to comfortably reach the benthos.

Each volunteer involved in the trial selected the Sony CCD 700 TVL, primarily as this camera did not spin when the vessel was drifting and thus the operator had more control over the direction of the cameras field of view, was easier to operate and had less chance of entanglement in the modules due to its shape. The feedback from volunteers at this stage was intrinsically important to the project. Firstly, it provided sound advice of the pros and cons of the various cameras, leading to the selection of the most appropriate camera. Secondly, it allowed volunteer feedback to structure the project methodology, which may mitigate negative interactions between volunteers and the equipment in the future, whilst also giving participants a sense of ownership over the project.

3.3.2.3. Data collection

Following the completion of the camera trial and arrival of the Sony CCD 700 TVL cameras, the project manager travelled to meet each volunteer and give them their camera, verbal instructions on how to use them and an information sheet containing written instructions, artificial reef cluster location coordinates and contact details. Volunteers were asked to visit each cluster of the artificial reef modules and a nearby natural reef every month and record up to 15 minutes of footage. However, the feedback from several of the participants indicated that the memory (SD) cards included with the cameras were not large enough to store the footage the fishers were asked to collect. Thus, the duration of the monitoring was changed from 15 minutes on each cluster and natural reef area, to around five minutes on each, and to at least 15 minutes in total per month on each cluster. For each video, volunteers were also asked to complete a record in a logbook. The logbooks collected information on: (i) submersion time of the camera (to check it was for an adequate period of time); (ii) whether on natural or artificial reef (to help with metadata analyses and comparing differences between the natural and artificial reefs); (iii) which species were caught and their total size (to see if these species were similar to the species sighted in the footage) and any general comments or environmental observations (to help identify any outliers, patterns or different variations in the footage, such as different species in relation to time of day, or change in turbidity after a storm).

Logbooks were large with limited text and were taken on board the vessel during monitoring (Appendix 2.1). Volunteers were asked to transfer data to researchers at Murdoch University. Initially a cloud (internet) storage method, using the Dropbox software package, was trialled as this would automatically download any videos uploaded by volunteers to the researchers. This software, however, proved was too complex for the volunteers to use and thus USB sticks were employed. Once filled with video footage, the USBs could be mailed directly to Murdoch University, picked up by the project manager when visiting the fishers and/or be dropped off at the nearest Department of Fisheries office. While, in addition to the above methods, the logbook could be scanned or photographed and emailed. The project aimed to collect video footage and the corresponding logbook notes monthly from each participant.

3.3.3. Critical review of the original citizen science methodology and recommendations for future recreational fisher monitoring programs

Although some data were collected in the pilot project (See chapter 2), due to a number of environmental, operational and communicational issues, the quality and quantity of the resultant data were not high. Below follows a critical discussion and review of each of the steps in the citizen science aspects of the methodology and a suite of recommendations.

3.3.3.1. Contacting and recruiting fishers

There are several ways in which the previous method of contacting and recruiting fishers could be enhanced, to try and recruit a higher and more engaged level of volunteers (*i.e.* citizen science champions). The scope of the promotion and advertising campaign should be greater and more thorough, to generate a larger pool of applicants from which the best candidates can be selected. Such a media campaign should include both traditional and non-traditional media elements.

Traditional media elements would be centred on a press release (from project partners including Recfishwest and Murdoch University), followed by active engagement with interested parties, such as print, audio and visual media outlets. Audio platforms such as ABC Southwest and talkback radio (*i.e.* 6PR) would be ideal for this promotion of the project and generating interest among potential volunteers. Targeted interviews could also be conducted on pre-existing fishing radio programs, such as John Curtis's fishing reports on ABC Radio, as these shows are well known amongst recreational fishers. Similarly, the filming and inclusion of segment about the project on a Western Australian fishing program (such as Fishing Western Australia) would reach a large audience and offer the chance to show visually, what potential volunteers could partake in. Articles could also be published in popular fishing magazines such as Western Angler and the West Australian Fishing Magazine. By combining with organisations such as Recfishwest and/or the Department of Fisheries, the project could develop a media release with the Minister for Fisheries, which would increase the chances of TV stations doing a segment for the news. Advertisements and promotions would also be conducted through state newspapers such as The West Australian/Weekend West and Sunday Times and local newspapers, such as The Busselton-Dunsborough Mail, South Western Times, Bunbury Mail and the Bunbury Herald. Hardcopy advertisements and information sheets could also be put up on local bulletin and notice boards and given to tackle and camping stores within relatively close proximity to the artificial reefs and boat ramps.

Given the increasing influence of social media in recent years, any media campaign should include Facebook, Twitter and Instagram. There are a number of ‘group’, ‘community’ and ‘pages’ on the Facebook on which the project could be promoted *e.g.* Fishing Busselton and South West WA, Busso 4x4 Camping and Fishing, Busselton Fishing WA, Geographe Bay Yacht Club, Bunbury and Districts Power Boat and Fishing Club, Fishing Bunbury, Bunbury Fishing and Diving, Bunbury 4x4 and Fishing, Fishing South West WA, South West Artificial Reefs Community Facebook Page (Fig. 3.2) and Recfishwest. While, the current project did utilise Recfishwest’s electronic newsletter (E-news), which is send to over 50,000 recreational fishers in Western Australia, the Department of Fisheries have a similar newsletter (Catch!, see http://www.fish.wa.gov.au/fishing-and-aquaculture/recreational-fishing/catch-e-newsletter/Pages/default.aspx), which is emailed to all fishers who have any current fishing licence and those that subscribe separately, that could also be utilised.

The material released during the media campaigns should focus on the relatively simplistic nature of the data collection and the fact that fishers deploy the cameras during their normal fishing activity and thus don’t have to do separate trips or decrease their fishing experience and/or opportunities. Secondly, the releases should seek to instil a level of ownership of the artificial reefs and stewardship for the marine resources in the area, to engage the volunteers and give them a sense of purpose for the project and its relevance for the local marine environment. Finally, the last message that could be included would be the social benefits from contributing to a citizen science project such as those discussed earlier (subsection 3.2.2).

Fig. 3.2. The South West Artificial Reefs Community Facebook Page.

The main purpose of the media campaigns would be to recruit a sizable pool of volunteers. By acquiring a large suite of potential participants, filters can then be applied to select the most appropriate of those participants (*i.e.* champions). The greater the proportion of highly motivated and engaged volunteers, the more data likely to be collected. A higher level of recruitment of volunteers on each of the artificial reefs may be beneficial (*i.e.* recruiting backup fishers) in the case that participants leave the project for any reason. Similarly, a continued source of volunteers, as the result of engagement through regular media releases or updates would also be beneficial if the volunteer attrition rate increased.

3.3.3.2. Camera trial

While the camera trial was successful and no doubt increased the level of engagement with the volunteers, there were a number of issues with the camera (see chapter 2). Essentially, the quality and quantity of data gathered from the Sony CCD 700 TVL cameras was not statistically or scientifically adequate to test the hypothesis regarding the efficacy of citizen science monitoring of artificial reefs. In future, a trial involving a greater number of different types of camera should be conducted to ensure the quality of the video footage recorded is high enough for robust scientific analyses. Of course, this may led to a greater number of cameras being purchased for the trial and more expense, but better quality cameras would increase the value and accuracy of the project, noting too that this would increase the cost of the project.

One camera that should be trialled in future projects of a similar nature is the GoPro Hero 4™. This camera was initially excluded from the selection process as it did not feature a live feed back to the boat. This was considered a critical part of the criteria as it would enable the fishers not to get the camera equipment snagged in the artificial reef modules. However, its likely GoPros attached to buoys will have a lesser chance of entanglement than the live feed cameras. This is because they aren't attached to a drifting boat and the only chance of entanglement is getting dropped directly on top of the modules. The chance of this happening is minimal, however can be rectified by retrieving the snagged equipment by pulling from a direction against the current or snagged position to unsnag the equipment. The GoPro camera is smaller and more user friendly, it also records better quality footage (than the other tested cameras) which can increase the accuracy in the results of the data analysis. For example, a comparison of 10 minutes of footage on the same artificial reef yielded 20 more species on the GoPro than the Sony CCD 700 TVL, as only fish at a close proximity could be accurately identified in the footage collected using the latter camera (J. Florisson unpublished data; see later).

3.3.3.3. Data collection

The process of data collection should be changed to make the project more applicable and desirable for fishers, to decrease the level of bias, to make it operationally and logistically simpler for volunteers and to collect better qualitative and quantitative data from the locations. Thus, a new methodology is proposed. Fishers will be asked to deploy a Baited Remote Underwater Video system (BRUV) in a set randomised zone (See Chapter 4, Fig. 4.9) near one cluster of artificial reef modules for

40 minutes. A BRUV system uses either a single camera or two cameras (stereo-video to accurately measure distances) filming the area around a bait used to attract fish, the bait bag is placed close to the camera at a distance ranging between 0.5 and 1.5m (Ellis and DeMartini, 1995; Willis and Babcock, 2000; Heagney *et al*, 2007; Mallet and Pelletier, 2014). BRUVs are most commonly used to survey variations in fish assemblages between sites, changes in assemblages over time (for example, diurnal variations) and interactions of species attracted to the baits and how these species interact with the surrounding ecosystem, thus overcoming previous limitations to these types of sampling. Each fisher will also deploy the same BRUV setup in an area of nearby natural reef for 20 minutes on the same day. This methodology follows that developed by Recfishwest in their monitoring program. The BRUV setup will consist of a GoPro Hero 4^{TM} camera on a pipe sled (filled with 5kg of lead), attached to a buoy with 35m of rope. Fishers will also be asked to use a similar logbook as in the initial phase, the only difference being the addition of new locational information including the grid and randomised deployment coordinates.

A lack of clear and consistent instructions, like those given in the initial phase of this project, can increase error and spatial and temporal sampling biases and result in selective data collection (Dickinson *et al,* 2010), for example a volunteer only recording footage from one of the five clusters of artificial reef modules. To reduce spatial bias, it is recommended that volunteers will only be required to sample in one square on a grid, which encompasses a single artificial reef module cluster. The grid size will be standardised and each individual cell numbered and randomly assigned to a specific volunteer(s). This will reduce spatial bias by ensuring all reef clusters are sampled equally, theoretically at least. Likewise, if the same area of natural reef is monitored by all fishers, this would not be representative of natural reef fish assemblage composition due to lack of sampling location diversity. Natural reefs will be sampled for a period of 20 minutes, preferably on the same day as the artificial reefs. The location of the reef does not need to be known as the fishers would not feel comfortable in disclosing that information, and its unlikely fishers would monitor the same natural reefs as they would all likely have their own favourite areas of natural reef. Sampling sites should be representative of the surrounding region to be unbiased, if not, this can also introduce levels of bias to citizen science research. If the habitat types surrounding sampling sites are not representative of the larger regional landscape, then differences in species occurrences or abundance may reflect spatial sampling bias rather than true geographic differences in population size (Lawler and O'Connor, 2004 and Niemuth *et al*, 2007).

Temporal biases caused by lack of standardisation across sampling occasions during the current project were caused by unseasonal bad weather and timing delays with camera importation and variability from changes to instructions and guidelines. To mitigate this, participants in the future will be required to deploy the BRUV for at least 20 minutes, but no longer than 30 minutes (including a standard error time period of ± 10%) once a month in their set grid cells. The recording time of at least 20 minutes will allow the bait plume to travel far enough and attract a sufficient number of species for robust statistical analyses. There will not be a restriction on the number of replicate recordings collected in a grid cell in each month. The reason for only having a minimum level of replication is that the stricter the instructions the greater the chance of losing volunteer interest and participation. The presence of this minimum level of participation is that Dickinson *et al,* (2010) found that 'when programs have no prerequisites for minimum effort (that is, any type of effort is allowed), samples may be highly biased, resulting in inaccurate data collection.

With the original data collection method, volunteers are required to stay in the vicinity of their camera while filming, however, the BRUV may be attached to a buoy with a rope, rather than the camera being attached to the monitor on the boat (as with the original method). This would allow the volunteer to leave the immediate drop zone, and therefore they can actively fish for the period while the camera is deployed. This is considered attractive to the participants as they can actively fish and target specific species, rather than focusing on a small monitor screen for 15 minutes while drifting (as they did in the initial phase). A stationary benthic BRUV attached to the buoy is also likely to have a smaller chance of being snagged in the artificial reef module. This is because it isn't moving and drifting with a boat, instead being stationary on the ocean floor, thus mitigating risk in relation to drifting into modules. Although the use of bait with a BRUV could be viewed as a selective attractant increasing bias, all animals passing through the field of view, in response to the effect of bait or not, can be recorded (Armstrong *et al*, 1992). The lack of size selection, and the powerful sampling replication afforded by multicamera (BRUV) units avoids false negatives (Tyre *et al*, 2003) and allows standardised sampling at any depth, time of day and type of benthic topography (Cappo *et al*, 2007).

3.3.3.4. General volunteer management

Volunteer management is an important facet of any citizen science project. The benefits of correct volunteer management include low attrition rates, thus increasing cost efficiency by not having to promote and advertise for more volunteers, increased quality in the data set by having engaged and passionate volunteers and smoother communication and volunteer engagement throughout the project. A good relationship between volunteers and researchers can also give the volunteer the ability to discuss the research and wider ecological issues with scientists, experience something unique, see animals and habitats they didn't know existed in the area, master new skills and develop an appreciation of the effort involved in collecting ecological data (Wilson and Godinho, 2013).

It is recommended that the way volunteers were managed in the first phase of the project be altered to achieve more desirable project results and better relationships with volunteers. One way to develop a better rapport between the volunteers and the project managers would be for communication to occur at least once a week by phone and once a month in person (depending on project funding, this option may not be viable, or instead could be undertaken by a 'champion' volunteer, the most engaged and effective participant with good communication skills). The purpose of the phone call would be to check for any change in attitude from the volunteer towards the project, check that the equipment is functioning correctly and answer any questions the participants have, as well as disseminating results back to the fishers. Volunteers should be seen once a month by a project manager or engagement officer (or champion volunteer) to discuss aspects of the project and any issues and to collect copies of the video recordings. Such a meeting would eliminate the data collection and transport issues encountered during this study. It also shows the volunteers that the coordinators and engaged and involved in the project and presents an opportunity for the two way dissemination of information between the two parties as well as an opportunity for the presentation of any project findings to the participants. If the costs associated with this level of engagement are beyond the scope of the project, face to face data collection and engagement could be completed by project partners in regional governmental offices, such as staff from the Department of Fisheries who have offices in both Bunbury and Busselton. The contact should be at a standardised time for each fisher, and fishers should be able to have phone contact during office hours and email contact outside office hours. This would potentially foster positive engagement, for the volunteers to know that they have this level of support.

To make it easier for the fishers and to reduce error in the data collection, fishers would be given a clear, concise and simple set of standardised written instructions. The instructions would also have contact details for project managers and local safety information. These instructions would be have large pictures to show the steps, large text and be water proof so that they can be utilised while monitoring. Four times a year there would also be a gathering of volunteers and project managers. This would aim to increase relationships and the quality of the volunteer network, to discuss the project and for project managers to disseminate project results to that date. The gathering could also be extended to involved organisations such as Recfishwest and the Department of Fisheries as well as the general public. This could help increase attendance, sustain interest and engage the general public to give the local community a sense of stewardship over the project and the artificial reefs. It’s also another opportunity for volunteers to discuss any issues they are encountering with the project structure and equipment. A short film of the best segments of footage captured from the cameras would also be shown to keep volunteers interested, engaged and passionate about the project. After the project there would also be several other events, these would include a community seminar to discuss the findings to stake holders, local fishers, end users and the general public. A post project survey or interview would also be conducted with volunteers to gauge attitudinal variation at the end and throughout the project, what skills and knowledge they obtained and how they felt the project went. The purpose of this exercise would be analyse social and emotional variation in the volunteers to help with future citizen science projects, and to see if the volunteers would be interested in contributing to similar projects in the future.

3.3.3.5. Recommendations for future research

While this citizen science project yielded only small quantities of data (see Chapter 2), this was most likely due to unseasonal weather patterns, lack of volunteer communication and logistic difficulties with importing the cameras. Although this limited success could be interpreted as a setback in the case for using recreational fishers as cost-effective means to monitor artificial reefs, it's important to consider that this project is a pilot study, which had an evolving methodology. The following dot points represent key considerations that should be incorporated into any future project to employ citizen science to monitor artificial reefs.

- The method of contacting and recruiting volunteers should be enhanced, by using traditional and social media, with a greater scope for promotion and advertising to recruit a large quantity of better quality volunteers.
- Smaller GoPro cameras should be utilised on BRUV structures to maximise the quality and quantity of data as well as simplify the equipment and procedure for fishers.
- Clear and concise instructions and monitoring protocols will decrease volunteer attrition rates as well as spatial and temporal biases, while increasing the accuracy and quality of the footage.
- Positive outcomes of correct volunteer management can be optimised by adequate communication and engagement with the volunteers.

Chapter 4: Using Baited Remote Underwater Video systems to field test artificial reef monitoring technology and methodologies suited to citizen science

4.0: Abstract

Baited Remote Underwater Video (BRUV) systems, constructed from readily available materials, were deployed randomly around the Dunsborough artificial reef in a simplified but randomised sampling regime, *i.e.* to mirror fishing movements undertaken by recreational fishers, to test the applicability of this method for future use as a citizen science artificial reef monitoring tool. The video footage was analysed to determine whether there was a difference in fish assemblages between artificial reef modules and the surrounding area, *i.e.* videos observing areas in which artificial reef modules were, and were not, observed in the camera's field of view. The results demonstrated that the mean number of species and the number of benthic and epibenthic species were greater on footage recorded when the camera faced the modules. There was also a differences in the species composition, with species such as *Pentaceropsis recurvirostris* (Longsnout Boarfish), *Halichoeres brownfieldi* (Brownfields Wrasse) and *Pseudolabrus biserialis* (Red Banded Wrasse) being recorded in greater abundances on videos facing the modules, whereas some species such as *Dasyatis brevicaudata* (Smooth Stingray), *Trygonoptera personata* (Masked Stingaree) and *Trygonorrhina fasciata* (Southern Fiddler Ray) were more abundant on videos facing away from the reefs. Such a trend is due to benthic and epibenthic species (such as *P. recurvirostris*, *H. brownfieldi* and *P. biserialis*) preferring the shelter, light shade and habitat complexity supplied by the modules while other species like the Batoids (*D. brevicaudata*, *T. personata* and *T. fasciata*) may prefer surrounding sand and seagrass meadows to forage for prey. It was concluded that the BRUV technology employed here could be used, by citizen scientists, to monitor the fish faunas of artificial reefs in Dunsborough, and elsewhere. However, as this study has also demonstrated that there were significant differences in the characteristics of the fish faunas recorded depending

on the direction the camera was facing, consideration is needed to design an unbiased and robust quantitative monitoring regime.

4.1: Introduction

Monitoring of marine environments by resource and environmental managers and/or researchers can provide robust quantitative data that is of sufficient quality to inform management decisions. However, the draw backs of using governmental and tertiary education providers to undertake research programs is that these projects can be expensive and time consuming. One method to reduce some of these costs is to utilise citizen scientists to undertake community monitoring, as such programs can cover a larger area, in less time at a lower cost (Hill and Wilkinson, 2004; Silverton, 2009; Dickinson *et al*, 2010; Wiersma, 2010; Baltais, 2013; Wilson and Godinho, 2013; Sullivan *et al*, 2014). In recent years there has been an increase in the use of citizen science for collecting monitoring data, particularly over large spatial data sets cost effectively (Silverton, 2009; Dickinson *et al*, 2010; Baltais, 2013; Lambert, 2014), and there are currently several marine-based citizen science projects being undertaken in Western Australia (*e.g.* Department of Fisheries, 2012c; Fairclough *et al*, 2014; Lambert, 2014). As mentioned in Chapter 2, following the deployment of the two artificial reefs in Geographe Bay there is a legislative requirement to monitor the structural integrity of the reefs on an annual basis, as a condition of government approvals to deploy the reefs. In a similar manner to the work undertaken in Chapter 2 a citizen science monitoring regime for the reefs is currently being designed by Recfishwest, using Baited Remote Underwater Video (BRUV) systems to monitor artificial reefs, rather than the a 'drop camera' method tested earlier (see Chapter 2).

The overall aim of this chapter was to determine i) the effectiveness of another method of video capture of fish on artificial reefs, *i.e.* BRUVs, and ii) the effect of randomly placing the BRUVs in the vicinity of the artificial reef clusters and thus the field of view of the camera pointing towards or away from the modules. Specifically, the second of the above aims tested the hypothesis that the characteristics of the fish fauna recorded from BRUVs directly facing the artificial reef modules will be different from the fish assemblages recorded from BRUVs facing away from the modules. Thus, the results of this study include provide an indication was to whether randomised BRUV deployment is a viable method to employ in citizen science monitoring program for artificial reefs and whether or not additional methodological guidelines need to be put to ensure consistent and accurate data collection.

4.2: Materials and methods

4.2.1: Study site

This study was conducted on the artificial reefs located in in Geographe Bay near Busselton. The artificial reef is located approximately 5 km from the Dunsborough boat ramp at 33°3.962'S 115°9.980'E. Full details of the composition and design of the artificial reef and on Geographe Bay and its environmental characteristics are given in subsection 2.2.1.

4.2.2: Sampling regime

Forty seven underwater videos, each of ~17 minutes in duration, were obtained from Baited Remote Underwater Video (BRUV) systems (see Fig. 4.1) deployed around the Dunsborough artificial reef on 10th and 19th of March 2015. BRUVs are weighted frames that contain single or multiple cameras to film an area around a bait bag, which is used to attract fauna, these systems can be orientated horizontally or vertically and be deployed on the seafloor or in the water column (Mallet and Pelletier, 2014). On each sampling occasion, four BRUVS were deployed in succession to collect video footage. The first BRUV was deployed close to the artificial reef centre point with each subsequent camera deployed along a spiral path through the artificial reef area, using a GPS for navigation. Note that this sampling design was developed by Recfishwest and involved no input from staff and students at Murdoch University. The methodology was chosen to replicate, in part, the movements of recreational fishers and sample randomly areas in and around the artificial reef modules to test the validity of a randomised BRUV deployment method for potential future use with citizen scientists.

Fig. 4.1: Construction of the custom made BRUV. From right to left: Cementing pipe fixtures with weights already inside the legs (skids), the finished BRUV frame trialling with camera position, and final product about to be deployed on the artificial reef.

Once deployed, each camera was submerged for ~20 minutes before being retrieved. Upon retrieval, the video footage was extracted and GPS coordinates of the location recorded. The BRUV was then rebaited and redeployed in a random location along the spiral trajectory. Sampling lasted for around six hours on each day.

The BRUVS employed in this study were designed and constructed from readily available materials. The frame for each BRUV, which covered an area of around 580 mm x 450 mm, was constructed from class 9 Polyvinyl Chloride (PVC) irrigation pipe, which is rated to 8.88 atmospheres and thus able to withstand pressures associated with water depths to at least 78 meters. Lengths of pipe and the associated fittings are glued together with green PVC cement, traditionally employed for gluing pressurised water pipes. The frame is stabilised by two skids/platforms, each filled with four 680g lead weights, making the BRUV negatively buoyant, with a total weight of 5.5 kg. Pipe brackets were used to mount a camera, a rope tie point (both on top) and the bait arm suspended underneath. The bait arm (or boom) is suspended 150 mm above the substrate and has a length of 600 mm from the BRUV central point, with a bait bag placed 500 mm from the camera (Ellis and DeMartini, 1995; Willis and Babcock, 2000;

Heagney *et al*, 2007). The bait bag, which was 180 mm x 100 mm, was constructed from plastic mesh.

Before each deployment, 500 g of Australian Sardine *Sardinops sagax*, or congeneric species *Sardinops* spp., was placed into the bait bag. These species are widely used in similar studies due to their soft oily flesh, which is known to attract fish (McLean *et al*, 2010; Watson *et al*, 2010; Bassett and Montgomery, 2011; Goetze *et al*, 2011; Mallet and Pelletier, 2014). Moreover, Dorman *et al*, (2012) tested various bait types in BRUVs and concluded that the use of Australian Sardine, as a standardised bait for BRUVs, is justified for use along the west coast of Western Australia.

A GoPro Hero 4 Silver Action Video Camera ™ was mounted to the BRUV and used to record the video footage. This camera was chosen as it has an ultra-wide angle lens and is able to recorded video footage with resolution of 1080p at 60 frames per second. To make the camera more suitable for use in the study the standard housing was replaced with waterproof housing to increase the depth rating from 40-60 m and Battery BacPac ™ was used to extend battery life to around over three hours.

4.2.3: Video metadata

Once footage was uploaded, it was classified and grouped for video metadata analyses. To assist with classification and analyses, videos attributes were recorded including footage number, whether the camera was facing a) one or more of the modules or b) none of the modules, quality rating and observational notes. The footage quality was rated using the same methods as Chapter 2, using a scale of 1-10 (Fig. 2.4). Of the 47 videos collected, a random subset of 15 facing the modules and 15 facing away were selected for data extraction.

4.2.4: Observation protocols

For each of the 30 videos, the Max-N, for each species, *i.e.* the largest number of individuals of a species on a single frame of footage, was calculated (Priede and Merret, 1996; Willis and Babcock, 2000). This measure of abundance was employed as it avoids the possibilities of fish double counting and gives a conservative estimation of relative fish density (Priede *et al*, 1994; Cappo *et al*, 2004; Watson *et al*, 2005; Gomelyuk, 2012). Unlike in Chapter 2, Count-N was not calculated, as in the earlier chapter this was used to estimate the number of fish that were unable to be identified, and such problems determining the identify of species in this chapter were greatly reduced by the higher resolution of the footage (see later). Although all videos were approximately the same length, *i.e.* ~17 minutes, to ensure direct comparability among videos a standardised viewing time of five minutes was established between 7 and 12 minutes. This 5 minute period was analysed for extracting the number of modules observed, various metadata, number of species, ecological group affinities and mean abundance of individuals (Max-N).

Each species recorded was also assigned to an ecological group affinity using the Nakamura (1985) classification (screenshots from the footage with example classifications can be seen in Appendix 4.1). Under this scheme, each species is assigned to a type based on their typical spatial position with regard to the reef (Tessier *et al*, 2005; Bortone, 2007). Thus, A type species are found proximate to/or inside holes and crevices on the reef and are thus classified as *benthic*. B type species are found closely associated with the reef, but not in direct contact are known as *epibenthic* and C type species are loosely associated with structure, often found schooling above it and constitute *pelagic* species (Nakamura, 1985; Bortone, 2007; Wartenburg and Booth, 2014).

4.2.5: Statistical analyses

A data matrix containing the Max-N for each species in each video was subjected to the DIVERSE routine in Primer v7 (Clarke *et al*, 2014b) with the PERMANOVA+ add on (Anderson *et al*, 2008) to calculate the number of species and ‘total’ number of individuals. The data for each of the biotic variables was used to construct a Euclidean distance matrix and subjected to one-way Permutational Analysis of Variance (PERMANOVA; Anderson, 2001) to determine whether the values for each of those measures differed significantly between the videos recorded from BRUVs facing towards the artificial reef modules and those facing away. The null hypothesis that there was no significant difference was rejected if the significance level (P) was ≤ 0.05. Prior to undertaking these analyses, the data for the number of individuals were square-root transformed, while the number of species did not require transformation. The arithmetic means and associated 95% confidence intervals were calculated and graphed to visually determine the cause of any significant differences.

To undertake multivariate analyses, the untransformed data matrix used above was fourth-root transformed to down-weight the contributions of species with consistently relatively high values and balanced them with the values of rarer species and used to construct a Bray-Curtis similarity matrix. This matrix was then subjected to the same one-way PERMANOVA test described above, only this time operating a multivariate sense. The above Bray-Curtis similarity matrix was then subjected to non-metric Multi-dimensional Scaling (nMDS; Clarke, 1993) to produce an ordination plot to explore visually, any trends among the fish compositions on the video recorded facing different directions.

Finally, a shade plot, was produced from the fourth-root transformed fish fauna data for each video, averaged for those 15 samples facing towards and those 15 samples facing away from the modules. This plot was used to visualise the trends exhibited by the Max-N abundances of the various fish species on the video recorded facing different directions. As mentioned in Chapter 2, this plot is a simple visualisation of the frequency matrix, where a white space for a species demonstrates that the taxon was never collected, while the depth of shading from grey to black is linearly proportional to the density of that taxon (Clarke *et al*, 2014; Valesini *et al*, 2014).

4.3: Results

4.3.1: Video metadata

From the total of 47 videos, 30 videos were randomly selected, with the camera in 15 of those videos facing one or more of the modules (*i.e.* facing modules), whereas in the other 15 videos the no modules were observed in the footage (*i.e.* facing away). Each of the videos ranged between 17 and 20 minutes in duration, with a five minute section between 7 and 12 minutes analysed qualitatively for quality using the scale shown in Fig. 2.4. The quality of the footage ranged between 7 and 9 (out of ten; Fig. 4.2). The average quality level of all the videos was 8.13 and was similar in videos facing modules (8.40) and those facing away (7.86).

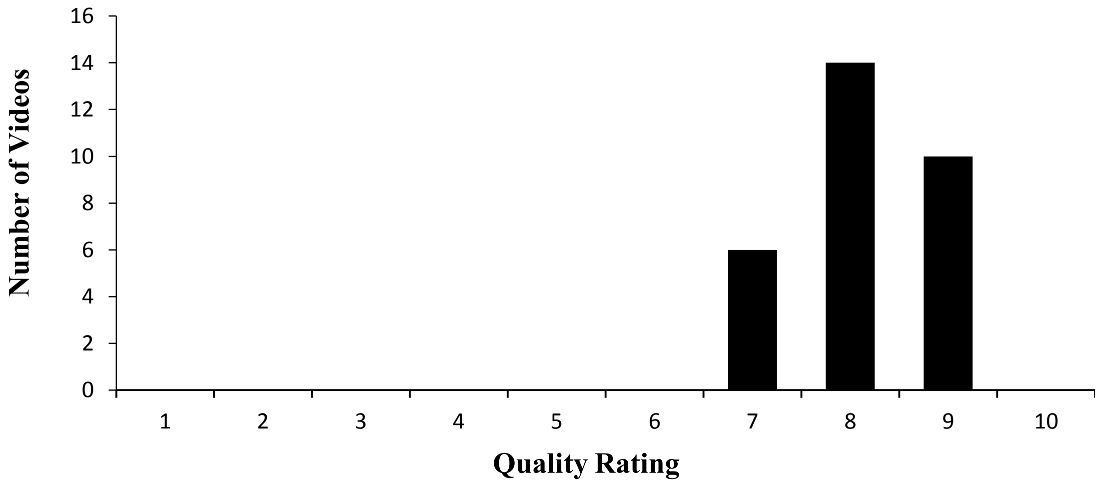


Fig. 4.2: The quality rating of the 30 videos collected using BRUVS on the Busselton artificial reef.

Of the 30 videos collected 50% was footage observing areas with no artificial reefs. Out of the other 15 video that captured at least one of the artificial reefs modules in the field of view, 11 (~73%) observed one module, 4 (~27%) observed areas with two modules and none filmed areas with more than two (Fig. 4.3).

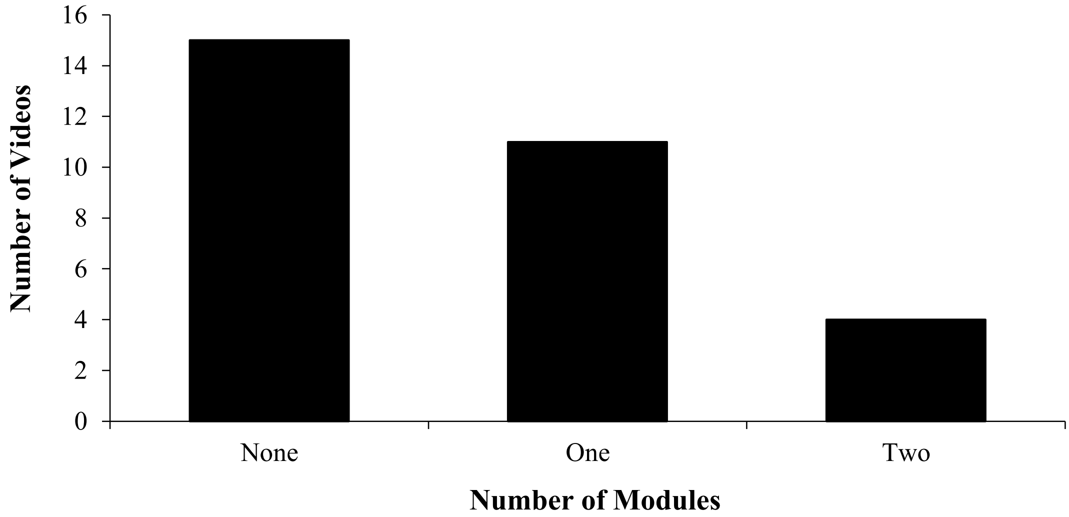


Fig. 4.3: The number of modules observed in each of the 30 videos analysed. Note: half of the videos intentionally observed no modules.

4.3.2 Descriptive metrics

A total of 33 species of fish and one species of mollusc were identified from the five minute sections of footage from the 30 videos (*i.e.* 2 hours and 30 minutes in total) and together represented each of the three Nakamura (1985) ecological group affinities (A, B and C). The 44% of the species recorded (15) constituted the 'A Type' as they were benthic, while the next most numerous affinity was B (epibenthic), which was represented by 12 species (Fig. 4.4). Thus, together species that were cryptic and closely associated to structure respectively species made up 79% of the total number of species were thus more speciose than the pelagic fauna (C type), which comprised 7 species. It should be noted that while *Sepioteuthis australis* (Southern Calamari) is not a teleost or elasmobranch, it has been included in the data sets as it is a species targeted by recreational fishers.

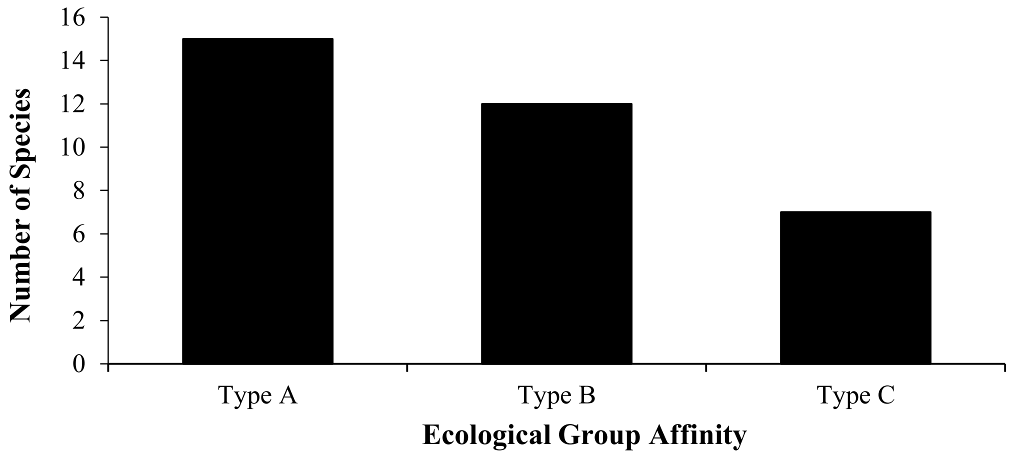


Fig. 4.4: Numbers of species assigned to each of the three Nakamura (1985) ecological group affinities, *i.e.* A (benthic), B (epibenthic) and C (pelagic).

The greatest mean number of species was recorded in footage where two modules were observed in the field of view (Fig. 4.5). In such footage, species belonging to type B were more numerous (2.75) than those in types A (1.25) or C (1). In contrast, the lowest mean number of species was recorded on videos where no modules were observed and on these videos there was little difference between the mean number of species in each of the three ecological groups (all ~ 0.5 species/video). Footage in which, one module was observed fell between the two 'extremes', with slightly greater mean numbers of species in types A and B (both ~1) than C (0.45; Fig. 4.5). Cameras facing modules, *i.e.* those with one of two modules in the field of view) had approximately 36.3% more A species and 50% more B species than camera footage not facing modules (Fig.4.6). However, cameras not facing modules had a higher level of 'Type C' (pelagic) species, recording 25% more than footage observing modules.

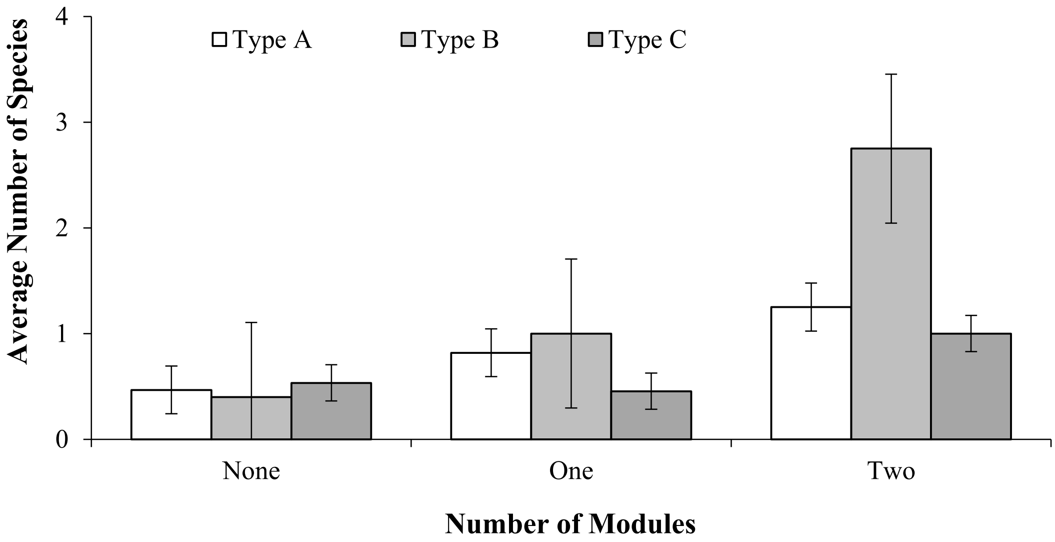


Fig. 4.5: The average number of species recorded belonging to each three Nakamura (1985) ecological group affinities, *i.e.* A (benthic), B (epibenthic) and C (pelagic), observed in each video with different numbers of modules in the field of view. Error bars represent ± 1 standard error.

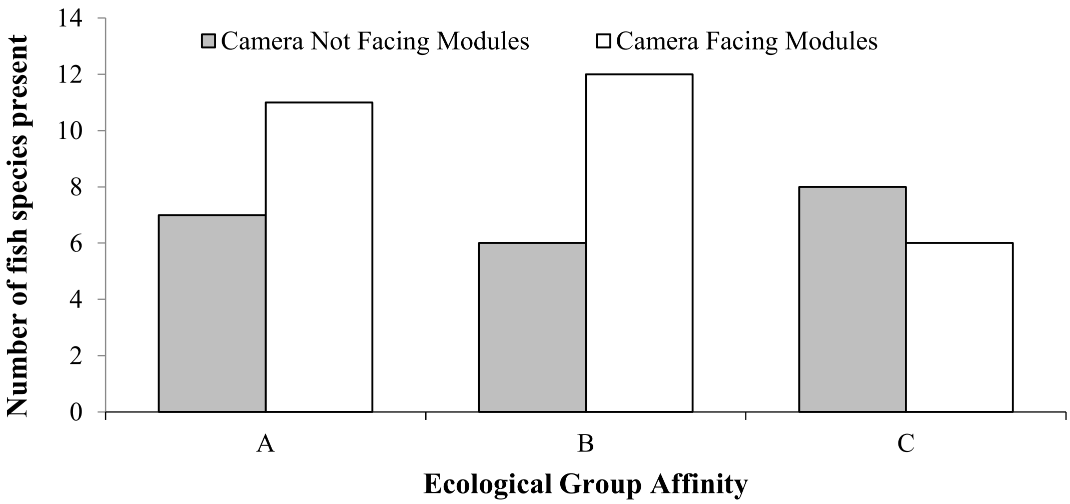


Fig. 4.6: The number of species present in each of the three Nakamura (1985) ecological group affinities, *i.e.* A (benthic), B (epibenthic) and C (pelagic) in videos where the camera was facing towards or away from the artificial reef modules.

The mean number of species increased sequentially with the amount of modules in the field of view of the camera, with by far the greatest values recorded for two modules (5) than either 1 (2.3) or none (1.4; Fig.4.7).

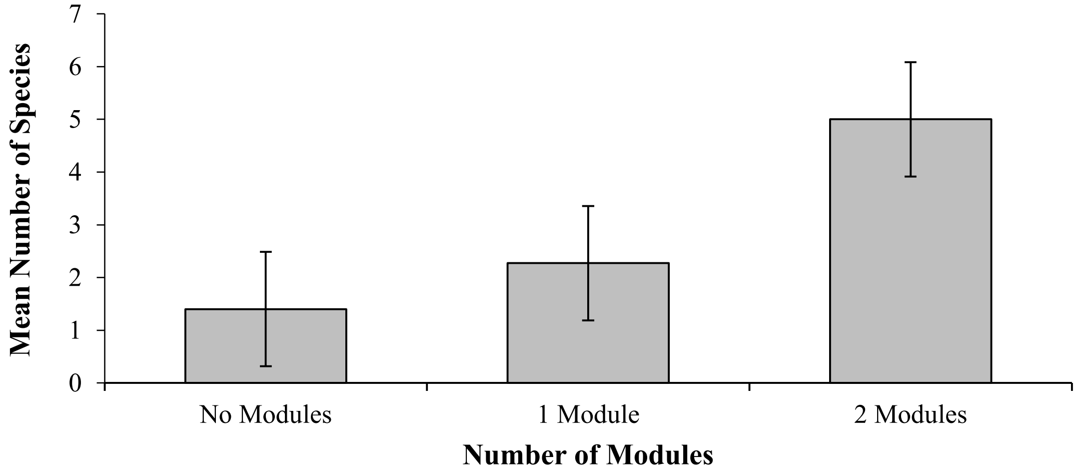


Fig. 4.7: The average number of species observed in videos with different numbers of modules in the field of view. Error bars signify the variability of mean number of species in the differing amounts of modules.

Average mean abundance (calculated from the total Max-N averaged across a suite of videos) increased sequentially with the number of modules in the field of view. Thus, the lowest average mean abundance was recorded for camera facing away from the modules (~27) and 31% than the greatest average mean abundance of (~39) recorded from videos in which to two modules could be seen (Fig. 4.8).

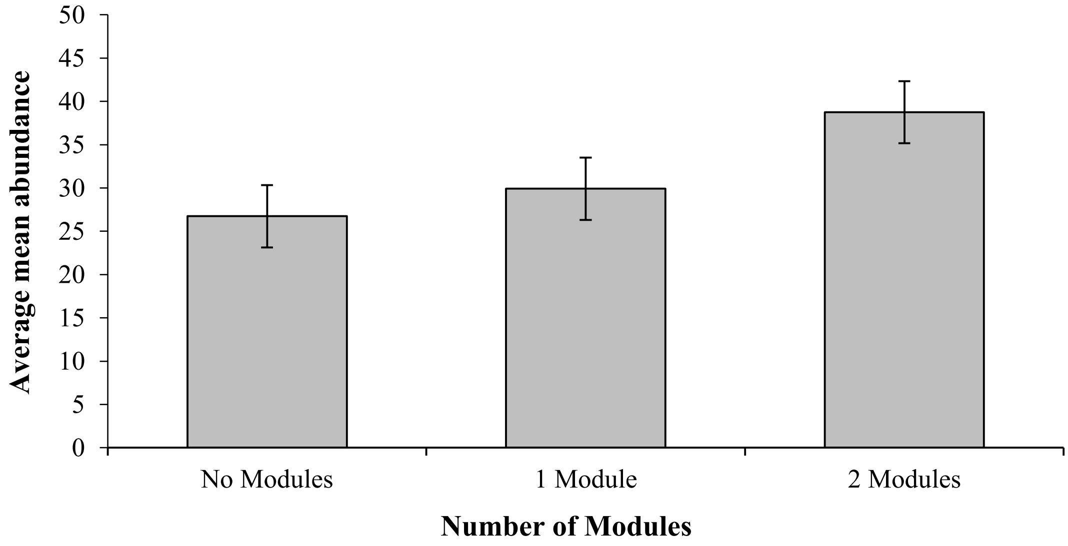


Fig. 4.8: The averaged mean abundance observed in videos with different numbers of modules in the field of view. Error bars signify the variability of average mean abundance in the differing amounts of modules.

A total of 34 species were identified from the 30 videos analysed in this study (Table 4.1). Of those species, 29 were recorded in footage observing artificial reef modules, 21 species were recorded in footage were no modules were observed and 17 species (50%) were recorded in both areas. It is also noteworthy that 12 species (~35%) were recorded only in footage that observed artificial reef modules, while 5 species (~15%) were recorded only in footage that contained no artificial reef modules (Table 4.1). Relatively similar total number of individuals was also recorded with 484 footage with modules and 401 on footage without modules.

A suite of ten species contributed over 90% to the total number of individuals recorded around the Busselton artificial reef. Of those ten, three were particularly abundant namely *P. georgianus* (Sand Trevally), *C. auricularis* (Western King Wrasse) and *N. obliquus* (Footballer Sweep), with each species representing not only more than ~5% to the total number of individuals overall, but also on the sets of videos facing towards and away from the modules. Such was the dominance of *P.wrighti* that is represented almost 60% of the total fish fauna and almost 70% on the videos facing away from the modules.

While the seven top ranked species were present there were some differences in abundance with greater counts of particularly *C. auricularis*. Species such as *Chromis klunzingeri* (Blackhead Puller), *Trachurus novaezelandiae* (Yellowtail Scad) and *Trachinops noarlungae* (Yellow Head Hula Fish) all represented >1% of the total number of individuals recorded when the camera was facing the modules, but were absent on videos where the camera faced away. Although none of the four species only recorded on footage facing away from the modules contributed >1% to the total number of individuals, it is noteworthy that those species comprised the two of the three elasmobranch species, *i.e. D. brevicaudata* (Smooth Stingray) and *T. personata* (Masked Stingaree) and the recreationally important *C. auratus* (Pink Snapper).

Table 4.1: Average individual mean abundance (#), percentage composition (%) and rank (R) of individual species recorded in footage facing modules and not facing modules. Total number of species and individuals are also provided. Grey shading indicates species that contributed ~>5% to the total number of individuals.

	Facing Modules			Not Facing Modules			Total		
Species Name	#	%	R	#	%	R	#	%	R
Pseudocaranx georgianus	231	48.53	1	278	69.33	1	509	57.51	1
Coris auricularis	83	17.44	2	39	9.73	2	122	13.79	2
Neatypus obliquus	33	6.93	3	20	4.99	3	53	5.99	3
Parequula melbournensis	14	2.94	5	10	2.49	4	24	2.71	4
Anoplocapros amygdaloides	14	2.94	5	10	2.49	4	24	2.71	4
Austrolabrus maculates	15	3.15	4	1	0.25	10	16	1.81	5
Pempheris klunzingeri	9	1.89	7	7	1.75	5	16	1.81	6
Chromis klunzingeri	13	2.73	6				13	1.47	7
Trachurus novaezelandiae	13	2.73	6				13	1.47	7
Seriola hippos	5	1.05	9	6	1.50	6	11	1.24	8
Diodon nicthemerus	8	1.68	8	2	0.50	9	10	1.13	9
Trachinops noarlungae	8	1.68	8				8	0.90	10
Upeneichthys vlamingii	5	1.05	9	2	0.50	9	7	0.79	11
Sepioteuthis australis	2	0.42	11	4	1.00	7	6	0.68	12
Ophthalmolepis lineolatus	5	1.05	9	1	0.25	10	6	0.68	12
Myliobatis australis	3	0.63	10	3	0.75	8	6	0.68	12
Trygonorrhina fasciata	2	0.42	11	4	1.00	7	6	0.68	12
Glaucosoma hebraicum	2	0.42	11	3	0.75	8	5	0.56	13
Dasyatis brevicaudata				4	1.00	7	4	0.45	14
Chelmonops curiosus	3	0.63	10				3	0.34	15
Lagocephalus lunaris	2	0.42	11	1	0.25	10	3	0.34	15
Anoplocapros lenticularis	2	0.42	11	1	0.25	10	3	0.34	15
Pentaceropsis recurvirostris	2	0.42	11				2	0.23	16
Chrysophrys auratus				2	0.50	9	2	0.23	16
Cheilodactylus nigripes	2	0.42	11				2	0.23	16
Halichoeres brownfieldi	2	0.42	11				2	0.23	16
Eubalichthys mosaicus	2	0.42	11				2	0.23	16
Parazanclistius hutchinsi	1	0.21	12				1	0.11	17
Pseudolabrus biserialis	1	0.21	12				1	0.11	17
Parapercis haackei	1	0.21	12				1	0.11	17
Trygonoptera personata				1	0.25	10	1	0.11	17
Suezichthys cyanolaemus				1	0.25	10	1	0.11	17
Neosebastes bougainvillii	1	0.21	12	0	0.00		1	0.11	17
Parpercis ramsayi	0	0.00		1	0.25	10	1	0.11	17
Total number of species		**29**			**21**			**34**	
Total number of individuals		**484**			**401**			**885**	

4.3.3 Statistical analyses

One-way PERMANOVA demonstrated that there was a significant difference between the mean number of species recorded from video collected from cameras facing towards or away from the modules (Table 4.2). On average, cameras facing towards the modules recorded ~7.5 species, compared to 5 on videos where the camera was not facing modules (Fig. 4.9a). In contrast to the number of species, mean number of individuals (the total Max-N for each video) was shown by PERMANOVA not to differ significantly between the two types of videos. In both cases, ~30 individuals were observed within the five minute period (Fig.4.9b).

Table 4.2: Mean squares (MS), Pseudo-*F* (p*F*) values and significance levels (*P*) for a one-way PERMANOVA test on (a) number of species and (b) mean total number of individuals (the total Max-N for each sample) calculated from the 30 videos recorded with camera facing towards or away from the artificial reef modules.

(a) Number of species	**df**	**MS**	**p*F***	**P**
Camera direction	1	43.2	6.88	0.013
Residual	29	6.3		

(b) Number of individuals	**df**	**MS**	**p*F***	**P**
Camera direction	1	1.94	1.78	0.212
Residual	29	1.09		

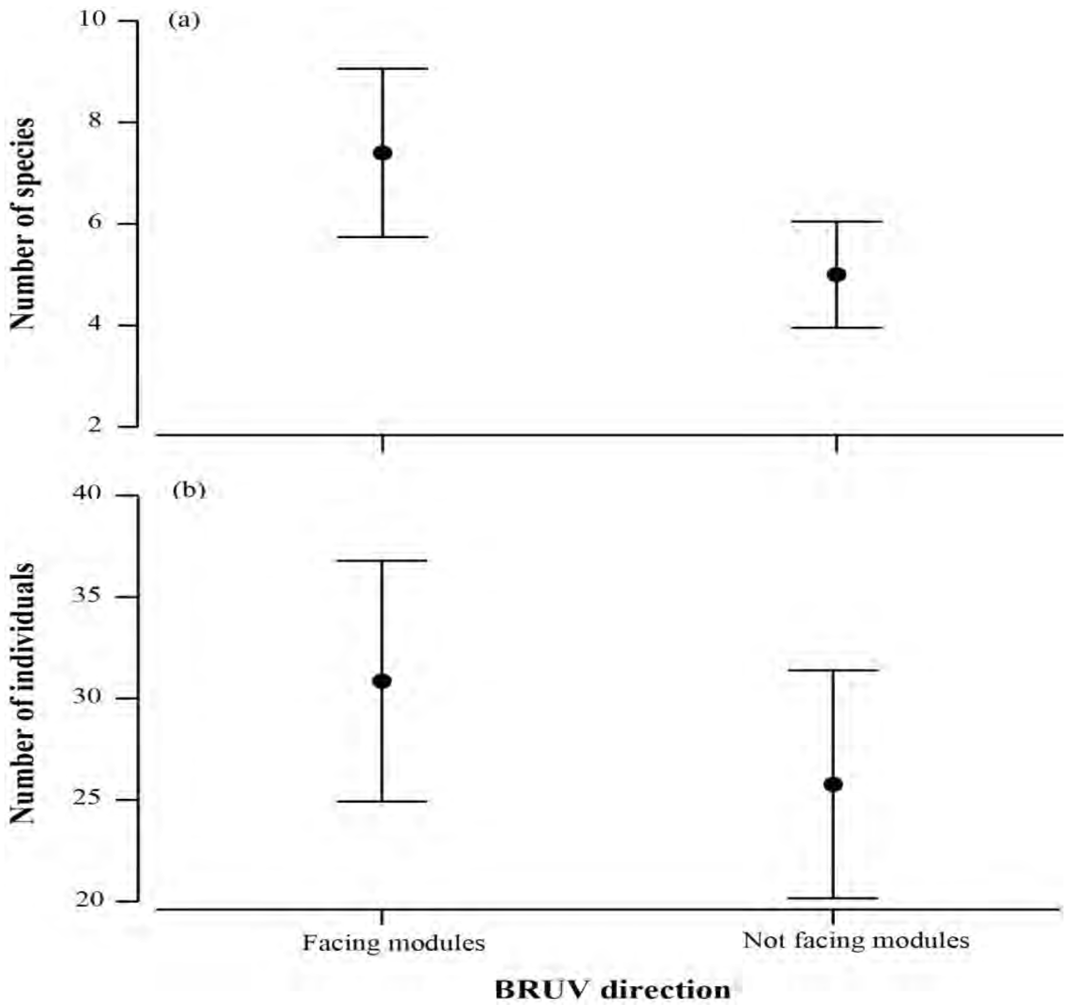


Fig. 4.9: (a) mean number of species and (b) mean total number of individuals (the total Max-N for each sample) calculated from the 30 videos recorded with camera facing towards or away from the artificial reef modules. Error bars represent 95% confidence limits.

One-way PERMANOVA detected a significant difference between the fish faunas recorded with the camera facing towards *vs* away from the artificial reef modules (Table 4.3). This difference is illustrated on the nMDS ordination plot, where the points representing the two camera angles are broadly separated on opposite sides of the plot. Thus, those samples obtained from cameras facing the modules are located on the left hand side of the ordination and only intermingle with five of the samples obtained from cameras facing away from the plot (Fig. 4.10). Note that each point represents a single sample and that the magnitude of the differences exhibited on the plot maybe increase if the samples were averaged.

Table 4.3: Mean squares (MS), Pseudo-*F* (p*F*) values and significance levels (*P*) for a one-way PERMANOVA test, employing a Bray-Curtis resemblance matrix constructed from the fourth-root transformed Max-N data calculated from the 30 videos recorded with camera facing towards or away from the artificial reef modules.

	df	MS	p*F*	P
Camera direction	1	3858	3.29	0.005
Residual	29	1174		

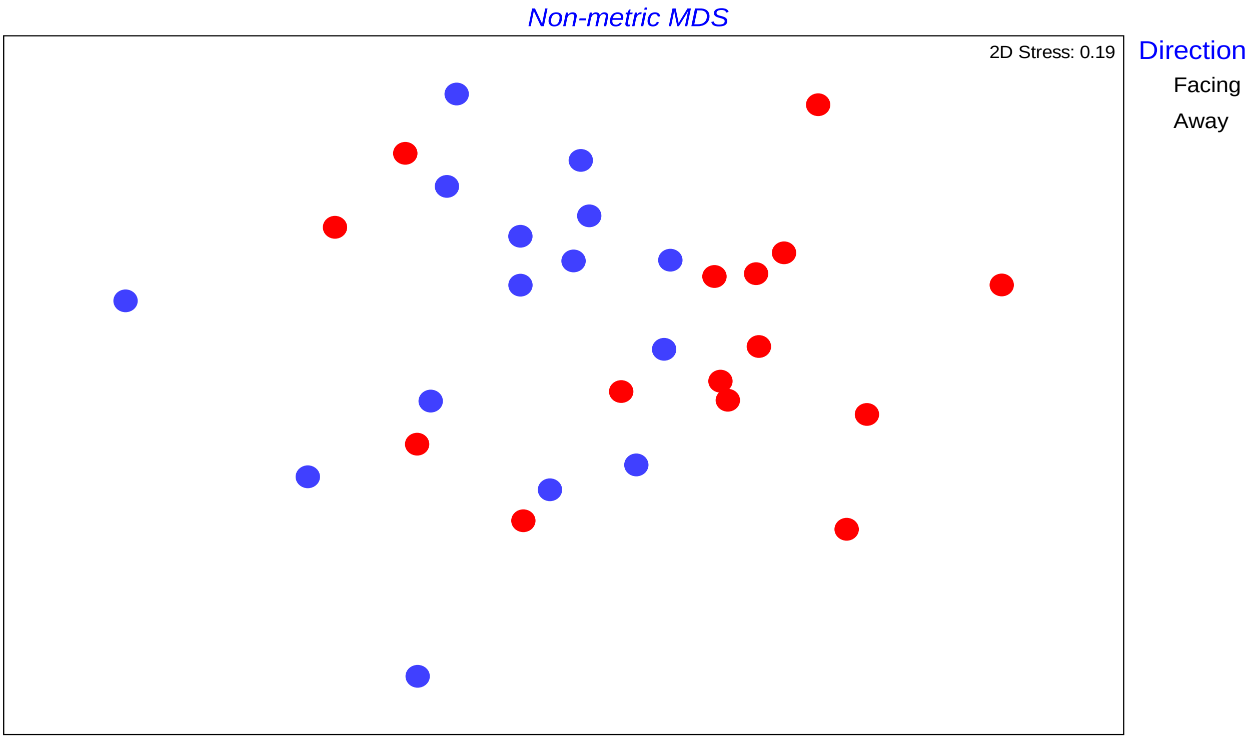


Fig. 4.10: nMDS ordination plot derived from Bray-Curtis similarity matrix a constructed from the fourth-root transformed Max-N data calculated from the 30 videos recorded with camera facing towards ● or away from the artificial reef modules ●.

Interpretation of the shade plot, which was constructed from the same pre-treaded data used to produce the nMDS plot, demonstrated that the faunas were dominated by *P. georgianus* and that it occurred in approximately equal abundances regardless of the camera direction (Fig. 4.11). There was also a suite of five species that were relatively abundant in both groups of samples, *i.e. C. auricularis*, *N.obliquus, A. maculates Parequula melbournensis* (Southern Silver Belly) and *Anoplocapros amygdaloides* (Western Smooth Boxfish) , but were present in greater numbers on videos recorded facing the modules. Several species such as *D. brevicaudata, C. auratus*, *T. personata*, *Suezichthys cyanolaemus* (Bluethroat Rainbow Wrasse) and *Parpercis ramsayi* (Sand

Perch) were only found on videos facing away from the modules, whereas the reverse was true for fishes, *e.g. C. klunzingeri*, *T. novaezelandiae, Pentaceropsis recurvirostris* (Longnose Boarfish), *Cheilodactylus nigripes* (Magpie Perch) and *Halichoeres brownfieldi* (Brownfields Wrasse), however, in almost all cases the abundances of these species were low (Fig. 4.11).

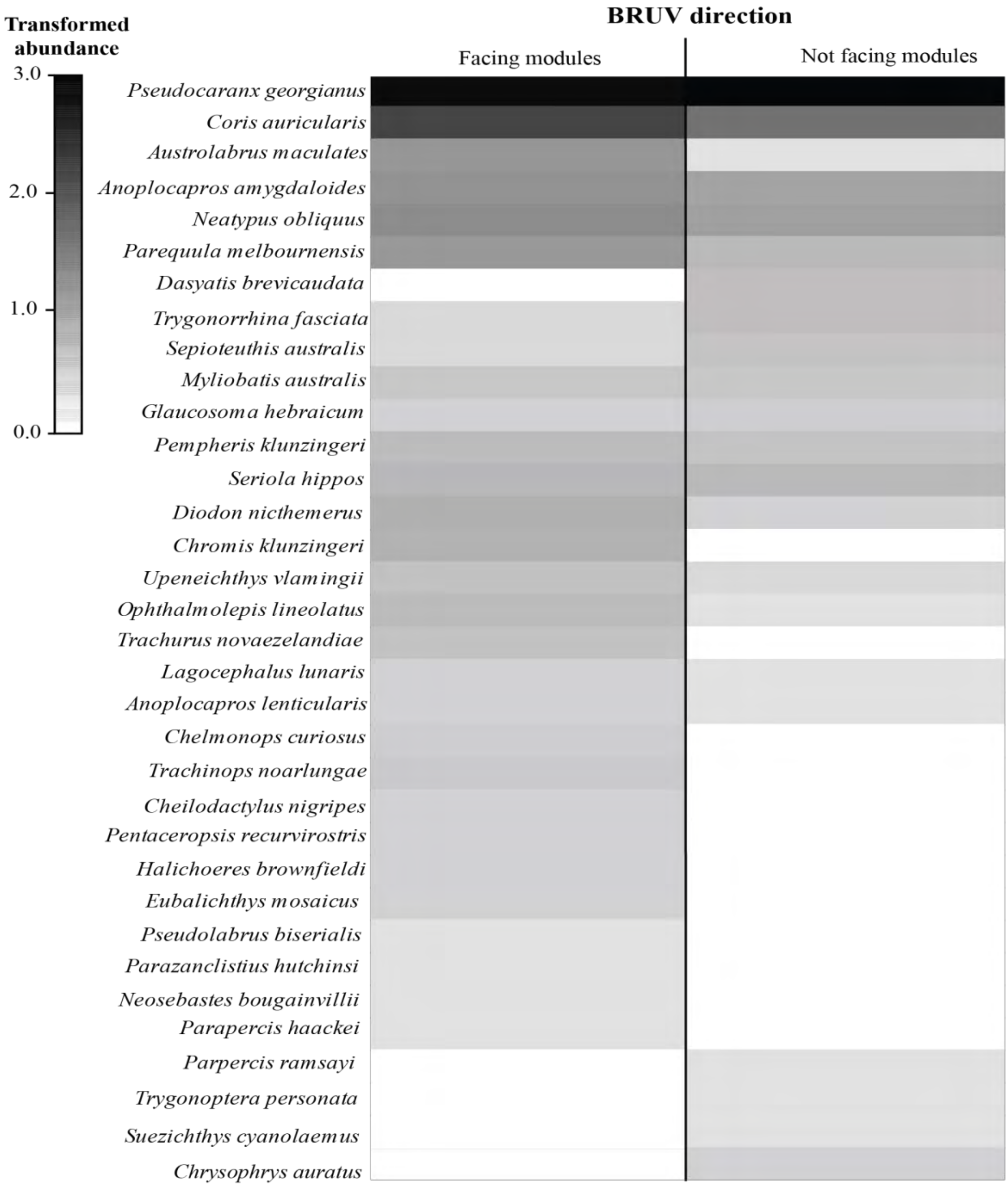


Fig. 4.11: Shade plot of the fourth-root transformed Max-N data calculated from the 30 videos recorded with camera facing towards or away from the artificial reef modules.

4.4: Discussion

The characteristics of the fish faunas living in and around the artificial reef in Busselton were quantified by recording the maximum abundance of each species identified in 30 videos obtained from Baited Remote Underwater Video (BRUV) systems. Of these videos, 15 were obtained when the camera was facing one or more of the modules, whereas the other 15 were obtained when the camera was facing away from those modules. The resultant data were used to test the hypothesis that the characteristics of the fish fauna (diversity, abundance and faunal composition) would change depending on the direction the camera were facing. A secondary aim was also to test the effectiveness of another method of video capture of fish on artificial reefs.

4.4.1: Video metadata

The video footage was collected by a researcher (not affiliated with this project or Murdoch University), who followed a standardised methodology for each replicate and thus the duration of all videos was approximately equal at ~17 minutes. This was in stark contrast to the citizen science approach (detailed in Chapter 2), in which video length ranged from 10 seconds to 13 minutes. As a result, a less biased approach to standardisation was able to be applied, *i.e.* comparing a set length of footage from defined start and end points (this chapter) *vs* calculating an average count for each species per minute (Chapter 2), which of course would bias diversity measures based, in some part, on the number of species (Clarke and Warwick, 2014). The qualitative index for quantifying video quality scored the videos in this Chapter with an average rating of 8.13 (out of 10), far higher than the 3.65 recorded in Chapter 2. This was due to both the higher resolution of the GoPro Hero 4™ *vs* the Sony CCD 700 TVL and the lack of turbidity encountered during the time the BRUVs very deployed. Therefore, while under calm conditions and when visibility is good the GoPro Hero 4™ should obtain higher quality footage, it remains to be seen whether this would still be the case on days were turbidity were higher.

4.4.2: Characteristics of the fish faunas facing towards and away from the artificial reef modules

4.4.2.1: Ecological groups

Although the artificial reef modules are in relatively close proximity to one another, there were some changes in the habitat recorded when the camera was facing towards or away from the modules. The benthos observed on footage facing away from the modules was predominantly sand, with occasionally the edges of beds of the seagrass *Posidonia sinuosa* (Oldham *et al*, 2010), while those facing the modules recorded lower amounts of seagrass and, of course, the modules, which had established a relatively rich epibiotic community. In light of the habitat availability the Nakamura (1985) classification of ecological group for fish, which is based on their vertical distribution in the water column and their position relative to reef (Tessier *et al*, 2005) , was modified to; Type A, *benthic* species were in direct contact with the seagrass and/or sand substrate, Type B, *epibenthic* species were in the immediate vicinity but not in direct contact of the other substrates and that Type C, *pelagic* species, were found mid-water above the different substrates.

Footage in which modules were observed recorded 37% more Type A and 50% more Type B species than footage where modules were not observed. Such a trend is not unexpected as, Type A and Type B fish are benthic and epibenthic, respectively, species, and thus would be more likely to be found in areas containing reef (artificial or natural) as the presence of reef increases habitat complexity and can provide shelter, food and induce different behavioural aspects of these species (Ody and Harmelin, 1994; Charbonnel *et al*, 2002; Sherman *et al*, 2002). Fewer numbers of species of Type C (pelagic) fish were recorded in both environments than type A or B species, a result which mirrors that of Tessier *et al* (2005) on natural/artificial reefs off Reunion Island (SW Indian Ocean). When comparing the two environments, slightly fewer numbers of Type C species recorded in footage facing modules (6) than away (8). As many of these species are pelagic and some highly mobile, one might not expect there to be a difference in the numbers of these type of species, particularly when the reefs are benthic, rather than pelagic in the case of a fish aggregation device. Nevertheless, as many of the pelagic species are higher order predators, such as *Seriola hippos* (Samson Fish) and *C. auratus* (Pink Snapper), their distribution may be related more to the presence of potential prey species rather than their attraction to the reef or bare habitat.

4.4.2.2: Numbers of species and individuals

It is also noteworthy that, the number of species representing each of the ecological groups increased sequentially along with the numbers of modules observed in the footage. This may indicate that the presence of increasing modules, which, in turn, increases habitat complexity may be beneficial in increasing diversity.

A suite of studies, undertaken throughout the world, have demonstrated that the number of species and abundance was greater on artificial reefs than natural reefs/ surrounding habitats (*e.g.* Bombace *et al*, 1994; Rilov and Benayahu, 2000; Sherman *et al*, 2001; Charbonnel *et al*, 2002; Folpp *et al*, 2013). This was partially true in this study, where there was a significant increase in the number of species and a slight (but not significant) increase in the abundance of fish on footage facing towards rather than away from the reef.

The increased number of species recorded in the present study is likely due to the creation of complex habitat and shelter (Svane and Peterson, 2001; Sherman, 2002; Hunter and Sayer, 2009), the source of food (Cresson *et al*, 2014), vertical profile (Kellison and Sedberry, 1998), edge effects (Dorenbosch *et al*, 2005) and potential upwelling effects (Yanagi and Nakajima, 1991) provided by the artificial reefs. As with the numbers of species in each ecological group increasing with the number of modules, the same was true for the total number of species. This increase could be explained by the additional modules increasing the surface area for colonisation of epifauna and associated organisms, thus fuelling further biomass production (Cresson *et al*, 2014) creating more feeding opportunities. Another possible reason for the increase is that more modules provide a higher level of habitat complexity providing more shelter and differing environmental conditions (hydrological, temperature and light) (Svane and

Peterson, 2001; Hunter and Sayer, 2009), which could propagate higher abundances of more different types of species.

While, there was a sequential increase in the mean number of individuals recorded with increasing numbers of modules, and a larger number of fish recorded on videos facing towards rather than away from the reef, these differences were low and also subjected to relatively high levels of variability. Thus, in the case of the latter comparisons, no significant difference was detected. Such a trend is likely influenced by the variability in the numbers of *P. georgianus* (Sand Trevally) a highly schooling pelagic species, recorded in the individual samples. This species dominated the fish fauna to such an extent that it represented almost 60% of the total fish fauna and almost 70% on the videos facing away from the modules.

Of the 34 species identified, 12 were only recorded on footage facing modules, with 5 species being found only on footage not facing modules and 17 species being found on both suites of footage. Of the five species observed solely in areas without modules, three are mainly found in/on seagrass meadows and sand, and two of these species elasmobranchs, namely *D. brevicaudata* (Smooth Stingray) and *Trygonoptera personata* (Masked Stingaree). Both of these species are more commonly found over sand and seagrass (White, 2006; Duffy and Paul, 2003). All of the 12 species only recorded in videos facing the modules were fish typically associated with reef or rock habitats, including two species of wrasse (Labridae) and two species of boarfish (Pentacerotidae). Furthermore, all of these species were attributed to ecological group types A and B except for *Trachurus novaezelandiae* (Yellowtail Scad), which was only recorded in a single video.

Fifty percent of the species were recorded by cameras facing towards and away from the modules. Of these 17 taxa, 9 are associated with both rocky reef and seagrass/sand, while another 3, namely *P. georgianus*, *Parequula melbounensis* (Southern Silver Belly) and *Myliobatis australis* (Southern Eagle Ray) are predominantly found over purely sand or seagrass habitats (Froese and Pauly, 2015). The presence of these species around the modules could be attributed to several factors including the fact that modules are deployed on sand and are typically located in close proximity to seagrass meadows. The intermingling of these three ‘substrate types’ thus creates a mosaic of habitats, which the above species are able to exploit. It is also hypothesised that the modules and their associated epiphyte community may attract fish from nearby ‘alternative’ habitats. For example, *P. wrighti* and *P. melbournensis*, which were ranked first and fourth overall in terms of abundance, respectively, feed predominantly on copepods (Platell *et al*, 1997), which are themselves attracted to artificial reefs by other invertebrates feeding on the organic matter produced by the reef (Cresson *et al*, 2014). Another suite of species (5), found to occur in both sets of footage, are predominantly associated with rocky habitats, namely *Glaucosoma hebraicum* (Western Australian Dhufish), *S. hippos* (Samson Fish), *Austrolabrus maculates* (Black Spotted Wrasse), *Pempheris klunzingeri* (Rough Bullseye) and *N. obliquus* (Footballer Sweep) (Froese and Pauly, 2015). The last three fish are small, schooling species that feed on invertebrates associated with the reef (May and Maxwell, 1986; Platell and Potter, 2001; Bray, 2011). Therefore, the shade, shelter and food production caused by the artificial reef modules may aggregate these species. The fact that these species were also recorded in footage where modules were not observed could be attributed to the fact that modules are very close by, and/or these species are moving between modules or that the species were attracted from the modules into the cameras field of view due to the bait plume or behaviour of other species.

Both *S. hippos* and are *G. hebraicum* are larger species, reaching 180 and 122 cm, respectively and are high trophic-level predators (Smallwood *et al*, 2013). Their presence in both data sets could be a combination of i) attraction to the bait plume, ii) being in transit between territories or modules as they are both highly mobile, and/or iii) they were attracted to the area due to the aggregation of species. In the context of the last point, it is relevant that Rowland, (2009) identified 17 key prey items for *S. hippos,* of which 7 (representing 32.9% of their diet) of the prey item species were recorded in the footage on the reefs. Some of these species in the diet and seen in the footage included: *S. australis* (Southern Calamari), *T. novaezelandiae* (Yellowtail Scad) and various Labrids. It's also noteworthy that *G. hebraicum* feeds on fish species such as *C. auricularis*, which ranked second in terms of abundance, and others *e.g.* members of the Pempheridae (*i.e. P.klunzingeri*) and Ostraciidae (*i.e. A. amygdaloides*; Platell *et al*, 2010).

4.4.3: Recreationally important species

One of the purposes of monitoring is to evaluate structures against proponents' objectives and one of these main objectives is the propagation of recreational target species (Department of Fisheries Policy, 2012b). As the South West Artificial Reef Trial was partly funded and mainly advocated for by recreational fishers, one of the main objectives for the reef was the increase of recreationally important species such as *C. auratus* (Pink Snapper*), S. hippos* (Samson Fish) *and P. dentex* (Skipjack Trevally). Although this study identified *S. hippos* and *C. auratus* on the artificial reefs, it did not identify any *P. dentex*, although a very similar and targeted species, *P. georgianus* was the most abundant species identified in the study contributing to 57.51% of the total fish assemblage, this species also has the same edibility rating as *P. dentex* (Hutchins and Swainston, 2012). Recreational target species can be defined as those species that are edible (Watson *et al*, 2007) and thus to analyse the assemblages in relation to target species, the edibility scale from Hutchins and Swainston (2012) will be utilised. The scale ranges from 0-4 with 0 being a fish not generally eaten (usually due to its size or physical morphology) and 4 being the most prized table fish. Some of the species identified in this study are poisonous to ingest and are thus omitted from the data set. These include *Diodon nicthemerus* (Globe Fish), *Anoplocapros amygdaloides* (Western Smooth Boxfish), *Anoplocapros lenticularis* (White Barred Boxfish) and *Lagocephalus lunaris* (Rough Golden Toadfish). These four species are poisonous as they belong to the Order Tetradontiformes, all of the species in this order can produce tetrodotoxin, a lethal natural toxin that if ingested, can result in paralysis and even death for humans (Edgar, 1997 and Hutchins and Swainston, 2012). These four species were all observed in footage facing and not facing artificial reef modules, however they only contributed 4.52% to the overall fish assemblage.

Of the 30 species edible, 8 species had a edibility value of 0, meaning that they weren't dangerous to ingest, but were the lowest possible option, possibly due to size of the species, taste or physical morphology (for example lack of edible flesh or size and amount of bones). No category one fish were identified in the footage. Footage observing artificial reef modules had 16.67% more category two species, in other words it has 16.67% more recreationally targeted species. Footage observing artificial reefs also had 50% more category three species (See Fig. 4.8). The highest quality of edible fish is category 4. Footage recorded facing away from the artificial reef modules had 50% more category 4 fish than footage observing modules, however it must be noted that only two category four fish were observed, *C. auratus* (Pink Snapper) *and G. hebracium* (Western Australian Dhufish), and *C. auratus* was found only in footage not facing modules, thus the 50% increase. The use of edibility to gauge the succession of recreational target species has shown that at all levels of edibility, there has been a larger number of target species observed in footage facing modules except for category four (only category fish species identified in the study) and category one, in which no species were observed.

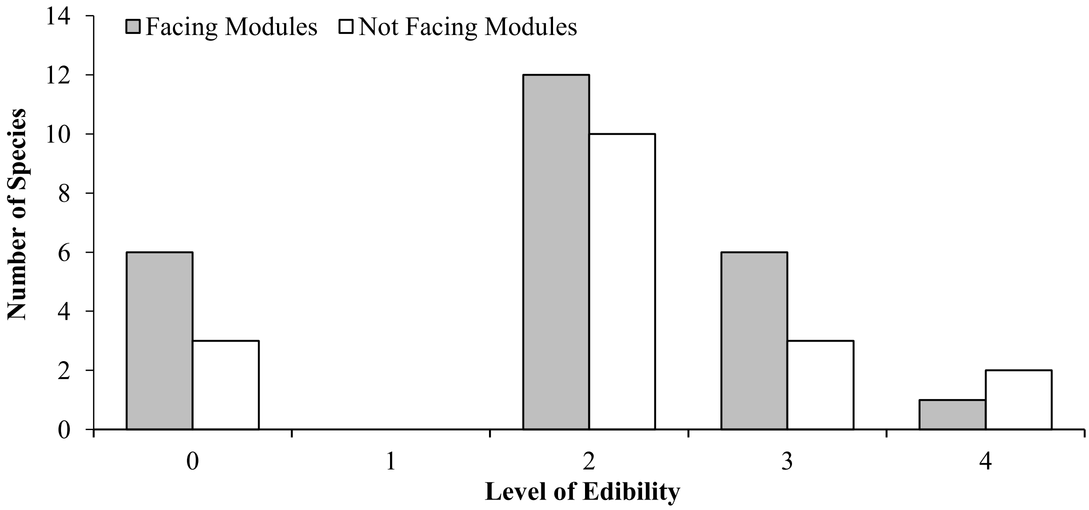


Fig. 4.8: The number of species and their level of edibility (and thus recreational priority level) from footage facing modules against footage not facing modules. The level of edibility increase with the numerals where 0 is the worst possible edible fish and 4 is the best possible edible fish.

4.4.4: Implications for citizen science

Given some of the problems with the methodology of the citizen science approach to monitoring the fish faunas of artificial reefs using recreational fishers employed in Chapter 2 (see also Chapter 3) and the use of a different technological approach here to collect video footage, there is the opportunity to comment on the applicability of BRUVS for use in citizen science projects to monitor artificial reefs. This technology was first developed to count abundances of juvenile *Pristipomoides filamentosus* (Crimson Jobfish) in Hawaii in 1995 (Ellis and DeMartini, 1995) and, since then, their use has increased rapidly throughout the world and particularly in Australia. For example, Mallet and Pelletier (2014) identified 52 BRUV-based researcher papers globally, 32 or over 60% of which originated in Australia since 2003.

As mentioned in the materials and methods, the BRUVs employed in this study comprised a weighted frame constructed from PVC pipe filled with lead fishing weights, costing ~\$75.00 per unit, on to which a GoPro Hero 4™ was mounted (costing ~\$475). Although I was not involved in the deployment of the BRUVS, from watching the video footage obtained there are two ways in which the units could be improved. Firstly, the addition of a second camera would increase the field of view and also, if facing a sufficiently different direction, would help overcome some of the above differences in direction of the camera on the fish fauna captured in the footage. Secondly, it was noted that some larger Batoids such as *D. brevicaudata* and *Trygonorrhina fasciata* (Southern Fiddler Ray) were observed rotating the BRUV and thus it might be worthwhile increasing the weight of the frames. The rotation of BRUVs were a negative factor in this study as the structures in the field of view dictated the grouping of that particular fish faunal data being filmed, whether facing modules or not facing modules. If the BRUVs were rotated from facing a module to facing no modules or from facing the surrounding area to facing an artificial reef module, the data were not included from that footage. Although, this only occurred once throughout the study.

As mentioned earlier, the quality of the footage obtained from the BRUVs (GoPro Hero 4™) was of a higher quality than that obtained from the Sony CCD 700 TVL camera (Chapter 2). This enabled a larger proportion of the fish to be identified and also increased the ease of identifying particular species thus resulting in more accurate results. The former type of camera are starting to be utilised more frequently in research projects due to their recent reductions in size and cost, and increases in quality of footage recorded and data storage capacity. For example, these types of camera have been used to monitor reef fish communities in marine protected areas (*e.g.* De Vos *et al*, 2014), analysing fish interactions with artificial structures (*e.g.* Hammar *et al*, 2012) and seagrass assessments to help monitor dugong and sea turtle habitats using citizen scientists (*e.g.* McKenzie *et al*, 2014). Furthermore, a study by Letessier *et al*, (2015) compared low-cost small action cameras to traditional cameras. The purpose of the study was to 'assess the capacity of GoPro™ action cameras to provide accurate stereo-measurements of fish in comparison to the Sony handheld cameras that have traditionally been used for this purpose' (Letessier *et al*, 2015). The results found that there was a strong correlation ($R^2 = 0.94$) between the cameras' length measurements of the same individual fish and that any 'difference in measurement accuracy becomes negligible for purposes of comparing population size structure' (Letessier *et al*, 2015). The study concluded supporting the use of small action cameras such as GoPro™ cameras as they provide reductions in cost and increases in effective sampling efforts (as easier to use) when compared to traditional equipment for stereo-measurements such as the Sony handheld cameras.

The methodology employed in this Chapter was conducted for pilot purposes and was purposely simplified to field-test a potential sampling regime able to be completed by citizen scientists. The method involved starting from the reef centre point (Fig. 4.12) and randomly deploying the BRUVs at intervals outwards on a spiral path. Although this method provided adequate data, for the purposes of this chapter, there are several ways it could be improved if it is to be utilized in a citizen scientist monitoring program. Rather than using a spiral, participants could employ a grid system to guide their sampling efforts. In such a scheme, participants would be allocated a suite of grid squared (denoted by GPS co-ordinates), within which they could deploy the BRUV wherever they wish (Fig. 4.12). This would allow a higher level of randomisation, whilst still following a standardised approach. This would also decrease chance spatial biases due to participants not selected sites objectivity. However, it should be noted that once footage is collected, it would have to be screened to see whether artificial reef modules were in the field of view before analysis.

It is also recommended that each BRUV be deployed for a longer period of time than the 17-20 minutes employed here. A deployment time of 50 minutes will increase footage length, but still allow three deployments of a BRUV before needing to recharge the battery. From a science perspective, this increase in video length allows more measurements to be collected on a larger number of species and individuals and thus increases the reliability of the results. It is therefore relevant that both Watson (2006) and Watson *et al*, (2010) stated that at least 36 minutes of footage is required to accurately obtain measures on the majority of fish species and that, if possible, 60 minutes is advisable to obtain measures of numerous targeted species. From a citizen science perspective, increasing the soak time of the equipment would allow the participants to go fishing during the interim period, without having to stop every 10-15 minutes to deploy the camera/BRUV. It is suggested that this would increase the fishers' enjoyment and thus increase the fishers' involvement and motivation towards the project, which are vital aspects to successful citizen science projects (Rotman *et al*, 2012). The soak duration of 50 rather than 60 minutes is to allow time to deploy and retrieve BRUVs with a one hour period.

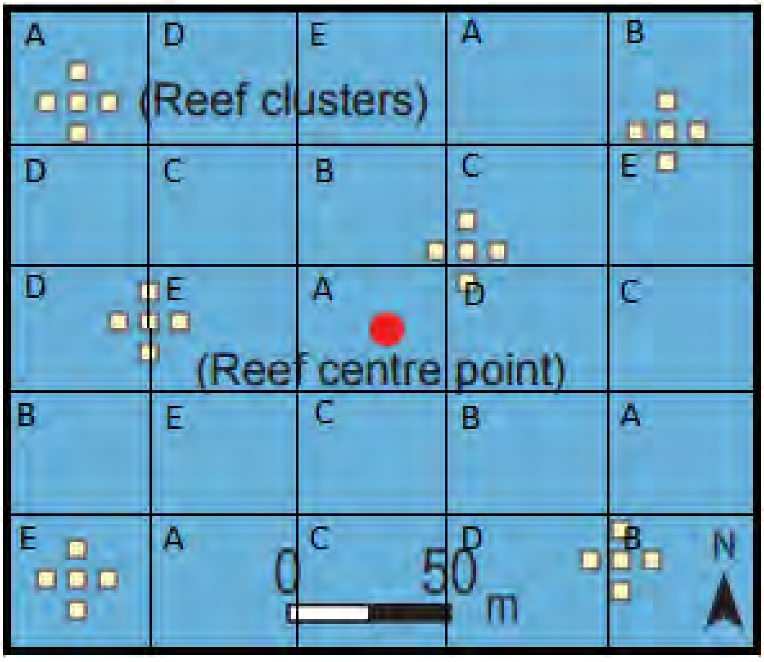


Fig. 4.12: Schematic of the proposed grid system, which could be utilised to randomise sampling and reduce spatial biases. In this example there are five citizen scientists (A-E) who would each be responsible for collecting data for a small suite of grid squares. (Base map modified from Department of Fisheries, 2015).

4.4.5: Summary

This study has demonstrated that several characterises of the fish fauna of areas around artificial reefs change, when monitoring using BRUVs, depending on the direction the camera is facing. The overall number of species and the numbers of benthic (A) and epibenthic (B) species were higher in footage facing modules, while the number of pelagic (C) species and numbers of individuals did not change. The composition of the fish fauna changed too depending on the direction of the camera. In general, 17 of the 34 species were recorded in both data sets, however, the abundance was generally slightly greater when the camera faced the modules. Other suites of species were also identified that were only recorded in a single data set. For the purpose of developing monitoring methods that could potentially be employed by citizen scientists, this project was successful. The equipment and methodology collected high quality footage, which was able to be analysed. It is possible that this equipment and methodology, with suggested improvements could be developed and utilized in future citizen science projects aiming to monitor artificial reefs.

4.5: Appendix

Appendix 4.1: Some examples of ecological group affinity classification applied to species observed in this study by cameras facing artificial reef modules and cameras facing away from the artificial reef modules.

Facing towards	**Facing away**

Type A: *Pentaceropsis recurvirostris* (Longsnout Boarfish).

Type A: *Trygonorrhina fasciata* (Southern Fiddler Ray).

Type B: *Glaucosoma hebraicum* (Western Australian Dhufish).

Type B: *Anoplocapros amygdaloides* (Western Smooth Boxfish).

Type C: *Lagocephalus lunaris* (Rough Golden Toadfish) with *Pseudocaranx georgianus* (Sand Trevally).

Type C: *S. hippos* (Samson Fish).

<u>Chapter 5:</u> Conclusions

5.1: Summary

In April 2013, two artificial reefs were deployed in Geographe Bay, Western Australia. Each reef is made up of six clusters of five modules, with each module being a hollow cubic structure measuring three cubic meters and weighing ten tonnes (Fig. 2.1). The reefs are designed to create varied complex spaces and habitats, as well as to create shallow water upwelling to drive nutrients up into the water column (Haejoo 2011; Department of Fisheries, 2015). The purpose of the artificial reefs is to provide new habitats for key recreational fish species such as *C. auratus* (Pink Snapper), *S. hippos* (Samson Fish) and *P. dentex* (Silver Trevally). To comply with environmental assessments, legislative requirements to monitor the development of the artificial reefs were established. However, the costs associated with monitoring the artificial reefs are high, costing the State government ~$575,000 over a five year period (Department of Fisheries, 2015). One potential method to reduce the cost of monitoring is to use citizen science, *i.e.* recruiting normal citizens and asking them to undertake research with guidance from 'professional' scientists (Kruger and Shannon, 2000).

This project gave eight local recreational fishers towable 360^{o} rotating underwater cameras, which had a live feed, to record video footage of the fish utilising the artificial reef and nearby natural reefs. Unfortunately, due to lack of participation, the short timeframe of the project and unseasonal weather, only 3.1% of the expected data was received. This lack of data severely limited the range of statistical analyses that could be employed and thus the ability to test some of the proposed hypotheses. However, a preliminary assessment of the hypothesis that there is a difference in the fish assemblages of artificial and near-by natural reefs was undertaken. Furthermore, inferences regarding the use of citizen science and how best to improve the collection of robust data in projects of this nature were able to be addressed. In the case of the first point these demonstrated that artificial reefs had higher mean and maximum abundance, general number of species and number of species belonging to the ecological group affinities. Multivariate statistical analyses did not detect a significant difference between the fish faunal composition of artificial *vs* natural reefs. This was primarily due to the dominance of the labrid *C. auricularis* and the large amount of variability between individual replicates. These results need to be interpreted with caution, due to the limited amount of data available and thus, the results should be considered preliminary. More video footage is required to statistically analyse, in a robust quantitative manner, the fish faunas of the two types of reefs. Although this study experienced several limitations it is important to recognise that it was a pilot study and first of its type in Western Australia, and possibly the world and produced key positive outcomes that can be utilised in future research.

This small pilot study experienced teething problems with the citizen science aspects of the project, especially the management of volunteers. This resulted in limited data collection and usability of that resultant data. These citizen science issues discovered throughout the project instigated a review of citizen science literature from around the world to investigate the role of citizen science in the project and produce recommendations for future research. The investigation revealed that the use of citizen science is proliferating, due to the benefits it provides, such as cost efficiency and effectiveness, social benefits to volunteers and the possible creation of large temporal and spatial data sets (Silverton, 2009; Dickinson *et al*, 2010; Wiersma, 2010; Baltais, 2013; Wilson and Godinho, 2013; Sullivan *et al*, 2014). There are also, however, issues in relation to utilising citizen science in research, such as the commonly misconstrued stigma about the poor quality of the resultant data, as it is not collected by experts, and other issues such as volunteer attrition rates, poor management and potential for error and bias due to potential lack of objectivity in volunteers and variations in sampling effort over time and space (Conrad and Daoust, 2008; Dickinson *et al*, 2010; Wiggins and Crowston, 2011; Rotman *et al*, 2012).

An enquiry into aquatic citizen science projects in WA also formed part of the review and revealed an array of studies such as tagging, receiving biological donations (frames, guts and gonads), monitoring and identifying movement, patterns and range shifts in different species, however, research had yet utilized citizen scientists to monitor faunal communities on artificial reefs. The resultant data from the initial project period was lacking in both quality and quantity due to environmental, operational and communicational issues. An analysis of the citizen science approach to the methodology was undertaken finding that major issues impacting the project included; (i) the small number of volunteers attained and having no succession planning for volunteer withdrawal, (ii) loss of volunteers due to poor management, changes in the personal circumstances of the fishers and frustration at long periods of inactivity due to delays in acquiring permits and equipment, (iii) lack of clear and consistent instructions around sampling regime and (iv), lack of volunteer engagement and communication.

To surmount these issues, a critical review of the original citizen science methodology, providing future recommendations in relation to citizen science approaches, was developed. In brief, these included enhancing the methods of contacting and recruiting volunteers, providing simplified and consistent instructions and consistent communication and engagement with volunteers. It is anticipated that implementation of these recommendations would result in the collection of higher quality data in higher quantities, as well as more efficient volunteer management, engagement and communication in future monitoring programs that utilise citizen scientists.

To further test whether recreational fishers could provide a cost effective method of monitoring artificial reefs, the applicability of another potential monitoring approach that could be employed by citizen science was analysed, namely Baited Remote Underwater Video systems (BRUVs). BRUVs were built and deployed randomly around the Busselton/Dunsborough artificial reef in March 2015 to record the composition of the fish fauna. The purpose of this exercise was to deploy BRUVs, which were constructed with readily available materials, in a simplified but randomised sampling regime, to test the applicability of this method for future use as a citizen science artificial reef monitoring tool. This study analysed the hypothesis that there is a difference in fish assemblages between cameras facing towards artificial reef modules and those facing away, *i.e.* cameras facing the surrounding area. This was done by analysing the randomly deployed BRUVS and extracting data on the abundance of species from 15 videos observing artificial reef modules and 15 videos observing areas in the artificial reef area but with no artificial reef modules in the cameras field of view.

The results demonstrated that artificial reef modules had higher numbers of species and more benthic and epibenthic species than the areas surrounding the modules. Footage with no modules observed did have a larger number of pelagic species recorded. However, there was no significant difference in the general abundance of individuals, which may be due to the dominance of the highly pelagic and schooling *P. georgianus*, (Sand Trevally) which represented 60% of all individuals recorded. The composition of the fish fauna changed depending on the direction of the camera. In general 17 of the 34 species were recorded in both data sets, however, the abundance was generally slightly greater when the camera faced the modules. Other suites of species were also identified that were only recorded in a single data set. It was concluded that there is a difference in the fish assemblages deducted from the preliminary results and thus such differences need to be account for in any monitoring program undertaken using BRUVs. The results also demonstrated that this technology and methodology could potentially be used by citizen scientists to monitor artificial reefs in the future.

In summary, it is concluded that recreational fishers did not provide a cost effective means for monitoring artificial reefs in this project. This is a consequence of the paucity of data resulting from an absence of volunteer engagement in a pilot project conducted over a short time frame, in which unseasonal weather limited the time participants could safely spend out on the water. Although the limited time frame in which this project was undertaken with delays in approvals, equipment requisition and the resultant falls in participation led to poor data acquisition, the results of this analysis and research do suggest that recreational fishers can provide an effective means for monitoring artificial reefs. Specifically, it is evident from chapter three, that with improved and simplified methods and technology, large quantities of high quality data can be collected and thus increase the validity and robustness of the conclusions garnered in studies of this kind. Thus, this study provides strong evidence that recreational fishers and other citizen scientists can be effective in monitoring artificial reefs if they follow the key recommendations provided in this thesis.

5.2: Key Recommendations and Future Work

5.2.1: Key Recommendations

While the benefits of citizen science are vast, the potential issues such as bias and lack of useable data can deleteriously impact on the success of a research project (Milne *et al*, 2006; Conrad and Daoust, 2008; Crall *et al*, 2010; Dickinson *et al*, 2010; Conrad and Hilchey, 2011). To decrease the probability of potential issues and to maximise the efficiency of using citizen science, it is a recommendation that future projects should analyse the suitability and approach for using citizen science while the project is in the planning phase. Although citizen science is growing in popularity and significance in the scientific community (Conrad and Hilchey, 2011; Baltais, 2013), it is not the best choice for all scientific projects. For example, citizen science can be a good choice for projects needing to sample large areas in a short timeframe with low funding, in contrast, projects with substantial funding and carried out over longer timeframes, that require specific expertise in sampling and detailed data to answer specific questions may be more applicable to research and management organisations (Hill and Wilkinson, 2004). A contextual example would be that a study looking at the seasonal growth rates and residency of *P. georgianus* (Sand Trevally) and *C. auricularis* (Western King Wrasse) to assess whether the southern clusters of the Dunsborough artificial reef were producing biomass, would be more suited to professional scientists, while collecting footage while fishing and also collecting catch and effort data is suited to citizen scientists, in this case, recreational fishers. There are several attributes that may help future projects determine the approach to utilising citizen science. These attributes can be seen in Fig. 5.0. This figure is a conceptual diagram stating the attributes that are more closely associated with either citizen science or professional scientific projects.

Time and funding are shared by both groups. This is because although some projects with small timeframes may be associated with citizen science (Hill and Wilkinson, 2014), others can exceed 50 years (Couvet *et al*, 2008; Gommerman and Monroe, 2012), and while citizen science projects can also be associated with low costs (Hill and Wilkinson, 2014) other citizen science projects may have high costs, to make the project more cost effective on a per observation or datum basis over time (Goldstein *et al*, 2014). It should be noted that this conceptual diagram could not possibly fit all attributes associated with citizen and professional scientific research, nor be applicable to all future potential projects. The applicability of citizen science is highly dependent on project context. The conceptual diagram is a representation of certain attributes more associated with citizen science based projects and professional scientific research and should be considered only while planning framework around potential future citizen science projects.

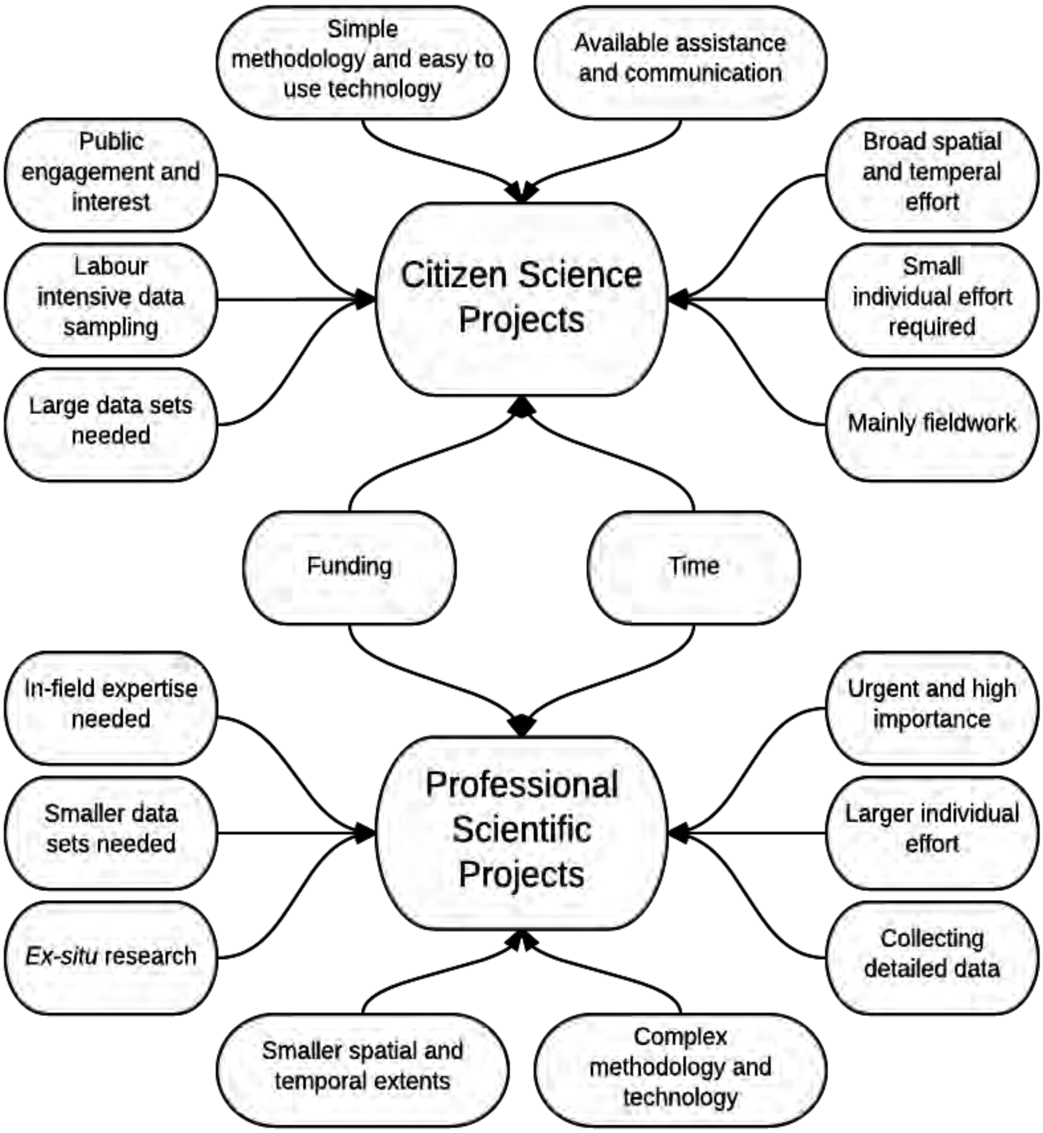


Fig. 5.0: A conceptual model showing the different attributes generally associated with citizen science projects and non-citizen science projects (attributes were adapted from Hill and Wilkinson, 2004; Gommerman and Monroe, 2012 and through reviewing the citizen science methodology in the pilot project in Chapter 3).

The following recommendations are a result of the analyses of the findings of the two studies in this thesis (artificial reef *vs* natural reef and artificial reef modules *vs* areas surrounding modules) using changes in fish assemblages as potential evidence of enhancement, stemming from the artificial reefs. Globally variations in fish assemblages have been shown statistically to be a product of artificial reef enhancement (Shulman, 1984; Santos and Monteiro, 1997; Charbonnel *et al*, 2002; Sherman *et al*, 2002; Arena *et al*, 2007; Granneman and Steele, 2015). The future recommendations below are a product of this study and are only a guideline to establishing the framework in future studies. While they may be beneficial to some studies, they may not apply to all studies wishing to utilise the members of the public for monitoring artificial reefs.

Recreational fishers were used as citizen scientists to monitor the fish assemblages on the South West Artificial Reef Trial to see whether the artificial reefs had enhanced the fish assemblages. While the pilot project (Chapter 2) did not detect a difference in the assemblages, the BRUV study (Chapter 4) found a significant different in the fish assemblages, showing a more enhanced fish community around the artificial reef modules. This enhancement also applies to recreational fishers with 52.63% more target species observed around the artificial reef modules (based on edibility ratings; Hutchins and Swainston, 2012). Data were limited due to many factors including teething issues with the management of volunteers. A critical analysis of the original citizen science methodology in the pilot study produced several recommendations for any similar future studies. The key recommendations from the findings include:

- The contacting and recruiting volunteers should be enhanced by using traditional and social media, with a greater scope for promotion and advertising to recruit a large quantity of better quality volunteers. This will also allow a higher level of succession planning to alleviate potential volunteer attrition.
- Clear, concise and consistent instructions and simplified monitoring protocols will decrease volunteer attrition rates as well as spatial and temporal biases, while increasing the accuracy and quality of the footage.
- Volunteer management can be optimised by adequate and consistent communication and engagement with the volunteers. More experienced volunteers (local champions) can also assist with communication between the two parties. Two-way communication should be utilised when needed to disseminate results and information with volunteers and for volunteers to give feedback, data, observations and other details to project managers when relevant.
- Positive engagement will increase volunteer attendance and interest, fostering stewardship and ownership of the reefs for the volunteers and local community.

The technology and methods used throughout this study varied. The equipment utilised for the pilot project (Chapter 2), the Sony CCD 700 TVL underwater fishing camera kit provided poor quality data and the methodology used in the study varied throughout, with large amounts of spatial and temporal bias. The BRUV study used a GoPro Hero 4™ which provided much better quality footage at a similar cost. The methodology used in the latter study was testing randomised BRUV deployments, and while it yielded a much higher level of data, it can still be improved. The key recommendations from the methodology and technology used in this thesis include:

- Any cameras utilised should be adequately trialled for ease of use, safety issues, performance, data storage capabilities and the quality of the footage before purchasing.
- Using small action cameras such as the GoPro™ can reduce cost while increasing footage quality and effective sampling efforts.
- Simplified BRUVs are easier to operate than drifting rotational cameras attached to the vessel, they are also less likely to get entangled in the modules.
- BRUVs are not totally selective as they capture all species on the screen, however, they should be deployed for at least 36 minutes to obtain measures on the majority of fish species.
- The sampling regime should consist of randomised and standardised squares on a grid, of which fishers are allocated specific squares to monitor with given boundary co-ordinates. This will reduce spatial and temporal bias as well as bias related to sampler objectivity, while increasing the ease of sampling for the fishers.
- If possible, a large timeframe should be allocated for the project to reduce the impacts of unforeseen circumstances, such as unseasonal weather and delays in permits and delivery of equipment.

5.2.2: Future Work

This project was subjected to restrictive and limiting factors but more importantly, discovered ways to overcome these issues. After receiving limited results from the pilot study, and testing the applicability of randomised BRUV sampling, logical future work in this area would include an extension of this study based on the valid recommendations from this thesis. The recommendations provided in this thesis are a large positive outcome from this project and should be utilised in future work to increase the effectiveness of utilising recreational fishers to collect data. Depending on the time and monies available, key recommendations from this thesis should be considered in order to maximise volunteer participation and interest, as well as maximise quality and quantity of data generated. This will help to increase the robustness of estimates of the fish assemblages inhabiting the artificial reefs, and thus their efficacy in enhancing recreational fishing in their locale. By increasing the number of volunteers (equipment costs pending) and ensuring that they stay committed to the project, *i.e.* reduce the "drop-out rate" more data can be collected and the validity of any conclusions drawn will be strengthened. Potential future studies could also analyse spatial and temporal variations within the assemblages. An investigation into the temporal variation could include the effects of diurnal and seasonal variation on the composition of fish faunas, which has been done in many different studies globally (Sale, 1980; Holbrook *et al*, 1994; Santos *et al*, 2002; Felix-Hackradt *et al*, 2013; Henriques *et al*, 2013; Lopez-Perez *et* al, 2013). This would be useful to see whether the fish fauna of the artificial reefs changes temporally and, if so, whether it follows similar patterns to natural reefs. A temporal analysis would also allow insight into which species utilise the artificial reef for long periods of time, certain times of the day or certain parts of the year as well as identify resident, transient and seasonal or migratory species.

Spatial variation of the artificial and natural reefs should also be further explored. Only a small proportion (just over 10%) of the footage from the pilot study was of natural reefs. Future work should include larger amounts of data collected from nearby natural reefs, a 50:50 ratio of monitoring artificial and natural reef should be aimed for. This is important as most studies compare the fish assemblages of natural and artificial reefs (Bombace *et al*, 1994; Rilov and Benayahu, 2000; Arena *et al*, 2007; Burt *et al*, 2009; Hunter and Sayer, 2009; Koeck *et al*, 2014; Granneman and Steele, 2015) to assess the performance of the artificial reef. The performance of the artificial reef includes whether it's enhancing surrounding fish faunas and ecosystems as well as how the reef is meeting other specific objectives, such as facilitating the propagation of recreational target species. Depending on funding and timing in relation to approvals for artificial reef development, a 'before and after' study could be undertaken. This would analyse the fish assemblages and surrounding ecosystem before and after the deployment of artificial reefs. Such a study may be cost prohibitive, but would be beneficial from a biological and environmental point of view and may fast-track artificial reef development and deployment in the future. The Bunbury and Dunsborough reefs should also both have the same amount of monitoring effort to analyse any differences and similarities in the fish assemblages to compare how the spatially separate artificial reefs are fulfilling objectives and enhancing fish fauna. Finally, data collected should be compared with other monitoring studies occurring in the area by organisations such as Recfishwest and the Department of Fisheries. This could help reinforce similar findings, fill in knowledge gaps and justify the methodology, technology and the use of recreational fishers as citizen scientists creating an effective monitoring tool.

The role of recreational fishers in scientific research could be further expanded in future work. Fishers are already used as cost effective approaches to citizen science projects in WA by providing tagging services, biological donations and information and observations though logbooks and software, saving researchers and organisations costs in acquiring samples and data internally. Although these fishers provide a large amount of data and samples, intrinsic to research and fisheries management, they could be used more effectively for ecological monitoring. In future work, recreational fishers could monitor seagrass, mangrove, wetland and coral reef habitats as these systems are bioindicators for ecosystem health, detecting changes in the ecosystem, water quality, contaminant exposure and human disturbance (Orth *et al*, 2006; Smale *et al*, 2011; Mackenzie *et al*, 2012; Department of Water 2013; Fisher *et al*, 2014). Fishers could also monitor the fish assemblages of the aforementioned habitats as well as other habitats affected by human disturbance, natural variation and climate change, as composition of fish assemblages can show prevalence of introduced or pest species (these species themselves can be used as an indicator for system health), fish out of their natural species ranges (possibly a result of climate change), fishing pressure, effects of marine protected areas, level of biodiversity and effects of human disturbance on population sizes as well as other changes in the ecosystem (Whitfield and Elliot, 2002; Kennard *et al*, 2005; Claudet *et al*, 2006; Dulvy *et al*, 2008; Smale *et al,* 2011; Pecl *et al,* 2014). Fishers could also monitor the objectives of other habitat enhancement and stock enhancement activities in WA, through the use of cameras to capture footage of the structures and/or surrounding fish faunas as well as recording catch and effort information. Some of these stock and habitat enhancement activities that could be monitored in future work include the distribution and density of stocked *Argyrosomus japonicus* (Mulloway), *Acanthopagrus butcheri* (Black Bream) and *Metapenaeus dalli* (Western School Prawn). Footage of the fish assemblages, as well as catch and effort data could also be collected around the Fish Aggregation Devices deployed off the coast of Perth and Jurien Bay, the Ocean Grown Abalone Farm off Augusta (purpose built commercial artificial reef) as well as further data on the South West Artificial Reef Trial and future habitat enhancement initiatives.

In conclusion, this study has determined the factors that diminish the effectiveness of utilizing recreational anglers to collect data regarding the colonisation and use of artificial reefs by fishes and their efficacy in enhancing recreational fishing. More importantly however, the project provided guidelines that should followed to increase the usefulness of using recreational fishers to provide sound scientific information in the future.

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Appendix II. Artificial Reefs: Types, applications, trends in deployment and the development of a costeffective method for monitoring their fish faunas

Artificial Reefs: types, applications, trends in deployment and the development of a cost-effective method for monitoring their fish faunas

Submitted by

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This thesis is presented for the Degree of Honours in Marine Science

2015

Murdoch
UNIVERSITY

School of Veterinary and Life Sciences

DECLARATION

I declare that the information contained in this thesis is the result of my own research unless otherwise cited, and contains as its main content work which has not previously been submitted for a degree at any tertiary institution.

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Thomas Andrew Bateman

2nd November 2015

Abstract

The focus of this thesis is on the design and use of artificial reefs and the development of a cost-effective method for monitoring their fish faunas. A review of habitat enhancement structures around the world, focusing primarily on artificial reefs, found that these structures have been used for a wide range of purposes such as sediment stabilization, mitigation of illegal trawling, enhancing recreational fisheries and the provision of additional habitat and nurseries for threatened fish stocks. Over time there has been a growing trend in the use of purpose built reef modules as opposed to the use of materials of opportunity. Within Australia this has been most evident in the shift away from the use of tyres and steel vessels, to the use of specially designed concrete reef modules. As these structures can require financial investments within the millions, it is important to evaluate their effectiveness through post deployment monitoring. A central part of the citizen science monitoring project being developed by Recfishwest is the use of university students to extract information from the Baited Remote Underwater Video (BRUV) footage collected by recreational fishers. This study found that whilst observers recorded similar numbers of species and abundance (total MaxN), significant differences were present between their faunal compositions. This indicates that if inexperienced observers are used in the future as part of a cost-effective monitoring project observer bias may be a potential source of error in the data and should be mitigated through observer training. Statistical analysis of footage collected from the Bunbury and Dunsborough artificial reefs using BRUVs found a significant difference in species composition between the footage from the two reefs but not between camera positions. However, increased camera soak time and footage collection over a greater temporal scale are needed to increase the reliability of the data. Whilst improvements to the sampling regime are recommended, the use of cost-effective BRUVs shows potential as an effective method for monitoring the fish fauna of artificial reefs using citizen science.

Contents

Acknowledgements

Firstly, I would like to say how very grateful I am to my supervisors Jennie Chaplin and James Tweedley for the opportunity to continue my studies through honours as well as the tremendous help they have both provided. Jennie's experience and guidance has taught me a lot, and I am very appreciative of the time and support she has given throughout the year. James's enthusiasm, cheerfulness and statistical knowledge have also been indispensable during this project and I am very thankful for his help.

I would also like to thank all the other members of the Murdoch Fish and Fisheries Research Centre, some of whom I have gotten to know very well and who's advice and friendship I will always remember. The long hours spent in the office and labs were made far more enjoyable thanks to the company and laughter of Max Wellington and Cole du Plessis. I would also like to thank Daniel Yeoh and James Florisson, who having gone though honours previously, have been able to offer valuable advice. I would like to thank Murdoch University and Recfishwest for the funding provided through the Recreational Fishing Initiatives Fund and the Fisheries Research and Development Corporation, which made this project possible. The input from Recfishwest, Ecotone Consulting, and the Department of Fisheries, in particular Paul Lewis, has been much appreciated and I am very thankful for their assistance.

Finally, I would like to express my sincere gratitude to my parents, Andrew and Helga, for the support they have given over not only this year but for the whole of my university studies. I would never be where I am today without their guidance and encouragement. Thank you to everyone who has made this year as enjoyable as it has been, I feel very fortunate to have had the opportunity to do honours at Murdoch University and for all I have gained from the experience.

Chapter 1: General introduction

This chapter provides an introduction to this thesis. It focuses on the rationale of the research undertaken, details how this supports and enhances the research activities of two larger projects on artificial reefs and describes how the thesis is structured.

1.1 Background

Habitat enhancement structures, which include artificial reefs, are structures purposely placed on the substrate that mimic characteristics of natural structural habitat and concentrate populations of marine flora and fauna (Jensen 2002). The practice of creating artificial reefs has been around for thousands of years and the scale of their use around the world ranges from simple artisanal fisheries, to large-scale commercial operations (White et al. 1990, Nakamae 1991, Grove et al. 1994). Artificial reefs have been deployed to suit a broad range of purposes concerning both fisheries management and environmental protection including coastal defence and sediment stabilization (Harris 2009), prevention of illegal trawling and habitat protection (Ramos-Esplá et al. 2000, Jensen 2002), and the provision of additional habitat and nurseries for fish stocks, including threatened species (Pickering et al. 1999, Claudet and Pelletier 2004).

1.2 Relationship to other projects on artificial reefs in Western Australia

This thesis forms part of two broader projects on artificial reefs, as follows.

The first entitled *"Can recreational fishers provide a cost effective means for monitoring artificial reefs?"* is funded by Recfishwest. This project aims to develop a relationship between recreational fishers and fishery scientists and investigate the potential for a community based, cost effective monitoring program to assess the success of habitat enhancement schemes in attracting target faunal species. Researchers from Murdoch University are the principal investigators on this project.

The second, entitled *"The application, needs, costs and benefits of habitat* *enhancement structures in Western Australia and cost effective monitoring methods"* is funded by the Fisheries Research and Development Corporation (FRDC). Two of the stated aims of that large multidisciplinary project are relevant to this thesis, namely;

1. Identify what habitat enhancement structures are currently available throughout the world and what benefits each type may have for recreational and commercial fishing as well as identifying the benefits for aquaculture and the environment.
2. Determine cost effective methods to monitor habitat enhancement structure developments using easily available materials and data collection by community and industry groups.

Recfishwest is the principal investigator, with Murdoch University, the Department of Fisheries and Ecotone Consulting being project partners. It should be noted at the outset that the role of the research undertaken in this thesis was not to achieve the above-stated aims of these two projects, but to contribute to achieving those goals.

In light of the aims of the above research projects, the contents of this thesis can be divided into two main components; (1) literature-based research on the types of habitat enhancement structure used throughout the world, focusing on the trends in artificial reef construction and their use within Australia, and (2) research and evaluate a cost-effective method for monitoring the fish fauna of artificial reefs. The following two sections outline the background and rationale for each section.

1.3 Habitat enhancement structures

Although there has been growing interest from many government and community organisations in the construction and deployment of habitat enhancement structures for a wide variety of purposes, limited guidelines are available that provide advice on which type of structure(s) are best suited to meet the desired objective. Without such information, there is increased risk of duplicating years of trial and error through suboptimal reef design and ineffective management and incurring large expenses in the process (Diplock 2010). Thus, the completion of a review of the types of habitat enhancement structure available, their design and construction, benefits and drawbacks and suitability to meeting the aims of the various user groups is required. Given the recent increase in the construction and deployment of habitat enhancement structures in Australia, a critical synthesis of this information can be used to help guide the future development and use of such structures.

When providing guidelines for future deployment of habitat enhancement structures in Australia it is important to reflect on the past use of such structures and investigate how trends have changed as our knowledge in this area has expanded. Such a review of historical trends is possible in Australia as habitat enhancement structures, predominately artificial reefs, have been employed for ~50 years. Although reviews of the types of reefs deployed within Australia have been conducted before (Pollard and Matthews 1985, Kerr 1992, Branden et al. 1994, Coutin 2001), the most recent was undertaken 15 years ago, during which time numerous new habitat enhancement structures have been constructed. Moreover, these early reviews demonstrated that most reefs had been constructed primarily using waste material such as used tyres and decommissioned vessels, whereas recently deployed reefs, such as those in Geographe Bay in Western Australia, have focused on the use of purpose built modules specially designed for the aims of the user groups.

1.4 Monitoring fish communities on artificial reefs

The deployment of purpose-built artificial reefs requires a significant financial investment and it is thus important to determine whether those reefs have achieved their desired goals. In the case of reefs that have been deployed to attract particular fish species (usually those targeted by recreational fishers), it is important to regularly monitor the fish assemblages of these reefs and how these assemblages change over space and time (Carr and Hixon 1997, Pickering and Whitmarsh 1997, Pickering et al. 1999, Holmes et al. 2013). A range of methods have been developed that are available to monitor the fish communities of artificial reefs and other habitats, each of which has its own particular sets of strengths and weakness (see Kingsford and Battershill 1998). One of these methods, Baited Remote Underwater Video (BRUV) monitoring, has become increasingly popular in recent years, driven by advances in camera and computer technology and a growing demand for the use of non-destructive/extractive monitoring techniques (Harvey and Cappo 2000, Cappo et al. 2003).

Baited Remote Underwater Videos have been widely used to assess fish assemblages in the past and have been found suitable for use in citizen science projects as they remove the need for skilled observers in field (Langlois et al. 2010, Lowry et al. 2012, Holmes et al. 2013). The use of BRUVs has also been shown to attract a greater number and diversity of fish species, providing a more accurate representation of the whole community than that recorded using unbaited cameras (Cappo et al. 2003, Watson et al. 2010).

Some of the limitations with the use of BRUVs are that the effects of the bait can vary significantly depending on the environmental conditions of the day and to avoid repeated counts of the same fish, only a relative abundance is obtainable (Willis and Babcock 2000, Lowry et al. 2012, Harvey et al. 2013). It has also been noted that there is potential for bias towards predatory species, however, this may be beneficial when monitoring recreationally targeted species as the majority of these species are predatory (Willis et al. 2000, Malcolm et al. 2007). The post field video processing time is also considered a limitation of using BRUVs. Compared to traditional diver underwater visual census, which requires very little post fieldwork, underwater video footage requires detailed lab analysis to extract numerical data (Harvey et al. 2013).

During 2013, Two purpose-built artificial reefs were deployed in Geographe Bay, Western Australia, as part of an artificial reef trial project funded by Royalties for Regions ($1,860,000) and from revenue generated from recreational fishing and boat licences ($500,000; Department of Fisheries Western Australia 2015). The aim of the deployment was to attract key recreational fish species such as Pink Snapper (*Chrysophrys auratus),* Samson Fish (*Seriola hippos)* and Silver Trevally (*Pseudocaranx dentex)* and thus enhance local fishing (Department of Fisheries Western Australia 2015). More detailed information on these reefs is provided in Section 4.2.

Given the purpose of these structures, both Recfishwest and the Department of Fisheries Western Australia are involved in the monitoring of the fish fauna of the two artificial reefs. Due to the relatively high cost of scientific monitoring, Recfishwest are particularly interested in the development of more cost-effective monitoring methods using citizen science. Such a monitoring regime would also have the added benefit of engaging local recreational fishers and promoting the reefs in the surrounding areas. Recfishwest has decided to investigate the possibility of employing recreational fishers to carry out long-term monitoring of the Geographe Bay artificial reefs using BRUV systems constructed from low cost materials.

A central part of the artificial reef monitoring approach envisaged by Recfishwest is that university students, as a part of their studies in a relevant area (*e.g.* marine science), will analyze the footage and extract data on the fish communities of the artificial reefs from the BRUV footage collected by the recreational fishers. However, the use of observes with limited experience in logging data from underwater footage must be accounted for and biases such as that between multiple observers understood and managed. For example, previous observational studies of fish assemblages that the scale of difference found between counts and species identification from novice and highly experienced observers was comparable to ecologically meaningful variation if such data represented real differences among sites (Williams et al. 2006). Furthermore, such variation between observers was found to be particularly prevalent when dealing with cryptic and fast moving species (Thresher and Gunn 1986, Thompson and Mapstone 1998, Williams et al. 2006).

Thus the presence of significant amounts of observer bias could clearly compromise the monitoring data set. There is, therefore, a need to investigate the amount of observer bias that might be present among observers with broadly equivalent educational and recreational fishing experience, but limited experience in extracting data from BRUV footage.

1.5 Thesis structure

This thesis comprises six chapters.

Chapter 1. General introduction.

This chapter provides an introduction to this thesis and describes the rationale for undertaking the various research components.

Chapter 2. The design and application of habitat enhancement structures

This literature review summarises information on the types of habitat enhancement structures employed throughout the world. It critically reviews the effectiveness and drawbacks of various designs and construction materials and provides an easy to use pictorial summary (*i.e.* a heat map) to aid end users in choosing the most appropriate construction material for new habitat enhancement structure deployments.

Chapter 3. Trends in artificial reef construction, design and management in Australia.

This chapter builds on the work of Kerr (1992) and provides a historical overview of the trends in the characteristics of artificial reefs within Australia (*i.e.* construction materials, design, location and purpose) have changed over the past 50 years, from the deployment of the first artificial reef in 1965 to the present day.

Chapter 4. Observer bias in the analysis of baited remote underwater video footage.

This chapter determines the level of bias present between four observers with similar educational qualifications and recreational fishing experience, who all viewed the same suite of underwater video footage recorded on an artificial reef using baited remote underwater video.

Chapter 5. Analysis of a cost-effective method for monitoring artificial reefs.

This chapter details the results of an investigation to determine the types of information that can be extracted from baited remote underwater video footage collected by Recfishwest and Ecotone Consulting on two artificial reefs.

Chapter 6. General conclusion.

This chapter provides a brief overview of the key findings of the research undertaken in this thesis and provides some direction for future research.

Chapter 2: The design and application of Habitat Enhancement Structures in the marine environment

2.1 Introduction

Habitat Enhancement Structures (HESs) have been used worldwide for a variety of purposes concerning fisheries enhancement, environmental management and sustainability (Seaman and Spraque 1991, Seaman and Tsukamoto 2008, Bortone et al. 2011). These structures are regarded as "*any purpose-built structure or material placed in the aquatic (oceanic, estuarine, river or lake) environment for the purpose of creating, restoring or enhancing a habitat for fish, fishing, and recreational activities*" (Department of Fisheries Western Australia 2012). The primary application of HESs in the past has been the enhancement of local fisheries with the most common form of this technology being Artificial Reefs (AR) (Seaman and Spraque 1991, Seaman and Tsukamoto 2008, Bortone et al. 2011). More recent applications of this technology, however, have shown that HESs can fill a variety of roles in, for example, species conservation (Pickering et al. 1999, Claudet and Pelletier 2004), the provision of additional specific types of habitat (Spanier and Almog-Shtayer 1992), aquaculture and sea ranching (Nakamae 1991, Grove et al. 1994, Fabi and Fiorentini 1996), tourism (Branden et al. 1994), illegal fishing mitigation (Ramos-Esplá et al. 2000), habitat restoration (Clark and Edwards 1994), and habitat protection (Jensen 2002).

The design of HESs incorporates both engineering and biological elements. Successful HESs must be designed to meet the needs of their intended purposes (such as enhancing fish stocks) along with the regulatory requirement of structural stability and integrity (Harris 1995). An adequate understanding of the waves and currents at the proposed location as well as the possible changes in the hydrodynamics of the area is essential to developing an effective HES (London Convention and Protocol/UNEP 2009). In addition, the material(s) chosen for the construction of a structure must be appropriate for the intended purpose and their properties thoroughly evaluated and understood. Although there is great interest in the development and deployment of HESs from many government and community organisations, there are limited guidelines available for the best application of various types of structure. Thus, the aim of this review is to summarise information on the types and use of HESs around the world.

2.2 History of HES design

The earliest HESs were made from natural, locally abundant materials, such as rocks, logs and bamboo, referred to as "Materials of Opportunity" or MOP (Harris 1995, Harris et al. 1996). In more recent years, however, these natural materials have been supplemented by the use of more modern MOP, *e.g.* retired ships, car tyres, abandoned oil and gas rigs and concrete rubble (Seaman and Tsukamoto 2008).

The initial high use of cheap and abundant materials was due to the fact that the construction of HESs has traditionally been sparsely funded, and that the principal benefactors have been proponents of recreational and commercial fishing and/or scuba-divers (Harris et al. 1996). As a result, many of the ARs constructed in the early 1990's were poorly managed and have been described as a hit-or-miss dumping operation of unsightly scrap material (Pickering and Whitmarsh 1997). Consequently, much effort has been placed in the design and management of HESs and thus there is growing trend towards the use of purpose-built structures (Pickering and Whitmarsh 1997).

Experimentation with purpose built concrete modules began in Japan in 1952 and was soon followed by the formation of the first national HES program (Grove et al. 1994). The subsequent development of Japan's Coastal Fishery Enhancement and Development Program (ENSEI) in 1977 provided greater funding and dedicated research into the effects and benefits of new AR materials and designs (Nakamae 1991, Grove et al. 1994, Jensen 2002, Bortone et al. 2011). International collaboration at events such as the International Conference on Artificial Reefs and Related Artificial Habitats (CARAH) has also been a fundamental step in allowing HES researchers from across the world to share their knowledge on the role that HESs can play in management of fisheries and the marine environment (Grove et al. 1994).

2.3 Materials of Opportunity

Materials of Opportunity used to construct HESs include a wide range of natural materials, *e.g.* rock, shell, or trees and modern human-made materials, *e.g.* concrete debris, retired ships, car tyres, and decommissioned oil and gas rigs. As mentioned previously, due to the low costs, MOP have historically been the dominant material used to construct HESs. Moreover, it is considered as an effective method of recycling the material for productive purposes, whilst simultaneously reducing the cost of constructing HESs (London Convention and Protocol/UNEP 2009). Although modern MOP are generally more durable than their natural counterparts, they also require greater care and management due to the possible negative environmental impacts (Harris 1995, Harris et al. 1996, Seaman and Tsukamoto 2008).

2.3.1. Natural rock and concrete rubble

The use of natural rock to create HESs dates back to the 1600's, where large rock beds were created on sandy substrates in Japan to increase the harvest of kelp (Nakamae 1991). Nowadays, concrete rubble and natural rock are still some of the most common materials used for constructing HESs and their use as a tool for marine fisheries enhancement has been well documented (*e.g.* Bohnsack and Sutherland 1985, Baine 2001). These materials are employed to provide a hard rocky substrate, which can then be colonised by a wide variety of epifaunal species (Jensen 2002). Thus, this type of AR has shown to be very successful in creating algal beds (particularly for kelp (Nakamae 1991)), providing rock lobster habitat (Pickering and Whitmarsh 1997) and mitigating against the effects of rocky habitat loss (Hueckel et al. 1989).

The popularity of this material is partially due to the fact that it can be easily sourced from a variety of places such as construction sites, demolished buildings and bridges, local quarries and channel dredging works. Rock and concrete rubble are also often deployed by simply dumping the material off a barge into the sea using bulldozers, reducing both the cost and time required for deployment (Fig. 2; Lukens and Selberg 2004). Comparisons between HESs constructed from rock, prefabricated concrete shelters and steel vessels off the southern California coast found that quarry rock was the preferred reef material even though it was less effective than prefabricated concrete shelters in attracting fish. Moreover, rock was considered a better material than the others due to its low cost, ease of handling, and reduced scouring and sedimentation around the HES (Turner et al. 1969).

Fig. 2.1: Dumping of quarry rock and concrete rubble for the creation of an offshore artificial reef. Reproduced from Nell (2010).

Although, once submerged, both concrete rubble and natural rock have been found to be very durable and stable, some material may contain high levels of heavy metals, which can be liberated into the environment by leaching and the materials should be assessed prior to deployment (London Convention and Protocol/UNEP 2009).

Rocks with high amounts of quartz are particularly favourable as this mineral is composed of silicon dioxide, one of the main components of many natural reefs and is fully 'compatible' with the environment (London Convention and Protocol/UNEP 2009).

Another consideration when using rock or concrete rubble in constructing HESs is the size of the rocks used. For most applications, large rock is preferred as it provides more interstitial space. In contrast, small stones have been found to pack tightly and the resultant spaces may easily be filled with sand, gravel and rock chips (Lukens and Selberg 2004).

2.3.2. Tyre reefs

Each year, millions of tyres are produced throughout the world. Although some are able to be reused through retreading or burnt as fuel, the majority are disposed of in landfill sites (Collins et al. 1995, Collins et al. 2002). As a result, used tyres have been widely used in the construction of HESs. However, they are now regarded as unsuitable for use in the marine environment following a number of poorly designed and managed projects. The initial view was that once submerged underwater, tyres would be protected from ultraviolet degradation and the stable chemical environment would help limit the leaching of chemicals from the rubber (Collins et al. 2002). The open shape of the tyre, which causes problems for land disposal, was seen as an advantage when creating HESs because it creates multiple habitats, and thus niches and shelter for juvenile fish and invertebrates (Collins et al. 1995). In light of this, the use of used tyres in AR construction appeared an excellent solution by recycling tyres in an ecologically amenable way and proving cheap and readily available materials for the creation of additional fish habitat (Sherman and Spieler 2006).

A review by Collins et al. (1995) found that ARs constructed from tyres were most abundant in south-west Pacific and the Atlantic seaboard of the USA. For example, > 70 tyre reefs have been built along the Atlantic seaboard and 54 tyre reefs deployed in Malaysia using > 1.5 million individual tyres (Kerr 1992). This material has been widely used in Australia too, with over 30 tyre reefs having been constructed.

Tyre ARs, when initially deployed, were found to be effective at attracting target fish species, particularly in Australia where valuable recreational and commercial species such as *Sillaginodes punctatus* (King George Whiting) and *Chrysophrys auratus* (Pink Snapper) were caught in higher numbers around these reefs than around nearby natural reefs (Branden et al. 1994). Soon after deployment, however, monitoring revealed that the positive buoyancy of the tyres was causing many of the reefs to break apart and wash up on nearby beaches (Collins et al. 1995). Another major concern with the use of tyres is their tendency to flex during storms, causing any rigid epifaunal species on the tyres surface to be dislodged and thus 'lost'. This finding is exemplified by the study of Fitzhardinge and Bailey-Brock (1989) who compared the growth of corals on tyres, concrete and metal in Hawaii and observed that the latter two substrates were far more effective at increasing coral biomass due primarily to the flexing of the tyres in rough weather.

The Osborne tyre reef in Florida, USA, is a clear example of how poorly designed HESs can cause more harm than good to the surrounding environment. In 1967, local fishers and environmental resource manages initiated a project to build a large tyre AR offshore of Broward County. The reef was built using 1-2 million banded, but un-ballasted, car and truck tyres (Sherman and Spieler 2006). Since deployment of that reef, storms and strong ocean currents have caused the bands to give-way and break apart the reef, causing many of the tyres to wash up on nearby beaches. Those that remain in the water can still be identified by brand name owing to a complete lack of epifaunal growth (Fig. 2.2). Moreover, many continue to drift along the benthos causing severe damage to nearby natural reefs (Sherman and Spieler 2006).

Fig. 2.2: Photograph showing an area of the Osborne tyre artificial reef. Reproduced from Sherman and Spieler (2006).

Some studies have demonstrated that heavy metal such as zinc, which represent 1-2% of the weight of a tyre, leach and accumulate on hydroids (*Halecium* spp.) growing on the tyre's surfaces (Collins et al. 1994). These findings, combined with the previous experience of tyre ARs, have led to the use of tyres in the marine environment being discouraged and even banned in a number of countries. Moreover, such is the level of concern; several environmental groups have recommended the removal of existing tyre reefs (Dorer 1978, Sherman and Spieler 2006).

2.3.3. Retired ships and other steel-hulled vessels

The long history of accidental shipwrecks on the seafloor has allowed the value of ships as HESs to be well studied over many years (London Convention and Protocol/UNEP 2009). Steel-hulled vessels, selected for their hull integrity, are considered by many AR builders to be a durable material in the marine environment. For example, such structures may last for > 60 years, depending on vessel type, physical condition, location of deployment and the severity of local storms and wave action (Lukens and Selberg 2004). A study of the disposal and recycling options available for retired ships carried out by the United States Navy determined that deploying those ships as ARs provided the best economic outcome. This is because, as well as being the least expensive disposal method, the reefing of retired ships has the potential to provide economic offsets, such as increased revenues from tourism, recreational diving, sport fishing and improved commercial fishing (Hess et al. 2001).

Steel vessels generally have a high vertical profile and large surface area for colonization by epibenthic species, which makes them effective at attracting both pelagic and benthic fish species (Lukens and Selberg 2004). Although primarily used for tourism and sport fishing purposes, the reefing of retired vessels has been suggested for a number of other HES purposes, such as providing deep water nurseries for species under heavy fishing pressure such as *Epinephelus itajara* (Atlantic Grouper) (Hess et al. 2001, Lukens and Selberg 2004).

One of the most successful retired ship projects commenced in Queensland, Australia in the late 1960's. The project scuttled vessels with the aim to increase the diversity and abundance of flora and fauna and to enhance particular fish stocks within the local area. Between 1968 and 1990, 14 vessels were scuttled in waters off Moreton Island at depths of 10-22 m to create the Curtain Artificial Reef. Encouraged by this reef's success, other derelict vessels were acquired over a period of 20 years and strategically placed on the seabed to allow divers to navigate easily from one vessel to another without surfacing (Branden et al. 1994). The Curtain AR has since become a major tourist attraction and supports abundant fish life, with good populations of *Epinephelus lanceolatus* (Queensland Grouper), *E. damelli* (Black Rockcod), *Rachycentron canadus* (Cobia) and *Acanthocybium solandri* (Wahoo), as well as several species of elasmobranch (Branden et al. 1994).

There are a number of considerations, however, when deploying retired ships for use as HESs including the presence of pollutants such as polychlorinated biphenyls, radioactive material, petroleum products, heavy metals (*e.g.* lead, mercury and zinc) and asbestos, which are all commonly present in retired ships and thus need to be removed before the vessel can be sunk (Hess et al. 2001, Lukens and Selberg 2004).

Consideration also has to be given to the fact that steel hulls are not as suitable as rock or concrete for colonization by epibenthic flora and fauna due the sloughing of steel from corrosion (Gregg et al. 1994).

2.3.4. Rigs to Reef

The structures used as offshore oil and gas production platforms, hereafter collectively referred to as “rigs”, have been deployed as ARs. Such structures have been shown to host large and diverse fish communities (Seaman et al. 1989, Love et al. 1994, Rooker et al. 1997). For this reason, many rigs provide a recreational opportunity for both sport fishing and scuba diving (Stanley and Wilson 1989, Love and Westphal 1990, Schroeder et al. 2000). Rigs-to-Reefs (RTR) is the practice of converting decommissioned offshore rigs into ARs. This program, developed by the Minerals Management Service in the USA, aims to preserve established habitat and productive fishing grounds and reduce the cost of removing decommissioned rigs by deploying them as ARs. Such reefs have already successfully been created from decommissioned rigs in the United States, Brunei and Malaysia (Twomey 2010).

Once an oil or gas structure is properly plugged and abandoned, there are three removal options available for converting the structure into an AR (Dauterive 2000). The first method, which is most common in deeper applications, uses explosives to severe the jacket legs of the rig, causing the structure to topple over to a horizontal position on the sea floor (Fig. 2.3). Although this method offers the lowest costs and time, it has the disadvantage of using explosives, which can harm marine life associated with the structure and it eliminates shallow and mid-water habitats (Klima et al. 1988). However, studies have shown that the portions of the rig damaged during reefing are quickly recolonized by fauna (Schroeder and Love 2004).

The second method employs divers to sever the structure at the base using mechanical or abrasive cutters, followed by the lifting of the entire structure from the seafloor and towing it to a new location (Fig. 2.4). This method is typically only used for rigs in water less than 30 m due to the safety of the divers. Although this method is expensive and labour intensive, it causes minimal damage to the marine habitat on the rig (Lukens and Selberg 2004).

The third removal method involves the partial removal of the upper portion of the rig, which is then placed on the sea floor next to the standing bottom portion (Fig. 2.5). This method allows the bottom portion of the habitat to stay intact, whilst the top portion provides a lower profile to complement the standing section, and increases the overall surface area of the structure for habitat enhancement relative to toppled methods (Dauterive 2000).

Studies by Stanley and Wilson (1997) on the effects of these three different methods of converting rigs to reefs demonstrated that the density and size of fishes were greater near the surface than the bottom of standing oil and gas platforms and that partially removed platforms had a slightly higher fish density than toppled platforms. The size of the rig, water depth, distance from shore, proximity to final reef site and potential resale value of the rig have been identified as the primary factors dictating whether it is cost effective for an obsolete platform to become a permanent reef (Wilson et al. 1987, Lukens and Selberg 2004).

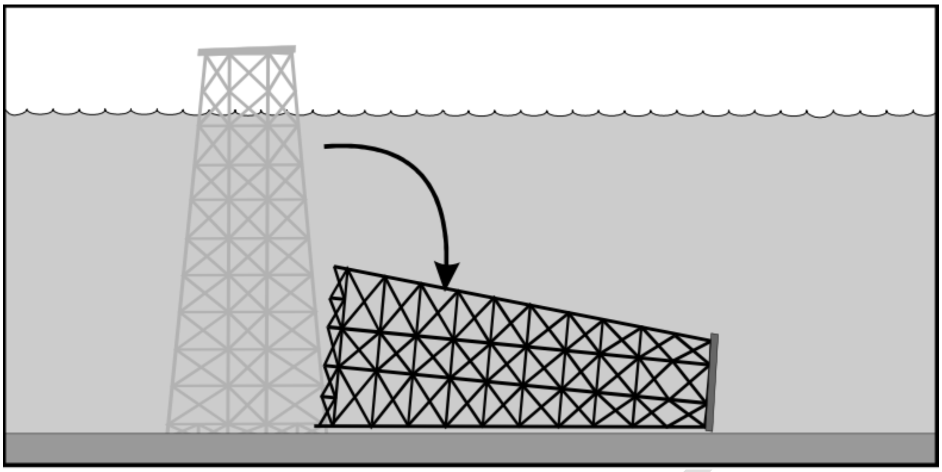

Fig. 2.3: Toppling method for reefing of decommissioned rigs. Reproduced from Dauterive (2000).

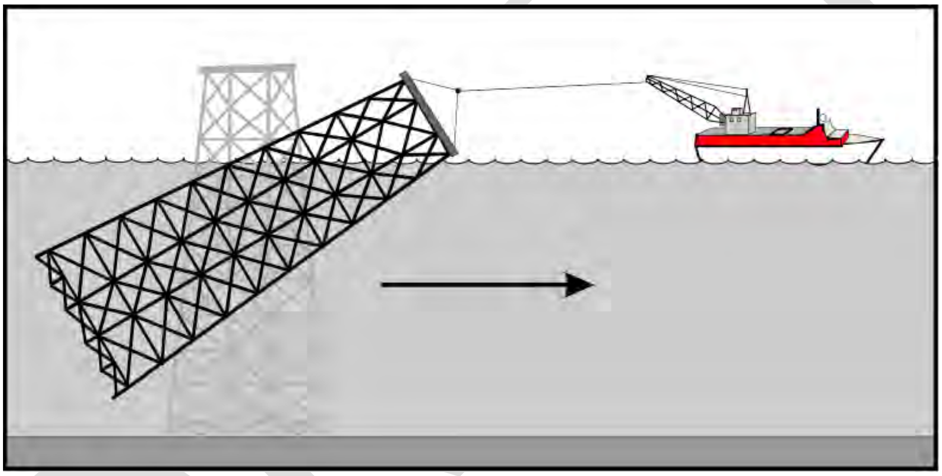

Fig. 2.4: Sever and lift method for reefing of decommissioned rigs. Reproduced from Dauterive (2000).

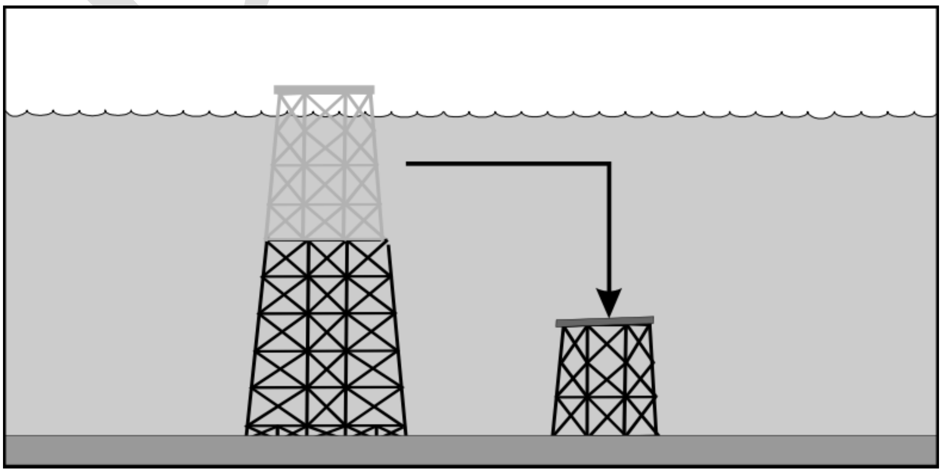

Fig. 2.5: Partial sever method for reefing of decommissioned rigs. Reproduced from Dauterive (2000).

2.4. Purpose-built Habitat Enhancement Structures

Experimentation with purpose-built reef modules began in 1952, following the development of a government subsidy program in Japan and has since gained popularity worldwide (Grove et al. 1991, Pickering and Whitmarsh 1997). The trend towards the construction and use of purpose-built HESs began when directed efforts were made to take advantage of new knowledge on fish behaviour and oceanic processes (Grove et al. 1991, Grove et al. 1994, Jensen 2002). The merging of knowledge on fish behaviour and the physical environment gave HES designers a more rational approach to developing HESs that could target specific species and environments (Grove et al. 1991).

In contrast to earlier structures, these engineered designs did not incorporate MOP into their construction. Thus the materials utilized to construct purpose-built HESs are able to be selected for their durability, resistance to corrosion/abrasion, strength, structural/design demands and compatibility with the marine environment (Lukens and Selberg 2004). In countries such as Japan and Korea, all new HES modules are required to be tested and monitored for at least two years before government assessment determines whether they can be deployed within public waters (Diplock 2010).

Concrete has been found to be a very favourable material for reef construction following a number of HES trials (Pickering and Whitmarsh 1997). This material has been found to be durable in seawater, easily moulded to different specifications and has a similar epifaunal community development to natural coral reefs (Fitzhardinge and Bailey-Brock 1989). Steel is also very popular constructing material in AR construction and is often used in combination with concrete and for larger AR structures due to the weight considerations of concrete (Lukens and Selberg 2004).

2.4.1 Fish Aggregating Devices

Association with floating structures in open waters during one or more life history stages has been recorded for > 300 fish species belonging to 96 families (Castro et al.

2002). It is generally believed that fish utilise these objects primarily for protection from predators (Hunter and Mitchell 1968), as a meeting location (Soria et al. 2009), as a source of food and to increase the survival of eggs and juveniles (Gooding and Magnuson 1967). A Fish Aggregating Device (FAD) is any purpose-built, moored and positively buoyant (floating or submersible) structure that is designed to attract and/or aggregate fish in order to facilitate fishing activities (Department of Fisheries Western Australia 2012). Fish Aggregating Devices are generally classified as either surface, mid-water or drifting and can be made from a wide variety of materials. Floating palm fronds with rock or concrete filled tyre anchors are still used extensively in many artisanal fisheries, and although generally short lived (*i.e.* 3-6 months), they effectively attract large numbers of pelagic fish species such as *Coryphaena hippurus* (Dolphin fish) and *Katsuwonus elemis* (Skipjack Tuna) (White et al. 1990, Grove et al. 1991). Technological advances and the development and use of more durable FAD designs and materials have made modern FADs an important tool in many commercial and recreational fisheries. Modern anchored FADs can be placed in waters up to 2000 m deep and incorporate flashers and netting to attract fish and increase structural complexity, respectively (Gates et al. 1996). These devices are commonly employed by recreational fishers and may reduce the fishing pressure on demersal species, by making it easier for fishers to target faster growing and more abundant pelagic species, which aggregate at the FADs (Dempster and Taquet 2004). Drifting FADs on the other hand are primarily used by commercial purse seine fishermen to congregate large schools of tuna (Bromhead et al. 2003). To this end, GPS locaters and fish sonars are often incorporated into their design allowing them to be easily tracked and allowing fishers to detect the school size and even fish species congregating at the FADs (Castro et al. 2002).

Although beneficial to some areas by reducing fishing pressure on benthic species, the over use of FADs can lead to depletions in pelagic fish stocks. Thousands of FADs are deployed each year and overall global information on their use is limited (Macfayden *et al.* 2009). As well as this, poorly constructed FADs have a tendency to break away from their mooring during heavy seas and may become a serious navigation hazard.

2.4.2 Benthic Production Reefs

The first generation of purpose-built Benthic Production Reefs (BPR) was developed in Japan in the 1950's to enhance those local fisheries that were depleting (Bohnsack 1987a). Initially these reefs had simple designs that consisted of small, hollow concrete cubes or cylinders with "windows" in the sides. However, due to their success, by the 1990's there were over 100 different designs in use, each developed for different species and environmental conditions (Grove et al. 1994). The success of these BPRs showed that despite the greater initial cost involved, the use of reef designs that incorporated not only the biological requirements of target species, but also the engineering aspects relating to material design, placement and performance, produced far greater benefits than earlier reefs made from MOP (Pickering and Whitmarsh 1997).

Benthic Production Reefs are designed not only with the aim of attracting and congregating fish, but to permanently create more productive fishing areas through the creation of additional habitat and nursery grounds. The ability to deflect horizontal ocean currents upwards, thereby inducing upwelling, has also been incorporated into the design of some BPRs (Bohnsack and Sutherland 1985, Grove et al. 1994). Many of the world's most productive fishing grounds occur in regions where, to compensate for the offshore migration of the surface water, bottom water wells up toward the shoreline, bringing with it nutritious seston and the primary organisms thriving in them (Grove et al. 1994).

2.4.2.1. Design of benthic artificial reefs

Size, shape, void space and the number and size of openings are all important factors in the design of BPRs and reef requirements vary greatly depending on the target species and environmental conditions (Pickering and Whitmarsh 1997). Studies done in Korean waters found marked preferences among different species for particular reef designs and a significant relationship between reef structure and catch volume (Kim et al. 1994, Lee and Kang 1994). Dice shaped reefs were found to be the preferred habitat of rockfish, whilst turtle dome reef units attracted primarily demersal species (Lee and Kang 1994). Cylinders with large holes along the sides were found to be effective at attracting finfish, with larger, hollow structures consistently found to have the highest species diversity (Kim et al. 1994). Other studies have also shown that whilst larger individual reef units have been found to hold greater biomass densities, these populations are generally made up of larger but fewer individuals. Multiple smaller reefs on the other hand were shown to attract greater numbers of smaller individuals and species and are recommended in preference to a single larger reef unit in terms of overall recruitment (Bohnsack et al. 1994). It has been noted, however, that smaller reef units have limited value as nurseries for juvenile fish and for increasing overall production, and thus, in terms of enhancing fisheries, larger reef units with a combination of unit sizes is most effective (Moffitt et al. 1989, Bohnsack et al. 1994).

Direct relationships have been identified between increased reef production and reef volume up to a critical point of 4000 m^3, with reef areas between ~2300 m^2 – 4600 m^2 required to reach equilibrium and permit propagation (Ogawa et al. 1977, Bohnsack et al. 1994). Reef height will also greatly influence the species composition at the reef, with taller individual reef modules being more effective at attracting transient pelagic species. Demersal and benthic species however such as lobsters, which rarely venture above 1m from the seabed will be more affected by the horizontal spread of the reef rather than the vertical height (Bohnsack 1987b).

The structural complexity, particularly the presence and variety of crevices, also plays a significant part in species composition and productivity of an AR. Topographically complex ARs, in comparison with more simplistic shapes, are found to have greater numbers and species of fish associated with them due to the greater number of individuals able to find shelter from predation (Clark and Edwards 1994). Another important consideration in AR design is that fish will generally not venture into dark, closed compartments with only a single exit, preferring spaces with many openings and a free flow of water. For small fish in particular, which require places to rest, the deployment of AR units at right angles to strong currents can provide effective shelter on the lee side (Dean 1983).

2.4.2.2. Shallow-water benthic artificial reefs

Shallow-water (10-30 m) benthic AR structures are generally constructed from concrete as mentioned previously, due to its moldability and structural integrity in the marine environment (Fitzhardinge and Bailey-Brock 1989, Pickering and Whitmarsh 1997). The "Fishbox" design, which has been used on the east and west coasts of Australia, is a 17 ton hollow concrete cube unit with a reinforced concrete cross brace (Fig. 6; HaeJoo 2015b). These structures were designed to attract a wide range of recreationally important fish species by creating complex spaces and habitats and diverting nutrient-rich water up the water column (Department of Fisheries Western Australia 2015). After only two years of deployment the reefs have seen the number of fish species in the vicinity of the reefs quadruple, with a high presence of target species such as *Chrysophrys auratus* (Pink snapper) and *Pseudocaranx dentex* (Silver Trevally) (Department of Fisheries Western Australia 2010, 2015).

Fig. 2.6: "Fish Box" reef module deployed in Geographe Bay, Western Australia. Reproduced from HaeJoo (2015b).

Benthic Production Reefs have also been successfully used in the aquaculture of molluscs, where often the environmental conditions are ideal but there lacks hard substrate within the vicinity for the organisms to attach themselves and establish a population (Badalamenti et al. 2002, Fisheries Research And Development Corporation 2015). A number of ARs have been trialled for use in the farming of wild abalone, a highly valued and sought after product, in Flinders Bay, Western Australia (Fisheries Research And Development Corporation 2015). Some of the benthic reef types trailed include solid concrete blocks, hollow concrete blocks, round concrete tubes and standard besser blocks. The most recent and successful reef design is a purpose built module designed specifically for abalone ranching. Each unit is 1.2 m^2 by 600 mm high, with a total surface area of 4.5 m^2 (Fig. 7; HaeJoo 2015a). The design includes improved shelter for juveniles to increase survival rates and grooves in the concrete to help trap waterborne macro algae and improve the food supply. Each reef unit is predicted to harvest up to 10 kilograms of abalone annually, equating to roughly 30 individuals (Fisheries Research And Development Corporation 2015).

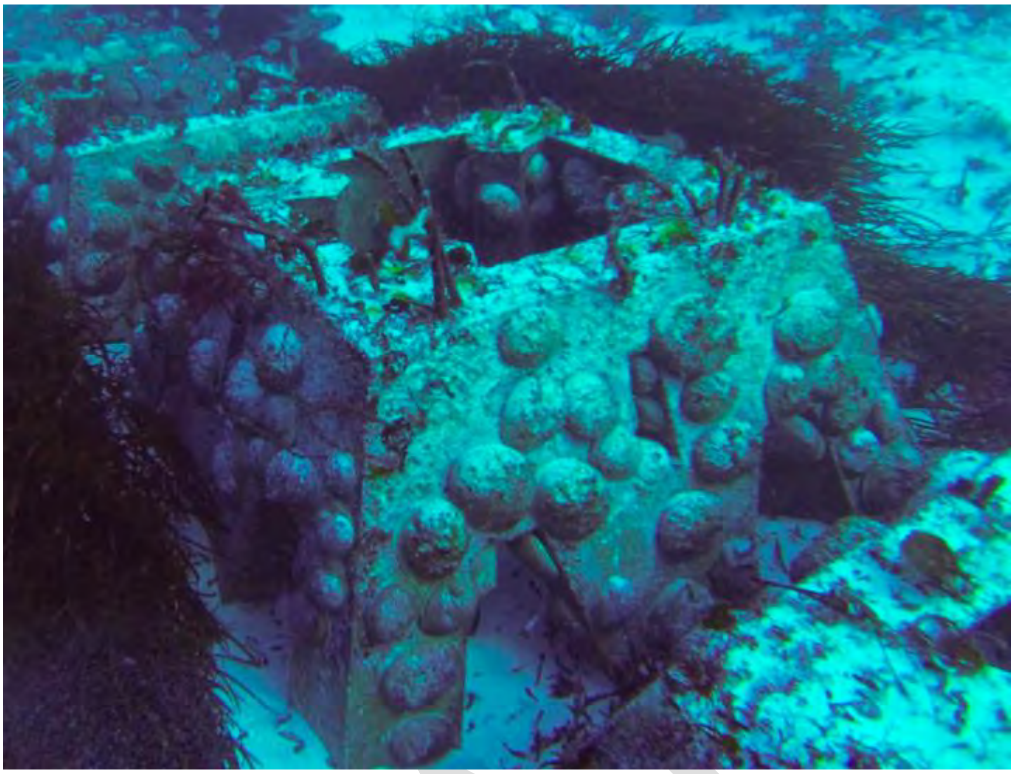

Fig. 2.7: An abalone reef module in Flinders Bay, Western Australia. Reproduced from HaeJoo (2015a).

2.4.2.3. Deep-water benthic artificial reefs

Deep-water (30-150 m) benthic ARs are generally larger than shallow water reefs and constructed from steel, making them lighter and easier to deploy than concrete units of similar size. These reefs are effective at congregating pelagic fish species as well as providing shelter and protection for deep-water demersal species. The “Fish Cave” reef units, which have been deployed at the Wild Banks Reef within Moreton Bay, Queensland, are a good example. These units are 11 m tall, 11 m wide, weight 14.4 ton, and were designed to increase the numbers of pelagic species such as mackerel and wahoo which are targeted by recreational fishers and spearfishermen (Queensland Department of National Parks 2015). The title of the world's largest reef unit is held by a steel reef named the "*Ocean Cross*". This reef unit was installed in 1991 in the Sea of Japan and has a bulk volume of 3600 m^3, with a height of 9 m and maximum horizontal dimension of 27 m (Grove et al. 1994).

2.4.3. Habitat protection reefs

Anti-trawling reefs are generally constructed from a combination of concrete blocks and steel arms that aim to catch and tear through trawling nets. Although these structures are generally less complex and provide less diverse habitat than other purpose built ARs, their extra weight and profile make them effective deterrents to illegal trawling (London Convention and Protocol/UNEP 2009).

European fisheries have been deploying ARs regularly over the past 30 years with the majority aimed at protecting their Mediterranean seagrass beds, which have been severely damaged in the past due to illegal trawling (Jensen 2002). Following baseline surveys in the waters off the SE Iberian peninsula which showed that up to 48% of the *Posidonia oceanica* meadows had been damaged by trawls, 1.5 m^3 concrete blocks with 0.5 m steel arms were deployed over an area 5 400 000 m^2 to help deter illegal trawling in the marine reserve (Sánchez-Lizaso et al. 1990).

Since the deployment of 358 blocks in 1992 no illegal trawling has been recorded in the area (Ramos-Esplá et al. 2000). Post deployment monitoring of the damaged seagrass beds in the Tabarca reserve has shown promising results with *P. oceanica* shoot density increasing from 10 to 60 shoots per m^2 in the 6 years after deployment of the reef (Jensen 2002).

2.4.4. Electrodeposition reefs

Electrodeposition is the process of accreting calcium and magnesium salts on to a cathode using a low electric current. This process was first descried by Hilbertz in 1977, and can be used to grow extremely hard calcium carbonate limestone deposits on any steel template (Hilbertz et al. 1977). The “Biorock” material is primarily made up of the mineral aragonite, the same compound that makes up coral skeletons, making it ideal for use in the marine environment (Goreau 2012). Initial studies with this technology found that within 2 months, a coating with a thickness of 5-10 mm of material can be formed around the template (Van Treeck and Schuhmacher 1999).

The process has found use all across the Caribbean, Pacific, Indian Ocean, and Southeast Asia, with most projects taking place in Indonesia (Goreau 2014). As the template used to grow the material can be made into any shape, it can be utilized for a number of purposes such as repairing damaged coral reefs and the creation of custom dive sites. These effects however are not residual and only occur only when the electrical field is on. As the technology is still experimental there is also limited research into the possible harmful chemicals that may be produced as by-products of the reaction (Lukens and Selberg 2004).

2.4.5. Artificial seagrass

Seagrass meadows are extremely valuable coastal ecosystems, both ecologically and economically. They provide a number of high-value ecosystem services and it has been proven that fisheries revenue from an area increases when the size and condition of its seagrass meadows improve (Orth et al. 2006, Shahbudin et al. 2011). Additionally, seagrass meadows provide effective sediment stabilization and reduce wave energy, thus providing significant coastal protection (Orth et al. 2006). The reduced hydrodynamic conditions and stabilised sediment caused by the meadows create conditions more suitable for the seagrass itself, enabling further meadow growth in a positive feedback loop (Shahbudin et al. 2011). Unfortunately, seagrass meadows around the world are declining for various reasons with reported cases of seagrass loss increasing tenfold over the last 40 years in both tropical and temperate regions (Orth et al. 2006).

Artificial seagrass has been used extensively in seagrass community research, as the artificial beds can be placed next to natural meadows and easily sampled without damaging the natural seagrass (Virnstein and Curran 1986, Bartholomew 2002). Artificial seagrass has also been widely used as a soft engineering method to protect shorelines from erosion and as an alternative habitat for various marine organisms (Shahbudin et al. 2011). Artificial seagrass beds can be made from a range of materials and customized to mimic the target seagrass species. Studies on artificial seagrass made from green polypropylene ribbons designed to mimic *Thalassia testudinum* (Turtle grass) showed extremely rapid colonization by seagrass-associated epifauna (Virnstein and Curran 1986).

A major consideration when using artificial seagrass it that the material used in their construction is generally not biodegradable and rough weather may cause the beds to break apart, leading to possible negative environmental impacts. Future research in seagrass rehabilitation includes the development of biodegradable artificial seagrass that can be placed in locations that are generally suitable for seagrass re-establishment, but are sub-optimal for initial settlement. This artificial meadow would then provide the ecosystem engineering function to promote the growth of natural seagrass in its vicinity and then simply biodegrade, thus reducing any disturbance by removing the artificial beds (Innorex 2014).

2.4.6. Multi-Function Artificial Reefs

Multi-Function Artificial Reefs (MFARs) are offshore, underwater structures that can be designed to protect coastlines, reduce erosion, enhance marine habitats and provide a valuable recreational resource. The addition of environmental and recreational amenity to coastal protection facilities provides a range of benefits, which come at a critical time when shoreline modification is accelerating (Black 2001). Additionally offshore coastal protection does not impair visual amenity and can mitigate the need for rock emplacements along the shoreline that can isolate people from the coast (Harris 2009).

Multi-Function Artificial Reefs will generally have a primary goal such as reducing beach erosion, and a variety of secondary goals such as providing recreational dive sites and increasing local marine biomass. One example of this is the use of AR modules for constructing submerged breakwaters for shoreline stabilization. Breakwaters work by causing larger waves to break on the structure whilst allowing smaller waves to pass unaffected. This allows normal coastal processes to occur in the lee of the reef, whilst effectively reducing the wave energy of larger waves and stabilizing the adjacent beach (Harris 2009).

Along the Southern Caribbean shore of the Dominican Republic 450 Reef Ball™ units were installed to form a submerged breakwater for shoreline stabilization, environmental enhancement and eco-tourism. The units used for the breakwater were 1.2m high Reef Ball™ units and 1.3m high Ultra Ball units, with base diameters of 1.5 and 1.6m, and masses of 1600 to 2000 kilograms. The breakwater was installed in water depths of 1.6 m to 2.0 m, to suit the areas 0.4 m tidal range (Harris 2009). Monitoring over the next three years saw the shoreline increase by over 10m, with no adverse impacts recorded on adjacent beaches. As well as stabilizing the shoreline the reef provided a popular diving and snorkelling site owing to the enhanced marine habitat (Harris 2009). Similar projects have been carried out in other parts of the Caribbean, including the Cayman Islands, where a 5-row submerged breakwater reef has protected the shoreline from two category five hurricanes and still remains stable (Harris 2009).

Artificial Reefs deployed as breakwaters need to be designed to withstand the large forces created by breaking waves, wave induced currents, and scour that occurs in the surf zone. For units placed on hard substrate, the main concerns are the strength of the unit and its resistance to sliding and over turning. The weight of the individual unit will contribute to its overall stability and may require pinning to the seafloor for additional stability. For units placed on sand, scour and settlement are the primary concerns and can be prevented by either drilling rods into the substrate through the unit at an angle or by placing the units on an articulated mat (Harris 2009).

Another type of MFAR is an artificial surfing reef, which provides both social and economic benefits through activities such as surfing, diving, fishing and tourism. Artificial surfing reefs also aid in stabilizing beaches much in the same way as shallow water breakwaters and have been used widely in Australia and New Zealand in place of rock walls or other shoreline defences (Mead and Black 1999, Jackson and Corbett 2007). Although the use of breakwaters for shoreline protection is not new, the recent development of more subtle and versatile offshore coastal protection has become achievable though sophisticated modelling programs which aid in the design process (Jackson and Corbett 2007, Mead 2009).

An example of one of these reef types is the Narrowneck Artificial Reef on the Gold Coast, constructed for both coastal protection and improved surfing. Built in 1999-2000, the reef was constructed using over 400 sand-filled geotextile containers that were dropped into place using a hopper dredge (Jackson and Corbett 2007). Although the reef requires long period, clean swell to replicate the modelled waves, it has proven successful in improving the surfing quality in the area and often waves that break on the reef will link up to waves on the inner sand bars, significantly increasing the quality of the surf break (Jackson et al. 2007).

The reef has also provided a suitable substrate for development of a diverse ecosystem and has become a popular fishing and diving location. As a result it has been designated as a no anchoring zone to preserve the current growth. Additionally, the type of geotextile used promotes soft growths that do not present a safety hazard to surfers (Jackson and Corbett 2007). One consideration when using this reef type is the possibility of needing to remove the reef if adverse effects become present. Multi-function artificial reefs should be designed with this in mind and a removal method should be determined before placement.

2.4.7. Urban waterfront habitat enhancement

Recent research into the use of HESs has looked at incorporating this technology into structures along urban waterfronts. As construction along coastlines and within canals continues to increase, especially in countries such as Australia where the vast majority of people live along the coast, alternations to the natural movement of sand, as well as removal of habitat has reduced much of the nearshore biodiversity. Urban structures built in the marine environment are generally not designed or managed to provide habitats for the communities of marine organisms that could colonize them. However, by incorporating the current knowledge of nearshore marine communities and ARs, the urban waterfront may be capable of supporting a significant proportion of regional aquatic biodiversity (Duffy-Anderson et al. 2003).

Two key differences have been identified between natural rocky shores and human-made structures; slope and microhabitat availability (Dyson 2009). Seawalls and other nearshore infrastructure generally provide vertical habitats, whereas rocky shores have very heterogeneous topography (Chapman 2003, Lam et al. 2009). This limits the type and distribution of many intertidal plant and animal species on human created structures (Bulleri and Chapman 2010). To counter this, researchers have suggested designing and building structures such as seawalls with a combination of surface slopes and textures (Dyson 2009). Incorporating microhabitats such as cavities which retain water during low tide and other analogous features, which are lost when rocky shores are developed, can also have a positive effect on the shoreline biodiversity (Dyson 2009).

Recently built seawalls in Sydney Australia have already incorporated this research into their design with the aim of incorporating intertidal habitats into seawalls in a cost-effective manner that neither compromises safety or engineering requirements (Fig. 2.8). Pools created within the Sydney Harbour seawalls have shown to increase the diversity of species of algae and sessile animals many-fold, especially higher up the shore line where environmental conditions are harshest (Bulleri and Chapman 2010). Additional factors such as surface texture, shading, connectivity and water flow have all been identified as affecting nearshore marine communities. By considering these aspects in the design of future projects, diverse communities, similar to those found on natural rocky shores can be established (Moreira et al. 2006). This would provide not only ecological benefits but also cultural, recreational and educational values to the users of these coastlines (Dyson 2009).

Fig. 2.8: Intertidal ‘rock-pools’ built into the vertical face of a sea wall in Sydney Harbour Australia, designed to retain water during low tide. Reproduced from Bulleri and Chapman (2010).

2.5. Application of habitat enhancement structures

A wide variety of designs, configurations and materials exist that can be utilized when developing a HES. Ensuring the material and design used are suited to the purpose will maximize the potential benefits from a HES. Prior to commencing a HES project, factors such as location, intended purpose, target species, cost, government regulations and environmental impact should be carefully considered. The following heat map matches the designs and materials used for creating HESs with their effectiveness for a range of different factors (Fig. 2.9).

This heat map aims to provide a simple guide as to the most suitable HES for specific purposes and environments. It can also be used to show that it may be effective to combine a number of different materials and designs in order to gain the maximum benefits from a habitat enhancement project. For example the high vertical profile of a large steel hulled ship will attract large numbers of pelagic fish whilst placing rock beds nearby will increase the amount of hard substrate for rock lobster and other benthic species to inhabit, making these two materials a good combination when designing a recreational fishing and diving reef. It should be noted, however, that the effectiveness of any of these structures and the materials used in their manufacture depends strongly on their engineering quality and management, which has not been covered in detail here (Collins et al. 1994, Pickering and Whitmarsh 1997).

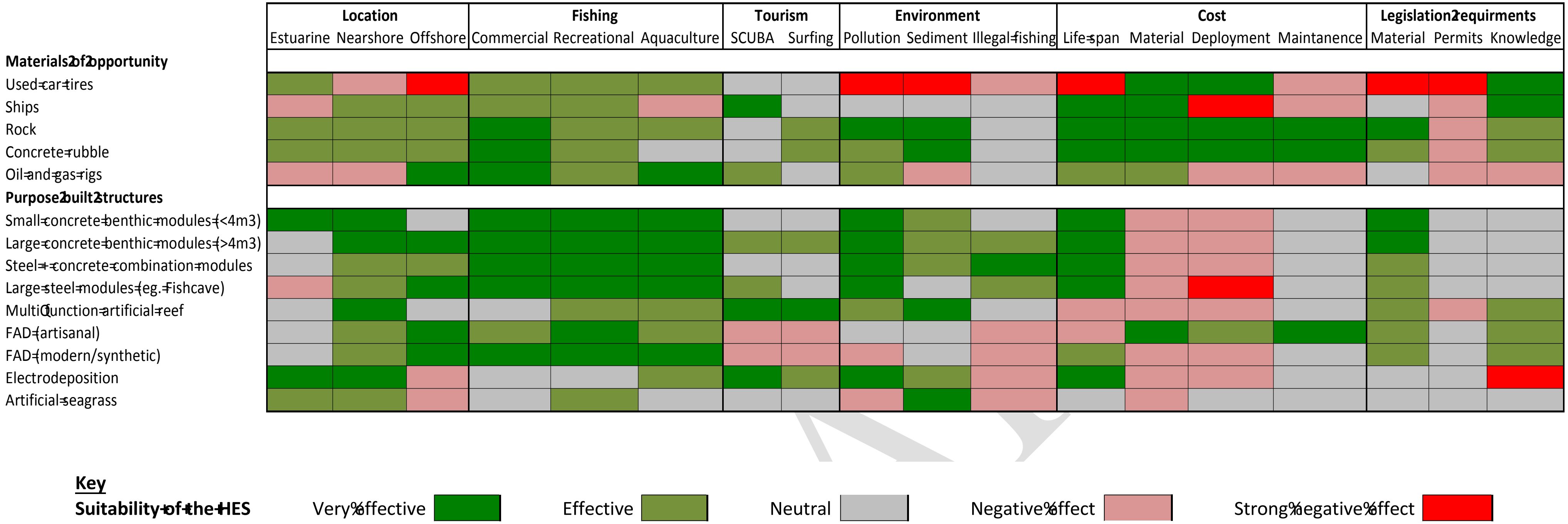

Fig 2.9. Heat map of the benefits and cost of deploying different types of HESs in different environments. Note: the cost and legislation requirements have been based on Australian government requirements.

2.6. Conclusion

Research into the past and present use of HESs has allowed for significant advances in both the management and design of these structures. Modern purpose-built reefs have clear advantages over earlier structures, including; lower negative environmental impacts, increased longevity, and effective species-specific designs. However, the increased cost of purpose-built HESs has meant MOP are still frequently used within artisanal fisheries which struggle with budgetary constraints. In such circumstances, effective management and planning will determine the success of such projects.

As detailed here, HESs can be an important tool in the management of fisheries, capable of producing more productive fishing grounds, protecting threatened habitats and species along with added tourism and recreational benefits. The incorporation of this technology into future urban waterfront infrastructure will also aid in improving the biodiversity of modified coastlines and harbours. The current review should allow project managers to easily identify which HESs will be most suited to their intended purpose and help guide the future development and use of HESs around the world.

Chapter 3: Trends in artificial reef construction, design and management in Australia

3.1 Introduction

Archaeological evidence has shown that Australian aboriginals have used artificial reefs for thousands of years, built from natural materials such as rock and wood (Carstairs 1988). Modern artificial reef construction however began in the 1960's, sparked by work in the Virgin Islands and California, as well as early reviews of worldwide artificial reef developments (Pollard 1989). The trajectory of artificial reef development within Australia has been similar, albeit on a smaller scale to artificial reef development around the world, with early reefs consisting almost entirely of materials of opportunity, such as used tyres, vehicle bodies, scuttled vessels and concrete rubble (Pollard 1989, Kerr 1992).

Concerted scientific effort over the past 15 years, including a number of reef module trials, and input from global leaders in the field such as Japan and Korea, has provided valuable knowledge of the factors which influence the recruitment and succession of fish and epibiotic communities on artificial reefs, as well as the impact these structures have on ecological processes in the surrounding environment (Carr and Hixon 1997, Pitcher and Seaman Jr 2000, Department of Fisheries Western Australia 2010, Lowry et al. 2010). This knowledge, combined with more stringent legislation requirements, has triggered a surge in the use of modern purpose-built artificial reef modules within Australian waters, as they offer a number of significant benefits over reefs made from materials of opportunity (Pickering and Whitmarsh 1997, Department of Fisheries Western Australia 2010, Diplock 2010).

Previous reviews of artificial reefs in Australia *e.g.* Pollard and Matthews (1985), Kerr (1992), Branden et al. (1994), Coutin (2001), have provided information on early reef developments. As of 2001, the majority of artificial reefs within Australia were still made up of tyres (37%) or ships (22%) with only a small portion made from concrete (6%) (Coutin 2001). However, limited work has been done on collating data on Australia's most recent reef developments over the past 15 years, in which time a number of artificial reef programs have been developed, aimed at improving the quality and management of artificial reefs (Department of Fisheries Western Australia 2015, Fisheries Victoria 2015, New South Wales Department of Primary Industries 2015).

The aim of this chapter is to undertake a literature search to identify trends in artificial reef construction within Australia, since the deployment of the first artificial reef in 1965 to the present day. The chapter considers where and when artificial reefs were deployed, what the reefs were constructed from, and their primary purpose. It identifies trends in artificial reef design, location and purpose, and assesses how these patterns have changed over the past 50 years.

3.2 Materials and Methods

This work builds on previous analyses of artificial reefs in Australia conducted by Pollard and Matthews (1985), Kerr (1992), Branden et al. (1994), Coutin (2001) . It combines the data presented in those documents with those obtained during contemporary literature searches. These searches were conducted in search engines (*e.g.* Google and Google Scholar) and documents indexed in scientific databases (*e.g.* Scopus, Web of Science and Murdoch University). Keywords employed as search terms included "artificial reefs" and "habitat enhancement structures", with additional words such as "Australia" and the names of Australia's various coastal states and territories. For each reef, information such as the location, year of deployment, materials of construction (Table 3.1), purpose and builder/funder were obtained and stored in a database. Note that for the purpose of this report, the literature search was limited to purposely-placed benthic artificial reefs and thus accidental shipwrecks or floating Fish Aggregation Devices (FADs) have been excluded.

Table 3.1: Classification and description of materials used in the construction of artificial reefs.

Materials of opportunity (MOP)	
Category	***Description***
Tyres	Used vehicle tyres of any size.
Steel vessels	Steel hulled ships and other steel vessels that have been purposely scuttled for the creation of an artificial reef.
Rubble	Quarry rock and concrete rubble/waste purposely deployed to create an artificial reef.
Mixed MOP	Combination of two or more materials of opportunity at a single reef.
Purpose-built	
Category	***Description***
Concrete modules	Concrete modules of any size built specifically for use in the construction of an artificial reef *e.g.* concrete fish boxes and Reef Balls.
Steel modules	Steel modules of any size built specifically for use in the construction of an artificial reef, *e.g.* steel fish caves.
Geotextile bags	Geotextile bags, which can be filled with material such as sand, that have been specifically designed for use in artificial reef construction.
Mixed	Mixture of materials of opportunity and purpose-built modules at a single reef. Generally occurs when a reef is added to over multiple years.

3.3 Results and Discussion

To date, 121 artificial reefs were found to have been deployed in Australian waters (Fig.3.1). While artificial reefs are present in each state and territory with a coastline, their numbers differ markedly. Relatively large numbers of artificial reefs were found in Victoria (28), South Australia (26), Queensland (22) and New South Wales (21), while lower numbers were present in Western Australia (11), Northern Territory (9) and Tasmania (4). The highest densities of artificial reefs were found close to major cities and/or within sheltered bays, such as the Gulf of St Vincent and Moreton Bay. In contrast, remote coastlines, such as the Kimberley in Western Australia, and the Great Australian Bight, do not contain any artificial reefs with only a single reef present in the Gulf of Carpentaria (Fig. 3.1).

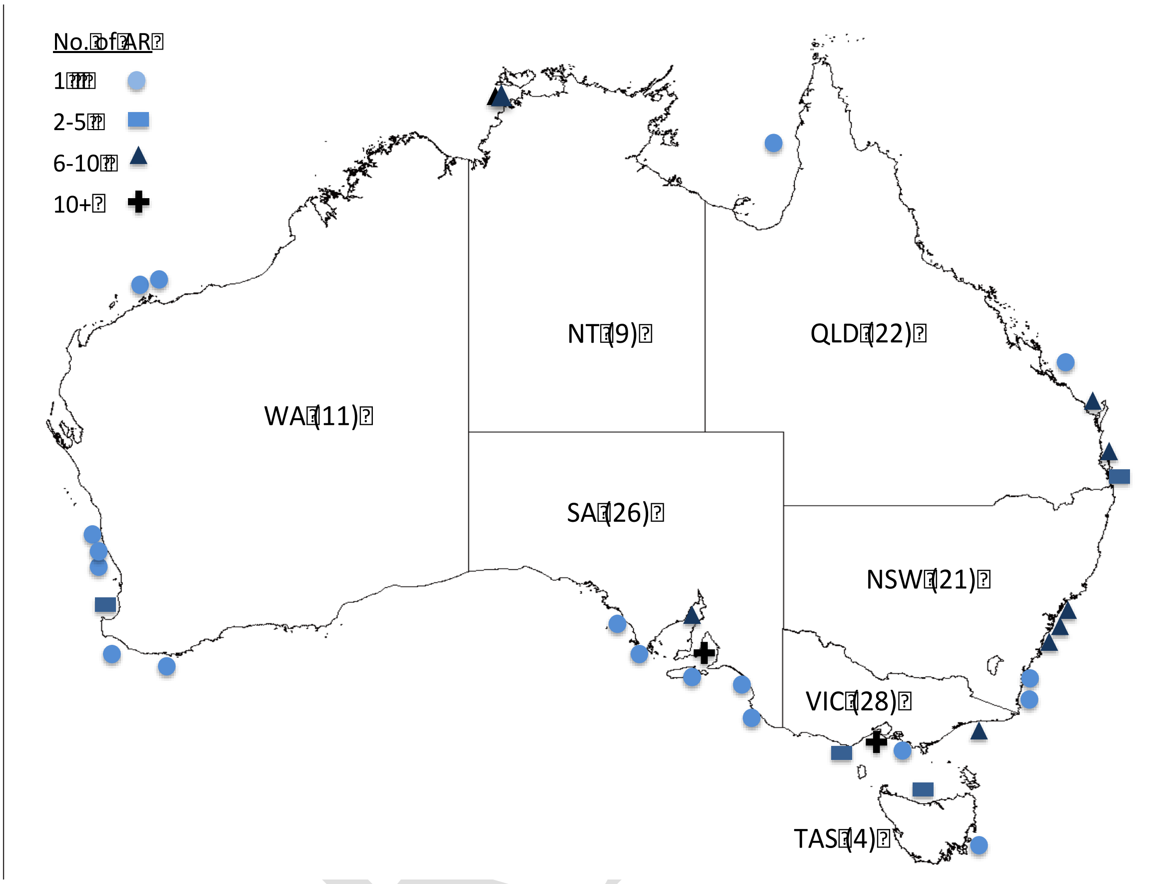

Fig. 3.1: Geographical distribution of artificial reefs (AR) in Australia. The numbers of artificial reefs in the waters of each state and territory are given in brackets.

Currently, 65% of artificial reefs in Australia are composed from materials of opportunity. In some locations, such as South Australia and the Northern Territory, all artificial reefs deployed to date have been constructed from materials of opportunity (Fig. 3.2). Victoria is the only location to date where the proportion of purpose-built reefs is greater than those constructed from materials of opportunity.

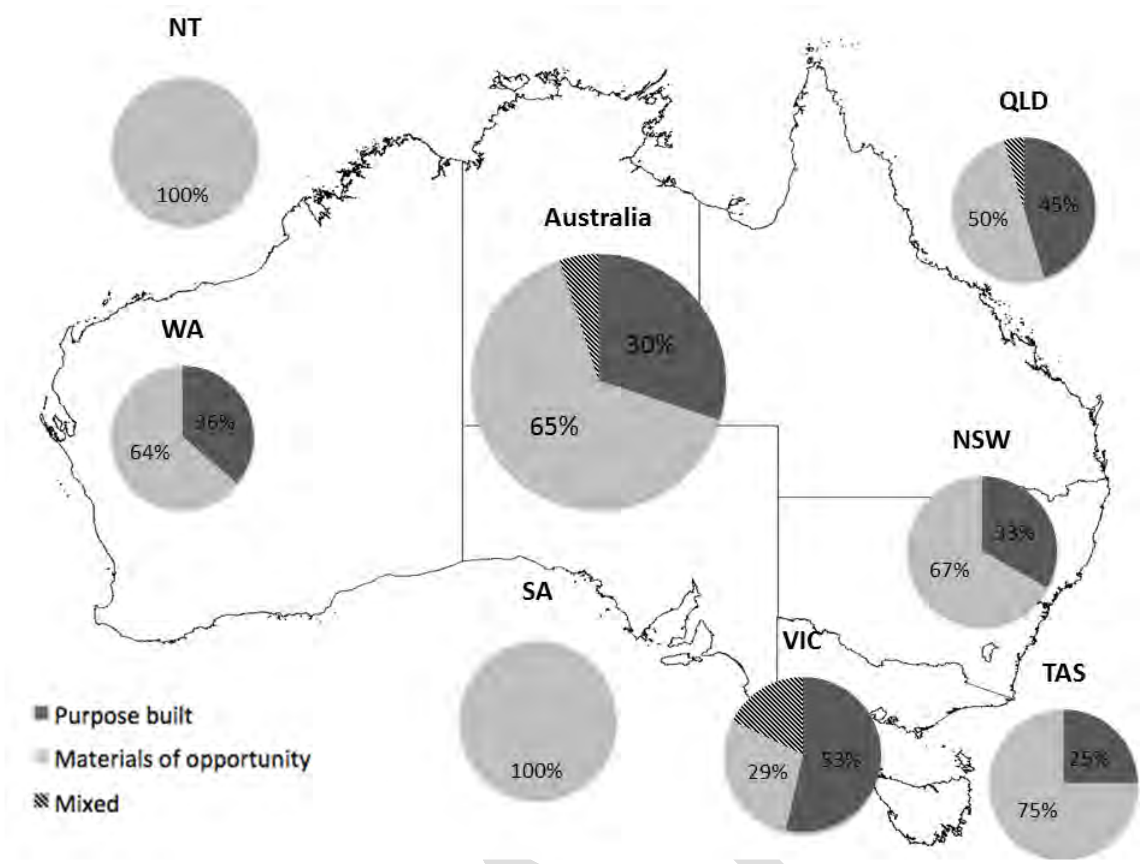

Fig. 3.2: The contribution of artificial reefs constructed from purpose-built material, materials of opportunity or both to the total number of artificial reefs in each state and territory and to Australia as a whole.

Among the purpose-built artificial reefs in Australia, the vast majority (34 out of 43) were found to be constructed from concrete modules, with only two reefs comprising steel modules and one of geotextile bags (Fig. 3.3). The constituency of reefs constructed from materials of opportunity was more diverse and included steel vessels (32), such as old warships, used tyres (28), as well as reefs constructed from a mix of waste materials (13). While rubble has been used, it has been so sparingly, with only five reefs purposely constructed to date from this material of opportunity (Fig.3.3).

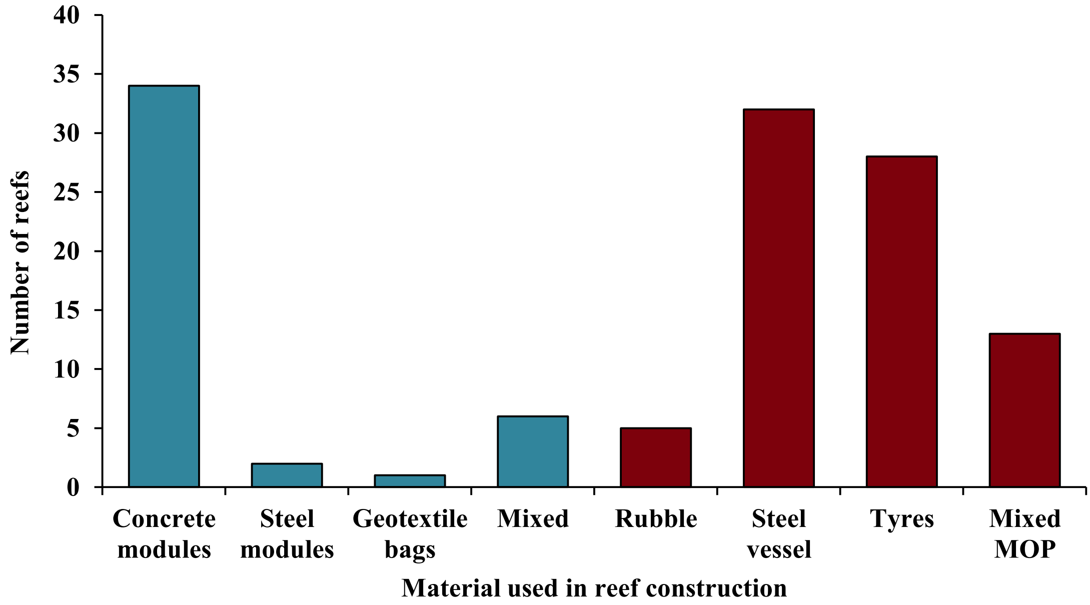

Fig. 3.3: The number of artificial reefs in Australia built from different materials. Purpose-built reefs indicated by blue and materials of opportunity indicated by red.

Australia's first artificial reef was deployed in 1965 in Victoria (Fig 3.4). The reef was placed by the Victorian Department of Fisheries and Wildlife, who laid 400 tonnes of concrete pipes over an area of 4 hectares to create an artificial reef in Port Phillip Bay, with two additional steel vessels added in 1967. Although this reef initially provided good fishing for Pink Snapper (*Chrysophrys auratus*), it was placed on fine silt which slowly caused the pipes to sink (Kerr 1992). Since the deployment of this first reef, another 120 reefs have been constructed throughout Australia's coastal states (Fig. 3.4).

The construction of reefs was found to fluctuate over the 50 year period with high numbers of reefs constructed between 1968-1973, 1982-1991 and 2009-2015 (Fig. 3.4). The highest number of reefs constructed in a single year was eight, which occurred in 1991 and 2011. While the construction of artificial reefs in some states, such as in Victoria, New South Wales and Western Australia, was spread out across the last 50 years, construction in South Australia and the Northern Territory occurred in distinct periods (Fig. 3.4). In the case of South Australia, deployment occurred almost exclusively between 1969 and 1973 and between 1983 and 1991, whereas construction in the Northern Territory occurred between 1982 and 1991, and 2011 and 2012.

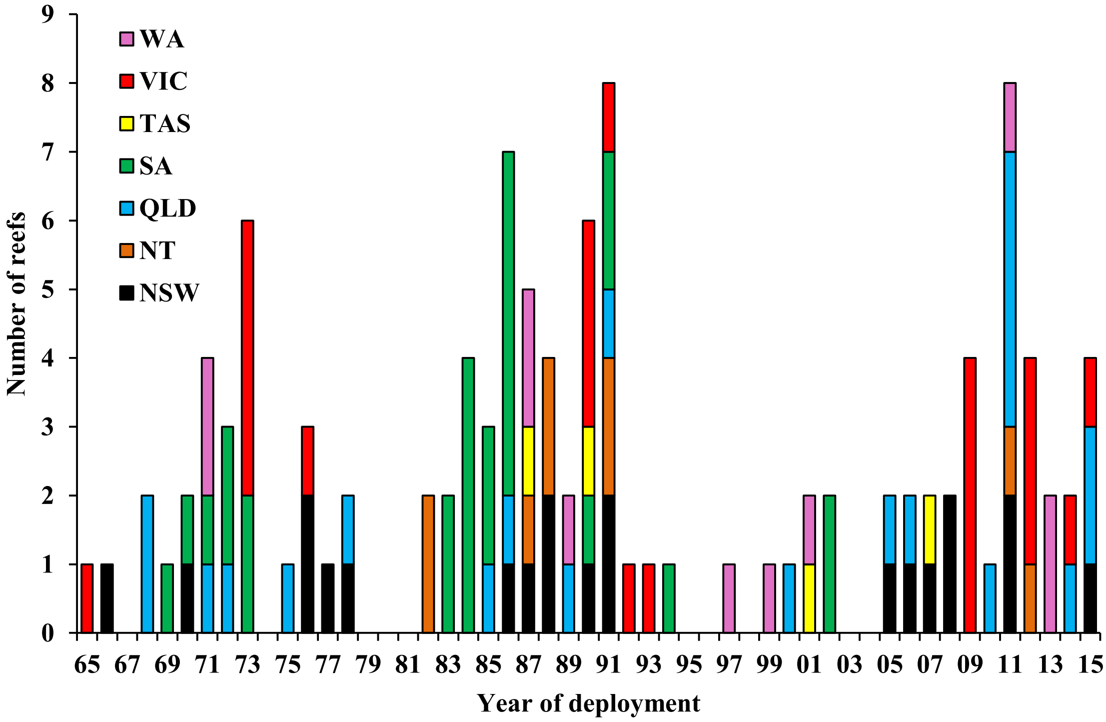

Fig. 3.4: The number of artificial reefs deployed within Australia waters between 1965 and 2015, and the state or territory in which they were deployed.

The materials used to construct the various artificial reefs found in Australian waters differ among states and territories (Fig. 3.5). Tyres, for example, are the primary constituent of artificial reefs in South Australia, representing 18 out of 26 reefs, but have been used sparingly in other states. New South Wales, Victoria, Queensland and Western Australia have all invested significant effort in the deployment of purpose-built reefs, particularly concrete modules.

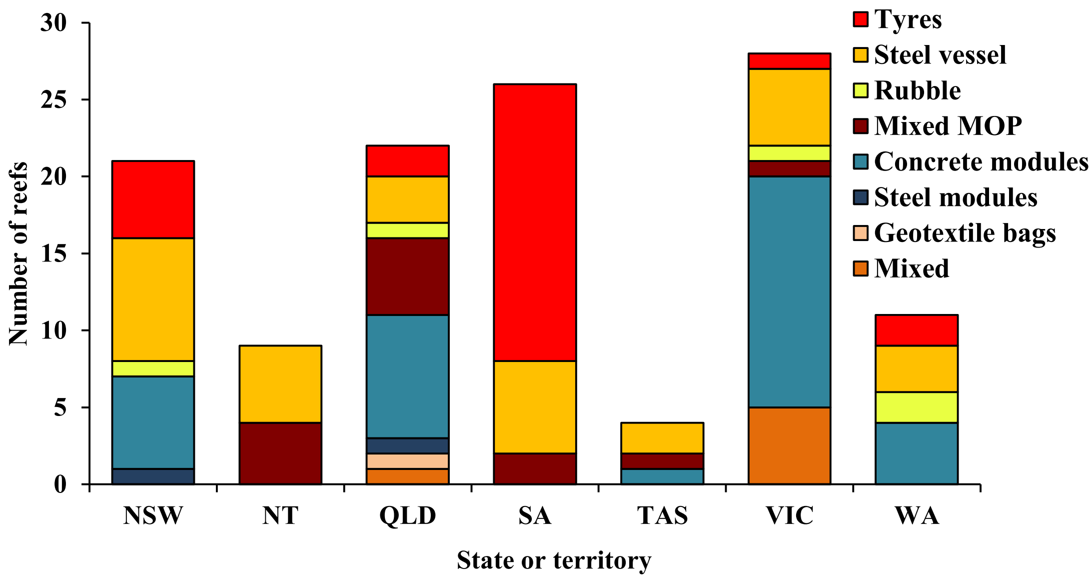

Fig. 3.5: The number of artificial reefs deployed in each of Australia's coastal state and territories and the materials used to construct them.

Over the past 50 years there has been a clear shift in materials used to construct artificial reefs in Australia. Australia's earliest artificial reefs were constructed predominantly from materials of opportunity, with the most abundant material being used tyres (Fig. 3.6). The use of materials of opportunity continued to be widely popular up until the early-90's, however during the mid-80's the relative proportion of reefs constructed from tyres decreased, and there was a switch to primarily the sinking of steel vessels. During the past 10 years however, artificial reefs have been constructed almost exclusively from purpose-built modules, primarily made from concrete (Fig. 3.6).

This early use of tyres for constructing artificial reefs within Australia likely reflects the availability and low cost of this material, and the view that this constituted recycling, whilst simultaneously creating additional habitat for fish and invertebrate communities (Sherman and Spieler 2006). Experience however has shown tyres to be unsuitable for use in artificial reef construction due a number of negative environmental impacts associated with their use in the marine environment, which have been described in Chapter 2.

Steel vessels, whilst being most popular during the mid-1980's, have continued to be used in reef construction, with the latest reef of this type deployed in Australian waters in 2011 (ex-HMAS Adelaide). The continued use of these types of reef materials is due to their popularity with SCUBA divers, and provision of tourism opportunities. Whilst steel vessels continue to be used to construct artificial reefs, the methods of deploying these vessels within Australian waters has changed significantly. There are now more stringent clean up and safety requirements for scuttling steel vessels, which in Australia is regulated under the *Environment Protection (Sea Dumping) Act 1981* (Department of the Environment 2015). Regulations designed to minimise negative environmental impact and the specific purpose of these reefs is likely to see them continue to be used in the future.

Although the first reef built from purpose-built concrete modules was employed in 1971, it was not until the 2000s, and particularly post 2010, that this type of material was widely used. Today it constitutes the dominant construction material for contemporary artificial reefs and is more widely used than other purpose-built materials, such as steel modules and geotextile bags. Although there is an additional cost involved, these purpose-built reefs have shown to provide significant benefits over materials of opportunity that has been described in detail in Chapter 2.

The shift in artificial reef design over the past 10 years has been brought about by the growing awareness of artificial reef technology in Australia as well as the provision of additional funds towards reef programs from recreational fishing licences, as has been done in New South Wales, Victoria, and Western Australia (Department of Fisheries Western Australia 2015, Fisheries Victoria 2015, New South Wales Department of Primary Industries 2015).

The vast majority of artificial reefs currently deployed in Australian waters (96 out of 121) have been constructed for the primary purpose of enhancing fishing activities (Fig. 3.7). The next most common purpose for artificial reef deployment was for recreational SCUBA diving, with 19 such reefs present in Australia, many of which were organised by diving clubs themselves. Small numbers of reefs have also been deployed by scientists and industrial partners for research, as well as two artificial surfing reefs (Fig 3.7). While a wide range of organisations, including community groups, fishing and diving clubs have deployed these structures, state and territory fisheries departments have installed ~65%.

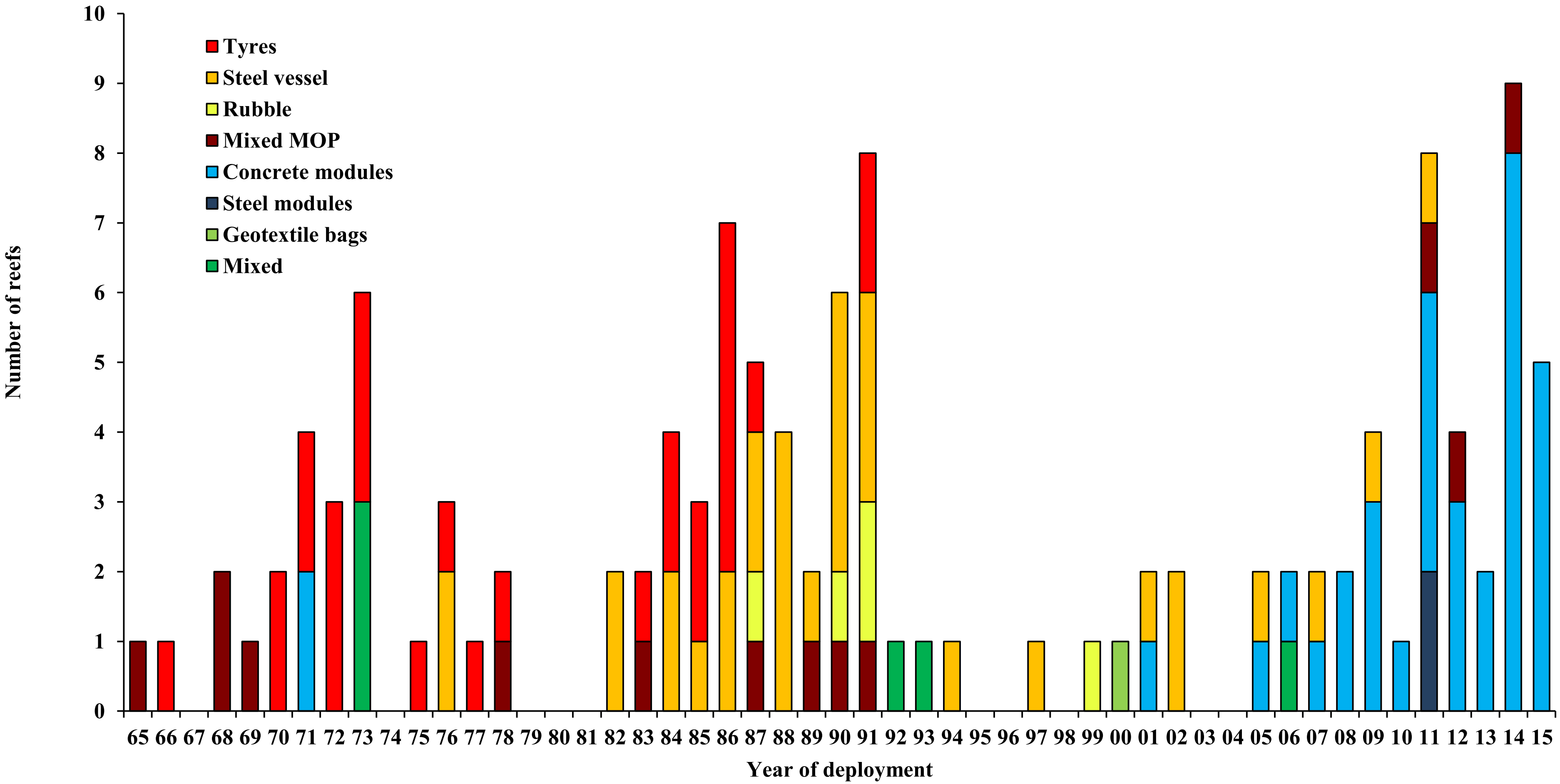

Fig. 3.6: The number of artificial reefs deployed in Australian waters each year since 1965 and the materials used to construct them.

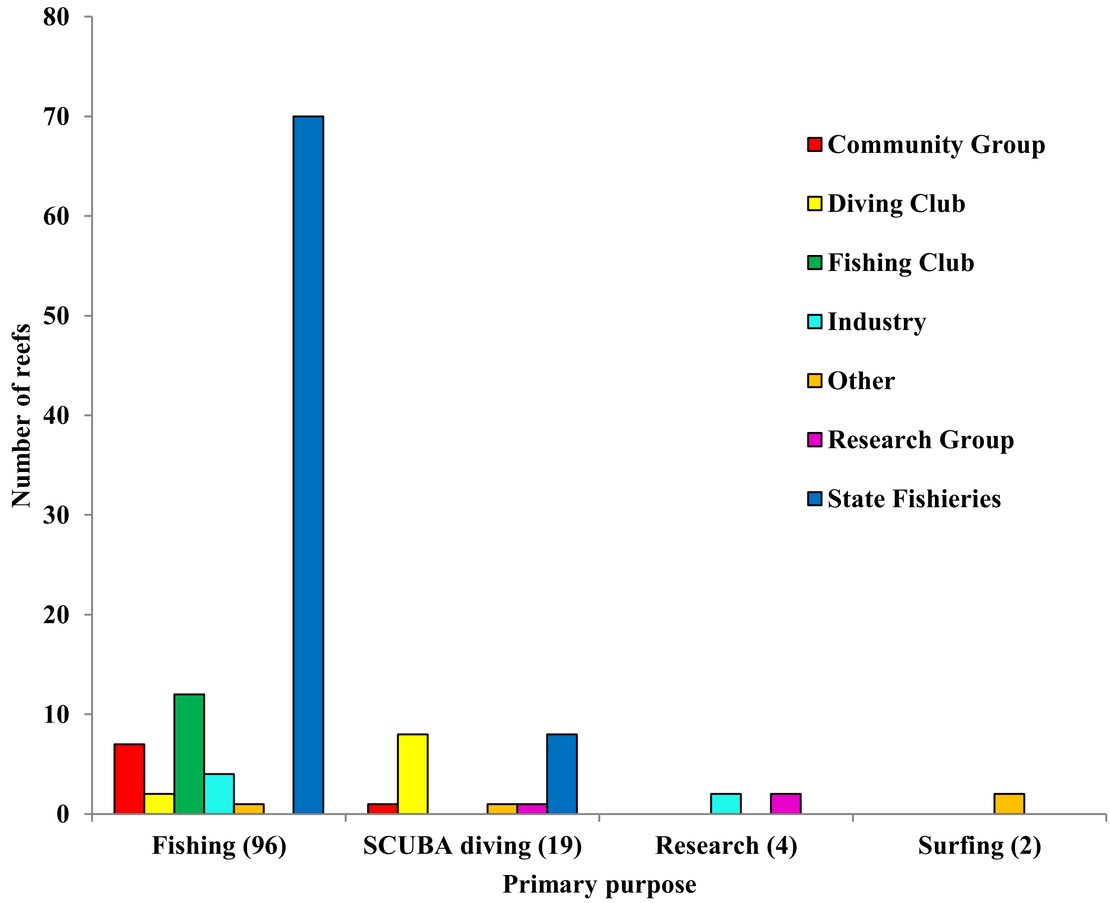

Fig. 3.7: Number of artificial reefs categorised by their primary purpose (noting that many have multiple purposes) and the groups that deployed the reefs over the past 50 years.

The focus on deploying artificial reefs for enhancing fishing activities is not surprising, as early reefs were often deployed and funded by commercial and recreational fishing groups, and more recently, funds from recreational fishing licences have been used by state fisheries to deploy artificial reefs (Kerr 1992, Department of Fisheries Western Australia 2015, New South Wales Department of Primary Industries 2015). Although these reefs may increase the presence of valuable recreational fish species, care is needed to ensure these reefs do not increase the vulnerability of target species to over fishing.

Although much is known about the effect of fishing on fish stocks, there is still limited information available on the effect of artificial reefs on fish stocks (Mace 1997). Fish species likely to be attracted to artificial reefs will be similar to those on adjacent natural reefs, some of which may be slow growing and long-lived species, vulnerable to over fishing (Carr and Hixon 1997, Pickering and Whitmarsh 1997). To minimise negative impacts, the introduction of management plans which assess fish stocks and monitor the performance of artificial reefs is essential (Carr and Hixon 1997, Baine

2001). Other recommendations for the management of artificial reefs include strict bag and size limits for fish, and an initial closure period for the reef to establish itself (Department of Fisheries Western Australia 2010). The effects on the surrounding environment such as tidal flow, wave action and sand movement should also be considered prior to the deployment of an artificial reef (Pickering and Whitmarsh 1997, Bortone et al. 2011).

3.4 Conclusion

Whilst Australia's artificial reef developments have previously been behind those of other countries, the past 10 years has seen a surge in interest in the use of modern purpose-built artificial reefs (Pitcher and Seaman Jr 2000, Coutin 2001, Diplock 2010). These purpose-built reef modules offer significant benefits over materials of opportunity, and the availability of additional funds through recreational fishing licence fees has been successfully used in New South Wales, Victoria, and Western Australia to fund artificial reef programs and reduce pressure on natural reefs and could potentially be utilized by other states in the future.

As the vast majority of Australia's artificial reefs have been deployed primarily for the purpose of enhancing recreational fishing, reefs have been deployed close to major cities and generally within popular fishing regions. Although this makes the reefs easily accessible, it also creates the potential for overfishing of target species. Future research should also aim to incorporate the socio-economic impacts of these structures and factors, such as reef visitation levels and catch rates, which have not been discussed in detail within this review. With the number of artificial reefs in Australia set to increase over the coming years, dedicated management and monitoring of these structures is essential (Carr and Hixon 1997, Pickering and Whitmarsh 1997).

Chapter 4: Observer bias in underwater video analysis

4.1 Introduction

Remote underwater video monitoring has been widely adopted for the non-destructive sampling of a broad range of organisms and environments (Somerton and Glendhill 2005, Harvey et al. 2013). It has been utilized in both shallow and deep-water marine environments and shown to be an effective method for comparing fish assemblages over large spatial scales (Stobart et al. 2007), assessing biodiversity (Malcolm et al. 2007, Harasti et al. 2015), monitoring marine protected areas (Cappo et al. 2003, Westera et al. 2003), and evaluating the effectiveness of artificial reefs (Folpp et al. 2011, Lowry et al. 2012).

Remote underwater video monitoring offers significant benefits over traditional diver visual census methods in that it reduces the need for skilled observers in the field and enables sampling of depths and for times not possible on SCUBA (Harding et al. 2000, Langlois et al. 2010, Lowry et al. 2012, Pelletier et al. 2012). The use of underwater video also has the additional benefit of providing a permanent data set, able to be retrieved at any time, allowing researchers access to a much wider suite of information (Cappo et al. 2003). Whilst this method enables the collection of large amounts of information in a relatively short time frame, it does have the limitation of requiring post-field video analysis to extract the data (Harvey et al. 2013). The processing, interpretation, image storage and retrieval of data can be a laborious task, which may result in a bottleneck of data analysis (Somerton and Glendhill 2005, Harvey et al. 2013).

As was explained in Chapter 1, Recfishwest is establishing a program for monitoring the fish faunas of two artificial reefs recently deployed off Bunbury and Dunsborough in Geographe Bay in south-western Australia. An essential part of this monitoring program is that it remains cost-effective. Recfishwest is therefore aiming to use recreational fishers, acting as citizen scientists, to deploy underwater cameras to collect footage that can be used to assess the characteristics of the fish faunas of these reefs. However, one limitation of this strategy is that it requires people to extract data from the footage collected by the fishers.

As implied above, in order for Recfishwest's strategy to monitor the fish faunas of the Bunbury and Dunsborough reefs to be possible, it is essential to find a cost-effective means for extracting data from the underwater video footage collected by the fishers. One possible solution that has been suggested is to get university students to extract information from video footage as part of their studies.

Whilst this method may counter the problems associated with data extraction, there is the potential for observer bias, as a number of different students will be involved in extracting data from the footage. Observer bias has the potential to render the data on fish faunas of the artificial reefs obtained via the footage collected by recreational fishers useless, as it could confound differences between observers with real spatial and temporal effects (Thompson and Mapstone 1998). It is therefore important to provide some assessment of the potential for observer bias in extracting data on fish faunas from such footage. The overall goal of this study was to make such an assessment.

The first specific aim of this study was to determine what level of observer bias, if any, is present among the observers when extracting the following information about fishes captured on remotely collected underwater footage; (i) the relative abundance (MaxN), (ii) species richness and (iii) species composition. Since observer bias was detected, the second aim was to develop a series of recommendations that can be implemented to reduce observer effects in the context of using university students to extract data from underwater video footage collected by recreational fishers.

4.2 Methods

4.2.1 Study Site

4.2.1.1 Geographe Bay

Geographe Bay is the southern most protected marine embayment in south-west Australia, with a low energy, but dynamic sandy coastline. The bay covers an area of roughly 290 square nautical miles, ranging from the north-west point of Cape Naturaliste (33° 32' S, 115°00'E), to the Bunbury breakwater (33° 18'S, 115° 39' E) (Bellchambers et al. 2006). This position gives the bay a northerly aspect with a predominately west to east longshore drift. The bay has a maximum depth of 30 m and normally experiences a semidiurnal tidal range of ~0.5 m (Bellchambers et al. 2006).

The substratum in Geographe Bay slopes gently seaward (~2 m km^{-1}) and is dominated by expansive areas (~70%) of monospecific seagrass meadows, comprised predominantly of *Posidonia sinuosa*, and peripheral assemblages of *Amphibolis Antarctica* (Walker et al. 1987, Mcmahon et al. 1997). The area experiences a Mediterranean climate, characterized by warm, dry summers and cool, wet winters (Walter 1973). The average annual rainfall of the area is approximately 806 mm, with the majority (85%) falling between May and October (Bureau Of Meteorology 2015).

4.2.1.2 Geographe Bay artificial reefs

Each of the Geographe Bay artificial reefs consist of 30 ten-tonne reinforced concrete 'Fish Box' modules, placed in clusters of five, which together cover area of approximately four hectares (Fig 4.1: Department of Fisheries Western Australia 2015). The reef modules were designed by HaeJoo, and contain curved cross braces to promote the upwelling of nutrients (HaeJoo 2015b). These reefs were deployed specifically to enhance recreational fishing within the bay and, in particular, to increase the abundance of target species such as Pink Snapper (*Chrysophrys auratus*), Samson Fish (*Seriola hippos*) and Silver Trevally (*Pseudocaranx dentex*). Both reefs are located close to towns, *i.e.* Dunsborough and Bunbury, and were deployed within 5 km of the nearest boat ramp. The Dunsborough reef is located at 115° 9.980’ E, 33° 33.962’ S, in 27 m of water, and the Bunbury reef is located at 115° 35.900’ E, 33° 18.500’ S at a depth of 17 m (Department of Fisheries Western Australia 2015).

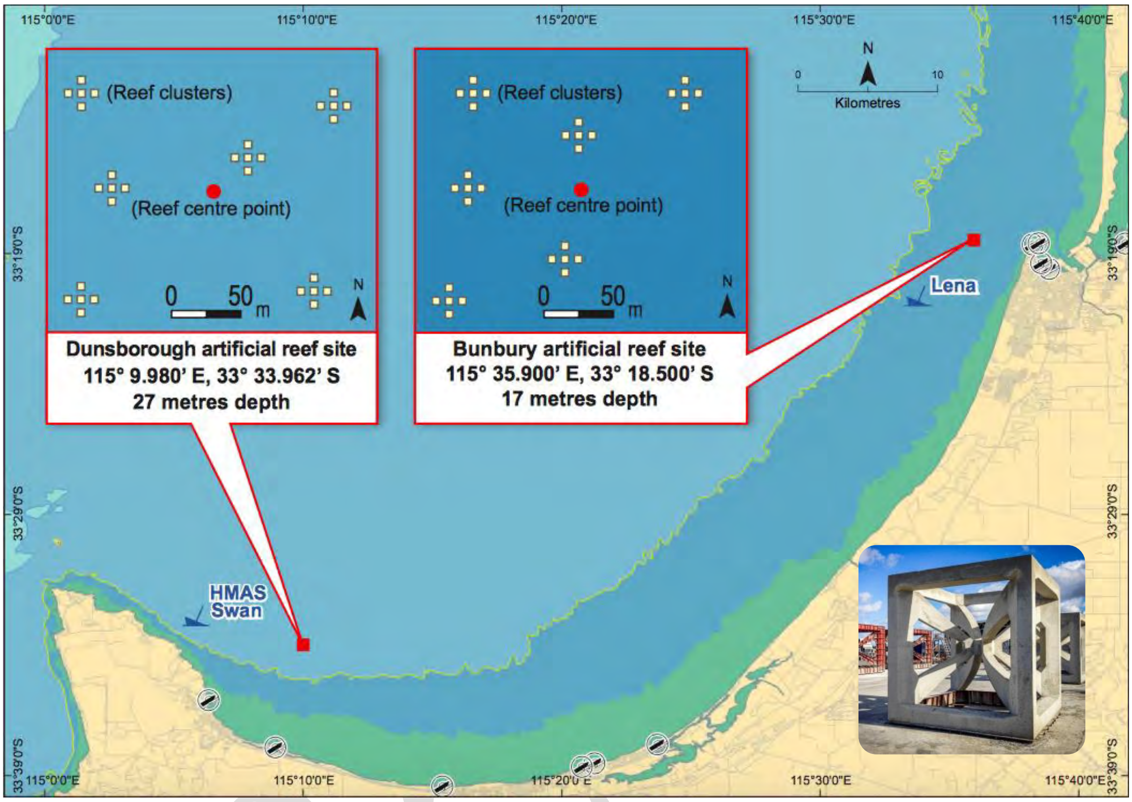

Fig. 4.1. The artificial reef deployment sites and cluster orientations. (Bottom right insert) The artificial reef ‘Fish Box’ module designed by HaeJoo. Reproduced from Department of Fisheries Western Australia (2015).

4.2.2. Source of data

All underwater video footage employed in this study was collected from the Dunsborough artificial reef during two sampling trips on the 10th and 19th of March 2015 using a Baited Remote Underwater Video (BRUV) system. The data collection, design of the sampling regime and the construction of the BRUV system, was performed solely by Ecotone consulting and Recfishwest with no input from staff or students from Murdoch University.

4.2.3. Sampling regime

The sampling method performed by Ecotone consulting and Recfishwest involved the haphazard dropping of BRUVs in the vicinity of the artificial reef modules using GPS for navigation. Each drop involved positioning the boat above a reef module and lowering the BRUV over the boat until it reached the sea floor. Camera submersion times averaged ~20 minutes. Upon retrieval, the video footage was extracted from the camera and the BRUV reset and rebaited before being deployed at a new location (Florisson 2015).

4.2.4 BRUV design

The frame of the BRUV was constructed from class 9 Polyvinyl Chloride (PVC) irrigation pipe, which is rated to 8.88 atmospheres and able to withstand pressures associated with water depths of up to ~80 m (Fig. 4.2). Sections of PVC pipe and pipe connections were glued together with PVC cement suitable for use on pressurized water pipes. The frame of the BRUV was stabilised by two skids, each filled with four, 680g lead weights, making the BRUV negatively buoyant, and giving it a total weight of 5.5 kg.

Fig. 4.2: Construction of the BRUV: Left to right: Cementing pipe fixtures with weights already inside skids, BRUV frame with camera attached, final product ready to be deployed on the artificial reef modules. Photos provided by Ecotone Consulting.

The bait arm of the BRUV was designed to be suspended 150 mm above the substrate with a length of 600 mm from the central point of the BRUV. The bait bag, which measured 180 mm x 100 mm, was constructed from plastic mesh and positioned

500 mm in front of the camera. Before each deployment, 500g of Sardine (*Sardinops* spp.) was placed inside the bait bag and securely fastened. This bait is widely used in BRUV studies as its soft, oily flesh has shown to be an effective attractant for fish (Stobart et al. 2007, Harvey et al. 2013, Mallet and Pelletier 2014).

Finally a GoPro Hero 4 Silver Action Video Camera ™, placed in a waterproof housing with an additional Battery BacPac ™, was mounted to the BRUV. This camera was chosen due to its small size and simple design, making it easy to work with whilst still providing high definition video footage, *i.e.* 1080p resolution at a frame rate of 60 frames per second (GoPro 2015).

4.2.5 Observers and video analysis

A total of four observers took part in this study. Each observer was required to be a recreational fisher who engaged in fishing activities at least once a month, and had completed a Bachelor of Science majoring in Marine Science in the past 3 years from Murdoch University. The four observers in his study included two volunteers, one university student who had logged data from the Recfishwest video footage as part of their university studies and the author. Whilst this study would have benefited from additional observers, limited funding and time constraints due to the availability of the video footage and the time it took each volunteer to watch the required amount of footage only allowed data from four observers to be obtained and analysed.

Prior to analysis, the provided raw videos were coded according to the trip collection date (t), camera number (c), and video data number. For example, a video collected on trip one, by camera one, with a video data number of 0001, would be coded (t1c1-0001). Two additional factors were given to each video that indicated the camera direction as facing reefs modules (F) or not facing reef modules (NF), as well as a unique observer number between 1 and 4.

Previous work by Florisson (2015) identified significant differences in the composition of fish species depending on whether the footage was collected facing or not facing reef modules. Thus whilst not being the main focus of this study, this factor was considered and incorporated into the statistical modelling.

Each observer was provided with the same set of 30 separate videos collected from the Dunsborough artificial reef by Recfishwest and Ecotone Consulting using BRUVs. Observers were instructed to analyse each video for a total of 5 minutes, between the allocated time slot of 7-12 minutes, giving a total of 150 minutes of footage analysed by each observer. Observers were given no species identification training but were provided with a copy of “Sea Fishes of Southern Australia” by Hutchins and Swainston (1986), as well as a number of links to online taxonomic data bases to assist in species identification.

Analysis of each video involved identifying each fish to the lowest possible taxonomic level and providing an index of its relative abundance, namely MaxN. MaxN is defined as the maximum number of individuals of each species observed in a single frame in the footage being analysed. MaxN is a widely used index in underwater video studies and provides a conservative measure of relative abundance that eliminates the chance of double counting (Willis and Babcock 2000, Cappo et al. 2003, Watson 2006). Whilst is not classified as a fish, *Sepioteuthis australis* (Southern Calamari), has been included within this study as it is an important recreational species with the Geographe Bay area and heavily targeted by fishers.

All video footage was reviewed using the multimedia program QuickTime. Abundance data from each observer were compiled into a single data matrix where each video had a unique identifier code as well as additional factors that indicated the observer and the camera direction. All following statistical analysis was performed from this single data matrix.

4.2.6 Statistical analyses

All statistical analyses were undertaken using the Primer v7 multivariate statistics software package, with the PERMANOVA+ add on (Anderson et al. 2008, Clarke and Gorley 2015). For all analyses, the null hypothesis of no significant difference between *a priori* groups was rejected if the significance level (p) was ≤ 0.05.

4.2.6.1 Univariate analyses

Two-way Permutational Multivariate Analysis of Variance (PERMANOVA; Anderson et al., 2008) was employed to determine whether the values for taxon richness (*i.e.* the number of taxa) and total MaxN (*i.e.* the sum of the MaxN values for each species in a sample) differed between observers and camera positions (facing towards and away from the artificial reef). Both of these variables were considered fixed. The DIVERSE routine was used to calculate, for each individual sample, the taxon richness and total MaxN.

Prior to subjecting the data for each dependent variable to two-way PERMANOVA, the extent of the linear relationship between the $\log_e$-transformed mean and $\log_e$-transformed standard deviation for each of the various sets of replicate samples for both variables was examined. This approach was used to determine whether the data for each variable required transformation to meet the test assumption of homogenous dispersions among *a priori* groups and, if so, to identify the appropriate transformation required (Clarke et al. 2014a). This analysis demonstrated that taxon richness required no transformation, whilst total MaxN required a fourth root transformation.

The pre-treated data, where required for each variable, were then used to construct separate Euclidian distance matrices and subjected to two-way PERMANOVA. Graphs of the transformed arithmetic means and associated ± 95% confidence intervals were plotted to visualise the extent of any differences between the main effects and/or interactions, noting that trends between observers are the main focus of this study.

4.2.6.2 Multivariate analysis

PERMANOVA, Analysis of Similarities (ANOSIM; Clarke and Green 1988) non-metric Multi-Dimensional Scaling (nMDS) ordination plots (Clarke 1993) and shade plots (Clarke et al. 2014b, Tweedley et al. 2015) were employed to elucidate whether the composition of the fish and cephalopod faunas identified on the BRUV footage differed between observers and camera positions and, if so, the species that were responsible for those differences.

The MaxN for each species in each individual sample was subjected to a fourth root transformation to down weigh the contributions of highly abundant taxa and balance them with those of less abundant taxa. These transformed data were then used to construct a Bay-Curtis similarity matrix and subjected to the same two-way PERMANOVA test described above for taxa richness and total MaxN, only this time employing multivariate data. However, in this instance, the sole purpose of the PERMANOVA was to determine if there was an interaction between the site and camera position main effects and, if so, to determine the extent of those interactions relative to each other and to those of the main effects (Lek et al. 2011). If the interaction was not significant, or relatively small in relation to the main effects, the matrix was then subjected to a two-way ANOSIM test. ANOSIM was preferred at this stage of the analysis because, unlike PERMANOVA, this test is fully non-parametric and thus more robust, and because the ANOSIM *R*-statistic provides a universal measure of group separation to test for significant interactions between region and position (Lek et al. 2011). The magnitude of the *R* statistic typically ranges between 1, when the compositions of the samples within each group are more similar to each other than to that of any of the samples from other groups, down to ~0, when within-group and between-group similarities do not differ (Clarke and Gorley 2015).

The same Bray-Curtis similarity matrix was then subjected to nMDS to produce an ordination plot, which provided a visual representation of the trends in faunal composition among observers. However, as this plot showed the position of all 120 samples it was hard to interpret accurately the trends among *a priori* groups. Therefore, a second nMDS plot was constructed, only this time from a distance among the centroids matrix. This matrix creates averages in the 'Bray–Curtis space' calculated from the groups of replicate samples, in this case averages of each observers videos from a single camera direction thus condensing the 120 samples into eight (Anderson et al. 2008). These plots, which show low-dimensional approximations to the pattern of group centroids in the full-dimensional space, are subsequently referred to as centroid nMDS ordination plots (Lek et al. 2011).

Finally, shade plots were employed to produce a visual display of the abundance matrix of variables (transformed and standardized species counts) against samples (groups of videos). As the PERMANOVA test demonstrated that the species composition differed among both observers and camera position, but that the interaction between these factors was not significant, the fourth-root transformed MaxN data for each species in each sample was averaged and used to create two data matrices. In the first the transformed data was averaged across the four observers and in the second it was averaged across the two camera positions. The data in these two matrices were standardized and subjected to the Shade plot routine. This produced a visual display of the abundance matrix of variables (transformed and standardized species counts) against samples (either observers or camera positions), where the white represents the absence of taxa in a sample and the intensity of grey-scale shading is linearly proportional to 'abundance' (Clarke et al. 2014b). The taxa (*y* axis of the shade plot) are ordered to optimise the seriation statistic (ρ) by non-parametrically correlating their resemblances to the distance structure of a linear sequence (Clarke et al. 2014a). This seriation was constrained by the family of the taxa so that taxa within the same family, regardless of their similarity to one another, were kept together and separate from other families. The order of both the samples (displayed on the *x* axis) in the case of the shade plot showing observers were determined independently by the results of a group-average hierarchical agglomerative cluster analyses employing resemblance matrices defined using Whittaker's index of association (Whittaker 1952, Valesini et al. 2014).

4.3. Results

The four observers identified a combined total of 46 taxa to species, three to genus and three to family (Table 4.1). The greatest number of taxa identified by a single observer was 36 (Observer 4), while the lowest number of taxa identified was 26 (Observer 3). Observer 4 recorded the highest total mean MaxN count, *i.e.* 34.1, while the mean MaxN counts for the other three observers ranged from 27 and 30 (Table 4.1).

All observers identified *Pseudocaranx* spp. and *Coris auricularis* as the first and second most abundant taxa. These two taxa dominated the data set and were found to make up ~70 % of the individuals identified by all observers. *Neatypus obliquus* was identified as the third most abundant species by Observers 1, 2 and 3, whilst the third most abundant species identified by Observer 4 was *Trachurus novaezelandiae.*

Thirteen of the species detected by Observers 1, 2 and 4 were not identified by Observer 3, including species such as *T. novaezelandiae*, *Parequula melbournensis*, and *Austrolabrus maculatus*. However, Observer 3 identified eight species that were not detected by any other observer, including *Caesioscorpis theagenes* and *Labroides dimidiatus. Meuschenia freycineti* was only identified by Observer 1, and Observer 2 was the only observer to identify *Eubalichthys mosaicus, Cheilodactylus nigripe, Halichoeres brownfieldi* and *Lagocephalus lunaris.*

Table 4.1: Species table showing the mean MaxN (X) and standard error (SE) of each of the 52 fish and cephalopod taxa recorded by each of four observers who analysed the same five minute portion of the same 30 videos recorded using BRUV on the Dunsborough artificial reef. For each taxon, a percentage contribution (%) and ranking by mean MaxN (R) was calculated. Abundant species *i.e.* those that contributed ≥ 5 % to abundance recorded by any observer are shaded in grey.

	Total				Observer 1				Observer 2				Observer 3				Observer 4			
Species	**X**	**SE**	**%**	**R**	**X**	**SE**	**%**	**R**	**X**	**SE**	**%**	**R**	**X**	**SE**	**%**	**R**	**X**	**SE**	**%**	**R**
Pseudocaranx spp.	17.97	0.05	60.1	1	17.33	1.79	60.39	1	16.97	1.58	57.51	1	18.20	2.04	66.59	1	19.37	2.41	56.79	1
Coris auricularis	3.83	0.01	12.8	2	3.97	0.57	13.82	2	4.07	0.63	13.79	2	3.27	0.56	11.95	2	4.00	0.62	11.73	2
Neatypus obliquus	1.63	0.26	5.43	3	1.40	0.47	4.88	3	1.77	0.57	5.99	3	1.57	0.49	5.73	3	1.77	0.56	5.18	4
Trachurus novaezelandiae	1.02	0.98	3.40	4	0.63	0.47	2.21	6	0.43	0.43	1.47	8					3.00	2.67	8.80	3
Anoplocapros amygdaloides	0.83	0.08	2.79	5	0.87	0.16	3.02	4	0.80	0.15	2.71	4	0.87	0.17	3.17	4	0.80	0.18	2.35	6
Parequula melbournensis	0.66	0.14	2.20	6	0.77	0.23	2.67	5	0.80	0.29	2.71	4					1.07	0.38	3.13	5
Austrolabrus maculatus	0.43	0.07	1.42	7	0.53	0.16	1.86	7	0.53	0.16	1.81	6					0.63	0.17	1.86	7
Pempheris klunzingeri	0.38	0.11	1.28	8	0.33	0.22	1.16	9	0.53	0.28	1.81	6	0.33	0.14	1.22	7	0.33	0.22	0.98	8
Seriola hippos	0.28	0.69	0.92	9	0.37	0.11	1.28	8	0.37	0.11	1.24	10	0.03	0.03	0.12	21	0.33	0.11	0.98	8
Diodon nicthemerus	0.21	0.05	0.70	10	0.20	0.09	0.70	12	0.33	0.13	1.13	11					0.30	0.13	0.88	10
Trachinops noarlungae	0.21	0.11	0.70	10	0.27	0.27	0.93	11	0.27	0.27	0.90	12					0.30	0.27	0.88	10
Myliobatis australis	0.20	0.04	0.67	12	0.20	0.07	0.70	12	0.20	0.07	0.68	14	0.20	0.07	0.73	12	0.20	0.07	0.59	14
Upeneichthys vlamingii	0.19	0.06	0.64	13	0.30	0.18	1.05	10	0.23	0.12	0.79	13				27	0.23	0.12	0.68	12
Trygonorrhina fasciata	0.17	0.04	0.56	14	0.20	0.09	0.70	12	0.20	0.09	0.68	14	0.10	0.07	0.37	16	0.17	0.07	0.49	15
Glaucosoma hebraicum	0.14	0.04	0.47	15	0.13	0.06	0.46	16	0.17	0.08	0.56	18	0.13	0.08	0.49	14	0.13	0.06	0.39	16
Chromis klunzingeri	0.13	0.07	0.42	16				33	0.43	0.28	1.47	8					0.07	0.05	0.20	22
Sepioteuthis australis	0.12	0.04	0.39	17	0.13	0.08	0.46	16	0.20	0.10	0.68	14	0.03	0.03	0.12	21	0.10	0.07	0.29	19
Dasyatis brevicaudata	0.11	0.03	0.36	18	0.10	0.06	0.35	19	0.13	0.06	0.45	19	0.07	0.05	0.24	17	0.13	0.06	0.39	16
Parapercis haackei	0.11	0.02	0.36	18	0.17	0.10	0.58	15	0.03	0.03	0.11	28					0.23	0.10	0.68	12
Caesioscorpis theagenes	0.11	0.08	0.36	18									0.43	0.33	1.59	5				
Labroides dimidiatus	0.10	0.01	0.33	21									0.40	0.24	1.46	6				
Lagocephalus sceleratus	0.10	0.03	0.33	21	0.13	0.06	0.46	16					0.27	0.08	0.98	9				
Cheilodactylus vestitus	0.09	0.01	0.31	23	0.07	0.05	0.23	21					0.23	0.20	0.85	10	0.07	0.05	0.20	22
Chelmonops curiosus	0.08	0.03	0.28	24	0.10	0.07	0.35	19	0.10	0.07	0.34	20	0.03	0.03	0.12	21	0.10	0.06	0.29	19
Nemadactylus macropterus	0.08	0.05	0.28	24									0.33	0.14	1.22	7				37
Ophthalmolepis lineolatus	0.07	0.03	0.22	26	0.03	0.03	0.12	26	0.20	0.09	0.68	14					0.03	0.03	0.10	27
Pentapodus vitta	0.06	0.06	0.20	27									0.23	0.23	0.85	10				
Pentaceropsis recurvirostris	0.06	0.02	0.20	27	0.07	0.05	0.23	21	0.07	0.05	0.23	23	0.03	0.03	0.12	21	0.07	0.05	0.20	22
Chrysophrys auratus	0.05	0.020	0.17	29	0.07	0.05	0.23	21	0.07	0.05	0.23	23					0.07	0.05	0.20	22
Pictilabrus laticlavius	0.04	0.014	0.14	30									0.17	0.07	0.61	13				
Anoplocapros lenticularis	0.04	0.018	0.14	30					0.10	0.06	0.34	20	0.03	0.03	0.12	21	0.03	0.03	0.10	27
Parapercis ramsayi	0.04	0.037	0.14	30	0.07	0.05	0.23	21	0.03	0.03	0.11	28					0.07	0.05	0.20	22
Nemadactylus valenciennesi	0.03	0.037	0.11	33									0.13	0.06	0.49	14				
Parazanclistius hutchinsi	0.03	0.016	0.11	33	0.03	0.03	0.12	26	0.03	0.03	0.11	28	0.03	0.03	0.12	21	0.03	0.03	0.10	27
Lagocephalus spp.	0.03	0.016	0.11	33													0.13	0.06	0.39	16
Suezichthys cyanolaemus	0.03	0.296	0.08	36	0.03	0.03	0.12	26	0.03	0.03	0.11	28					0.03	0.03	0.10	27

Table 4.1 continued: Species table showing the mean MaxN (X) and standard error (SE) of each of the 52 fish and cephalopod taxa recorded by each of four observers who analysed the same five minute portion of the same 30 videos recorded using BRUV on the Dunsborough artificial reef. For each taxon, a percentage contribution (%) and ranking by mean MaxN (R) was calculated. Abundant species *i.e.* those that contributed ≥ 5 % to abundance recorded by any observer are shaded in grey.

Species	**X**	**SE**	**%**	**R**	**X**	**SE**	**%**	**R**	**X**	**SE**	**%**	**R**	**X**	**SE**	**%**	**R**	**X**	**SE**	**%**	**R**
Pseudolabrus biserialis	0.03	0.062	0.08	36	0.03	0.03	0.12	26	0.03	0.03	0.11	28					0.03	0.03	0.10	27
LABRIDAE spp.	0.03	0.018	0.08	36													0.10	0.06	0.29	19
Neosebastes pandus	0.03	0.014	0.08	36	0.03	0.03	0.12	26	0.03	0.03	0.11	28					0.03	0.03	0.10	27
Lagocephalus lunaris	0.03	0.014	0.08	36					0.10	0.06	0.34	20								
Trygonoptera mucosus	0.03	0.008	0.08	36	0.07	0.05	0.23	21									0.03	0.03	0.10	27
Cheilodactylus nigripes	0.02	0.016	0.06	42					0.07	0.05	0.23	23								
Halichoeres brownfieldi	0.02	0.017	0.06	42					0.07	0.05	0.23	23								
Achoerodus gouldii	0.02	0.014	0.06	42									0.07	0.07	0.24	17				
Eubalichthys mosaicus	0.02	0.012	0.06	42					0.07	0.05	0.23	23								
Platycephalus spp.	0.02	0.012	0.06	42	0.03	0.03	0.12	26									0.03	0.03	0.10	27
Scorpaenodes smithi	0.02	0.012	0.06	42									0.07	0.05	0.24	17				
Trygonoptera ovalis	0.02	0.014	0.06	42									0.07	0.05	0.24	17				
Meuschenia freycineti	0.01	0.008	0.03	49	0.03	0.03	0.12	26												
MONACANTHIDAE spp.	0.01	0.008	0.03	49													0.03	0.03	0.10	27
OSTRACIIDAE spp.	0.01	0.008	0.03	49													0.03	0.03	0.10	27
Trygonoptera personata	0.01	0.012	0.03	49					0.03	0.03	0.11	28								
Number of taxa		**52**				**32**				**34**				**26**				**36**		
Total mean MaxN		**29.9**				**28.70**				**29.50**				**27.33**				**34.10**		

4.3.1 Univariate analysis

Whilst there was slight variation, PERMANOVA showed no significant difference between either the mean number of species (Table 4.2A; Fig. 4.3A), or the relative abundance of species (Table 4.2B; Fig. 4.3B) identified per sample between observers. Significant differences were detected between the number of species on facing and not facing camera footage (Table 4.2A). Observers 2 and 4 identified the most species per sample, averaging just over 6 species, whilst the lowest mean number of species identified per sample was 5 (Observer 3). The highest mean abundance was recorded by Observer 4, with a mean of ~30, with the lowest recorded by Observer 3 with a mean of ~26.

Table 4.2: Mean squares (MS), Pseudo-*F* (p*F*) values and significance levels (*P*) for a two-way PERMANOVA test on (A) number of species, between observers and camera position and (B) abundance (total MaxN) counts between observers and camera position.

(A) Number of species	df	MS	*pF*	*P*
Observer	3	11	1.88	0.148
Position	1	64.53	11	0.003
Residual	112	656.9		

(B) Abundance	df	MS	*pF*	*P*
Observer	3	0.045	0.68	0.55
Position	1	0.089	1.35	0.23
Residual	112	7.41		

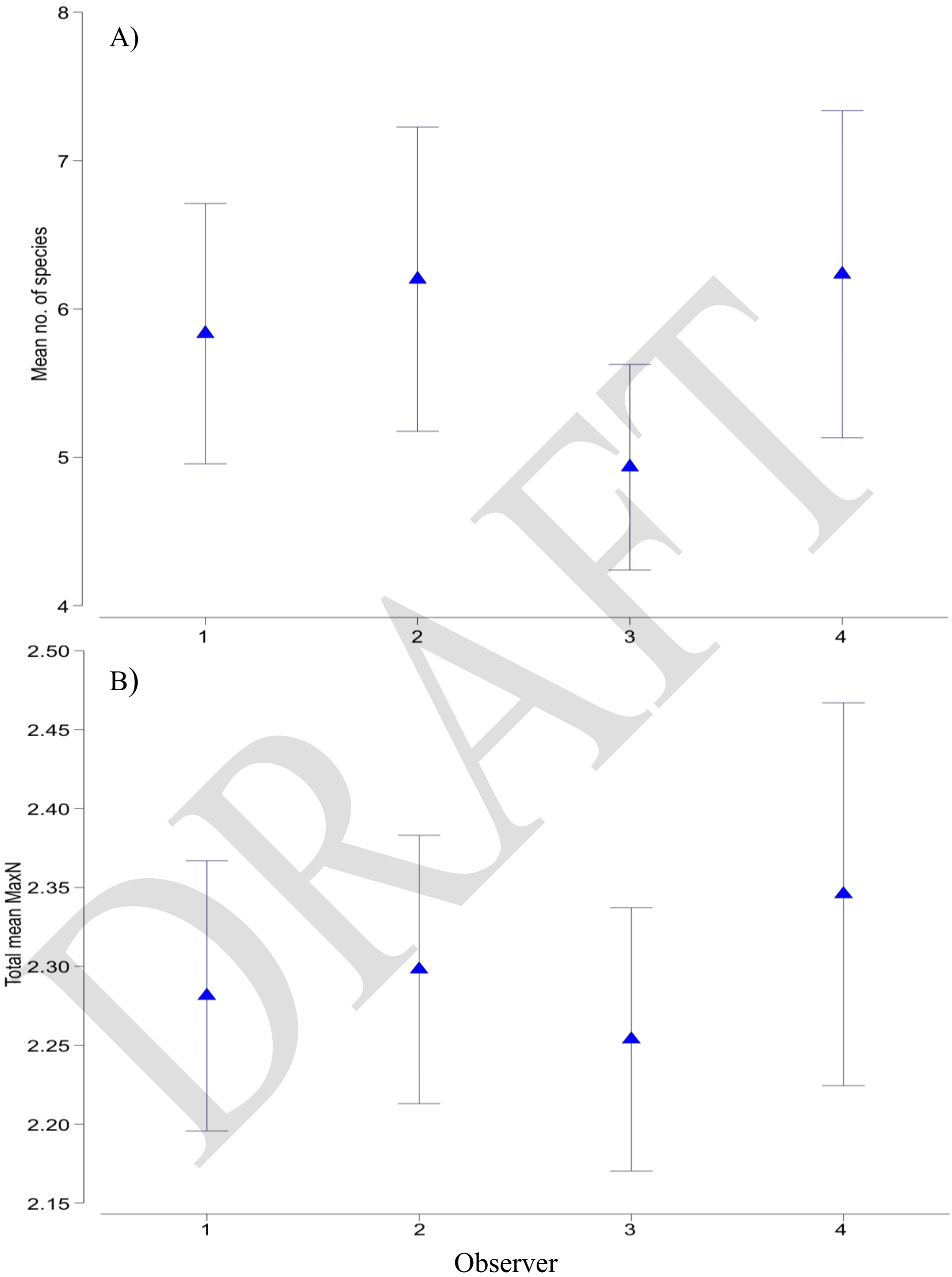

Fig 4.3. (A) Mean number of species identified per sample by each observer and (**B)** the fourth root transformed, total mean MaxN identified per sample by each observer. Error bars represent 95% confidence intervals.

4.3.2 Multivariate analysis

PERMANOVA demonstrated that the composition of species identified by the four observers differed significantly (Table 4.3). ANOSIM found that the data collected by Observers 1, 2 and 4 were not significantly different, but were invariably significantly different to the data collected by Observer 3 (Table 4.3). These trends are highlighted in the 3-dimentional nMDS plot that shows a clear grouping of samples from Observer 3, whilst the remaining three observer samples show no clear pattern (Fig. 4.5A). Significant differences in species composition were also detected by observers between footage from facing and not facing samples (Table 4.3). This is shown visually in the nMDS centroid plot that shows clear grouping of facing and not facing samples by all observers as well as a close grouping between Observers 1,2 and 4 (Fig. 4.5B).

Table 4.3: Mean squares (MS), Pseudo-*F* (p*F*) values and significance levels (*P*) for a two-way PERMANOVA test on the species composition between observers and camera position.

Species composition	df	MS	*pF*	*P*
Observer	3	3145	2.46	0.002
Position	1	11115	8.69	0.001
Observer x Position	3	0.83	0.66	0.83
Residual	112	1.43E+05		

Table 4.4: The coefficient of correlation (R) and significance levels (*P*) for ANOSIM analysis results of the species composition between observers. Significant differences indicated in bold.

Observer	R	*P*
1 vs 2	-0.049	0.976
1 vs 3	**0.141**	**0.001**
1 v 4	-0.055	0.986
2 v 3	**0.174**	**0.001**
2 v 4	-0.042	0.949
3 v 4	**0.185**	**0.001**

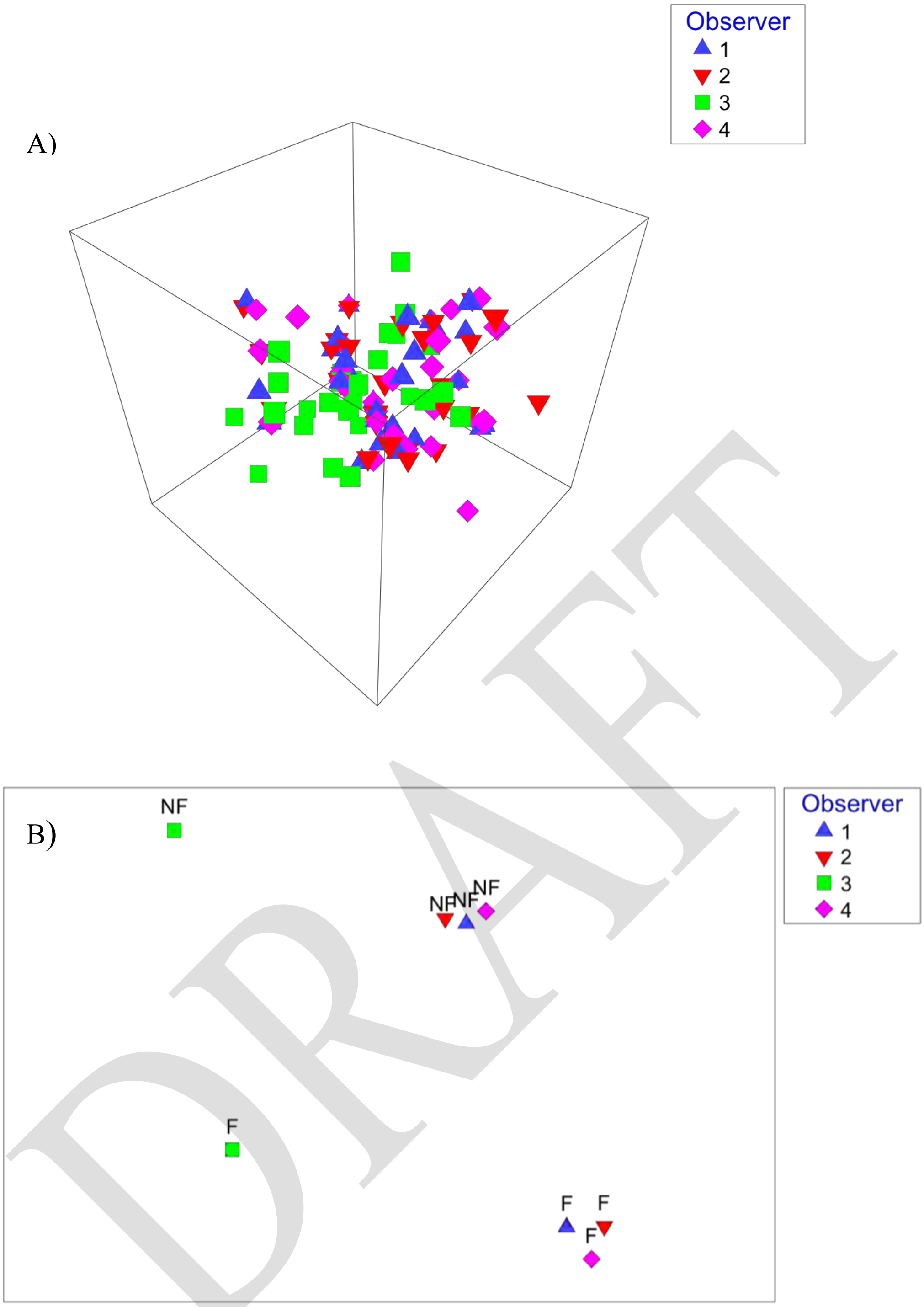

Fig 4.5. A.) A 3d nMDS plot constructed using the Bay-Curtis Similarity matrix, using fourth root transformed data of the MaxN for each species in each sample coded by observer. **B.)** A 2d centroid nMDS ordination plot, derived from distance among centroid matrices constructed from the Bay-Curtis Similarity matrix, created using fourth root transformed data of the MaxN for each species in each sample coded for observer.

A shade plot showing the mean MaxN of species identified highlights trends in species and families identified between the four observers (Fig. 4.6). *Pseudocaranx* spp., *Anoplocapros amygdaloides* and *Coris auricularis,* dominated the data set and were found in similarly high abundance by all observers. Other species found in similar abundance by all four observers were *Neatypus obliquus, Myliobatis australis*, and *Glaucosoma hebraicum*. A hierarchal conglomerative cluster analysis of the similarity between observers showed that the species composition of Observers 1 and 4 had the highest similarity (91%). This was followed by Observer 2, who showed a similarity of 89% to Observers 1 and 4, whilst Observer 3 showed the lowest similarity to the other observers with a species composition similarity of 70% (Fig 4.6). Variation between Observer 3 and the other observers was found to be highest for taxa within the families Labridae, Cheilodactylidae and Monacanthidae (Fig 4.6).

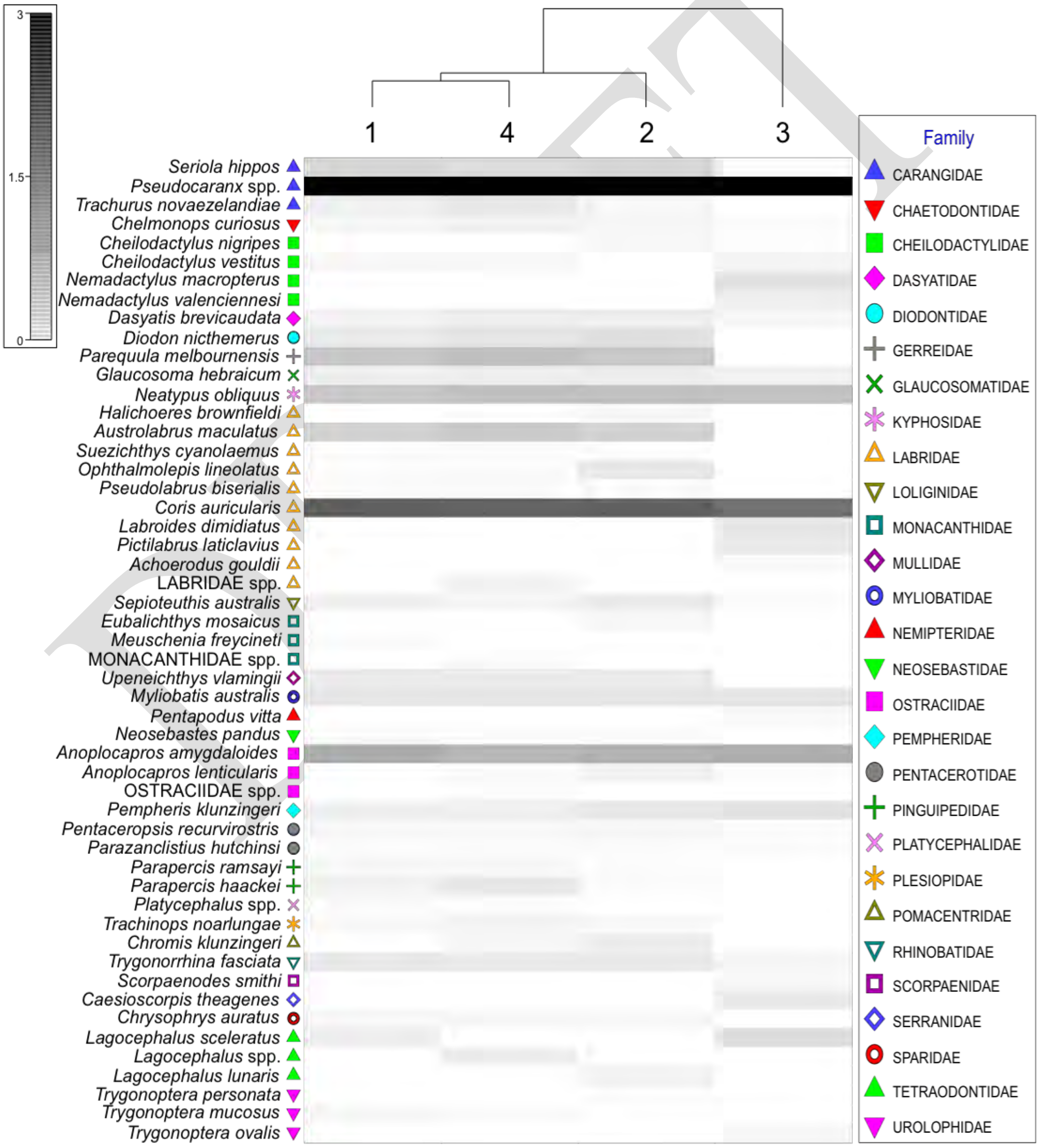

Fig 4.6: Shade plot illustrating the fourth root transformed relative abundance (MaxN) of species with shading intensity being proportional to abundance. Relative abundance (MaxN) counts are categorized by observer, and species are ordered by their family.

As with the shade plot comparing the species composition between observes, a shade plot showing the species composition between facing and not facing footage highlights that a small number of species dominated the data set and comprised the majority of individuals (Fig 4.7). Overall the relative abundance and number of species was found to be higher on footage that was collected facing the reef modules. Whilst the most abundant species *Pseudocaranx* spp., was found to be in similar densities on both facing and not facing footage, *Coris auricularis* and *Anoplocapros amygdaloides* were found in higher densities on facing footage (Fig. 4.7).

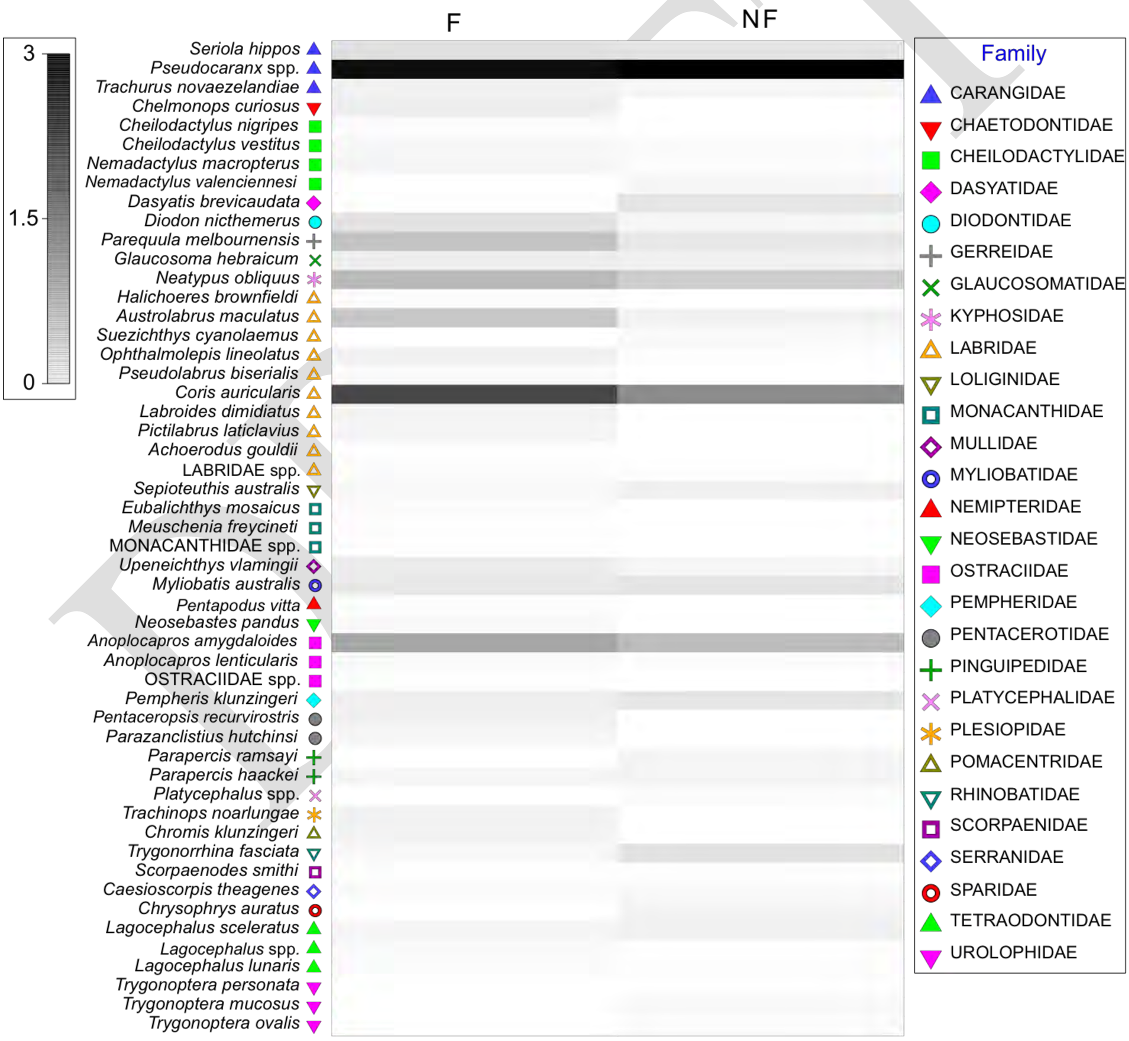

Fig 4.7: Shade plot illustrating the fourth root transformed relative abundance (MaxN) of species with shading intensity being proportional to abundance. Relative abundance (MaxN) counts are categorized by facing (F) and not facing (NF) camera positions, and species are ordered by their family.

4.4 Discussion

The detection and management of observer bias is key to maintaining the quality of data collected in any monitoring study (Harding et al. 2000, Pattengill-Semmens and Semmens 2003, Williams et al. 2006). This study has provided a preliminary assessment of the extent of bias among four observers in extracting data on the abundance and composition of fish from underwater footage of an artificial reef deployed off Dunsborough. The study found that, whilst the fish fauna data extracted from the footage by three of the observers were similar, there was significant variation between the results obtained by these three observers and those obtained by a fourth observer (Observer 3). Whilst the difference between the numbers of species or the number of individuals identified among the four observers were not statistically significant, there was a significant difference in the overall species composition. This indicates that individual fish on the footage were misidentified in some cases, particularly by Observer 3, rather than unsighted.

Abundance estimates of *C. auricularis* were fairly consistent across all observers, however, there was strong variation in the abundance of other Labridae species. Past studies have shown that species within the family Labridae are particularly difficult to identify, and labrids have been a primary source of error with less experienced observers (Williams et al. 2006). This is likely due not only to the physical similarity of many of these species but also their tendency to hide among structures and vegetation (Hutchins and Swainston 1986, Froese and Pauly 2015).

Differences were also seen within the family Carangidae, particularly in the abundance of *T. novaezelandiae*. Species within the family Carangidae have also been previously difficult to identify due to the fast moving, schooling behaviour of some of these species (Thresher and Gunn 1986). It is possible that variation in the abundance of *T. novaezelandiae* was due to confusion with *Pseudocaranx* spp., which was identified in high numbers by all observers. These two taxa show similar behavioural characteristics and colour markings, and could be easily confused if both are present in a fast moving school (Hutchins and Swainston 1986). Species within the family Monacanthidae also showed variation across observers. These species also exhibit similar behaviors and colour between species and are potentially confused by observers who are not familiar with the species (Hutchins and Swainston 1986).

Although this study has focused primarily on the detection of observer bias, it has also been noted that similar to previous work by Florisson (2015), all observers identified significant differences between the species composition on facing and not facing footage. This is likely due to habitat preference between different species, as well as the increased availability of food and shelter provided by the artificial reefs. Previous studies have shown that species abundance was greater on artificial reefs than the surrounding area and it is possible that the additional shelter and habitat created by the Geographe Bay artificial reefs promotes an increased abundance of fish species (Sherman et al. 2002, Folpp et al. 2011). However the limited data available means only assumptions can be made, and further investigation is required to determine the effects that camera apposition has on assessing the fish fauna of artificial reefs and if this should be taken into consideration in future monitoring.

Reducing observer bias in future studies

The limited taxonomic experience of observes and familiarity with species that were present on the video footage is likely a key cause of the variation between observers. Although all observers had similar educational qualifications and were recreational fishers, observer bias was still present. The provision of additional experience through observer training has shown to be an effective method of reducing bias (Thompson and Mapstone 1998). Previous studies of observer bias in underwater visual census by divers have shown that with experience, observer bias rapidly diminishes and only minor variation is present between well trained individuals (Williams et al. 2006, Yoklavich and O'Connell 2008).

Training of individuals to conduct video analysis should be done using a range of environments and organisms likely to be encountered, using footage that has been previously reviewed by an experienced observer (Tissot 2008). Initially, inexperienced observers should be guided through a number of videos and issues of identification should be discussed as they arise. Once observers begin to log information on their own, these data can be quantitatively compared to those of a more experienced observer to detect the level of variation. Tissot (2008) recommends a minimum similarity of 90% between observers before individuals can be left to conduct their own analysis.

Providing observers with the opportunity to have species identifications reviewed by a more experienced observer/taxonomist would help to increase the quality of data. One of the key benefits of using underwater video is the ability to view the footage multiple times if ever there is confusion with the identification of a species. This can be easily achieved by having observers take snapshots from the footage of a species they were unclear on the identification of and send it to a reviewer. These images could then be used to create a database over time that could be used as a reference in future monitoring of reefs in southwest Western Australia.

Another method of potentially reducing observer bias is by focusing the analysis on a narrower range of taxa (Thresher and Gunn 1986, Williams et al. 2006). As this study included all species present in the field of view, observers may have been overwhelmed at times with large numbers of fish and species occurring simultaneously, and miss cryptic or less common species (Smith 1989, Samoilys and Carlos 2000). As the south-west artificial reefs were deployed primarily to increase the abundance of target recreational fishing species, analysis of footage could focus primarily on the abundance of recreational species such as *Chrysophrys auratus* and *Seriola hippos*, to provide better abundance estimates on these key species, as well as reduce the time taken to analyse footage.

Varying water clarity and light can also affect the ability to identify species and provide accurate measurements of relative abundance (MaxN). Harasti et al. (2015) found that standardizing the field of view to approximately 2 m behind the bait bag significantly reduced the effects of water visibility. This can be estimated visually by the observer, by ensuring the bait bag is a set length *e.g.* 1 m, and using it as a reference.

Conclusion

Species identification appeared to be the primary source of variation among observers, particularly of species within the family Labridae, Carangidae and Monacanthidae. Fortunately the use of remote underwater video allows for easy detection of bias. It is possible to minimise the risk of observer bias via the use of adequate training and support for species identification. Future study on observer bias would benefit from a larger sample pool, possibly comparing observers of varying experience levels, as well as the effect of observer training. Future study with a broader data set is also recommended to determine the full extent of the effects that camera position has on monitoring the fish fauna of artificial reefs.

Chapter 5: Analysis of a cost-effective artificial reef monitoring method

5.1 Introduction

An essential component in assessing the biological performance of an artificial reef is the design of a robust monitoring program which can accurately detect changes in the abundance and diversity of fish fauna through space and time (Holmes et al. 2013). A wide variety of methods have been used to monitor marine communities in the past and the chosen technique should be based on the type of information required, the specific indices that need to be measured, the repeatability of the method, the level of precision required to detect change, as well as the environmental conditions in which monitoring will take place (Willis and Babcock 2000, Smale et al. 2011). The available time and financial resources to collect data must also be considered, as this can vary significantly depending on the selected monitoring regime (Langlois et al. 2010).

A frequent stumbling block encountered in many monitoring programs is the collection of sufficient data over large temporal and spatial scales when resources are limited (Baird et al. 2000). One solution to this is the use of volunteers to collect information. The use of volunteers, referred to as "citizen science", to collect biological data is well established in both marine and terrestrial environments (Viswanathan et al. 2004, Wiber et al. 2004, Conrad and Daoust 2008, Conrad and Hilchey 2011, Gollan et al. 2012). The benefit of citizen science is that it allows a portion of monitoring costs to be borne by the volunteers, and has shown to increase stewardship of the resource (Pattengill-Semmens and Semmens 2003). However, with all volunteer based projects, monitoring regimes need to be developed that are both simple and effective, to ensure reliable data collection (Harding et al. 2000).

Recfishwest is currently involved in the development of a citizen science project aimed at using recreational fishers to collect information on the fish fauna of the Geographe Bay artificial reefs using underwater video monitoring. The goal of this project is the development of a cost-effective alternative to the use of dedicated researchers to carry out long-term biological monitoring of the artificial reefs.

Initial trials by Recfishwest involved the use of rotating remote underwater cameras, which provided a live feed of the video footage being collected to avoid collision with reef modules whilst monitoring. Analysis of the footage collected in these initial trials, however, showed this technique to be ineffective at monitoring the fish fauna of the artificial reefs. This was a result of the low quality of the footage collected by the cameras, and to high amounts of camera movement in rough weather while being suspended from the boat, both leading to an inability to distinguish between species (Florisson 2015). This led to a decision by Recfishwest, with the aid of Ecotone consulting, to trial the use of Baited Remote Underwater Video (BRUV) systems constructed from low cost materials.

This aim of this chapter was to investigate the types of information that can be extracted on the fish fauna of the Dunsborough and Bunbury artificial reefs by analyzing BRUV footage collected by Recfishwest and Ecotone Consulting. This data was used to assess the ability of this method for monitoring the fish fauna on the reefs and how the fish assemblages on the Dunsborough and Bunbury artificial reefs varied.

5.2 Materials and Methods

5.2.1 Study Site

5.2.1.1 Geographe Bay

Geographe Bay is the southern-most protected marine embayment in south-west Australia and covers an area of roughly 290 square nautical miles. The bay has a maximum depth of 30 m and normally experiences a semidiurnal tide, with tidal movements averaging 0.5 m (Bellchambers et al. 2006). A more detailed description of Geographe Bay can be found in Section 4.2.

5.2.1.2 Geographe Bay artificial reefs

The Dunsborough reef is located at 115° 9.980' E, 33° 33.962' S, in 27 m of water, and the Bunbury reef is located at 115° 35.900' E, 33° 18.500' S at a depth of 17 m (Department of Fisheries Western Australia 2015). Each artificial reef consists of 30 ten-tonne reinforced concrete 'Fish Box' modules, placed in clusters of five, covering an area of roughly four hectares (Department of Fisheries Western Australia 2015). A more detailed description of the Geographe Bay artificial reefs can be found in Section 4.2.

5.2.2 Source of data

BRUV footage of the Dunsborough and Bunbury artificial reefs was collected from three separate sampling trips. Data collection took place on the 10th and 19th of March 2015 at the Dunsborough reef and the 25th of May 2015 at the Bunbury reef. Data collection, the design of the sampling regime and the construction of the BRUV was performed solely by Ecotone consulting and Recfishwest, with no input from staff or students from Murdoch University.

During the final stages of this thesis, a preliminary species list was provided by the Western Australian Department of Fisheries (DoF), who have been monitoring the artificial reefs using a combination of Diver Operated Video (DOV) and BRUV since the deployment of the reefs in 2013 (see appendix Table A5.1). The species list provided by the DoF contains a preliminary list of species that have been identified from six separate monitoring surveys of the Geographe Bay artificial reefs. Due to the short notice in which this information was obtained, it has not been included within the analysis of the results, however it has been used as comparative data set to assess whether the trends observed in the footage collected by Recfishwest and Ecotone consulting, are mirrored by that of a broader data set.

5.2.3 Sampling regime

The sampling method performed by Ecotone consulting and Recfishwest involved the haphazard dropping of BRUVs in the vicinity of the artificial reef modules using GPS for navigation. Each drop involved positioning the boat above a reef module and lowering the BRUV over the boat until it reached the sea floor. Camera submersion times averaged ~20 minutes, and upon retrieval, the video footage was extracted from the camera. The BRUV was then reset and rebaited before being deployed at a new location (Florisson 2015).

5.2.4 BRUV design

The frame of the BRUV used in this study was constructed from class 9 Polyvinyl Chloride (PVC) irrigation pipe. The frame of the BRUV was stabilised by two skids, each filled with four 680g lead weights, making the BRUV negatively buoyant. The bait used in this study was 500g of Sardine (*Sardinops* spp.), which was enclosed within a plastic mesh bait bag. The camera used to capture video footage was a GoPro Hero 4 Silver Action Video Camera^{TM}, which was placed in a waterproof housing. A more detailed description of the BRUV design can be found in Section 4.2.

5.2.5 Video analysis

Prior to analysis, the provided raw videos were coded according to their trip collection date (t), camera number (c), and video data number. For example a video collected on trip one, by camera one, with a video data number of 0001, would be coded (t1c1-0001). Two additional factors were given to each video that indicated the 'reef' that the footage was collected from and the camera 'position' as either facing reefs modules (F) or not facing reef modules (NF). The reason for including camera position as a factor in this study is due to previous work by Florisson (2015) and the findings of Chapter 4 of this thesis, which identified significant differences between the faunal compositions on footage collected from BRUVs facing towards reef modules and those facing away.

Thirty-three videos were analysed in total, with 24 from Dunsborough (12 facing reef modules, 12 not facing reef modules), and 9 from Bunbury (5 facing reef modules, 4 not facing reef modules). Each video was viewed for a 10-minute period between 7 and 17 minutes, giving a total of 330 minutes. Analysis of each video involved identifying each fish to the lowest possible taxonomic level, usually species, with the exception of *Pseudocaranx* spp., which require detailed examination (*i.e.* scale counts) to confidently distinguish between *Pseudocaranx dentex* and *Pseudocaranx wrightii* (Smith-Vaniz and Jelks 2006). An index of relative abundance (MaxN) was also recorded for each individual species. MaxN is defined as the maximum number of individuals of each species observed in a single frame over the sample period. MaxN is a widely used index in underwater video studies and provides a conservative measure of relative abundance that eliminates the chance of double counting (Willis and Babcock 2000, Cappo et al. 2003, Watson 2006). Whilst is not classified as a fish, *Sepioteuthis australis* (Southern Calamari), has been included within this study as it is an important recreational species with the Geographe Bay area and heavily targeted by fishers.

It has been noted that recommended soak for BRUVs varies between 30 and 60 minutes in order to detect the majority of target species (Watson 2006, Watson et al. 2010, De Vos et al. 2014). However, this study was limited by the length of the videos collected and could only allow for a 7-minute bait soak time followed by a 10-minute analysis of the footage. All video footage was reviewed by the author on an Apple Macintosh laptop computer using the multimedia program QuickTime.

Abundance data from each video were compiled into a single data matrix where each video had a unique identifier code as well as additional factors that indicted the reef that the footage was collected and the camera direction. All following statistical analysis was performed from this single data matrix.

5.2.6 Statistical analyses

All statistical analyses were undertaken using the Primer v7 multivariate statistics software package, with the PERMANOVA+ add on (Anderson et al. 2008, Clarke and Gorley 2015). In all analyses, the null hypothesis of no significant difference was rejected if the significance level (p) was ≤ 0.05.

5.2.6.1 Univariate analyses

Two-way Permutational Multivariate Analysis of Variance (PERMANOVA; Anderson et al., 2008) was employed to determine whether the values for taxon richness (number of taxa) and total MaxN (*i.e.* the sum of the MaxN values for each species in a sample) differed among sites (Bunbury and Dunsborough) and camera positions (facing towards and away from the artificial reef). Both of these variables were considered fixed. The DIVERSE routine was used to calculate, for each individual sample, the taxon richness and total MaxN.

Prior to subjecting the data for each dependent variable to two-way PERMANOVA, the extent of the linear relationship between the log*e*-transformed mean and log*e*-transformed standard deviation for each of the various sets of replicate samples for both variables was examined. This approach was used to determine whether the data for each variable required transformation to meet the test assumption of homogenous dispersions among *a priori* groups and, if so, to identify the appropriate transformation required (Clarke et al. 2014a). This analysis demonstrated that taxon richness required a square root transformation, whilst total MaxN required a log(x+1) transformation.

The pre-treated data for each variable was then used to construct separate Euclidian distance matrices and subjected to the two-way PERMANOVA described above. Graphs of the transformed arithmetic means and associated ± 95% confidence intervals were plotted to visualise the extent of any differences among main effects.

5.2.6.2 Multivariate analysis

PERMANOVA, Analysis of Similarities (ANOSIM; Clarke and Green 1988) non-metric Multi-Dimensional Scaling (nMDS) ordination plots (Clarke 1993) and a shade plot (Clarke et al. 2014b, Tweedley et al. 2015) were employed to elucidate whether the composition of the fish and cephalopod faunas on the artificial reefs differed among sites and camera positions and, if so, the species that were responsible for those differences.

The MaxN for each species in each individual sample was subjected to a log(x+1) transformation to down weigh the contributions of highly abundant taxa and balance them with those of less abundant taxa. These transformed data were then used to construct a Bay-Curtis similarity matrix and subjected to the same two-way PERMANOVA test described above, only this time employing multivariate data. However, in this instance, the sole purpose of the PERMANOVA was to determine if there was an interaction between the site and camera position main effects and, if so, to determine the extent of those interactions relative to each other and to those of the main effects (Lek et al. 2011).

If the interaction was not significant, or relatively small in relation to the main effects, the matrix was then subjected to a two-way ANOSIM test. ANOSIM was preferred at this stage of the analysis because, unlike PERMANOVA, this test is fully non-parametric and thus more robust, and because the ANOSIM *R*-statistic provides a universal measure of group separation to test for significant interactions between region and position (Lek et al. 2011). The magnitude of the *R* statistic typically ranges between

1, when the compositions of the samples within each group are more similar to each other than to that of any of the samples from other groups, down to ~0, when within-group and between-group similarities do not differ (Clarke et al., 2015).

The same Bray-Curtis similarity matrix was subjected to nMDS to produce an ordination plot, which provided a visual representation of the trends in faunal composition among the main effects. Finally, the log(x+1) transformed MaxN data for each species in each sample was then standardized and subjected to the Shade plot routine. This produced a visual display of the abundance matrix of variables (transformed and standardized species counts) against samples (each video), where the white represents the absence of a taxa in a sample and the intensity of grey-scale shading is linearly proportional to 'abundance' (Clarke et al. 2014b).

The order of both the variables and samples were determined independently (*i.e.* the order of variables is not influenced by the order of samples and *vice versa*) by the results of separate a group-average hierarchical agglomerative cluster analyses employing resemblance matrices defined using Whittaker's index of association (Whittaker 1952, Valesini et al. 2014). Species exhibiting similar patterns of abundance across the samples were thus clustered together on the resultant dendrogram (*y* axis of the shade plot), while the samples (displayed on the *x* axis) were ordered by similarities in their 'species' composition. Note that, for clarity, only those taxa that occurred in two of more of the samples (*i.e.* 24 out of 35 taxa) were included in the shade plot.

5.3 Results

5.3.1 Mean density of species at artificial reef locations

A total of 35 taxa, from 22 families, including 34 fish and 1 cephalopod, were identified on BRUV footage, with the majority of taxa identified to species level (97%). The only taxa that could not be identified to species from the footage were from the genus *Pseudocaranx*. The most specious families on the video footage were Labridae and Carangidae, which were represented by five and three taxa respectively.

Thirty-four of the 35 taxa identified were present on footage from the Dunsborough reef (Table 5.1). The most abundant taxa identified at the Dunsborough reef were *Pseudocaranx* spp., which represented ~48% of the total abundance. The following most abundant species were *Coris auricularis* and *Trachurus novaezelandiae,* which represented ~15% and ~8% respectively, of the total abundance. A total of 11 taxa were identified on footage from the Bunbury reef. The most abundant species found on this footage was *C. Auricularis*, which accounted for ~39% of the total abundance, followed by *Parequula melbournensis* (~31%) and *Neatypus obliquus* (~14%). Neither *Pseudocaranx* spp. nor *T. novaezelandiae*, were identified on footage from the Bunbury reef, however both *P. melbournensis* and *C. auricularis* were seen in higher abundance on the Bunbury reef, with mean MaxNs of 3.89 and 4.89 respectively, compared to 1.88 and 4.88 at Dunsborough reef. Of the 35 identified taxa, 23 taxa were restricted to the footage from the Dunsborough reef, whilst only a single species, *Trygonoptera personata*, was restricted to the footage from the Bunbury reef.

Table 5.1: Species table showing the mean MaxN (X) and standard error (SE) of each of the 35 fish and cephalopod taxa recorded using BRUVs on the Dunsborough and Bunbury artificial reefs. For each taxon, a percentage contribution (%) and ranking by mean MaxN (R) was calculated. Abundant species *i.e.* those that contributed ≥ 5 % to abundance recorded by any observer are shaded in grey.

		Total				Dunsborough				Bunbury			
Species	**Family**	**X**	**SE**	**%**	**R**	**X**	**SE**	**%**	**R**	**X**	**SE**	**%**	**R**
Pseudocaranx spp.	CARANGIDAE	14.06	1.99	47.94	1	19.33	1.78	54.34	1				
Coris auricularis	LABRIDAE	4.48	0.82	15.29	2	4.33	0.67	12.18	2	4.89	2.55	38.59	1
Trachurus novaezelandiae	CARANGIDAE	2.24	1.35	7.65	3	3.08	1.84	8.67	3				
Parequula melbournensis	GERREIDAE	1.88	0.42	6.41	4	1.13	0.27	3.16	5	3.89	1.14	30.69	2
Neatypus obliquus	KYPHOSIDAE	1.67	0.47	5.68	5	1.63	0.56	4.57	4	1.78	0.89	14.03	3
Anoplocapros amygdaloides	OSTRACIIDAE	0.85	0.16	2.89	6	1.13	0.18	3.16	5	0.11	0.11	0.88	8
Seriola hippos	CARANGIDAE	0.61	0.11	2.07	7	0.58	0.13	1.64	8	0.67	0.24	5.26	4
Austrolabrus maculatus	LABRIDAE	0.48	0.16	1.65	8	0.63	0.22	1.76	7	0.11	0.11	0.88	8
Upeneichthys vlamingii	MULLIDAE	0.36	0.18	1.24	9	0.50	0.25	1.41	9				
Trygonorrhina fasciata	RHINOBATIDAE	0.30	0.09	1.03	10	0.25	0.11	0.70	13	0.44	0.18	3.51	5
Sepioteuthis australis	LOLIGINIDAE	0.27	0.24	0.93	11	0.38	0.33	1.05	10				
Pempheris klunzingeri	PEMPHERIDAE	0.24	0.19	0.83	12	0.33	0.26	0.94	11				
Diodon nicthemerus	DIODONTIDAE	0.24	0.10	0.83	12	0.33	0.13	0.94	11				
Chelmolops curiosus	CHAETODONTIDAE	0.24	0.11	0.83	12	0.21	0.12	0.59	14	0.33	0.24	2.63	6
Myliobatis australis	MYLIOBATIDAE	0.21	0.07	0.72	15	0.21	0.08	0.59	14	0.22	0.15	1.75	7
Parapercis haackei	PINGUIPEDIDAE	0.15	0.09	0.52	16	0.21	0.12	0.59	14				
Dasyatis brevicaudata	DASYATIDAE	0.15	0.06	0.52	16	0.21	0.08	0.59	14				
Chyrosophyrs auratus	SPARIDAE	0.12	0.06	0.41	18	0.17	0.08	0.47	18				
Glaucosoma hebraicum	GLAUCOSOMATIDAE	0.09	0.05	0.31	19	0.13	0.07	0.35	19				

Table 5.1 continued: Species table showing the mean MaxN (X) and standard error (SE) of each of the 35 fish and cephalopod taxa recorded using BRUVs on the Dunsborough and Bunbury artificial reefs. For each taxon, a percentage contribution (%) and ranking by mean MaxN (R) was calculated. Abundant species *i.e.* those that contributed ≥ 5 % to abundance recorded by any observer are shaded in grey

Species	**Family**	**X**	**SE**	**%**	**R**	**X**	**SE**	**%**	**R**	**X**	**SE**	**%**	**R**
Cheilodactylus gibbosus	CHEILODACTYLIDAE	0.09	0.05	0.31	19	0.13	0.07	0.35	19				
Pentaceropsis recurvirostris	PENTACEROTIDAE	0.06	0.04	0.21	21	0.08	0.06	0.23	21				
Parapercis ramsayi	PINGUIPEDIDAE	0.06	0.04	0.21	21	0.08	0.06	0.23	21				
Meuschenia freycineti	MONACANTHIDAE	0.06	0.04	0.21	21	0.04	0.04	0.12	24	0.11	0.11	0.88	8
Aptychotrema vincentiana	RHINOBATIDAE	0.06	0.04	0.21	21	0.08	0.06	0.23	21				
Choerodon rubescens	LABRIDAE	0.03	0.03	0.10	25	0.04	0.04	0.12	24				
Chromis klunzingeri	POMACENTRIDAE	0.03	0.03	0.10	25	0.04	0.04	0.12	24				
Parazanclistius hutchinsi	PENTACEROTIDAE	0.03	0.03	0.10	25	0.04	0.04	0.12	24				
Aracana aurita	OSTRACIIDAE	0.03	0.03	0.10	25	0.04	0.04	0.12	24				
Eubalichthys mosaicus	MONACANTHIDAE	0.03	0.03	0.10	25	0.04	0.04	0.12	24				
Tilodon sexfasciatus	KYPHOSIDAE	0.03	0.03	0.10	25	0.04	0.04	0.12	24				
Lagocephalus sceleratus	TETRAODONTIDAE	0.03	0.03	0.10	25	0.04	0.04	0.12	24				
Trygonoptera mucosa	UROLOPHIDAE	0.03	0.03	0.10	25	0.04	0.04	0.12	24				
Trygonoptera personata	UROLOPHIDAE	0.03	0.03	0.10	25					0.11	0.11	0.88	8
Suezichthys cyanolaemus	LABRIDAE	0.03	0.03	0.10	25	0.04	0.04	0.12	24				
Pseudolabrus biserialis	LABRIDAE	0.03	0.03	0.10	25	0.04	0.04	0.12	24				
Species			**35**				**34**				**11**		
Mean MaxN			**29**				**36**				**13**		
# Samples			**33**				**24**				**9**		

5.3.2 Species diversity

PERMANOVA demonstrated that number of species differed significantly between the footage from the two reefs (Table 5.2A; Fig. 5.1A), but not between footage from different camera positions (Table 5.2A; Fig. 5.1B), with no significant interaction between reef and position (Table 5.2A). The mean number of species identified on the Bunbury and Dunsborough reef footage was roughly three and seven. As for camera position the mean number of species identified on facing and not facing footage was roughly six and five, respectively.

Table 5.2: Mean squares (MS), Pseudo-*F* (p*F*) values and significance levels (*P*) for a two-way PERMANOVA test on (A) number of species between reef and camera position and (B) abundance (total MaxN) between reef and camera position.

(A) Number of species	df	MS	*pF*	*P*
Reef	1	4.15	18.62	0.001
Position	1	0.163	0.73	0.396
Reef x Position	1	0.013	0.057	0.805
Residual	29	0.223		

(B) Abundance	df	MS	*pF*	*P*
Reef	1	8.21	37.16	0.001
Position	1	1.49	6.737	0.016
Reef x Position	1	0.919	4.16	0.051
Residual	29	0.221		

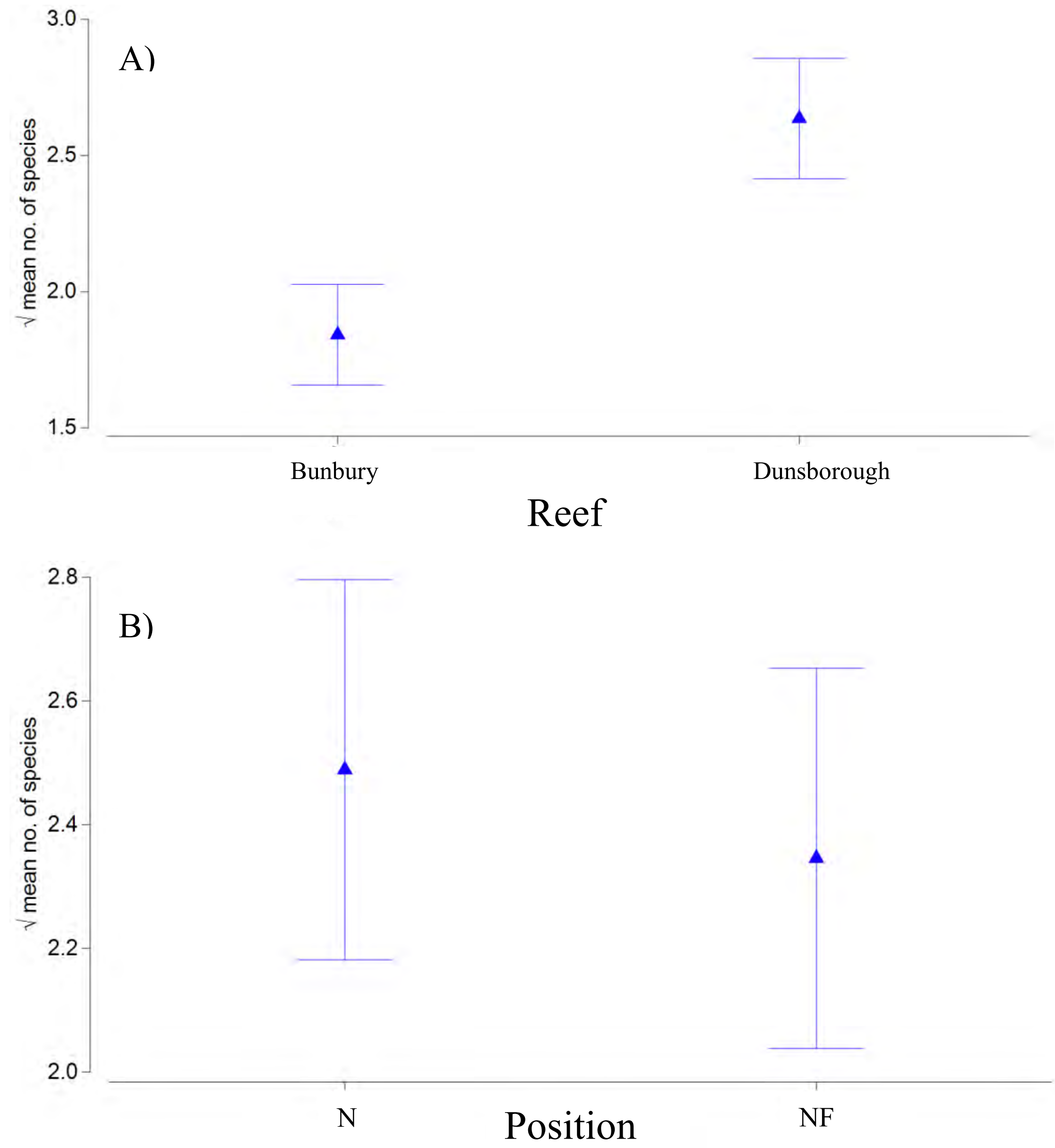

Fig. 5.1. Mean number of species, square root transformed, recorded at (A) the Bunbury and Dunsborough artificial reefs, and (B) by video footage facing reef modules (F) and not facing reef modules (NF). Error bars represent 95% confidence intervals.

5.3.3 Overall abundance

As for overall density, PERMANOVA identified significant differences between footage from the two reefs (Table 5.2B; Fig. 5.2A), and camera position (Table 5.2B; Fig. 5.2B). However, it should be noted the error values for relative abundance by position were large. As with the mean number of species, there was no significant interaction between reef and position in regards to abundance of species (Table 5.2B).

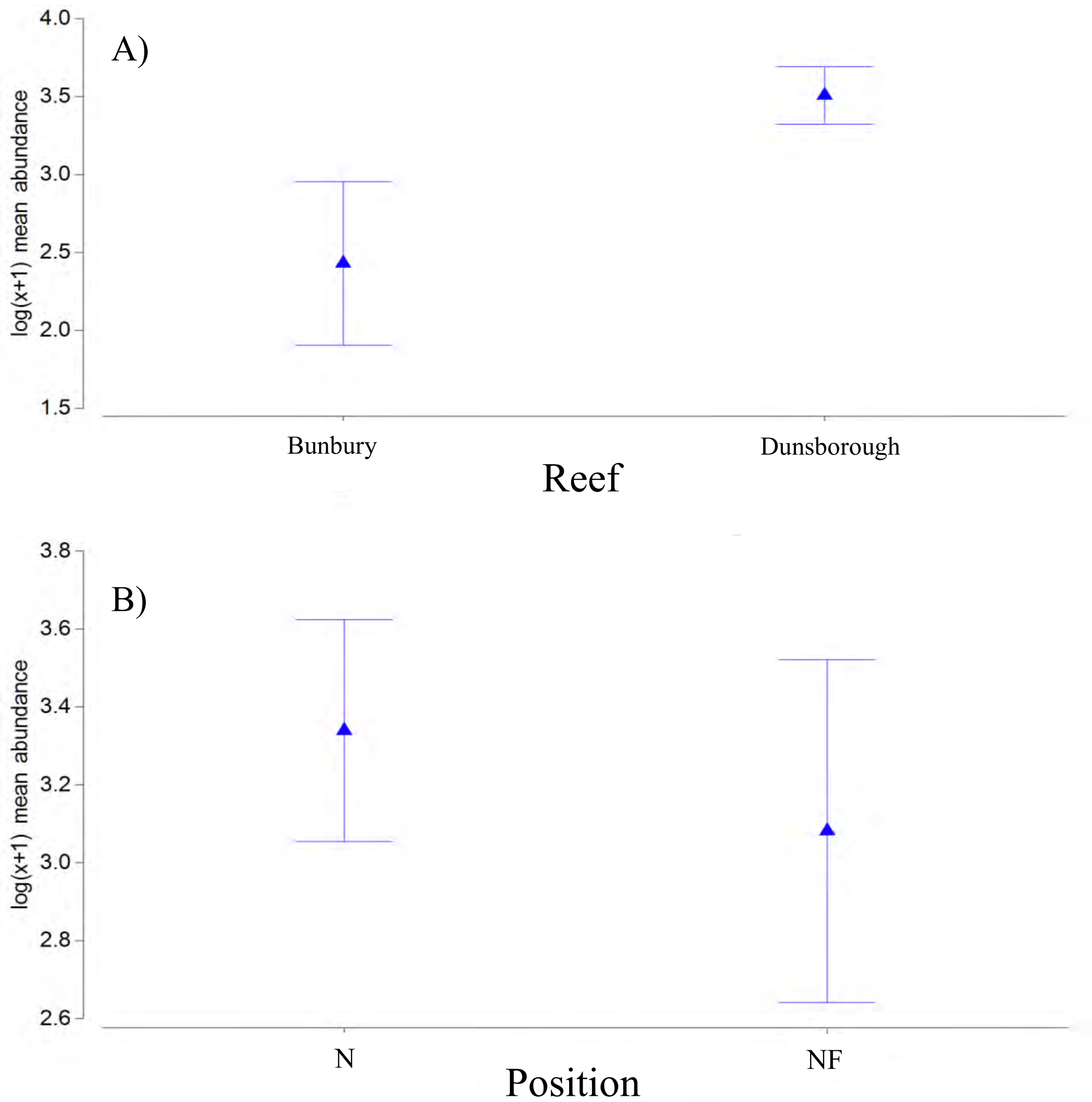

Fig 5.2. Mean abundance (MaxN), log(x+1) transformed, of individuals recorded at (A). the Bunbury and Dunsborough artificial reefs, and (B) by video footage facing reef modules (F) and not facing reef modules (NF). Error bars represent 95% confidence intervals.

5.3.4 Multivariate analysis

ANOSIM showed that the composition of species differed significantly between footage from the two reefs (Global R = 0.867, p = 0.001), but not for camera position (Global R = 0.071, p = 0.114), with PERMANOVA showing no significant interaction between reef and position (p = 0.817). The nMDS ordination plot, derived from the log(x+1) transformation of densities from all species, show clearly identifiable differences between regions (Fig.5.3A), whilst the differences between positions are less clearly observed (Fig. 5.3B).

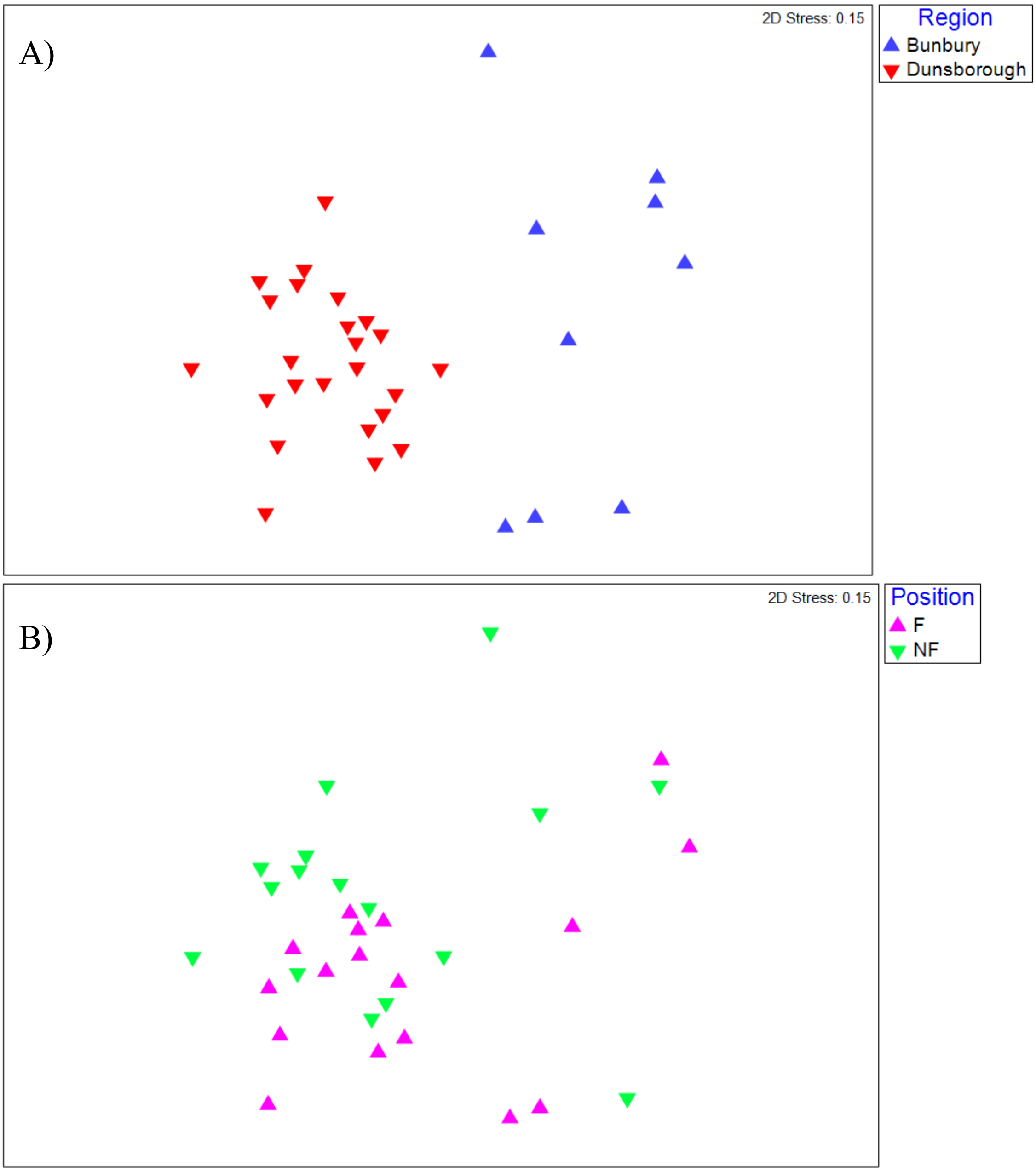

Fig. 5.3. An nMDS constructed using the Bay-Curtis Similarity matrix, using log(x+1) transformed data of the MaxN for each species in each sample. (A) Plot has been coded for reef with Dunsborough samples indicated by red, and Bunbury samples indicated by blue. (B) Plot has been coded for position with facing (F) samples indicated by purple, and not facing (NF) samples indicated by green.

A shade plot showing the percentage contribution to overall abundance of species which occurred in two or more samples only, highlights trends in individual species between both reef and camera position (Fig. 5.4). *P. melbournensis*, *S. hippos* and *C. auricularis* were found to occur frequently in samples from both reefs and camera positions; however *S. hippos* was found in lower numbers.

Species such as *Anoplocapros amygdaloides* and *Pseudocaranx* spp. were found in high numbers of video samples from the Dunsborough reef, but relatively few at the Bunbury reef. *T. novaezelandiae,* which was the third most abundant species at the Dunsborough site occurred only in three samples, however in very high numbers. The shade plot also shows that species such as *Pentaceropsis recurvirostris* were found only to occur in footage that was collected facing reef modules whilst others such as *Dasyatis brevicaudata* and *Trygonorrhina fasciata*, were far more abundant in footage not facing reef modules.

In regards to recreationally important fish species, whilst *S. hippos* was found in similar abundance regardless of the reef or camera position, *Glaucosoma hebraicum, Chrysophrys auratus* and *Pseudocaranx* spp. were only identified on footage collected from the Dunsborough artificial reef. *C. Auratus* was also only identified on footage that was collected facing away from reef modules (Fig 5.4).

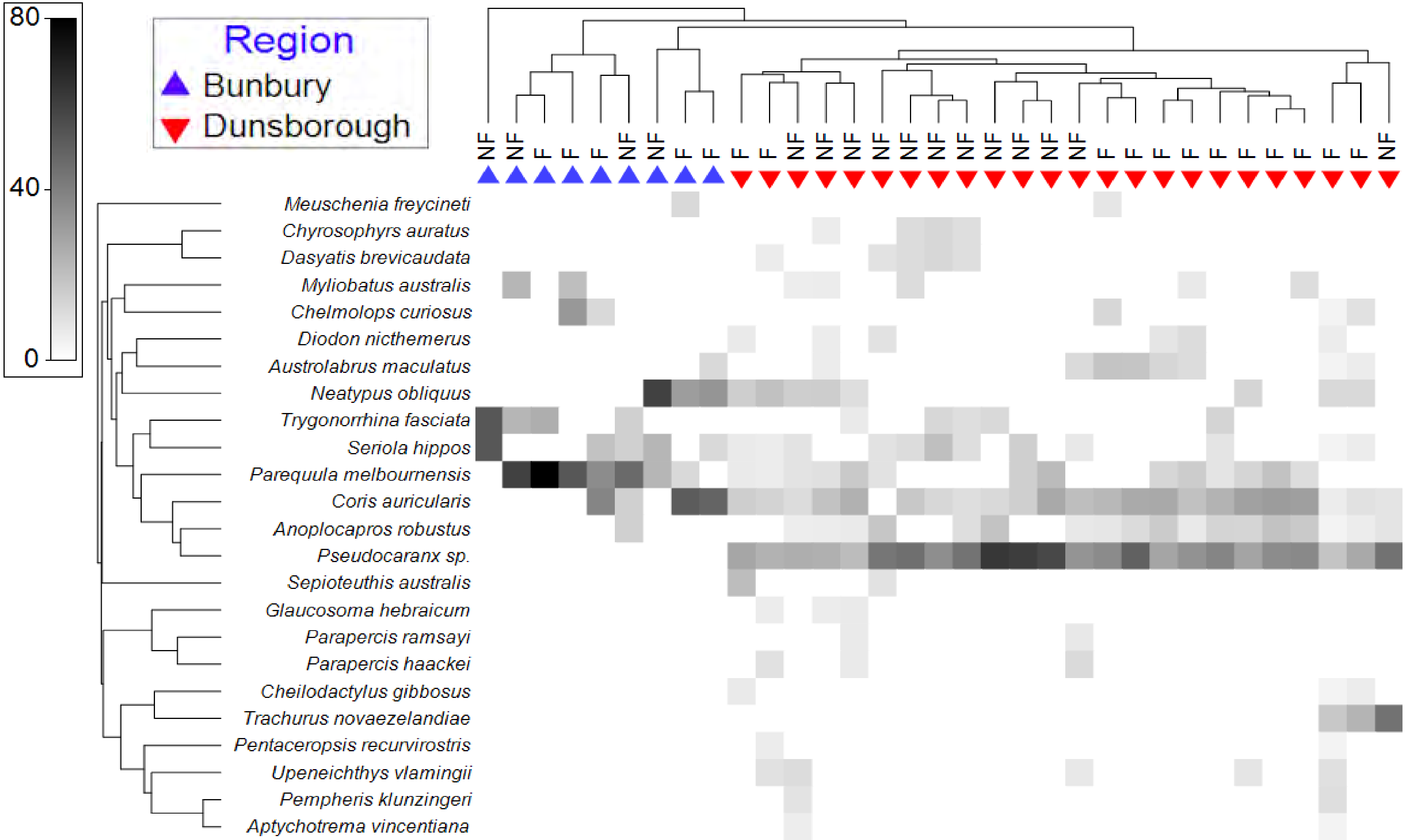

Fig. 5.4. Shade plot illustrating species that were identified in two or more samples. Data has been log(x+1) transformed and converted to percentage contribution for each sample. Cluster analysis has grouped species and individual video samples by their similarity. Darker shading represents a greater percentage contribution.

5.4 Discussion

A total of 330 minutes of BRUV footage was analysed from 33 separate videos to gather information on the diversity and abundance of fish species on the Dunsborough and Bunbury artificial reefs. This footage was opportunistically obtained as a preliminary assessment of the use of cost-effective BRUVs to monitor the fish assemblages of the artificial reefs in Geographe Bay.

Whilst this chapter has compared footage between the two artificial reefs and found significant differences in the fish fauna, the limited data and the fact that this study has not taken into account any temporal variation has meant that only assumptions can be made as to the cause of these differences. This is owing to difficulty in knowing whether or not the similarities and differences regarding the fish fauna on the footage is indicative of real variation between the two artificial reefs or owing to limitations of the data.

Data collected by the DoF as part of a monitoring program has provided a baseline of the species diversity that can be expected to be found on the artificial reefs. Whilst this study provides only a preliminary analysis of the diversity and abundance of species on the artificial reefs, it also offers an opportunity to assess what improvements can be made in future monitoring of the reefs using BRUVs and recreational fishers.

5.4.1 Trends in the data between reefs

Significant differences for both the species diversity and the overall abundance of species were identified between the footage from the two reefs, with the Dunsborough reef having a greater diversity and abundance of species. One of the most significant differences observed between the two reefs was the absence of *Pseudocaranx* spp. and *T. novaezelandiae* from the footage of the Bunbury reef. Whilst *T. novaezelandiae* was the third most abundant species found at the Dunsborough reef, it only occurred in three of the 24 samples, and it is possible that the species was missed by chance at the Bunbury reef due to the limited amount of footage collected. The high abundance of the species at the Dunsborough reef is a result of it being a schooling species that generally appears in high numbers, giving it a high MaxN count despite only occurring in a small number of samples (Hutchins and Swainston 1986, Froese and Pauly 2015).

Pseudocaranx spp. on the other hand was found in every video sample at the Dunsborough reef and would likely have been captured had it been present on the Bunbury reef in similar abundance at the time of collecting the footage. As this species has been detected at both regions by previous monitoring (Table A5.1), the lack of *Pseudocaranx* spp. on the BRUV footage from the Bunbury reef is likely not due to an absence of the species but rather a lower abundance, and possibly may have been detected with additional sampling. This may also be the case for other recreational target species such as *G. hebraicum* and *C. auratus*, which were only detected at the Dunsborough reef in this study, but have been shown to occur at both reefs (Table A5.1).

A wide variety of design and environmental factors can affect the abundance and diversity of species on artificial reefs. As the two reefs are constructed from identical materials and number of modules and located only 50 km apart it is expected that they would provide similar amounts of shelter and experience similar environmental conditions. Isolation from nearby natural reefs, however, has shown to be a key factor in determining the abundance of fish on artificial reefs. Specifically, research has shown that artificial reefs located further away from natural reefs have a greater abundance and diversity of both juvenile and adult species (Walsh 1985, Belmaker et al. 2005). These findings have been attributed to a lower level of predation on more isolated reefs and thus a higher abundance of prey species, such as *T. novaezelandiae* and *Pseudocaranx* spp. (Belmaker et al. 2005, Froese and Pauly 2015).

Another significant difference observed between the two reefs was the overall diversity of species. Thirty-five species from 22 families were identified overall, with 34 of these species found at the Dunsborough reef and 11 found at the Bunbury reef. Monitoring by the DoF identified a total of 57 taxa from six monitoring surveys, 25 of which were not recorded on the footage collected by Recfishwest and Ecotone consulting Table A5.1). Of the total number of species identified by the DoF, 44 and 38 were detected at the Dunsborough and Bunbury reefs respectively, using a combination of both BRUVs and DOV, with 31 taxa identified at both reefs using only BRUVs (Table A5.1). This indicates that whilst sampling was fairly effective at the Dunsborough reef, the lack of footage collected from the Bunbury reef may not have provided an accurate representation of the species composition on the reef.

5.4.2 Trends in data between camera direction

In contrast to previous research done by Florisson (2015), no significant difference was detected between footage collected facing and not facing reef modules. This is highlighted by relatively abundant species such as *Pseudocaranx* spp.*, P. melbournensis, C. auricularis* and *S. hippos,* which were found in similar frequencies in both facing and not facing footage. These species are all inquisitive and opportunistic feeders and would have been quickly drawn in by the bait as well as the action of other fish at the BRUV regardless of the position of the camera (Hutchins and Swainston 1986, Froese and Pauly 2015).

There were, however, a number of species that showed a distinct preference to a specific habitat. Cryptic species such as *P. recurvirostris*, which is known to be shy and hide among structure, was detected only in footage that was facing the reef modules (Hutchins and Swainston 1986). Ray species on the other hand such as *T. fasciata* and *D. brevicaudata,* were found to be far more abundant on the sand and seagrass on the outskirts of the reef modules. This is likely due to the feeding preference of these species which prey on items in the sand and do not seek the protection of structure (Hutchins and Swainston 1986, Froese and Pauly 2015). As these species were only found in small numbers however, their effect on the analysis of camera position would have been lessened by more abundant species such as *P. melbournensis, C. auricularis* and *Pseudocaranx* spp.

5.4.3 Recommendations for future study

One of the major factors likely to influence estimates of fish abundance and diversity is the length of time that the BRUV is positioned on the seafloor to record footage, known as the soak time (Gladstone et al. 2012, Harasti et al. 2015). Previous studies using BRUVs have generally employed soak times between 30-60 minutes with longer times recommended to attract more ‘delayed reaction’ species (Stobart et al. 2007, Gladstone et al. 2012, Harvey et al. 2013). Increasing the soak time of BRUVs does, however, add extra costs, as this increases the time need to collected samples and analyze footage.

Willis and Babcock (2000) recommend a BRUV soak time of at least 30 minutes as this provides reliable estimates of relative abundance without incurring extra costs that provide little or no benefit. A study using BRUVs to monitor fish communities in the Abrolhos Islands found that a minimum soak time of 36 minutes is needed to detect the majority of species, with 60 minutes recommend to capture numerous target species (Watson 2006). Future BRUV monitoring of the artificial reefs using recreational fishers should aim for a minimum soak time of 30 minutes, as this is likely to provide sufficient data on the fish communities of the artificial reefs as well as minimize sampling costs. Gathering data over a greater temporal scale would also be beneficial, as whilst the footage collected in this study may represent the faunal composition of the reefs on the day of sampling, it is not able to provide information on seasonal variation.

Although no significant difference was observed between the facing of the cameras in this study, it should be taken into account that there were a number of species that may potentially be missed or detected in lower abundances depending on the direction of the camera. Increasing the BRUV soak time may also aid in reducing the variation between facing and not facing footage as a larger bait plume will attract fish from a greater area and reduce the effects of camera facing. However, additional research is needed to determine how this factor will affect the data collected in the long term and future study should continue to take note of the camera facing.

Although monitoring by the DoF has not looked at the differences between facing and not facing footage, they have detected significant differences in species composition and abundance on different clusters of reef modules (Paul Lewis; Department of Fisheries WA pers.com. 2015). Variation between the clusters may be caused by a range of differences in ocean currents and sedimentation levels between exposed and protected reef modules (Pais et al. 2007). Haphazard dropping of BRUVs has been successfully used in the past to monitor fish assemblages, but it limits the amount of spatial analysis that can be done (Cappo and Brown 1996, Westera et al. 2003). By modifying the deployment method to ensure each cluster of modules is sampled separately and assigning each sample with a cluster code depending on its location (*i.e.* North cluster, South-West cluster etc.), analysis of the variation between clusters can be done in much the same way this study has compared the fish assemblages of the two artificial reefs.

Lastly, as well as comparing the two artificial reefs with each other, comparisons with natural reefs within Geographe Bay would also provide a good measure of the effectiveness of the artificial reefs (Carr and Hixon 1997). As the artificial reefs were designed to attract target species for recreational fishing, it would be useful to collect data on how the abundance of these species on the artificial reefs compares to that of natural reefs and whether the high visitation levels the artificial reefs receive from fishers is affecting fish populations (Carr and Hixon 1997, Department of Fisheries Western Australia 2015).

Considering the limited amount of data collected, as well as the fact that footage was collected from only a single trip to the Bunbury reef, and two to the Dunsborough reef, the use of cost-effective BRUV sampling does show potential to provide a successful long-term monitoring project. A number of significant differences were identified between the two reefs, but no distinct conclusions can be drawn due to the lack of data. However, these findings do warrant further investigation, and continued improvements to the sampling regime as well as monitoring over an extended temporal scale will provide more sufficient data to draw conclusions from.

5.5 Appendix

Table A5.1: Fish species recorded by the Department of Fisheries on the Bunbury and Dunsborough Reefs in the six monitoring surveys up to October 2014. Sampling was conducted using both Diver Operated Video (DOV) and Baited Remote Underwater Video (BRUV). Species are categorized by the region they were detected as well as the monitoring method that detected them. Shaded species are those that were not detected on the BRUV footage collected by Recfishwest and Ecotone consulting.

Species	Dunsborough	Bunbury
Anoplocapros amygdaloides	BRUV / DOV	BRUV / DOV
Anoplocapros lenticularus	BRUV	DOV
Apogon victoriae	DOV	BRUV / DOV
Aptychotrema vincentiana	BRUV	
Arcana aurita	BRUV / DOV	BRUV / DOV
Achoerodus gouldii	BRUV	
Aulohalaelurus labiosus		BRUV
Austrolabrus maculatus	BRUV / DOV	BRUV / DOV
Caesioscorpis theagenes	BRUV / DOV	DOV
Cheilodactylus gibbosus	DOV	BRUV / DOV
Chelmolops curiosus	BRUV / DOV	BRUV / DOV
Choerodon rubescens		BRUV / DOV
Chromis klunzingeri		DOV
Chrysophrys auratus		BRUV
Coris auricularis	BRUV / DOV	BRUV / DOV
Dactylophora nigricans	BRUV	
Dasyatis brevicaudata	BRUV	BRUV
Diodon nicthemerus	BRUV / DOV	
Eubalichthys mosaicus	BRUV	
Eupetrichthys angustipes	DOV	BRUV / DOV
Glaucosoma hebraicum	DOV	
Halichoeres brownfieldii		DOV
Helcogramma decurrens		DOV
Heniochus acuminatus	DOV	
Hypoplectrodes nigroruber		DOV
Meuschenia freycineti	BRUV	
Mustelus antarcticus	BRUV	
Myliobatus australis	BRUV	BRUV
Neatypus obliquus	BRUV / DOV	BRUV / DOV
Neosebastes pandus	BRUV	
Notolabrus parilus		BRUV / DOV
Ophthalmolepis lineolatus		BRUV
Parapercis haackei	DOV	DOV

Table A5.1 continued: Fish species recorded by the Department of Fisheries on the Bunbury and Dunsborough Reefs in the six monitoring surveys up to October 2014. Sampling was conducted using both Diver Operated Video (DOV) and Baited Remote Underwater Video (BRUV). Species are categorized by the region they were detected as well as the monitoring method that detected them. Shaded species are those that were not detected on the BRUV footage collected by Recfishwest and Ecotone consulting.

Species	Dunsborough	Bunbury
Paraplotosus albilabris	BRUV	
Parapriacanthus elongatus	DOV	
Parequula melbournensis	BRUV	BRUV / DOV
Paristiopterus gallipavo	BRUV / DOV	BRUV
Parma mccullochi	DOV	
Parupeneus crysopleuron	BRUV	
Pentapodus vittae		BRUV
Pempheris klunzingeri	BRUV / DOV	BRUV / DOV
Platycephelus sp.	BRUV	BRUV
Platycephelus speculator	BRUV	BRUV
Platycephelus longispinis	BRUV	
Pseudocaranx sp.	BRUV / DOV	BRUV
Pseudocaranx dentex		BRUV
Pseudolabrus biserialis	DOV	
Pseudorhombus jenynsii		BRUV
Seriola hippos	BRUV / DOV	BRUV
Siganus sp.		BRUV / DOV
Tilodon sexfasciatus	BRUV	BRUV
Trachinops noarlungae	DOV	
Trachurus novaezelandiae	BRUV / DOV	
Trygonoptera personata	DOV	BRUV
Trygonorrhina fasciata	BRUV	BRUV
Upeneichthys vlamingii	DOV	BRUV / DOV
Urolophus sp.	BRUV	
Total no. of species	**44**	**38**
Total no of species detected by BRUV	**31**	**31**

Chapter 6: Conclusion

This thesis describes the results of research on the design and application of artificial reefs and an evaluation of the efficacy of cost-effective methods for monitoring their fish faunas. A literature review of Habitat Enhancement Structures (HES) around the world, focusing primarily on artificial reefs, investigated the various materials, designs and uses of these structures (Chapter 2). The results demonstrated that these structures have been utilized for a wide variety of purposes ranging from sediment stabilization and mitigation of illegal trawling to the provision of additional habitat for nurseries, aquaculture and commercial and recreational fishing.

In order to maximise the effectiveness of these structures a variety of factors need to be taken into consideration to ensure the selected materials and designs are suited to the purpose. Whilst over 3000 articles have been published using the key words “artificial reefs” and/or “habitat enhancement structure(s)”, limited guidelines are available for the various materials and designs that exist (Tweedley, unpublished). Thus the data derived was used to construct a heat map (Fig 2.9) to provide advice for the best application of various materials and designs. This provides information to allow project managers planning to undertake a HES project to easily identify which designs and materials will be most suited to their intended purpose and help guide the future development of HESs.

Having researched the various designs, a literature review was taken to look at how trends in artificial reef construction within Australia have changed over time (Chapter 3). It was found that within Australia the past 10 years has seen a clear shift in the designs and materials used in artificial reef construction. Purpose-built concrete modules have replaced materials of opportunity (*i.e.* tyres and scuttled vessels) as the most prevalent reef building material. Whilst these materials require an additional cost, they provide significant long-term benefits such as increased reef longevity, species-specific designs and reduced environmental impact. With the number of artificial reefs set to increase in coming years, continued research is needed to provide up to date information on the use of these structures and their socio-economic performance, *e.g.* do they increase tourism and generate trade for local fishing stores.

The deployment of artificial reefs can require financial investments within the millions and it is therefore important to evaluate their effectiveness. In the case of reefs such as those deployed in Geographe Bay to attract target species and enhance recreational fishing, it is essential to monitor how the fish faunas associated with these structures change over space and time. The citizen science project being conducted by Recfishwest and Ecotone consulting offers a potential cost-effective method for monitoring the fish fauna of the Geographe Bay artificial reefs. The use of volunteers allows for gathering information over larger temporal and spatial scales than would otherwise be possible with limited resources. However, when using volunteers with limited experience it is important to ensure that the video data collected is reliable.

To investigate the impact of observer bias, Baited Remote underwater Video (BRUV) footage provided by Recfishwest and Ecotone consulting was analysed by having multiple observers collect information on the fish fauna present on the footage (Chapter 4). It was found that whilst observers recorded similar species diversity and abundance counts, significant differences were present between their records of species composition. This indicates that the use of observers with limited experience in logging data from underwater video footage may lead to significant variation in the data set due to observer bias. If university students are to be used as part of the Recfishwest monitoring project, it is recommended that participants should receive additional training, particularly in species identification, and go through an initial trial period where their results are compared to that of a more experienced observer until a minimum similarity of 90% is consistently recorded.

Statistical analysis of footage collected from the Bunbury and Dunsborough artificial reefs was done to identify what level of information could be obtained using a cost-effective BRUV sampling method (Chapter 5). Analysis of the data found that significant differences in the species composition were present between the two reefs, but that modifications to the sampling regime and a broader data set are needed to provide a more accurate comparison. It is recommend that future monitoring of the artificial reefs by recreational fishers should incorporate a minimum BRUV soak time of 30 minutes to provide an accurate representation of the target fish communities. As the Recfishwest monitoring project progresses and additional footage is collected over a greater temporal scale, a broader data set than what was available for this study will be able to be utilized and allow for a more accurate assessment and comparison of the fish faunas of the artificial reefs. Incorporating the monitoring of nearby natural reefs would also be effective in providing a comparative data set to assess the effectiveness of the Geographe Bay artificial reefs. A major limitation of this component was the amount of video footage that could be obtained within the time frame. However, this analysis was able to identify a number of factors such as observer bias and camera position that warrant further investigation and require additional research to better understand their implication on future monitoring of the artificial reefs using BRUVs and recreational fishers.

In summary, this research has provided information about patterns of artificial reef usage globally and in Australia, which aims to assist in the future development of artificial reefs. It has also provided a series of recommendations for training observers to minimise the risk of observer bias in future monitoring of the Geographe Bay artificial reefs. Finally, it has shown that a monitoring approach based on footage collected by custom-made BRUV devices has potential to provide a cost-effective means for monitoring the fish fauna of the Geographe Bay artificial reefs.

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Appendix III. Characteristics of the fish faunas of artificial reefs in Geographe Bay determined from video footage collected by recreational fishers

Characteristics of the fish faunas of artificial reefs in Geographe Bay determined from video footage collected by recreational fishers

Submitted by

Timothy Hugh Elliot Walker

This thesis is presented for the Degree of Honours in Marine Science

2016

Murdoch University

School of Veterinary and Life Sciences

Declaration

I declare that this thesis is my own account of my research and contains as its main content work which has not been previously submitted for a degree at any tertiary education institution.

Timothy Hugh Elliot Walker
………………………………………………….

Timothy Hugh Elliot Walker

31st October 2016

Abstract

The number of artificial reef deployments around Australia has increased in recent years due to their popularity amongst recreational fishers. As these reefs modify the environment and its associated fauna, monitoring is required to ensure that any negative impacts to the surrounding area are assessed and minimised. Given this and the high cost of purpose-built artificial reefs, there is a need to develop cost-effective monitoring methods to determine their faunal composition. To address this need, this thesis reviewed methods for monitoring the faunas of artificial reefs and utilised the Baited Remote Underwater Video (BRUV) method to survey the fish faunas of two artificial reefs in Geographe Bay.

Fourteen fauna monitoring methods, in their application to artificial reefs, were critically evaluated against five criteria, *i.e.* deployment, accuracy, precision, time and cost. Not all methods were found to be applicable to the different types of artificial reefs, with the accuracy of each technique depending upon the scale at which monitoring occurs and the type of fauna being targeted. The fastest and cheapest techniques were those that either utilised only minimal equipment and/or did not require observers. Remotely operated underwater video, particularly BRUVs, were found to provide a relatively inexpensive and effective tool for monitoring fish communities of artificial reefs.

This finding supported the choice of the BRUV method, which was deployed through citizen science, to monitor the fish communities of the Bunbury and Dunsborough artificial reefs in Geographe Bay, south-western Australia, between October 2015 and July 2016. The resultant videos were analysed, using two-way ANOVA, to determine if the number of taxa, total MaxN, Simpson’s Index, as well as the MaxN of several key recreational species, differed between reefs and over time, whilst PERMANOVA was utilised to identify whether the composition of the fish communities differed spatially and temporally. Most of the 60 taxa recorded were resident teleosts, however, nine species of elasmobranch were also recorded. In terms of the number of individuals, most were either pelagic or epibenthic and fed on zooplankton or zoobenthos. Significant differences were found among reefs in all variables, except Simpson's Index, with greater values typically being recorded on the Dunsborough reef. Monthly differences were detected for the number of taxa, total MaxN and the abundance of two recreationally important species, with greater values occurring mainly during summer. The greatest differences in the above univariate variables and fish community composition were always found for the reef factor, indicating that the location of the reefs to nearby habitat was predominantly responsible for shaping their associated fish communities. The lower, but still influential, temporal differences were influenced by seasonal changes in water temperature and oceanographic currents.

The data collected during this study demonstrate that BRUVs, deployed through citizen science, can be a useful and cost-effective tool for monitoring the fish faunas of artificial reefs.

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Acknowledgements

First and foremost, my thanks must go to all the volunteers who collected videos as part of Reef Vision. Without their hard work, in what was often less than ideal conditions, this project would not have been possible.

I would also like to thank both of my supervisors Dr Jennifer Chaplin and Dr James Tweedley, who took time out of their busy schedules to help me throughout the year. Their considered feedback and ideas were indispensable in helping shape this thesis. My thanks must also go to the staff at Recfishwest, in particular James Florisson, who spent a significant amount of time helping me with fish identification, as well as providing general guidance and feedback.

Thanks to all the staff and students in the Centre for Fish and Fisheries Research for their help throughout the year and for making this year an enjoyable one. On a personal note, thanks to my family, friends and of course, my partner Laura.

Financial support for this project was provided by the Fisheries Research and Development Corporation of Australia and Recfishwest, whilst scholarships from Murdoch University provided personal financial support.

Chapter 1: General introduction

1.1. Thesis structure

This thesis has determined the characteristics of the fish fauna present on two purpose-built artificial reefs deployed in Geographe Bay, Western Australia, over a 10-month period between October 2015 and July 2016 inclusive. To enable a thorough assessment of the fish assemblage data recorded during the study, the advantages and limitations of a range of commonly used fauna monitoring methods, in their application to artificial reefs, were critically reviewed. The research component of this thesis utilised one of these monitoring methods, Baited Remote Underwater Video (BRUV), deployed using a citizen science program, to record video footage on the two artificial reefs in Geographe Bay. These data were then used to elucidate whether the characteristics of the fish fauna differed between the two reefs, as well as over time. This chapter provides an overview to the thesis, by outlining a brief background to artificial reefs, the faunas they support and the legislated need to monitor them, before describing the rationale and aims of the study.

1.2. Artificial reefs

Habitat Enhancement Structures (HESs), which constitute both artificial reefs and Fish Aggregation Devices (FADs), are defined as materials purposefully placed in aquatic environments, primarily to modify ecological processes (Seaman, 2008; Department of Fisheries, 2012). These structures have been utilised around the world for a number of purposes, such as to increase the localised yield of recreationally and commercially targeted marine organisms, to act as a deterrent for trawling activity, to prevent coastal erosion and to provide additional sites for surfing and recreational diving (Bohnsack and

Sutherland, 1985; Baine, 2001; Simon et al., 2011). Types of HESs are separated based upon their area of deployment, with FADs being used in pelagic zones, while artificial reefs are placed exclusively on the substrate of aquatic environments (Seaman et al., 2011). Therefore, artificial reefs can be defined as materials purposefully placed on the substrate of aquatic environments, designed to meet a number of goals (Seaman, 2008; Seaman et al., 2011; Department of Fisheries, 2012).

Artificial reefs can be separated into two main types; (i) reefs composed of materials of opportunity, such as stone, wood, tyres, offshore oil platforms and shipwrecks, and (ii) those that are purpose designed and built, typically constructed from reinforced concrete and steel (Pickering and Whitmarsh, 1997; Baine, 2001). This thesis will focus solely on purpose built artificial reefs, omitting those composed from materials of opportunity as they are not classified as 'true artificial reefs' in Western Australia, as outlined in '*Policy on Habitat Enhancement Structures in Western Australia*' (Department of Fisheries, 2012). Purpose-built reefs can be placed into three broad categories; those deployed in (i) shallow water, (ii) deep water, and (iii) those designed to mimic seagrass. Shallow water artificial reefs are generally constructed from concrete and are placed between depths of 10-30 metres (m), primarily to provide habitat for recreationally important fish species and for use in aquaculture (Bateman, 2015; Fisheries Research and Development Corporation, 2015; Department of Fisheries, 2016). Deep water artificial reefs, consisting of large steel modules, are deployed between depths of 30-150 m and are used to attract pelagic and deep demersal fish species (Bateman, 2015). Reefs which mimic seagrass can be composed of a variety of materials and are used to reduce shoreline erosion and provide additional habitat for fish and other marine organisms (Shahbudin et al., 2011). The research component of this thesis focuses on shallow water artificial reefs, while the literature review evaluates the application of fauna monitoring methods to all the broad categories of purpose-built artificial reefs.

1.3. Use of artificial reefs by fish

Despite the widespread deployment of artificial reefs, often with the stated purpose of providing habitat for recreationally important fish species, the ways in which fish utilise these habitats remain largely unknown. Considerable debate exists over whether artificial reefs increase fish abundance through attraction, or by the production of new individuals. The attraction hypothesis asserts that fish are drawn to artificial reefs due to behavioural preferences, but do not increase the carrying capacity or biomass of fish in the surrounding environment (Bohnsack, 1989; Brickhill et al., 2005). Alternatively, the production hypothesis postulates that artificial reefs are able to increase the carrying capacity of the environment and biomass of fish in the area. This is believed to be due to a greater number of juveniles surviving to adulthood, as a result of additional feeding and sheltering opportunities provided by increased structural habitat (Bohnsack, 1989; Grossman et al., 1997; Pickering and Whitmarsh, 1997; Pickering et al., 1999; Brickhill et al., 2005; Lowry et al., 2014).

Until relatively recently, the production hypothesis was generally accepted by the scientific community and served as the rationale for most artificial reef deployments (Grossman et al., 1997; Brickhill et al., 2005). However, the primary assumption of this hypothesis, *i.e.* that reef fish are limited by the abundance of hard substrates (Bohnsack, 1989), has recently been challenged (Brickhill et al., 2005). It has instead been suggested that reef fish are not always limited by hard substrata and that, in some circumstances, recruitment variability acts as the predominant limiting factor (Mapstone and

Fowler, 1988). Therefore, it cannot always be assumed that the placement of artificial reefs will increase the production of fish, rather they have the potential to contribute towards overfishing by concentrating the distribution of fish and increasing their catchability (Bohnsack, 1989; Grossman et al., 1997; Brickhill et al., 2005).

Bohnsack (1989) has posited that the opposing theories of attraction and production are likely not mutually exclusive, rather they occur along a continuum. The degree to which an artificial reef attracts or produces fish is dependent upon a number of factors, including the characteristics of the surrounding habitat and the artificial reef, as well as the biology and behavioural preferences of different species (Bohnsack and Sutherland, 1985; Brickhill et al., 2005). Therefore, fish utilisation of artificial reefs is unlikely to be static and can be expected to change over different time scales according to abiotic factors, as induced by diurnal and seasonal changes, and biotic factors, as predicted by the ecological succession theory (McCook, 1994).

1.4. Monitoring artificial reefs

With the lack of scientific consensus over how fish utilise artificial reefs, and their potential to exacerbate overfishing, there is a need to monitor the biology of artificial reefs over the lifetime of their deployment. Yoccoz et al. (2001) defines monitoring as *“the process of gathering information about some system at different points in time for the purpose of assessing system state and drawing inferences about changes in state over time”*. Thus, monitoring can occur at the ecosystem, habitat, population or community level to measure a number of different variables including, but not limited to, species richness, diversity, abundance and biomass. The level at which monitoring occurs and the variables measured are determined by the specific objectives of the monitoring program (Katsanevakis et al., 2012), which are primarily conducted for scientific or environmental management purposes. The requirement for environmental and biological monitoring to inform management, is often codified into legislation at the National and State level. This is commonly required for projects that have the potential to negatively impact upon the environment, including the deployment of artificial reefs.

The *London Convention and Protocol on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter*, to which Australia is a signatory (International;International Maritime Organization, 2016), and the *Environment Protection (Sea Dumping) Act 1981* (Commonwealth; Department of the Environment, 2016a), have outlined the need for monitoring artificial reefs, in regards to their appropriate site and material selection. The requirement for biological and environmental monitoring of artificial reefs in Western Australia is covered under the *Fish Resources Management Act 1994* (Western Australia) and the *Environmental Protection and Biodiversity Act 1999* (Commonwealth; Department of Fisheries, 2012; Department of the Environment, 2016b). Therefore, depending upon the specifics of the project, there may be a legislated need to conduct biological monitoring of artificial reef deployments.

1.5. Rationale

The past ten years has seen a surge in the deployment of purpose built artificial reefs around Australia (Diplock, 2010; Bateman, 2015). These structures have typically been deployed for the purpose of enhancing recreational fishing, with reefs being located close to major cities and generally within popular fishing regions (Bateman, 2015). A recent deployment, known as the South West Artificial Reefs Trial, which began in 2013, conducted by the Department of Fisheries (Western Australia) and Recfishwest, involved the placement of artificial reef modules off Bunbury and Dunsborough in Geographe Bay, Western Australia (Government of Western Australia, 2013). As part of this trial, the Department of Fisheries (Western Australia) has undertaken an extensive monitoring program to ascertain the effect the reefs have had upon the surrounding biotic environment. With further artificial reef deployments scheduled, and already underway, around the state, *e.g.* off Mandurah, there is a need for the development of cost-effective methods to monitor their fauna (Florisson 2016, pers. comm., 5 May; Department of Fisheries, 2016; Recfishwest, 2016). This need was identified by Recfishwest and is currently being investigated, through funding provided by the Fisheries Research and Development Corporation Australia (FRDC-project number 2014/005), via a number of postgraduate research projects at Murdoch University. In part to meet funding requirements from the FRDC, a literature review critically evaluating the faunal monitoring methods available for artificial reefs was completed, which in turn helped to inform the evaluation of the BRUV method utilised in the research project.

As part of this research, Recfishwest has highlighted the potential of using citizen science to monitor the fauna of artificial reefs, as the technique, which uses volunteers, allows studies to overcome the expense and logistical difficulties associated with traditional marine monitoring (Cigliano et al., 2015; Hyder et al., 2015; Edgar et al., 2016). As a result of this, Florisson (2015) trialled the use of recreational fishers, as citizen scientists, to collect video footage on the fish fauna of the Bunbury and Dunsborough artificial reefs using live-action cameras. While Florisson (2015) was unsuccessful in collecting large quantities of data, the potential of using citizen science as part of a monitoring program was recognised, with the author making a suite of recommendations to develop the program. Following this research, Bateman

(2015) investigated the use of BRUVs as a means of monitoring the fish faunas of the artificial reefs of Geographe Bay, finding it to be both effective and low cost. However, this survey was only conducted over a small time frame resulting in limited data. As a result of these preliminary studies, this thesis has adopted the use of BRUVs, deployed through citizen science, to conduct a monitoring program of the fish communities of the artificial reefs of Geographe Bay, otherwise known as Reef Vision, over a significant time scale.

1.6. Aims

Given the need to develop cost-effective methods for monitoring the faunas of artificial reefs, the overall aim of this thesis was to build upon the previous work by Florisson (2015) and Bateman (2015) to determine the characteristics of the fish fauna present on the Bunbury and Dunsborough artificial reefs, using BRUVs deployed by recreational fishers. Specifically, the thesis has two main aims:

1. Conduct a critical analysis of the methods for monitoring the faunas of artificial reefs through a literature review (Chapter 2).

2. Determine the characteristics of the fish fauna present on two artificial reefs deployed in Geographe Bay, Western Australia, over a 10-month period between October 2015 and July 2016 inclusive (Chapter 3).

This thesis will provide; (i) a greater understanding of how fish utilise the artificial reefs of Geographe Bay, including determining whether the characteristics, and composition, of the fish fauna change throughout the year, and (ii) an evaluation of the utility of the monitoring program, which utilised

BRUV deployed through citizen science, indicating whether this method could be employed on future artificial reef deployments.

Chapter 2: A critical analysis of the methods for monitoring the faunas of artificial reefs

2.1. Abstract

With the increasing number of artificial reef deployments in Australia in recent years, it is essential that appropriate monitoring regimes are in place to assess their impact upon surrounding biota. An integral component of any monitoring regime is the selection of an appropriate sampling method. In this review, I evaluated 14 methods for monitoring the faunas of artificial reefs against five criteria *ie.* deployment, accuracy, precision, time and cost. This review found that not all methods can be applied effectively to all types of artificial reefs and that the accuracy of the method depends upon the scale at which it operates, as well as the type of fauna being targeted for monitoring. Furthermore, underwater visual techniques, which employ minimal equipment, and methods that do not require the deployment of observers, are the fastest and cheapest methods to utilise. Therefore, as each technique has different advantages and limitations, monitoring methods should be evaluated and utilised according to the key questions and logistical circumstances of each study, rather than applying a one size fits all approach.

2.2. Introduction

Habitat Enhancement Structures (HES) are structures or materials placed in aquatic environments for the purpose of modifying ecological processes. The most common form of HES are artificial reefs, which are defined, in the Western Australian context, as purpose-built structures deployed exclusively on the substrate of aquatic environments (Seaman, 2008; Department of Fisheries, 2012). Under this definition artificial reefs can be placed into three broad categories; shallow-water, deep-water and artificial seagrass meadows

(Table 2.1; Bateman, 2015), with each type being deployed in different scenarios. Artificial reefs are used to meet a range of goals including to assist in environmental conservation and to provide social utility, however, they are used primarily to enhance fisheries (Bohnsack and Sutherland, 1985; Baine, 2001). This is achieved by increasing the localised abundance of fish via their attraction and concentration, or by improving their production through the provision of additional habitat, thereby inflating the carrying capacity of the natural environment (Bohnsack and Sutherland, 1985; Bohnsack, 1989; Seaman et al., 2011).

Table 2.1. Photographs of an example from each of the three broad categories of artificial reefs. Adapted from Bateman (2015).

Shallow-water artificial reefs		Source
		(left) Fish Box module. Fig. 2 in Haejoo (2016), (right) Reef Ball. Fig. 1 in Reef Ball Foundation (2016)
Deep-water artificial reef	**Artificial seagrass meadow**	
		(left) Wild Banks artificial reef. Fig. 1 in Department of National Parks Sport and Racing (2016), (right) Artificial seagrass trial. Fig. 1 in NIWA (2007)

The deployment of artificial reefs is covered under a variety of legislation at the International, Commonwealth and State levels. Under International law they are covered by the *London Convention and Protocol on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter* (International Maritime Organization, 2016), to which Australia is a signatory. This agreement has been ratified into Australian Commonwealth legislation under the *Environment Protection (Sea Dumping) Act 1981*, which ensures appropriate site and material selection to minimise adverse impacts upon the environment and public (Department of the Environment, 2016a). Additional requirements may need to be met if the project has the potential to impact upon matters of national environmental significance, as defined under the Commonwealth legislation of the *Environmental Protection and Biodiversity Conservation Act 1999* (Department of the Environment, 2016b). In the state of Western Australia, the *Fish Resource Management Act 1994*, requires artificial reefs to be approved by the Department of Fisheries before deployment can occur, potentially requiring them to be monitored to ensure any negative impact upon the environment are assessed and minimised (Department of Fisheries, 2012). Therefore, a range of legislation requires that artificial reef deployments be monitored for a variety of reasons, including the need to assess their impact upon surrounding biota.

A plethora of different techniques are available for monitoring the faunas of natural and artificial reefs, however, there is no one ‘perfect’ method, as each one possesses its own inherent strengths, weaknesses and biases (English et al., 1997; Kingsford and Battershill, 2000; Hill and Wilkinson, 2004). Monitoring has been defined as *“the process of gathering information about some system at different points in time for the purpose of assessing system state and drawing inferences about changes in state over time”* (Yoccoz et al., 2001). As a result, each monitoring program must have specific objectives, informed by questions and/or hypotheses, which shape its design (Green, 1979; Bakus, 2007; Katsanevakis et al., 2012). It is these considerations that drive the level of investigation, from the ecosystem level to species specific studies, through the measurement of a range of variables, such as presence/absence, diversity, abundance and/or biomass (Katsanevakis et al., 2012). After the objectives of the study are defined, along with which variables will be measured, an appropriate monitoring technique or techniques must be chosen. Considerations towards sampling frequency and the type of statistical analysis to be used must be made at this stage, which will impact upon the monitoring method chosen. However, the logistical realities of each method, as well as the projects budget and time frame, must be considered. Thus, to ensure sound data are collected, care must be taken in selecting an appropriate method based upon the type of artificial reef being monitored, the purpose of the monitoring regime and the logistics of the study.

With the recent increase in deployment of artificial reefs in Australia, as well as the legislated requirements to monitor their impact on the surrounding environment, there is a need to critically analyse the suite of methods available for monitoring the fauna of these structures. As such, this review has critically analysed 14 monitoring methods, however, this does not represent an exhaustive list; rather these techniques are the ones most likely to be applicable for use with artificial reefs. The majority of these methods have been selected based on their use in coral reef and temperate rocky reef studies, as artificial and natural reefs share a number of biotic and abiotic attributes, *e.g.* habitat heterogeneity. Therefore, the advantages and limitations of these methods will likely be common between both habitats and allows for their inclusion in this review (Seaman, 2000). Methods drawn from other fields of research, such as fisheries assessments and emerging fields (*e.g.* environmental DNA analysis) have also been included due to their applicability across a wide range of habitats.

A total of 14 sampling methods (Table 2.2) were evaluated against five criteria, including:

- **Deployment:** Considerations for the ease of deployment and use of the method. This includes taking into consideration logistical issues such as transporting associated equipment, as well as the technical expertise and environmental conditions required to undertake the method.
- **Accuracy:** How close the method's estimates are likely to the 'true' population value, for both species richness and abundance. 'True' population values are extremely difficult to quantify, however, the assumption will be made that methods which provide higher estimates are more accurate. This assumption has been made as the majority of these methods employ visual observations, which are noted to under sample populations (Samoilys and Carlos, 2000). Thus, higher observations are likely to produce a value closer to the 'true' population value.
- **Precision:** The level of variation, between samples, of the population estimates. Lower variation is desired as this allows for the easier detection of change (Andrew and Mapstone, 1987; Samoilys and Carlos, 2000).
- **Time:** The overall time required to undertake monitoring, and analyse the results.
- **Cost:** The overall cost of method-specific equipment and the expense of undertaking monitoring and laboratory based analysis. The expense of undertaking monitoring and analysis is closely linked to time, as the longer the duration, the greater the cost, though laboratory work time is generally less expensive than field work time.

Considerations were also given to the effectiveness of each method for use with monitoring the three broad categories of artificial reefs (deep-water, shallow-water and artificial seagrass), their ability to undertake monitoring over a small (fine scale), moderate (medium scale) and wide areas (broad scale), as well as the methods ability to provide quantitative data.

Each method was given a subjective score out of 100, for each criterion, based upon the individualised summary tables. Scores of 0-20 will be designated as ‘very ineffective’, 20-40 as ‘ineffective’, 40-60 as ‘moderately effective’, 60-80 as ‘effective’ and 80-100 as ‘very effective’. This information will then be summarised in a ‘heat map’, providing a graphical representation of the qualitative data from each method in a matrix through the shading of tiles according to a colour scale (Wilkinson and Friendly, 2009). This scale ranged from red (very ineffective) to dark green (very effective) (Fig. 2.8). From the ‘heat map’ conclusions can be drawn as to the effectiveness of each method against the criteria, allowing for the observation of general trends.

Table 2.2. A summary of the fauna monitoring methods evaluated in this review.

Categories of fauna and their monitoring methods	Variations
Sessile/sedentary fauna	
Settlement tiles	Direct attachment Raised racks
Visual quadrats	Transect Random
Photo quadrats	Transect Random Photo point monitoring
Mobile fauna	
Stationary visual census	Nested sampling
Rapid visual technique	
DIDSON acoustic survey	
Sessile/sedentary and mobile fauna	
Visual transects	Point intercept Line intercept
Video transects	
Manta tow	
Towed video	Seabed tow Mid-water tow Towed diver video
Remotely operated underwater video	Linked Autonomous
Environmental DNA analysis	
Extractive methods	Fish trap Trawls Ichthyocide Hook and line
Fisher surveys	Onsite surveys Offsite surveys

2.2. Monitoring methods for sessile/sedentary fauna

2.2.1. Settlement tiles

Settlement tiles (or plates) are a monitoring method utilised in studying sessile benthic organisms, such as algae and invertebrates, and provide quantitative data on a fine spatial scale (Hill and Wilkinson, 2004; Muth, 2012; Janßen et al., 2013; Schloder et al., 2013; Guy-Haim et al., 2015). The method involves deploying a series of tiles, which can be attached directly to hard substratum and/or placed on raised racks (Fig 2.1; Mundy, 2000; Hill and Wilkinson, 2004). The tiles are later collected and analysed to determine the abundance and diversity of newly settled organisms (Muth, 2012; Ferse et al., 2013; Janßen et al., 2013; Guy-Haim et al., 2015). This method, in particular, has been used extensively in coral reef research (Field et al., 2007). In brief, as shown in Table 2.3 and Fig. 2.8, the settlement tile method was highlighted as providing relatively accurate species richness and abundance estimates, with a high level of precision, and could be utilised for monitoring sessile benthic organisms that settle directly onto the surface of artificial reefs. However, the deployment of the method can be difficult, time consuming and expensive.

Table 2.3. The advantages and limitations of the settlement tile method for monitoring sessile/sedentary fauna on artificial reefs.

Advantages	Limitations
Deployment	
• Settlement tiles can be deployed in a variety of locations, depending on the attachment method, allowing for site-specific studies (Field et al., 2007).	• The depth of tile deployment is limited by diver occupational health and safety. • The method is invasive as biotic samples are taken. • The equipment required for the deployment of tiles is cumbersome, regardless of the attachment method (Hill and Wilkinson, 2004). • Settlement plate material can bias settlement (Field et al., 2007). • The laboratory-based analysis requires considerable expertise to conduct species level identifications (English et al., 1997; Field et al., 2007).
Accuracy	
• The accuracy of the method has not been compared against other similar benthic monitoring methods. However, because the tiles are analysed in a laboratory it is assumed that it will allow for the accurate enumeration of organisms present (Kingsford and Battershill, 2000).	• Identifying settled taxa to species level can be difficult and require taxonomic expertise (Hill and Wilkinson, 2004). • Racks can alter the hydrodynamics of the water column and thus bias the settlement of organisms onto the tiles (Field et al., 2007).
Precision	
• The method has a high level of precision (Hill and Wilkinson, 2004).	
Time	
• Tiles, if mounted in racks, can be deployed quickly in the field (Field et al., 2007).	• Laboratory-based identification is time consuming (Hill and Wilkinson, 2004).
Cost	
	• The method is cited as being expensive, due to the high level of expertise and time required to identify the species present on the tiles (Hill and Wilkinson, 2004).

Fig. 2.1. Settlement tiles placed on raised racks (from Fig. 9 in Bremen (2014)).

2.2.2. Visual quadrats

The quadrat method was originally developed in the terrestrial plant ecology field (Beenaerts and Berghe, 2005), but has since been employed in aquatic environments. Deployment involves placing the quadrat(s) along transect lines or at random (Dodge et al., 1982; Miller and Ambrose, 2000), within a study area. The resultant quantitative data are usually based on estimates of the abundance or percentage cover of various organisms within the quadrat and provide information at fine spatial scales (Fig 2.2; Hill and Wilkinson, 2004; Beenaerts and Berghe, 2005). These estimates are primarily made by either direct visual observation (Lessios, 1996) or through point count methods (Fig. 2.2; Foster et al., 1991). The method is typically used for monitoring sessile and sedentary benthic communities and individual organisms (*i.e.* Taylor, 1998; Duarte and Kirkman, 2001; Pehlke and Bartsch, 2008; Parravicini et al., 2010; Mantelatto et al., 2013; Schonberg, 2015). Visual quadrats were shown to be a relatively easy method to undertake, which in conjunction with its accuracy in estimating species diversity and abundance, could be utilised to monitor sessile/sedentary organisms that live on, and immediately around the reef (Table 2.4, Fig. 2.8). Additionally, considerations must be made as to the time and financial investment required to undertake the method, as they can be considerable.

Table 2.4. The advantages and limitations of the visual quadrat method for monitoring sessile/sedentary fauna on artificial reefs.

Advantages	***Limitations***
Deployment	
• As observation takes place close to benthos, the method is not reliant on highly transparent water (Mantelatto et al., 2013). • Biological samples (specimens) can be taken *in situ* for further analysis and/or identification (Provost et al., 2013).	• Diver observers are limited in the duration and depth of their fieldwork by occupational health and safety. • Highly trained observers are required to collect the data (Mantelatto et al., 2013).
Accuracy	
• Visual quadrats typically capture cryptic species that may be missed in other methods (Obermeyer, 1998; Parravicini et al., 2010; Jokiel et al., 2015). • A number of studies have found visual quadrats to provide higher cover estimates for coral and benthic communities than photo quadrats, visual transects and video transects (Weinberg, 1981; Foster et al., 1991; Leujak and Ormond, 2007; Mantelatto et al., 2013). Though Jokiel et al. (2015) found the method to provide lower cover estimates for coral than both visual and video transects.	• Only organisms in the quadrat are sampled (*e.g.* 50 cm x 50 cm), so the method captures only a small area. • The method is likely to underestimate the abundance of species that occur in low densities due to the small area sampled (McClanahan and Muthiga, 1992; Leonard and Clark, 1993; Parravicini et al., 2010).
Precision	
	• Visual quadrats are regarded as having a moderate to high level of precision (Foster et al., 1991; Hill and Wilkinson, 2004; Jokiel et al., 2015).

	Advantages		Limitations
	Time		
•	The method requires little, if any, laboratory time and has been described in multiple studies as being overall relatively time efficient (Foster et al., 1991; Leonard and Clark, 1993; Mantelatto et al., 2013; Jokiel et al., 2015).	•	As all data is collected *in-situ,* fieldwork can be time intensive (Jokiel et al., 2015).
	Cost		
•	Quadrats are relatively inexpensive to produce (Leujak and Ormond, 2007; Jokiel et al., 2015).	•	The level of fieldwork required can make the method costly to carry out, particularly so if SCUBA is involved (Mantelatto et al., 2013).

Fig. 2.2. Observers conducting a visual quadrat (from Fig. 1 in Reef Watch Waikiki (2010))

2.2.3. Photo quadrats

The photo quadrat method is a modification of the visual quadrat method where data is recorded from photographs, taken using a camera mounted on a frame, rather than by *in situ* visual census (Fig. 2.3; Mantelatto et al., 2013). It provides fine spatial scale quantitative data, similar to the visual quadrat method, by providing abundance and percentage cover estimates of benthic organisms (Carney et al.; Roberts and Davis, 1996; Hill and Wilkinson, 2004;

Kutser et al., 2007; Gilby et al., 2015). A variation of the photo quadrat method is photo point monitoring, where quadrats are permanently fixed to the substrate to allow for the monitoring of change over time at a fixed location (Lanyon and Marsh, 1995; Lessios, 1996; Bak et al., 2005). The photo quadrat method provides relatively accurate abundance estimates, whilst delivering effective precision between samples (Table 2.5, Fig. 2.8). The method can be deployed relatively easily and could be utilised for surveying sessile/sedentary organisms that live on, and immediately around, artificial reefs. Though its ability to detect accurate species richness estimates may be limited, and prove to be a costly and relatively time intensive undertaking.

Table 2.5. The advantages and limitations of the photo quadrat method for monitoring sessile/sedentary fauna on artificial reefs.

Advantages	***Limitations***
Deployment	
• Fieldwork can be conducted by researchers without taxonomic expertise (Mantelatto et al., 2013). • The resultant photograph is a permanent record of the data that can be reanalysed later if required (Mantelatto et al., 2013).	• The extent of fieldwork conducted by divers is limited by occupational health and safety. • The method requires a high level of water clarity, more so than visual quadrats (Mantelatto et al., 2013).
Accuracy	
	• Only samples a small area. • Obscuring can occur, leading to missed or unidentified organisms (Weinberg, 1981). • Multiple coral studies have found the method to record lower species richness than visual quadrats (Leujak and Ormond, 2007; Mantelatto et al., 2013; Jokiel et al., 2015), though Weinberg (1981) found it to capture higher estimates than visual quadrats. • Benthic community studies have found the method to record lower cover estimates than visual quadrats (Weinberg, 1981; Foster et al., 1991).

Advantages	Limitations
Precision	
• The method has been noted to provide a moderate to high level of precision for the monitoring of coral communities (Foster et al., 1991; Jokiel et al., 2015).	
Time and Cost	
• Photo quadrats require less time in the field than visual quadrats, which reduces costs (Mantelatto et al., 2013; Jokiel et al., 2015).	• Analysis of the species in the photographs can take considerable amounts of time (Mantelatto et al., 2013; Jokiel et al., 2015). • Photographic equipment (including underwater lights) can be expensive (Mantelatto et al., 2013; Jokiel et al., 2015).

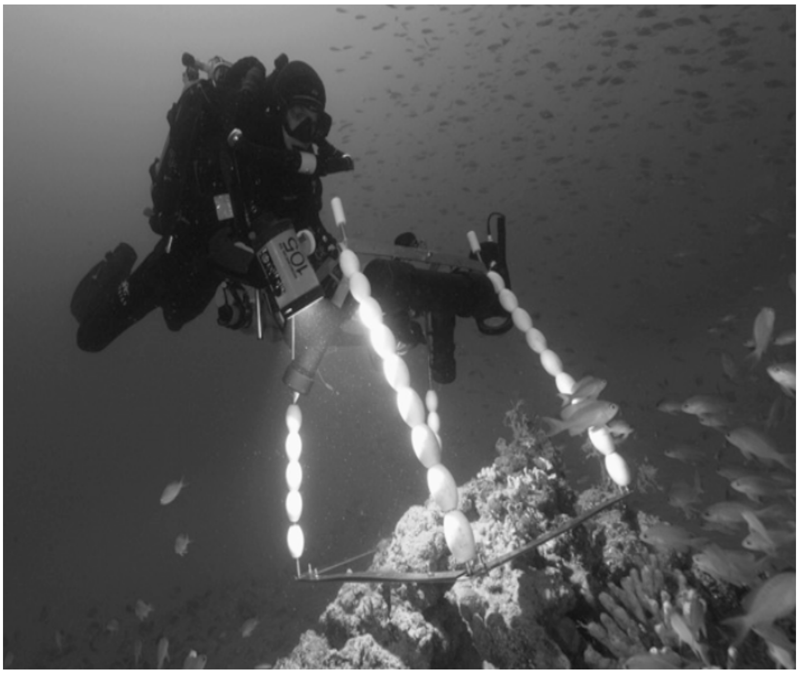


Fig. 2.3. A diver undertaking a photographic quadrat (from Fig. 3 from Deter et al. (2012)).

2.3. Monitoring methods for mobile fauna

2.3.1. Stationary visual census

The stationary visual census monitoring method was developed for studying reef associated fish (Bohnsack and Bannerot, 1986). The method involves a

SCUBA diver floating above a randomly selected point observing fish within an imaginary predefined cylinder (*i.e.* census area) around them (Cappo and Brown, 1996; Ayotte et al., 2015). This is typically done over a ten-minute period, which provides quantitative data on a medium to fine spatial scale (Bohnsack and Bannerot, 1986; Cappo and Brown, 1996; Hill and Wilkinson, 2004; Ayotte et al., 2015). The stationary visual census method is a technique which can be easily undertaken, in a short period of time, for low cost, though the accuracy of its species richness and abundance estimates may be limited (Fig. 2.8, Table 2.6). The method could be utilised for the monitoring of fish and/or mobile pelagic/demersal invertebrates (*i.e* cephalopods) utilising artificial reefs.

Table 2.6. The advantages and limitations of the stationary visual census method for monitoring mobile fauna on artificial reefs.

Advantages	***Limitations***
Deployment	
• Data collection is simple and requires minimal equipment (Hill and Wilkinson, 2004).	• The number of sampling events by divers is limited by occupational health and safety. • Field observers require considerable taxonomic skills.
Accuracy	
• The method avoids biases present in other underwater visual census techniques that utilise moving observers (*i.e* differences in swimming speeds) (Bohnsack and Bannerot, 1986) and induced behavioural responses of fish due to observer movement (Bohnsack and Bannerot, 1986; Colvocoresses and Acosta, 2007).	• The method only samples a small area (Colvocoresses and Acosta, 2007). • Subjectivity of the census area makes absolute densities unreliable (Hill and Wilkinson, 2004). • The method is likely to underestimate cryptic and demersal species (Riberio et al., 2004; Minte-Vera et al., 2008; Green et al., 2013). • Riberio et al. (2004) noted the method to have recorded significantly less species of reef fish than both visual transect and the rapid visual technique.

Advantages	Limitations
• Lowry et al. (2012) found the method to have recorded a higher species richness of estuarine fish than BRUV. However, it should be noted that the authors used a modified version of the method allowing the observer to move at the end of the initial period to note species not previously encountered.	• Both Colvocoresses and Acosta (2007) and Samoilys and Carlos (2000) found this method recorded lower abundances of reef fish compared to visual transects. • Interestingly, Minte-Vera et al. (2008) found that a smaller census area allowed for more accurate estimates of the abundances of small reef fish, and that increasing the census area allowed for more accurate estimates of large reef fish. This method, known as nested sampling, should be utilised to allow for the more accurate abundance estimations of both small and large fish.
Precision • The method has a moderate to high level of precision (Bohnsack and Bannerot, 1986; Hill and Wilkinson, 2004). *Time* • Samoilys and Carlos (2000) found the method to be faster, in terms of fieldwork, than visual transects. *Cost* • Stationary visual census surveys were found by Minte-Vera et al. (2008) to be cheaper than underwater visual transects.	

2.3.2. Rapid visual technique

The rapid visual technique has been used extensively for monitoring reef-associated fish (Sanderson and Solonsky, 1986; Kellison et al., 2012; Rizzari et al., 2014), providing medium to fine spatial scale qualitative data (Hill and Wilkinson, 2004). Data is collected by observers who swim randomly around a reef, at a constant depth and speed, for a set period of time searching for fish

(Hill and Wilkinson, 2004). Species are ranked according to when they are first observed, which allows for relative abundances to be calculated based upon the assumption that species encountered earlier are likely to be the most abundant (Jones and Thompson, 1978; Sanderson and Solonsky, 1986). The rapid visual technique, like the stationary visual census method, is a quick and cost-effective method, which can be carried out easily (Table 2.7, Fig. 2.8). Again, its species richness and abundance estimates must be treated with caution. It could be used to potentially monitor the abundance of fish and/or pelagic/demersal invertebrates (*i.e* cephalopods) utilising artificial reefs.

Table 2.7. The advantages and limitations of the rapid visual technique for monitoring mobile fauna on artificial reefs.

Advantages	***Limitations***
Deployment	
• The method can be used when conditions and/or habitats prevent the use of transects (Sanderson and Solonsky, 1986). • Minimal equipment is required for fieldwork (Hill and Wilkinson, 2004).	• Observers are limited in their dive range and time by occupational health and safety. • The use of field observers with considerable taxonomic skills is required.
Accuracy	
• The rapid visual technique has been shown to capture higher species richness and abundance than visual transects for reef fish (Kimmel, 1985) and greater abundance than remotely operated underwater video for reef sharks (Rizzari et al., 2014).	• The presence of a human observer may alter the behaviour of fish (Hill and Wilkinson, 2004). • The rapid visual technique is based on the assumption that species encountered earlier on in the sampling period are likely to be the most abundant (Jones and Thompson, 1978), which fails to account for differences in the spatial distribution of species (DeMartini and Roberts, 1982). This can lead to the overestimation of the abundance of widespread rare species and an underestimation of those with patchy but abundant distributions (DeMartini and Roberts, 1982).

Advantages	Limitations
	• This method is less able to detect cryptic species (Jones and Thompson, 1978). • The data generated is relative and does not provide quantitative abundances (densities) due to an unknown area being sampled (Kingsford and Battershill, 2000; Riberio et al., 2004; Taillon and Fox, 2004).
Precision • The method has a moderate level of precision (Sanderson and Solonsky, 1986; Hill and Wilkinson, 2004). *Time and Cost* • Data is collected relatively quickly and has low costs (Hill and Wilkinson, 2004), with Sanderson and Solonsky (1986) determining that this method is a useful substitute when time in the field and/or budget is limited.	

2.3.3. DIDSON acoustic survey

DIDSON (Dual frequency IDentification SONar) is an acoustic sounder that uses sonar to create video-like images (Fig. 2.4; Belcher et al., 2001; Moursund et al., 2003; Baumgartner et al., 2006; Martignac et al., 2015). The technology was originally developed for the United States Navy to detect underwater intruders in harbours (Belcher et al., 2001; Moursund et al., 2003) and has since been co-opted for ecological studies. The technology can be utilised to identify and quantify mobile fauna on a medium to large spatial scale (Kingsford and Battershill, 2000). It has been used extensively in monitoring fish migration, particularly at night (Galbreath and Barber, 2005; Baumgartner et al., 2006; Holmes et al., 2006; Pavlov et al., 2009), and fish assemblages in turbid and/or complex environments where visual or camera surveys would not provide reliable data (Frias-Torres and Luo, 2008; Becker et al., 2011; Crossman et al., 2011; Able et al., 2014). The DIDSON acoustic survey technique provides a quick and easy method to deploy. However, its usefulness may be limited by its expense, and issues inherent to the technology, which limit its species richness accuracy (Table 2.8, Fig. 2.4). In the right circumstances it could be utilised to record the abundance of fish and/or mobile pelagic/demersal invertebrates (*i.e.* cephalopods) utilising artificial reefs.

Table 2.8. The advantages and limitations of the DIDSON acoustic survey method for monitoring mobile fauna on artificial reefs.

Advantages	***Limitations***
Deployment	
• The method is non-invasive (Martignac et al., 2015). • The DIDSON unit is compact, lightweight and uses little power, allowing for easy deployment (Belcher et al., 2001; Moursund et al., 2003; Able et al., 2014). • The equipment can be employed in environments where it is too dark or turbid for other direct observation methods, or where extractive means are not practical (Belcher et al., 2001; Moursund et al., 2003; Baumgartner et al., 2006; Able et al., 2014).	• The deployment of the technology is currently limited to shallow depths (Galbreath and Barber, 2005), due to its relatively low detection range, 42 m (Belcher et al., 2001; Han and Uye, 2009).
Accuracy	
• Frias-Torres and Luo (2008) showed that DIDSON recorded a higher number of juvenile Goliath Grouper than remotely operated underwater video in a complex mangrove environment.	• The technology provides relatively low-resolution images. This can make it difficult to differentiate between species (Able et al., 2014), unless obvious morphological characteristics are present (Langkau et al., 2012), however, higher resolution models are in development.

Advantages	Limitations
	• The surrounding environment and the number of organisms present can impact the output image (Cronkite et al., 2006; Martignac et al., 2015). This likely contributes to its under sampling of small and benthic species which has been noted by Able et al. (2014) in estuarine habitats. • DIDSON was shown by Baumgartner et al. (2006) to mostly detect a lower abundance and species richness of migrating estuarine fish, than both standard cage trap and open-topped pop-nets.
Precision • The method has been noted as providing a high level of precision in species specific studies, but this is likely to be density dependent (Holmes et al., 2006).	• Precision is likely to be limited for studies covering multiple species, or in habitats with high diversity, as differences between observers could bias results.
Time • The technology provides real-time monitoring (Moursund et al., 2003). • The method can be used to sample large areas quickly (Kingsford and Battershill, 2000).	
Cost • The method has been cited by Martignac et al. (2015) as being of moderate cost, allowing for cost-effective monitoring.	

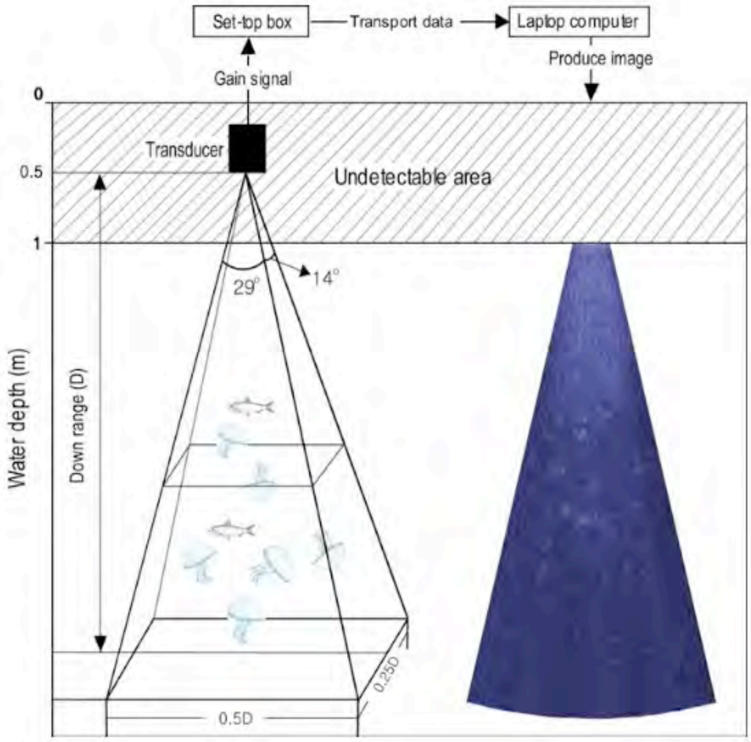


Fig. 2.4. A schematic representation of the sonar view (left), and a sonar image output from DIDSON (right) (from Fig. 2 in Han and Uye (2009)).

2.4. Monitoring methods for sessile/sedentary and mobile fauna

2.4.1. Visual transects

Visual transects are one of the most commonly used methods for monitoring reef fish (Sale and Douglas, 1981; Halford and Thompson, 1994; Samoilys and Carlos, 2000), and are also used extensively for assessing benthic communities (Lessios, 1996; Beenaerts and Berghe, 2005), providing quantitative data at a medium spatial scale (Sanderson and Solonsky, 1986; Beenaerts and Berghe, 2005). The method involves laying tape/rope down over a designated habitat, for a specified length with multiple replicates, which is then swum by an observer (Hill and Wilkinson, 2004). Variations of the method include the point intercept method, where organisms are only noted at specific points along the transect line, and the line intercept method, where organisms are only noted when they cross the transect line (Hill and Wilkinson, 2004). Enumeration of mobile organisms occurs via direct counting, while sessile organisms are usually estimated by percentage cover (Samoilys and Carlos, 2000; Beenaerts and Berghe, 2005). Visual transects provide a relatively easy method to deploy, however, the time required can be considerable (Table 2.9, Fig. 2.8). Additionally, the accuracy of the method can only be considered moderate. This method would be best suited for recording the abundance of fish and/or mobile pelagic/demersal invertebrates (*i.e.* cephalopods) utilising the artificial reef, and benthic organism on the reefs and in the surrounding area.

Table 2.9. The advantages and limitations of the visual transect method for monitoring the fauna on artificial reefs.

Advantages	***Limitations***
Deployment	
• Visual transects require only minimal equipment (Hill and Wilkinson, 2004).	• The deployment of transects and their use is limited by diver occupational health and safety. • The ability to lay the transect is limited by the structure of the habitat. • A taxonomic expert is required to conduct the fieldwork.
Accuracy	
• Samoilys and Carlos (2000) and Colvocoresses and Acosta (2007) found visual transects to record greater reef fish abundance estimates than the stationary visual census method.	• Both Leujak and Ormond (2007) and Jokiel et al. (2015) found visual transects to record lower species richness estimates for corals than visual and photo quadrats, as well as video transects. • Both Weinberg (1981) and Leujak and Ormond (2007) found the method to capture a lower coral cover estimate than visual and photo quadrats. However, Jokiel et al. (2015) found visual transects to record higher coral cover than both of the methods.

Advantages	*Limitations*
	• For reef associated fish Riberio et al. (2004) found visual transects to record a higher species richness than the stationary visual census method, but a lower level than the rapid visual technique. • Biases in the method can be introduced by variations in swimming speed and distance from the substratum between observers (Cheal and Thompson, 1997). • Some authors also consider the presence of an observer to potentially alter fish behaviour (Hill and Wilkinson, 2004). • Willis (2001) noted that visual transects underestimate the presence and abundance of cryptic fish species.
Precision	
• The method has a moderate to high level of precision (Sale and Douglas, 1981; Sanderson and Solonsky, 1986; Hill and Wilkinson, 2004).	
Time	
	• The time required to complete a sample, compared to other methods, varies between studies (Leonard and Clark, 1993; Leujak and Ormond, 2007; Jokiel et al., 2015). However, in general Abdo et al. (2004) considered it to be a relatively time consuming method.
Cost	
• As minimal equipment is needed to conduct visual transects the costs are limited (Leujak and Ormond, 2007; Jokiel et al., 2015).	

2.4.2. Video transects

The video transect method is a modification of the visual transect method, where a video camera is used to record the transect and analysed at a later date (Pelletier et al., 2011). Video transects are used for monitoring similar organisms as visual transects and provide quantitative data on a medium spatial scale (Abdo et al., 2004; Hill and Wilkinson, 2004; Pelletier et al., 2011). Like visual transects, video transects can prove to be a relatively easy method to deploy, however, both the time required and cost of the method can be considerable (Table 2.10, Fig. 2.8). Again, the accuracy of the method can only be considered moderate. This method would be best suited for recording the abundance of fish and/or mobile pelagic/demersal invertebrates (*i.e.* cephalopods) utilising the artificial reef, and benthic organism on the reefs and in the surrounding area.

Table 2.10. The advantages and limitations of the video transect method for monitoring the fauna on artificial reefs.

Advantages	***Limitations***
Deployment	
• As videos are analysed at a later time, taxonomic experts are not required to collect the footage (Pelletier et al., 2011). • The videos provide a permanent record of observations and can be reanalysed at a later date if required (Abdo et al., 2004).	• Divers are limited in their depth and duration of deployment by occupational health and safety.
Accuracy	
• Jokiel et al. (2015) and Leujak and Ormond (2007) found video transects to provide higher coral species richness estimates than visual transects.	• The accuracy of video transects for coral cover is variable with Leujak and Ormond (2007) finding the method to record a higher estimate than visual transects while Jokiel et al. (2015) found the opposite result.

Advantages	Limitations
	• Species identification can be more difficult on video compared to *in situ* observations. This is reflected in studies by Pelletier et al. (2011) and Holmes et al. (2013) who found that video transects recorded lower fish species richness than visual transects. • Langlois et al. (2010) and Watson et al. (2010) found that visual transects recorded a lower species richness of reef fish compared to remotely operated underwater video.
Precision	
• Video transects are generally thought to have a high level of precision for sessile/sedentary organisms (Hill and Wilkinson, 2004), though Jokiel et al. (2015) found it to have a relatively low level of precision for the same fauna. • The method has a moderate level of precision for mobile organisms, such as fish (Holmes et al., 2006; Langlois et al., 2010).	
Time	
• Video transects are a relatively quick method to undertake in the field (Abdo et al., 2004; Pelletier et al., 2011).	• Considerable laboratory time is required to analyse the videos and thus the overall time can be equal to, and sometimes greater than, the total time required for visual transects (Pelletier et al., 2011; Holmes et al., 2013; Jokiel et al., 2015).
Cost	
• The overall cost of the method is relatively low due to the limited amounts of time required to collect each sample, particularly when compared to visual transects (Pelletier et al., 2011).	• The equipment costs can be considerable, depending on the camera system used (Holmes et al., 2006; Jokiel et al., 2015).

2.4.3. Manta tow

The manta tow method is primarily used for the monitoring of organisms over broad spatial scales to provide semi-quantitative data (Hill and Wilkinson, 2004) (Miller et al., 2009). The method was initially developed for the monitoring of Crown of Thorns starfish (Chesher, 1969) and involves towing an observer behind a boat at a constant speed, who holds on via a ‘manta board’ (Fig. 2.5). The observer takes visual estimates, stopping at regular intervals to note them down (Miller et al., 2009). This method is used to monitor the percentage cover of benthic habitats (Rodgers and Cox, 1999; Kenyon et al., 2006; Zhang et al., 2006; Rajamani and Marsh, 2015) and for counts of larger invertebrates (Miller et al., 2009; Shiell and Knott, 2010) and fish (Richards et al., 2011; Miller et al., 2012). The manta tow method provides moderate to effective estimates of both sessile/sedentary and mobile fauna (Table 2.11 and Fig. 2.5). It has been shown to be an easy method to deploy that generally only requires a relatively low financial investment and timeframe to undertake. This method would be best suited for recording the abundance of fish and/or mobile pelagic/demersal invertebrates (*i.e.* cephalopods) and benthic invertebrates (*i.e.* large crustaceans) utilising the areas surrounding artificial reefs.

Table 2.11. The advantages and limitations of the manta tow method for monitoring the fauna on artificial reefs.

Advantages	***Limitations***
Deployment	
• The use of a boat to tow an observer results in large areas being easily sampled (Kingsford and Battershill, 2000).	• The duration to which observers can be towed is limited by occupational health and safety. • The method is limited to use in relatively shallow, clear water (Kingsford and Battershill, 2000; Hill and Wilkinson, 2004).

Advantages	Limitations
Accuracy	
• Manta tows have been shown to provide accurate data for estimating the relative abundance of Crown of Thorns starfish (Moran and De'ath, 1992). • The method has been found to effectively provide estimates of live coral cover (Miller and Müller, 1999).	• Manta tows are only able to determine relative abundances of sessile and sedentary organisms (Moran and De'ath, 1992; Hill and Wilkinson, 2004). • Several authors have shown that this method may not adequately detect cryptic individuals (Fernandes et al., 1990; Moran and De'ath, 1992; English et al., 1997).
Precision	
• Manta tows can provide high levels of precision for Crown of Thorns starfish and coral surveys (Moran and De'ath, 1992; Miller and Müller, 1999),.	• The method provides low and moderate levels of precision for dead coral categorisation and mobile organisms, respectively (Miller and Müller, 1999; Hill and Wilkinson, 2004; Miller et al., 2012).
Time	
• Manta tow surveys can be completed relatively quickly (Kingsford and Battershill, 2000).	
Cost	
• The method specific equipment is inexpensive (English et al., 1997; Kingsford and Battershill, 2000; Hill and Wilkinson, 2004). • The time-efficiency of the method lowers field-based expenses (English et al., 1997; Kingsford and Battershill, 2000; Hill and Wilkinson, 2004) and has been shown to be a relatively cost-effective monitoring option for Crown of Thorns starfish (Moran and De'ath, 1992).	

Fig. 2.5. An observer being towed over coral reef demonstrating the manta tow technique (from Fig. 2 in Miller et al. (2009)).

2.4.4. Towed video

The towed video method is similar to the manta tow technique, where a video camera, rather than an observer, is dragged behind a boat at a constant speed, along a predetermined transect (Machan and Fedra, 1975; Mallet and Pelletier, 2014). Unsurprisingly, both methods sample over the same spatial scale and result in data of the same resolution and quality being generated (Hill and Wilkinson, 2004; Assis et al., 2007). There are a number of variations of the towed video method, primarily based upon the camera's position in the water column (Table 2.12). As outlined in Table 2.13 and Fig. 2.8, the towed video method provides relatively accurate estimates of species richness and abundance for sessile/sedentary and mobile fauna. The method can be carried out quickly but its expense must be taken into consideration. This method would be best suited for recording the abundance of fish and/or mobile pelagic/demersal invertebrates (*i.e.* cephalopods) and benthic invertebrates (*i.e.* large crustaceans) utilising the areas surrounding the artificial reef.

Table 2.12. Variations on the towed video method, including the camera's position in the water column and the types of flora and fauna monitored.

Type of towed video	Position in water column	Organisms monitored	Studies
Seabed tow	Seafloor	Benthic organisms	Machan and Fedra (1975), Spencer et al. (2005), Rooper (2008)
Mid-water tow	Mid-water	Macro-fauna, algae, seagrass, habitat	Riegl et al. (2001), Assis et al. (2007), Norris et al. (1997), Morrison and Carbines (2006), Grizzle et al. (2008), Carbines and Cole (2009), McIntyre et al. (2015)
Video towed diver	Surface or mid-water	Benthic organisms	Jokiel et al. (2015)

Table 2.13. The advantages and limitations of the towed video method for monitoring the fauna on artificial reefs.

Advantages	***Limitations***
Deployment	
• Towed video can be deployed under harsh conditions that restrict the use of human observers. • The video recordings provide a permanent record. • The method is non-invasive.	• The method requires a relatively flat seafloor and high water clarity (Riegl et al., 2001; Grizzle et al., 2008). • Movement of the boat, due to course correction or weather, can impinge on the ability of the camera to stay at a constant depth (Grizzle et al., 2008).
Accuracy	
• By towing a video camera, rather than an observer, this technique is able to sample species that are scared by human interaction (Assis et al., 2007). • Jokiel et al. (2015) found towed video to be one of the more accurate coral monitoring methods for recording their percentage cover.	• The planar view of the cameras can lead to incorrect estimations of benthic cover (Carbines and Cole, 2009). • The technique is limited in its ability to identify small species (Rooper, 2008; Carbines and Cole, 2009).

Advantages	***Limitations***
• Towed video was found by Morrison and Carbines (2006) to record greater estuarine fish species richness and abundance than visual transects, remotely operated underwater video, fish traps and hook and line methods.	• Whilst the use of automated gear allows for the sampling of fish species affected by the presence of humans, other species may be scared by the gear leading to biases (Morrison and Carbines, 2006; McIntyre et al., 2015). • Jokiel et al. (2015) noted that lower numbers of coral species were recorded when using towed video compared to visual and photo quadrats, and visual transects. • Morrison and Carbines (2006) found towed video to capture lower species richness and abundance of estuarine fish than trawling.
Precision	
	• The method has a low level of precision for sessile/sedentary organisms (Hill and Wilkinson, 2004) and a moderate level for mobile organisms (Assis et al., 2007).
Time	
• The technique has been shown to be a relatively fast way of collecting data in the field (Riegl et al., 2001; Assis et al., 2007; Jokiel et al., 2015).	
Cost	
	• The expense of the gear can vary significantly depending on the level of sophistication required (Hill and Wilkinson, 2004; Rooper, 2008; Carbines and Cole, 2009; Jokiel et al., 2015), making the cost of the method dependent upon the study being conducted.

2.4.5. Remotely operated underwater video

The first underwater video systems, used in the application of marine biology, date back to 1949 (Barnes, 1952) and they have since been used for the monitoring of a variety of organisms including reef (Dunbrack and Zielinski, 2003; Watson et al., 2010; Chabanet et al., 2012) and deep demersal fish (Priede et al., 1994; Priede and Merrett, 1996), as well as benthic organisms (Tyne et al., 2010). There are a variety of modifications to the general method, which relate to the number of cameras and the presence or absence of bait (Table 2.14). They can be utilised to collect semi-quantitative data on fine to medium spatial scales, with stereo-systems also allowing for the measurement of fish lengths. As shown in Table 2.14 and Fig. 2.8, the remotely operated underwater video method can be deployed easily, at a relatively low cost, though the time investment required can be considerable. It provides relatively effective richness and abundance estimates for sessile/sedentary fauna, and moderate estimates for mobile fauna. This method would be best suited for recording the abundance of fish and/or mobile pelagic/demersal invertebrates (*i.e.* cephalopods) utilising the artificial reef, and benthic organism on the reefs and in the surrounding area.

Table 2.14. Types and specifications of remotely operated underwater video.

Type	Specifications	Studies
Linked	Temporary	Tyne et al. (2010)
	Permanent	Aguzzi et al. (2011), Jan et al. (2007)
Autonomous	Baited (Fig. 2.6)	Priede et al. (1994), Priede and Merrett (1996), Langlois et al. (2010), Lowry et al. (2012), Rizzari et al. (2014), Stobart et al. (2007)
	Unbaited	Dunbrack and Zielinski (2003), Francour et al. (1999); (Chabanet et al., 2012); Pelletier et al. (2012)
	Stereo (two cameras) (Fig. 2.7)	Watson et al. (2005), Watson et al. (2010), Langlois et al. (2015)
	Horizontal camera	Ellis and DeMartini (1995)
	Vertical camera	Willis et al. (2000)
	Lights	Bassett and Montgomery (2011)

Table 2.15. The advantages and limitations of the remotely operated underwater video method for monitoring the fauna on artificial reefs.

Advantages	***Limitations***
Deployment	
• The use of a camera, rather than an observer, is less invasive (Cappo et al., 2003). • Video recordings provide a permanent record (Cappo et al., 2003). • Video systems can operate at much greater depths, and for longer periods of time, than any underwater visual census method (Willis et al., 2000). For example, video systems have been successfully deployed in waters up to 4000 meters deep (Priede et al., 1994). • Video deployment requires less people, particularly skilled workers, compared to other methods (Willis et al., 2000; Cappo et al., 2003).	• Permanent linked systems are restricted in their location as after their deployment they are immovable. (Jan et al., 2007; Aguzzi et al., 2011). • Permanent linked systems can be fouled by organisms leading to obscuring of their cameras. • Cameras can only be deployed in areas with high water clarity (Harvey and Cappo, 2000). • The camera field of view can become obscured by environmental conditions, such as vegetated habitats, *ie*. Kelp forests (Willis et al., 2000). • Cameras are limited in their ability to be deployed in caves and structurally non-homogeneous habitats (Watson et al., 2005).

Advantages	Limitations
Accuracy	
• The use of a camera removes biases present in underwater visual census methods due to the potential attraction or repulsion of fish to divers (Willis et al., 2000; Watson et al., 2005). • Baited cameras have been noted as being particularly useful for measuring species richness and relative density of fish (Willis et al., 2000; Watson et al., 2005; Langlois et al., 2010) as they increase the abundance of carnivorous species without negatively affecting the abundance of herbivorous species, compared to unbaited cameras (Harvey et al., 2007). Though this point has been challenged (Watson et al., 2010). • Underwater video has been noted to provide higher reef fish species richness estimates than video transects by both Langlois et al. (2010) and Watson et al. (2010).	• It can be difficult to discriminate taxonomic detail on video, due to the reduction of light with depth, distance of organisms from the camera, and water quality, making species identification difficult (Kingsford and Battershill, 2000; Widder, 2004). • Unbaited video requires a larger number of replicates than baited video methods, due to the chance nature of encountering the target organisms (Watson et al., 2005). • Baited cameras have been noted to underrepresent cryptic species (Watson et al., 2005), site attached fish and those not attracted to bait (Watson et al., 2010). • Baited cameras can only be used to determine relative density because it is incredibly difficult to calculate the area of bait plume dispersal (Priede and Merrett, 1996). • Underwater video has been noted by Rizzari et al. (2014) to capture a lower abundance of reef sharks than the rapid visual technique, but a higher abundance than manta tow, a broad scale method. • Method has been found to record a lower species richness and abundance of fish compared to a range of other methods (Francour et al., 1999; Morrison and Carbines, 2006; Stobart et al., 2007; Frias-Torres and Luo, 2008; Lowry et al., 2012; Rizzari et al., 2014).
Precision	
	• The method has a low level of precision (Watson et al., 2010).

Advantages	Limitations
Time	
• The deployment time of cameras can range from short term, *i.e.* minutes-hours (Tyne et al., 2010) to permanent (Jan et al., 2007; Aguzzi et al., 2011). • Multiple camera drops can be completed in a day (Langlois et al., 2010). • The method requires generally less fieldwork, resulting in lower overall time (Watson et al., 2005).	• The processing time of video footage is considerable (Francour et al., 1999; Harvey and Cappo, 2000; Stobart et al., 2007), though Watson (2006) has shown it is possible to sample the majority of fish species recorded without analysing an entire one-hour drop.
Cost	
• The low amount of time required in the field, to deploy and retrieve the camera equipment, lowers costs. • The method has been cited as being cost effective compared to underwater visual census methods (Cappo et al., 2003).	• The expense of camera equipment can be considerable (Unpublished data by Watson as cited in (Watson et al., 2005)), though the recent application of GoPro cameras allows for a large reduction in costs (Letessier et al., 2015).

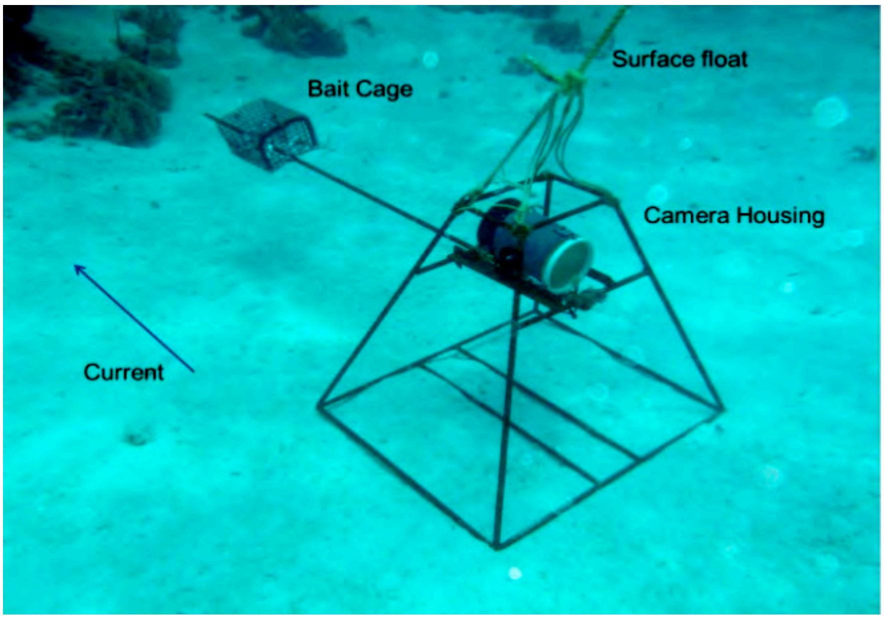


Fig. 2.6. A BRUV system (from Fig. 2 in The Gilis (2015)).

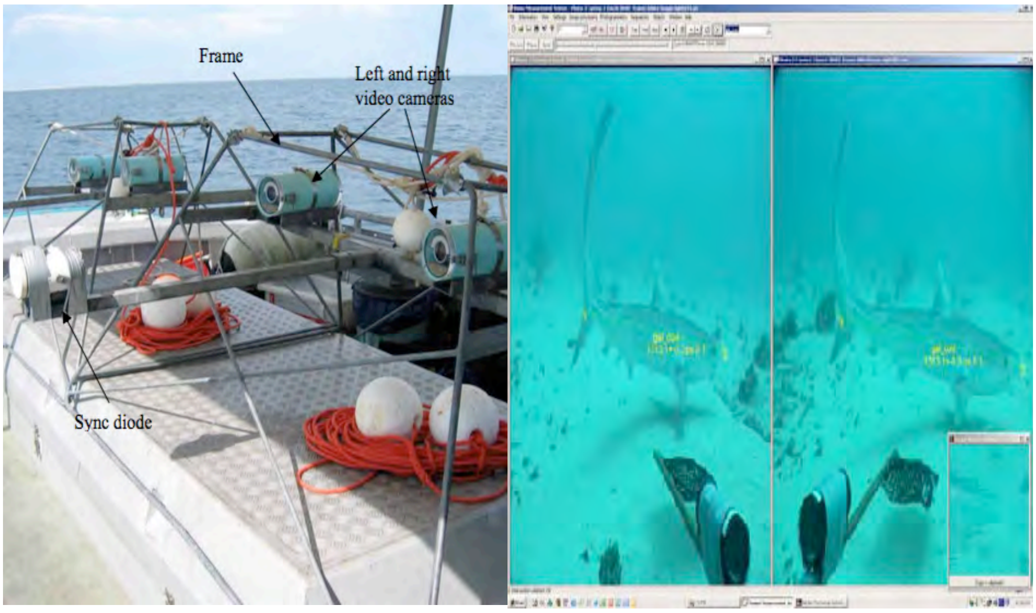


Fig. 2.7. A stereo-video system showing the two cameras on a module (left). Fig. 7 from Watson (2015), and a typical output from such a system allowing for length measurement of fish (right) (from Fig. 1 from America Pink (2016)).

2.4.6. Environmental DNA analysis

Environmental DNA (eDNA) analysis involves the collection and study of genetic material from environmental samples, *e.g.* water (Thomsen and Willerslev, 2015). The method was first developed to analyse the DNA of microbes from sediment (Ogram, 1987), but has since been applied to analysing more complex organisms from a variety of media (Ficetola et al., 2008). Recently the field has focused upon using the method to monitor the presence/absence of endangered and/or invasive species (Jerde et al., 2013; Goldberg et al., 2015; Spear et al., 2015), however, it has the potential to be applied across a broad taxonomic base to sample the DNA of entire communities (Goldberg et al., 2015; Thomsen and Willerslev, 2015). The eDNA method allows for monitoring on a medium to large spatial scale and the gathering of qualitative data. See Thomsen and Willerslev (2015) for an in-depth literature review of the method and its application. The eDNA method, as outlined in Table 2.16 and Fig. 2.8, has proven to be very effective for detecting species richness, of both sessile/sedentary and mobile fauna. However, its inability to record the abundance of organisms must be taken into consideration before it is used in any monitoring program. This method would be best suited for sampling the diversity of organisms, which occur in reference databases, found in the wider vicinity of reef modules.

Table 2.16. The advantages and limitations of the eDNA analysis method for monitoring the fauna on artificial reefs.

Advantages	***Limitations***
Deployment	
• The method only requires small environmental samples be taken (Thomsen et al., 2012). • The collection of only environmental sample makes the method relatively non-invasive (Thomsen and Willerslev, 2015; Valentini et al., 2016). • The technology can be used to sample structurally complex habitats, such as mangrove systems, where other methods can't be deployed (Thomsen et al., 2012).	
Accuracy	
• The method has been noted as being particularly efficient at sampling cryptic and rare species (Ficetola et al., 2008; Olson et al., 2012; Spear et al., 2015).	• The identification of DNA sequences relies upon reference databases, which are limited in geographical and taxonomic coverage (Kvist, 2013).
• The method has been found to be superior in detecting freshwater fish species over netting (Valentini et al., 2016) and to be the same as, or better than, a number of methods, including netting, hook and line, trawling and underwater visual census methods, in detecting fish species in marine environments (Thomsen et al., 2012).	• The method is unable to reliably estimate abundance, though advancements are being made towards this (Takahara et al., 2012; Kelly et al., 2014; Yamamoto et al., 2016). • There is the potential for contamination using this technique, and therefore potential false positive or negative results (Thomsen and Willerslev, 2015).

Advantages	Limitations
	• Methodological artefacts can bias detection towards some taxa and away from others. • There is the potential for the detection of species away from their source environment when there is moving water, despite DNA's relatively quick degradation (Thomsen et al., 2012).
Precision	
	• Precision is likely high, though it is only applicable to species richness, as the presence of DNA samples in a liquid medium is likely to be evenly spread, unlike the distribution of organisms.
Time	
• The technique requires little sampling time (Olson et al., 2012; Valentini et al., 2016).	
Cost	
• The method has been noted as being cost-efficient (Olson et al., 2012; Sigsgaard et al., 2015; Thomsen and Willerslev, 2015).	• The technique may require the identification of primers (Valentini et al., 2016), which take time and can be costly.

2.4.7. Extractive methods

Extractive methods rely upon the removal of organisms from their natural environment to ascertain a measurement of catch per unit effort (CPUE) (Cappo and Brown, 1996). This measure is primarily used to assess exploitation levels, but can also be used to estimate relative abundance (Richards and Schnute, 1986; Connell et al., 1998). There are a wide variety of extractive methods, which can provide quantitative data on a medium to broad spatial scale (Table 2.17). Extractive methods generally prove to be efficient in terms of time and financial considerations, however their deployment can be difficult and their ability to effectively sample species richness is somewhat limited (Table 2.18, Fig. 2.8). These methods would be best suited for recording the abundance of fish and/or mobile pelagic/demersal invertebrates (*i.e.* cephalopods) utilising the artificial reef, and benthic organism on the reefs and in the surrounding area, though the exact extractive method used would depend upon the local conditions.

Table 2.17. Commonly used extractive monitoring methods and their variations.

Method	Variations	Studies
Fish trap	O-shaped Z-shaped S-shaped Rotational Baited	Newman and Williams (1995), Langlois et al. (2015), Harvey et al. (2012b), Whitelaw et al. (1991), Morrison and Carbines (2006), Baumgartner et al. (2006), Fujii (2015)
Trawls	Mid-water Bottom Active netting	Říha et al. (2012), Sajdlova et al. (2015), Harmelin-Vivien and Francour (1992), Rozas and Minello (1997), Morrison and Carbines (2006), Spencer et al. (2005)
Ichthyocide	Rotenone Cyanide	Ackerman and Bellwood (2000), Prochazka (1998), Smith-Vainz et al. (2006), Willis (2001)
Hook and line	Handline Long line Drop-line	Morrison and Carbines (2006), Connell et al. (1998)

Table 2.18. The advantages and limitations of extractive methods for monitoring the fauna on artificial reefs.

Advantages	***Limitations***
Deployment	
• Extractive methods, such as ichthyocide, fish traps, and hook and line methods can be used to sample a wide variety of habitats and depths (Newman and Williams, 1995; Cappo and Brown, 1996). • Trawls can be used to sample large areas (Sajdlova et al., 2015).	• Extractive methods that rely upon the removal of organisms are invasive and can have a considerable negative impact upon the environment (Alverson et al., 1994; Ackerman and Bellwood, 2000; Smith-Vainz et al., 2006). • The ability to minimise the impact of extractive methods through the mark, release and recapture method is limited as it is not reliable for estimating abundances (Cappo and Brown, 1996). • Extractive methods, aside from trawling, sample relatively small areas.

Advantages	*Limitations*
	• The equipment required for trawling is cumbersome (English et al., 1997) and cannot be deployed in all habitats. • High densities of fish can lead to gear saturation for hook and line methods and result in an incorrect calculation of abundance. The ability of the fisher can also affect the usefulness of the method for sampling (Cappo and Brown, 1996).
Accuracy • Ichthyocides are useful for sampling the entirety of a fish community and are particularly good for collecting small and cryptic species (Ackerman and Bellwood, 2000; Willis, 2001). • Selectivity in fish traps can be useful in the targeting of specific species, or age classes (Wells et al., 2008).	• Trawls (Piasente et al., 2004; Wells et al., 2008), fish traps (Newman and Williams, 1995; Robichaud et al., 1999; Fujii, 2015) and hook and line methods (Cappo and Brown, 1996) can show selectivity of fish in terms of size and life stage. • Some fish species are known to actively avoid ichthyocide plumes, leading to biased sampling (Ackerman and Bellwood, 2000).
Precision • Ichthyocides show a high level of precision (Ackerman and Bellwood, 2000).	• Hook and line, trawl and traps can show considerable variability in their level of precision (Cappo and Brown, 1996; Rozas and Minello, 1997; Watson, 2015).
Time • These methods allow for quick sampling (Cappo and Brown, 1996; Harvey et al., 2012b).	
Cost • The hook and line method is one of the most cost efficient methods in terms of the gear used (Cappo and Brown, 1996).	

2.4.8. Fisher surveys

Fisher surveys are used to estimate recreational fishing effort and the associated recreational fishing-related mortality for a given area (Keller et al., 2016). The surveys are typically conducted in two ways, through onsite and offsite surveys (Hartill and Edwards, 2015). Onsite surveys involve face-to-face interviews with fishers at, or near, the site of activity (*e.g.* a boat ramp), while offsite surveys comprise phone, internet surveys or self-reporting of individuals taken from a larger population (Hartill and Edwards, 2015). This duel approach allows quantitative information to be collected on fine to broad spatial scales. As outlined in Table 2.19 and Fig. 2.8, fisher surveys are generally used sparingly as they prove ineffective in terms of their deployment, time and cost, whilst also only providing minimal effectiveness in terms of richness and abundance estimates. This method would be best suited for estimating recreational fishing effort, catch rates of target species in sites at, or around, artificial reefs, as well as the general experience of recreational fishers.

Table 2.19. The advantages and limitations of the fisher survey method for monitoring the fauna on artificial reefs.

Advantages	***Limitations***
Deployment	
• The use of human based surveys makes the method environmentally non-invasive.	
Accuracy	
• Onsite surveys can provide information, such as catch rates, that cannot be reliably obtained through other means (Smallwood et al., 2011).	• Onsite sampling can be unrepresentative (Hartill and Edwards, 2015). • The method can introduce potential errors in recall and misidentification of species (Ashford et al., 2010; Hartill and Edwards, 2015), as well as purposeful misinformation due to the reluctance by fishers to divulge information.
Precision	
	• The level of precision is unknown.
Time and Cost	
	• The collection of recreational fishing data is relatively time intensive, making it an expensive method (West et al., 2012; Hartill and Edwards, 2015).

2.5. Findings

To summarise, the following findings were drawn from the ‘heat map’ (Fig 2.8).

Reef types:

- All methods are appropriate for monitoring shallow-water reefs.
- The monitoring of deep-water reefs is suited to methods that do not require underwater observers, *eg*. underwater visual census.
- Nearly all methods are suitable for monitoring the faunas of artificial seagrass, however, remote underwater video and manta tow do not provide accurate information on sessile/sedentary faunas present in this environment.

Scale:

- Generally, the methods that are very effective for broad scale monitoring are not suitable for fine scale monitoring (*eg*. manta tow, towed video, eDNA analysis, DIDSON acoustic survey), and *vice versa* (*eg*. settlement tiles, visual quadrats, photo quadrats, stationary visual census).

Data:

- All methods provide some form of quantitative data, except for the rapid visual technique and eDNA.

Deployment:

- Underwater census methods that do not require equipment, such as stationary visual census and the rapid visual technique, as well as methods that do not require the deployment of observers, such as remotely operated underwater video, DIDSON acoustic surveys and eDNA analysis, are the methods that are easiest to deploy.

Species richness accuracy:

- Manta tow, towed video, remotely operated underwater video and eDNA analysis provide the best species richness accuracy estimates, for both sedentary/sessile and mobile fauna, as they are able to cover large areas or record species from a wide area.

Abundance accuracy:

- The most accurate methods for sessile/sedentary fauna are settlement tiles and visual quadrats as they are able to enumerate organisms on a fine scale. Whilst for mobile fauna manta tow, towed video and remotely operated underwater video methods are the most accurate as they can cover large areas or attract individuals from the wider environment.

Precision:

- eDNA analysis likely provides the highest level of precision, though it is only applicable to species richness, as the presence of DNA samples in a liquid medium is likely to be evenly spread, unlike the distribution of organisms.

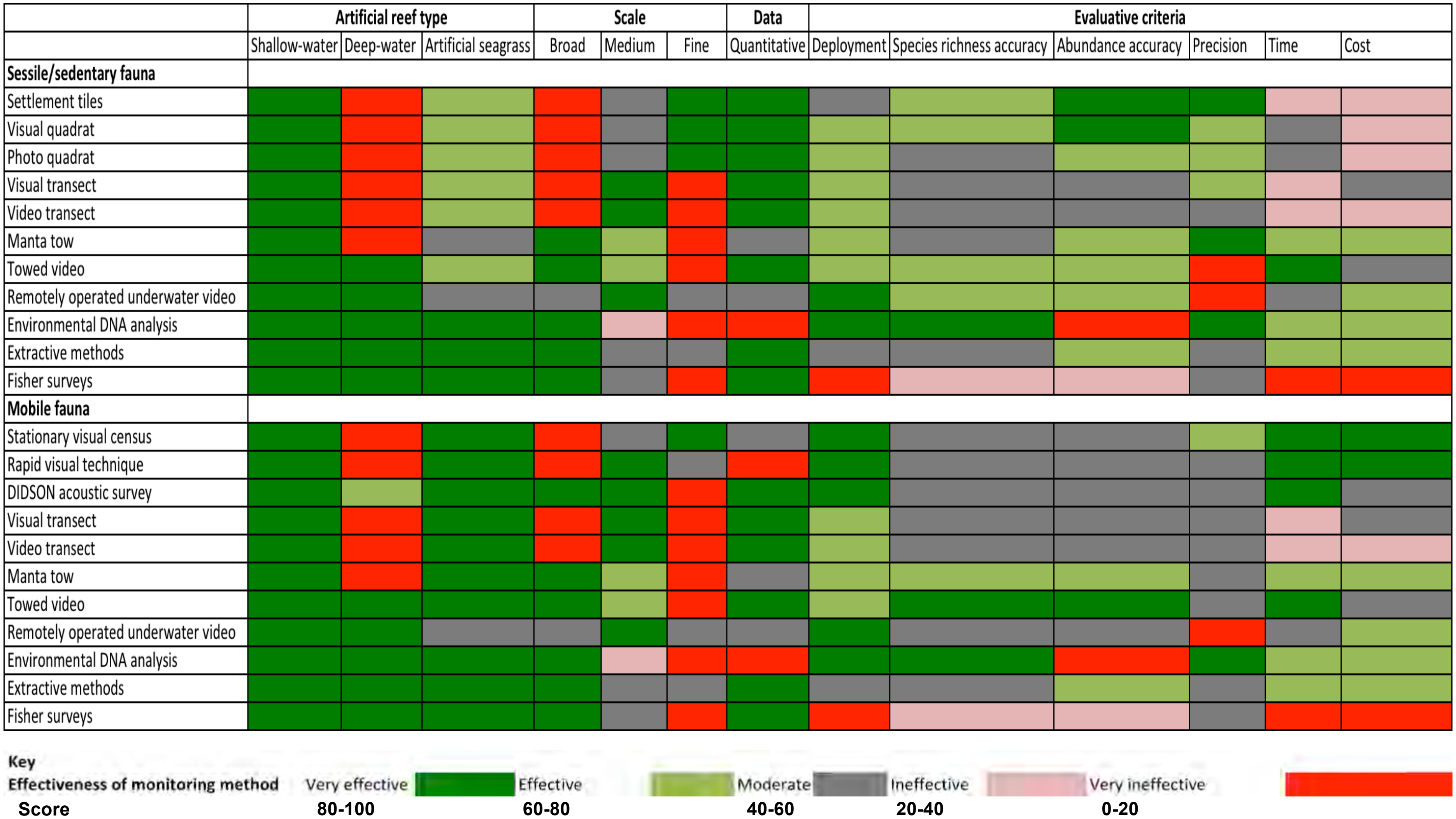
Time and cost:

- With the stationary visual census and the rapid visual technique having both low field and laboratory time, in conjunction with the need for minimal equipment, they have the lowest associated time and cost outputs.

As shown by this review, a plethora of methods can be employed to monitor the fauna (and flora) of artificial reefs. The characteristics of each method are different, meaning that they must be evaluated according to the circumstances of each study, rather than applying a one size fits all approach. As such, this review provides an evaluation of a range of fauna monitoring methods available for artificial reefs.

Of these highlighted methods remotely operated underwater video, which includes BRUV, was found to be easy to deploy, relatively inexpensive and able to provide moderately accurate data on mobile fauna (Fig. 2.8). As such, this technique was utilised as part of a citizen science program in the study of the fish faunas of the artificial reefs of Geographe Bay, which will be covered in Chapter 3.

Fig. 2.8. Heat map showing the relative effectiveness of each monitoring method against different artificial reef types, the scale at which they monitor, the type of data they provide and a range of evaluative criteria. They are ranked on a scale of 0 (red/very ineffective) to 100 (dark green/very effective).



Chapter Three: Characteristics of the ichthyofauna of the Bunbury and Dunsborough artificial reefs determined from Baited Remote Underwater Video

3.1. Abstract

Baited Remote Underwater Video was utilised, through a citizen science based sampling program, to monitor the fish communities of the artificial reefs of Geographe Bay in south-western Australia, between October 2015 and July 2016 inclusive. The resultant videos were analysed to determine if the number of taxa, total MaxN, Simpson's Index, as well as the MaxN of several key recreational species, differed between reefs and over time through a two-way ANOVA, while the composition of the fish communities were tested via a PERMANOVA. Most of the 60 taxa recorded were resident teleosts, while nine species of elasmobranch were also recorded. In terms of the number of individuals, most were either pelagic or epibenthic, and fed on zooplankton or the zoobenthos. Significant differences were found for the majority of variables between reefs, except for the Simpson's Index, with the Dunsborough reef generally displaying higher values. Differences between months were found to be significant for all variables, except for the Simpson's Index and the MaxN of *Chrysophrys auratus*; while the interaction of reef and month were significant for all variables, except for the Simpson's Index and the MaxN of *Chrysophrys auratus* and *Seriola hippos*. Differences between reefs always exerted the greatest level of influence, indicating that the habitat connectivity of the artificial reefs were predominantly responsible for shaping their associated fish communities. The lower, but still significant, differences obtained between months and the reef×month interaction indicated that temperature, as induced by seasonal changes, and oceanographic processes, also played a part in shaping the fish communities of the reefs. These results demonstrate that

BRUVs, deployed through citizen science, can be a useful and cost-effective technique for monitoring the fish faunas of artificial reefs.

3.2. Introduction

The composition of fish communities around the world has been shown to display significant variability between habitats. This has been observed between, and within, structured (*e.g.* reef, algae and seagrass) and non-structured habitats (*e.g.* Bare sand; Molles, 1978; Bell et al., 1987; Heck et al., 1989; Howard, 1989; Sogard and Able, 1991; Gray et al., 1998; Jenkins and Wheatley, 1998; Harman and Kendrick, 2003; Heck Jr et al., 2003). These differences are likely due to the provision and degree of structure within such habitats, as increased habitat complexity creates more shelter for fish and increases feeding opportunities (Bohnsack, 1989). As a result, habitats with high levels of structure, conferred through habitat complexity and vertical relief, have increased levels of fish diversity and abundance, compared to other habitats (Molles, 1978; Howard, 1989; Harman and Kendrick, 2003).

Artificial reefs mimic natural reefs by providing structurally complex habitats for fish to utilise, resulting in their increased localised abundance through either their attraction, or the production of new individuals (Bohnsack and Sutherland, 1985; Baine, 2001; Simon et al., 2011). They have been deployed around the world as a tool for fisheries management, to increase fish production in both industrialised and artisanal fisheries (Gil Chang et al., 2011; Santos et al., 2011). A number of factors can influence the associated fish communities of artificial reefs, including design aspects (*e.g.* rugosity, complexity, vertical relief, surface area), while their deployment location has also been found to play a significant role (Bohnsack and Sutherland, 1985). The importance of the location at which the reef is deployed is likely due to the degree of connectivity between the artificial reef and surrounding natural reefs, influencing the dispersal of individuals (Molles, 1978; Bohnsack, 1979; Gladfelter et al., 1980; Gascon and Miller, 1981; Walsh, 1985; Bombace et al., 1994). Furthermore, artificial reefs, like natural reefs, display seasonal differences in their fish communities (Hastings et al., 1976; Sanders Jr et al., 1985; Stephens Jr et al., 1994; Fujita et al., 1996; Bortone et al., 1997). These differences are likely driven by changing sea surface temperatures and oceanographic processes affecting recruitment, and in turn the fish communities present (Milicich, 1994; Booth and Brosnan, 1995; Pearce and Pattiaratchi, 1999; Taylor et al., 2013).

3.2.1. Rationale

Twenty five artificial reefs were deployed in Australia between 2009 and 2015, making it one of the peak deployment periods over the past 50 years (Bateman, 2015). Two of these reefs were deployed in April 2013 off Bunbury and Dunsborough in Geographe Bay, Western Australia, in a project known as the South West Artificial Reefs Trial, led by the Department of Fisheries (Western Australia), in conjunction with Recfishwest. These reefs were designed to increase the abundance of recreationally important fish species such as Pink Snapper *Chrysophorus auratus*, Trevally *Pseudocaranx* spp. and Samson Fish *Seriola hippos*, ultimately to provide improved recreational fishing opportunities (Government of Western Australia, 2013).

Under the *Fish Resources Management Act 1994* (Western Australia) and the *Environmental Protection and Biodiversity Act 1999* (Commonwealth) the biological monitoring of artificial reef deployments may be required. This contributed, along with other factors, to the undertaking of an in-depth biological monitoring program of the South West Artificial Reefs Trial by the Department of Fisheries (Western Australia; Department of Fisheries, 2012;

Department of the Environment, 2016b). With future deployments of artificial reefs planned for around the State, including some already underway, there is the need for the identification of cost-effective fauna monitoring techniques, as traditional monitoring programs can be expensive (Cigliano et al., 2015; Edgar et al., 2016). Recfishwest has highlighted this need, and through funding from the FRDC (FRDC-project number 2014/005), has instigated research into cost-effective fauna monitoring options for artificial reefs, from which this research project has developed.

3.2.2. Aims

This project utilised the cost effective method developed by Florisson (2015) and Bateman (2015) of deploying BRUV units, through citizen science, to monitor the fish faunas of the two artificial reefs of Geographe Bay. Specifically, this research aims to:

1. Determine whether the characteristics (including the number of taxa, abundance and composition) of the fish fauna differed between the Bunbury and Dunsborough artificial reefs from October 2015 to July 2016 inclusive.

2. Determine whether the characteristics (including the number of taxa, abundance and composition) of the fish fauna differed on a temporal scale between October 2015 and July 2016 inclusive, for both the Bunbury and Dunsborough artificial reefs.

3. Determine what groups of fish utilised the Bunbury and Dunsborough artificial reefs, and how, by assigning the observed taxa to habitat usage, feeding and residency guilds.

Following these aims, it was hypothesised that the fish communities of the artificial reefs of Geographe Bay will display both spatial and temporal differences, due to the influence of habitat connectivity, sea surface temperature and oceanographic processes. The data obtained from this study helped to increase our understanding of how fish utilise these reefs, in what abundances and during which parts of the year, as well as providing a judgement on the efficacy of BRUV technology, deployed through citizen science, for monitoring the fish faunas of artificial reefs.

3.3. Materials and methods

3.3.1. Study site

Geographe Bay is a protected marine embayment located 270 km south of Perth in south-western Australia (Figure 1; Bellchambers et al., 2006). It extends from the Bunbury breakwater in the north to Cape Naturaliste in the south-west, covering an area of approximately 470 km^2 (White et al., 2011). The bay has a relatively shallow bathymetry (maximum depth of 30 m) with a predominantly sandy substratum (Australian Government, 2008). Extensive seagrass meadows, primarily composed of *Posidonia sinuosa*, cover 60% of the bay and are estimated to provide over 80% of the benthic primary productivity for the area (McMahon et al., 1997; Australian Government, 2008). However, eutrophication from catchment runoff has led to accelerated algal growth, resulting in reduced seagrass cover in recent years (Australian Government, 2006).

Fig. 3.1. Satellite image of Geographe Bay, denoting its boundaries as marked by Bunbury in the north and Cape Naturaliste in the south-west. Inset image shows the location of Geographe Bay in Western Australia (Google, 2016).

South-western Australia experiences a Mediterranean climate, characterised by hot, dry summers and cool, wet winters (Hodgkin and Hesp, 1998). Rainfall is highly seasonal, with 60-70% falling between May and September, although the amount of rainfall has decreased markedly in the past 40 years (Hodgkin and Hesp, 1998; Timbal et al., 2006). The water temperature in the bay varies between a minimum of 14.8°C in winter to a maximum of 21.6°C in summer (McMahon et al., 1997).

Due to a lack of large rivers and estuaries feeding into the bay, its salinity remains close to full strength seawater throughout the year (Gallop et al., 2012). This minimal fluvial input, in conjunction with the low magnitude diurnal tide regime found in the region, and the presence of an extensive chain of offshore limestone reefs, results in the hydrodynamics of the local water column being driven predominantly by local wind processes (Pattiaratchi et al., 1997). Of these winds, the south-westerly summer sea breezes are the strongest (Pattiaratchi et al., 1997; Smale, 2012). The presence of these winds in the region would be expected to produce upwelling, however the Leeuwin Current suppresses this process (Twomey et al., 2007; Waite et al., 2007). This contributes to the oligotrophic nature of the region, resulting in reduced primary productivity compared to areas which experience upwelling (Twomey et al., 2007). The strength of the Leeuwin Current, which promotes the poleward movement of low nutrient warm water along the continental shelf, varies seasonally, with strongest flow during autumn and winter, and weakest flow during summer (Godfrey and Ridgway, 1985; Twomey et al., 2007; Waite et al., 2007). The weakening of the Leeuwin Current during summer facilitates the equatorward flow of the cold Capes Current and promotes the flushing of Geographe Bay (Pearce and Pattiaratchi, 1999; CoastWise, 2001).

A recent BRUV-based survey of the fish communities of Geographe Bay recorded 76 fish species, of which the most abundant were Western Striped Grunter *Pelates octolineatus*, Yellowtail Scad *Trachurus novaezelandiae* and Skipjack Trevally *Pseudocaranx wrighti* (Westera et al., 2007). Differences in fish communities were noted on small spatial scales throughout the bay as well as with distance from the shore. For a number of reef associated species, including Western King Wrasse *Coris auricularis*, higher abundances were noted at sampling sites in close proximity to rocky reefs, such as near Cape Naturaliste, while their abundance fell at sites further away. Additionally, the bay supports a number of commercial fisheries, including beach seine and gill net fisheries targeting Yelloweye Mullet *Aldrichetta forsteri*, Australian Herring *Arripis georgianus,* Western Australian Salmon *Arripis truttaceus*, Sandy Sprat *Hyperlophus vittatus*, Flathead Grey Mullet *Mugil cephalus*, Western Sand Whiting *Sillago schomburgkii* and the Fringe-Scale Round Herring *Spratelloides robustus*, as well as a trawl scallop fishery (Government of Western Australia, 2012). Boat-based recreational fishing effort for the area has been designated as low to moderate (Sumner and Williamson, 1999).

3.3.2. Geographe Bay artificial reefs

The Geographe Bay artificial reefs, which form the South West Artificial Reefs Trial, were deployed off Bunbury and Dunsborough in April 2013 by the Department of Fisheries (Western Australia). Each reef is comprised of 30 ‘Fish Box’ modules, placed in six clusters of five modules, deployed over a four-hectare area (Fig. 3.2). Each module, which measure 3 m^3 and weighs 10 tonnes, is constructed from steel-reinforced concrete with curved cross braces designed to promote upwelling (Haejoo, 2016). The centre point of the Bunbury artificial reef is located at 115° 35.900’E 33° 18.500’S and lies in ~17 m of water, while the Dunsborough artificial reef centre point is located at 115° 9.980’E 33° 33.962’ S at ~27 m depth (Fig. 3.3). Both reefs are deployed within 5 km of boat ramps to allow for easy boat based access by recreational fishers (Florisson, 2015).

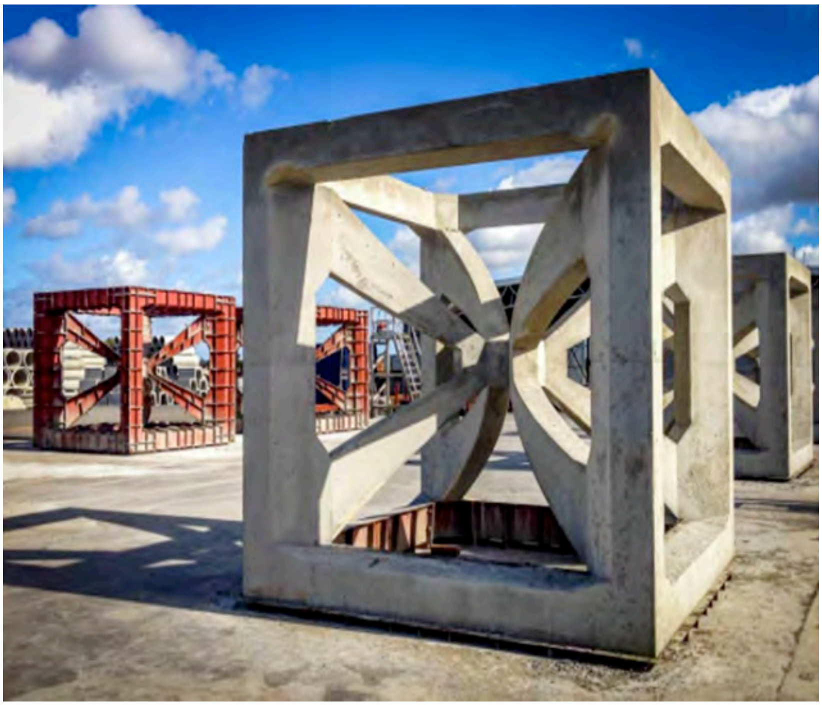


Fig. 3.2. An image of a 'Fish Box' unit, deployed as part of the South West Artificial Reefs Trial (Haejoo, 2016).

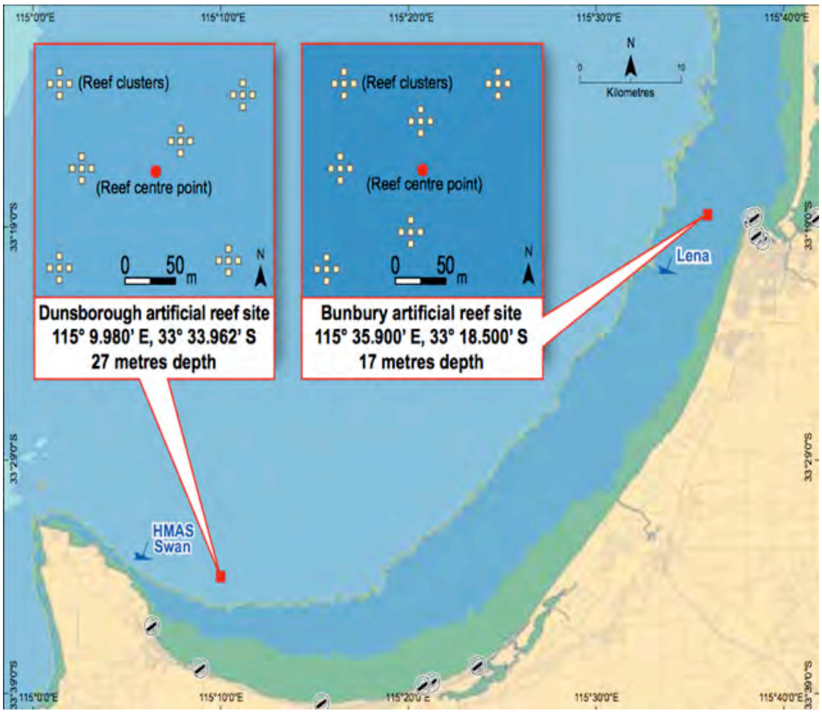


Fig. 3.3. A map displaying the location and co-ordinates of both the Bunbury and Dunsborough artificial reefs (Government of Western Australia, 2013).

3.3.3. Sampling regime

This project utilised underwater video footage, via BRUV, obtained through the 'Reef Vision' citizen science program, run by Recfishwest and Murdoch University. In this program recreational fishers, who lived in close proximity to the reefs and fished them regularly, were recruited via a targeted media campaign. Each potential participant was interviewed to ensure their suitability and, if selected, attended a short training workshop. These measures were undertaken to increase volunteer engagement and reduce attrition rates from the program (see Florisson, 2015). At the workshop, participants were provided with a BRUV unit, data storage devices, prepaid envelopes and bait vouchers. As the study by Florisson (2015) indicated, communication between the volunteers and the project managers/scientists was vital to maintaining their engagement. To encourage this a closed Facebook page was created and all participants invited to join (Fig. 3.4). This provided a platform for volunteers to interact with each other and the project staff by sharing photos and videos of their experiences, as well as discussing various topics and research findings (Tweedley et al., 2016).

A total of 12 primary volunteers were originally recruited, split evenly over both reefs. Two volunteers withdrew from the program part way through the year, whilst an additional volunteer was recruited, resulting in 11 volunteers overall, five for the Dunsborough reef and six for the Bunbury reef. However, videos were only received from nine participants. Sampling commenced in October 2015 and ran for one year, up to and including September 2016. Volunteers were asked to collect two, one-hour long video drops per month on their allocated reef, with the intention of collecting at minimum three videos per reef, per month. In an effort to maintain volunteer engagement, participants were allowed to choose the timing, within each month, and location, within their allocated reef, for the deployment of the BRUV units.

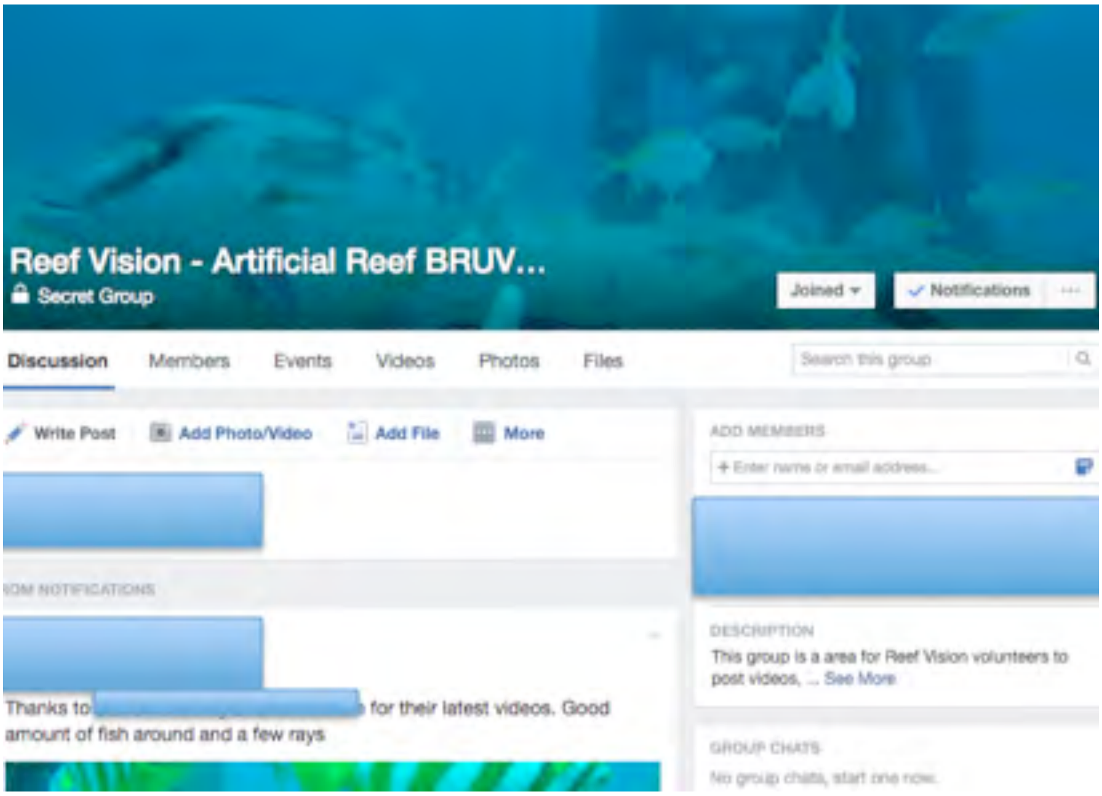


Fig. 3.4. A print screen of the 'Reef Vision' Facebook page, which facilitated communication between volunteers and project staff. Note that all volunteers names have been removed as per Human Ethics requirements (Facebook, 2016).

The BRUVs provided to the volunteers were designed, and purpose-built, for the study by Ecotone Consulting. Each unit was comprised of a 'sled' like frame, a plastic mesh bait bag and a GoPro Hero 4 Silver Action Video Camera^{TM} placed inside a waterproof housing with a Battery BacPac ^{TM} (Fig. 3.5). The GoPro^{TM} camera provided 1080 pixel resolution at 60 frames per second (GoPro Inc, 2016). The frame was constructed from Polyvinyl chloride pipe glued together using plumbers cement. The skids of the frame contained four 680 g lead weights, which provided stabilisation for the unit to ensure that it was deployed in an upright position. The bait arm was suspended 150 millimetres (mm) above the substratum and 600 mm from the centre of the BRUV unit. The mesh bait bag, which was held on the arm, measured 180×100 mm and was placed 500 mm in front of the camera. Volunteers were instructed to place one kilogram of Australian Sardines (*Sardinops sagax*) into the bait bag before deployment. This type of bait is routinely used in BRUV studies (Watson et al., 2005; Harvey et al., 2007; Stobart et al., 2007; Langlois et al., 2010; Watson et al., 2010; Langlois et al., 2015) as its oily flesh attracts a greater abundance of fish, compared to white flesh bait (Dorman et al., 2012).

Each volunteer was provided with a waterproof logbook and asked to record their name, the date on which the sampling took place, the reef location (*i.e.* Bunbury or Dunsborough), as well as the co-ordinates and/or the cluster on which the drop occurred (see Fig. 3.3), the time the BRUV unit was deployed and retrieved, number of boats in the area and any additional comments. Following deployment, the video footage was downloaded from the camera by the volunteer onto a USB stick and posted to Murdoch University for analysis. The USB stick was then returned via mail together with a bait voucher, prepaid envelope and a personal message of thanks, as well as a comment on the contents of the video.

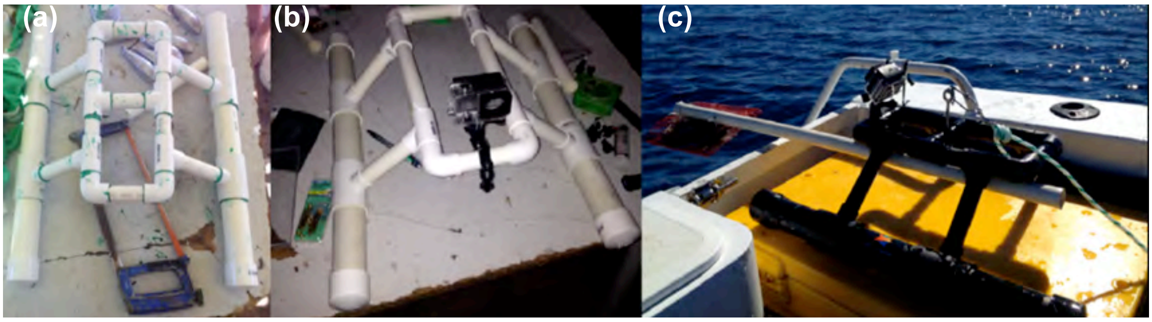


Fig. 3.5. A series of photographs showing the components and construction of the BRUV; (a) gluing of the sled, (b) mounting of the camera and (c) the completed BRUV prior to deployment (Florisson, 2015).

3.3.4. Data collection

Prior to analysis, each video was examined to determine the quality of the footage. Videos in which the alignment of the camera was altered (*i.e.* facing into the sediment or towards the surface of the water) were excluded, as were those in which the water and/or light clarity precluded the identification of fish. Following this a random subsample of four videos from each reef, in each month, were selected for analysis. However, there were two exceptions. The first was for the Bunbury reef in October 2015, when only three videos were collected and subsequently analysed (Table 3.1). This was a result of data collection only beginning part way through the month. The second was in June 2016 when poor weather caused difficulties in collecting data (Table 3.1). As a result, the data from this month, for both reefs, was combined with that collected in July to create a pooled June/July sample, following which four videos, per reef, were randomly selected and analysed. It is noted that it often took several weeks for video footage collected by the volunteers to reach the researchers, and therefore only data from October 2015 to June/July 2016 was analysed due to time constraints.

Each selected video was analysed, with the number of individuals of each fish and cephalopod species being recorded. Cephalopods were included in this study as they have been identified as one of the primary targets of recreational fishers in Western Australia (Government of Western Australia, 2015). The analysis of each video involved counting the MaxN, the maximum number of individuals from each species recorded in the field of view of the camera at any one time (Cappo et al., 2003). This abundance measure is employed ubiquitously in BRUV studies, as it provides an index of relative abundance whilst eliminating the chance of double counting (Babcock, 2000; Cappo et al., 2003). The MaxN of each species was recorded in five-minute intervals from when the BRUV touched the substrate, initially for 60 minutes as part of the preliminary analysis, and then for 45 minutes for the rest of the study (see Chapter 3.4.1). Taxa were identified to the lowest possible taxonomic level, usually to the species level, with staff from Recfishwest providing advice on identification when required. Fish that could not be identified to the family level, either due to their distance from the camera or from obscuring by physical (*e.g.* seagrass and the reef modules) or environmental conditions (*e.g.* turbidity and water clarity), were excluded from the study.

3.3.5. Allocation of species to guilds

Each taxon recorded during the study was assigned to a number of guilds, namely residency, habitat, and feeding guilds, as well as being given a recreational fishing status. Identified taxa were assigned to residency guilds depending upon how frequently they were observed in the video samples. Assigning mobile taxa to residency guilds is common in artificial reefs studies; however, there is not a single widely accepted categorisation method (*e.g.* Relini et al., 1994; Stephens Jr et al., 1994; Santos et al., 2005; Gül et al., 2011). Thus, to allow comparison with other studies a number of different definitions were combined to create a tiered system. The following residency guilds were used; **Transient:** Taxa that are never present in more than two consecutive months (Costello and Myers, 1996), **Resident level three**: Taxa which occurred in two or more consecutive months (Talbot et al., 1978), **Resident level two**: Taxa present in 50% or more of monthly samples (Relini et al., 1994), and **Resident level one**: Taxa present in at least 87.5% of monthly samples (Costello and Myers, 1996). Note that observations from both reefs were combined to create monthly averages from which the level of residency was assigned.

Each taxon was also assigned to a habitat guild based upon the area within the water column that they primarily inhabit, their position relative to the artificial reef modules and their behaviour recorded on the video footage. The habitat guilds used were taken from Nakamura (1985), which have been adopted as a benchmark for studies of fish assemblages of artificial reefs (see Bombace et al., 1994; Relini et al., 2002), who provided criteria for these guilds, while Wartenberg and Booth (2015) named them. The following guilds were used; **Benthic**: Taxa that primarily had contact with the reef surface, or occupied the reef structure, **Epibenthic:** Taxa that associated with the reef, but rarely made direct contact, and **Pelagic**: Taxa that tended to swim above the reef in the middle, and upper parts, of the water column. Note, traditionally benthic organisms, such as rays, were included in the benthic guild though their limited contact with the reef structure would have placed them in the epibenthic guild.

Additionally, feeding guilds were assigned to each species on the basis of the food resources they utilise, as determined from FishBase and the scientific literature (Froese and Pauly, 2016). For species whose diet and feeding behaviour was unknown, their categorisation was based upon closely related species. The feeding guild definitions in this study were taken from Elliott et al. (2007) who applied them to categorise seven guilds of estuarine fish species. These were; **Detritivore**: Taxa that feed on decaying organic matter and associated organisms, **Herbivore**: Taxa that consume plant material, including those that feed on phytoplankton, **Omnivore**: Taxa that feed on both plant and animal material, **Zooplanktivore**: Taxa that feed primarily on small crustaceans in the water column, **Zoobenthivore**: Taxa that feed on animals that live in, on, or immediately above the substratum, **Piscivore**: Taxa that feed predominantly on fish, and **Opportunist**: Taxa whose feeding behaviour and food preferences will likely change depending on food availability, thus consuming a wide variety of prey.

Finally, species were designated as **targeted** or **non-targeted**, based upon the extent to which they are targeted by recreational fishers. This subjective classification was provided by expert opinion from staff at Recfishwest, the peak body for recreational fishing in Western Australia.

3.3.6. Statistical analysis

3.3.6.1. Preliminary analysis

A pilot study was conducted to ascertain the length of each video that needed to be analysed to provide a robust assessment of the characteristics of the fish fauna present at the time of sampling. The purpose of this analysis was two-fold, firstly, to determine whether the BRUV deployment of one hour was sufficient and, if so, whether the data extraction (*i.e.* calculating MaxN for each species present in a video) could be done over a reduced duration of time, *i.e*. less than the total deployment time. This was done to potentially reduce the amount time required for analysis, as the number of videos received and their total duration was significant (*i.e*. 111 videos totalling ~10,000 minutes of footage; Table 3.1).

Table 3.1. The total number of BRUV videos received from the volunteers for both the Bunbury (Bun) and Dunsborough (Dun) reefs in each month and the total number of minutes of video recorded.

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Tot.	Min.
Bun	3	14	5	8	7	6	4	5	1	5	1	5	59	5611
Dun	5	4	7	8	6	6	4	5	2	5	4	1	52	4243
Tot.	8	18	12	16	13	12	8	10	3	10	5	6	111	9854

The pilot study, which was undertaken at the start of the project, was based on a suite of 10 videos, with each one being randomly selected from each reef, in each month, between October 2015 and February 2016. The MaxN of all fish and cephalopod taxa in each video was recorded in five-minute intervals, for 60 minutes. This provided an estimate of how the fish fauna recorded changed over time following the deployment of the BRUV and the dispersal of the bait plume.

The MaxN data were subjected to the DIVERSE routine in PRIMER 7 (Clarke and Gorley, 2015) to determine the number of taxa, total MaxN (*i.e.* the sum of the MaxN value for all taxa) and the Simpson's Index for each time interval in each replicate video. The resultant values for each univariate metric were then averaged to provide a single value for each five-minute interval at each reef and plotted as separate rarefaction curves.

Changes in species composition throughout time on each reef were also examined. In this case, the MaxN values of each species in each five-minute interval at each reef were square root transformed to down-weight the contribution of relatively abundant taxa, compared to those with lower MaxN values (Clarke and Green, 1988; Veale et al., 2014). The transformed data were then averaged across replicates for each reef for each five-minute interval and used to construct Bray-Curtis resemblance matrices. The matrix for each reef was firstly subjected to hierarchical agglomerative clustering (CLUSTER; Clarke et al., 2014b) to determine the sites that were 95% similar in terms of their species composition. Each matrix was also used to construct a non-metric Multi-Dimensional Scaling (nMDS) ordination plot (Clarke, 1993), which provides a visual representation of the differences in fish communities with time for both reefs. Circles denoting sites that had a similarity of 95% were then overlaid onto the nMDS plot.

The square-root transformed MaxN data for each time interval on both reefs were used to construct a shade-plot to visualise the trends exhibited by the abundances of the various taxa over time on each reef (Clarke et al., 2014a). The shade plot is a visualization of this averaged data matrix, where a white space for a species demonstrates that the species was not recorded, while the depth and colour of shading, ranging from grey shades through the spectrum to black, represents increasing values for the abundance of that species (Clarke et al., 2014a; Valesini et al., 2014). The averaged samples (on the x axis of the plot) are ordered from lowest to highest time interval for each reef. Fish and cephalopod taxa (on the y axis of the plot) are ordered to optimise the seriation statistic ρ by non-parametrically correlating their resemblances to the distance structure of a linear sequence (Clarke et al., 2014b).

3.3.6.2. Primary analysis

Four videos, for each month, for each reef, were chosen at random and analysed. This involved recording the MaxN of each fish and cephalopod taxon from the moment the BRUV settled onto the substrate until 45 minutes (see Chapter 3.4.1).

3.3.6.2.1 Univariate diversity and abundance indices

The MaxN data for each taxon in each video were subjected to the DIVERSE routine to calculate the number of taxa, total MaxN and Simpson's Index, as well as the MaxN data for three recreational species, *C. auratus*, *Pseudocaranx* spp. and *S. hippos*, to make a single data matrix. Prior to statistical testing each of the above six biotic variables were tested to ascertain if a transformation was required to meet the assumptions of ANalysis Of VAriance (ANOVA), *i.e.* homogeneity of variance and normality. This was achieved by plotting the $\log_e$ mean against the $\log_e$ standard deviation of every group of replicate samples and determining the slope of the relationship, comparing it to the criteria in Clarke et al. (2014b). This analysis indicated that the number of taxa and Simpson's Index required no transformation, the MaxN of *C. auratus* and *Pseudocaranx* spp. needed a square and fourth-root transformation, respectively and for total MaxN and the MaxN of *S. hippos* a log(*X*+1) transformation was necessary.

Following transformation, each of the six dependent variables was subjected to a two-way ANOVA to determine if the variable differed significantly between reefs (2 levels; Bunbury and Dunsborough) and among months (9 levels; October-June/July) and whether the reef×month interaction was significant. ANOVA tests were conducted using the Statistical Package for the Social Sciences (SPSS; Pallant, 2010). In these, and all subsequent tests, the null hypothesis of no significant difference among *a priori* groups was rejected if the significance level (p) was ≤0.05. When multiple factors in a univariate or multivariate ANOVA (*i.e.* PERMANOVA) were significant, the relative influence of each term in the model was quantified by calculating their contribution to the total of the mean squares. The outputs of the ANOVA tests were then used to select the appropriate factors to display on graphs. Note that untransformed, rather than back transformed, data were used for this purpose as the latter can mask patterns in the data (Rothery, 1988).

3.3.6.2.2. Multivariate analysis of guilds

The proportion of both the number of individuals and species in each of the habitat and feeding guilds were tested to determine if they differed between reefs, among months and whether the reef×month interaction was significant. As these data are multivariate in nature, Permutational Multivariate Analysis of Variance (PERMANOVA) tests were employed, using PRIMER 7 (Anderson, 2001; Anderson et al., 2008). Prior to analysis the percentage contribution data were square-root transformed and used to produce four separate Euclidean distance matrices. Each matrix was, in turn, subjected to two-way PERMANOVA and the results visualised as stacked bar graphs.

3.3.6.2.3. Multivariate analysis of fish community composition

The species composition data (*i.e.* the MaxN of each fish and cephalopod taxon) were transformed with dispersion weighting, followed by a square-root transformation. These transformed data were then used to construct a Bray-Curtis resemblance matrix, which was, in turn, subjected to two-way PERMANOVA using the same design as utilised in the multivariate analysis of guilds.

Dispersion weighting was employed to weight the contributions of highly abundant and rare taxa as many of them differed in their MaxN and the consistency in which they were recorded (Clarke et al., 2014b). This technique specifically downweights taxa whose abundances vary greatly among replicates (*e.g.* schooling species such as *T. novaezelandiae*) compared to those that occur more consistently (*e.g. C. auricularis*). The MaxN scores for each taxon were divided by the mean index of dispersion, *i.e.* the average of the variance to mean ratio in each video, in a particular reef, in a given month. This ensures that while the abundances of taxa differ, each has a similar variability structure (Clarke et al., 2006). A square-root transformation was then employed to balance the contributions of rare and common species.

The dispersion-weighted and square-root transformed data were also averaged over samples for each reef in each month and used to construct a Bray-Curtis resemblance matrix. This was subjected to a nMDS (Clarke, 1993) which provided a visual demonstration of the extent to which fish community composition differed across both reef in each month. The trajectory of the samples between months for each reef were overlain to enable ‘tracking’ of the temporal changes.

A shade plot (see Chapter 3.3.6.1) was constructed from the transformed and averaged data matrix to illustrate the trends exhibited by taxa with respect to reef and month. Note that as 60 species were recorded over the duration of the study, many of which only occurred in a few samples, the shade plot was restricted to those 34 species that had a frequency of occurrence of ≥ 5%. Samples on the x axis were arranged in chronological order separately for both reefs, while the taxa (y axis) were arranged in an order to optimise their seriation.

Finally, nMDS plots for each reef were produced from the Bray-Curtis resemblance matrix to illustrate the temporal changes in fish faunal composition of the six most abundant recreationally targeted fish taxa that occurred on each reef. Segmented bubbles of proportional sizes, representing the dispersion-weighted, square-root transformed and averaged MaxN abundances of the taxa were overlaid on the nMDS to illustrate how the abundances of those key species changed over time on each reef.

3.4. Results

3.4.1. Preliminary analysis

Rarefaction curves for the mean number of taxa, total MaxN and the Simpson's Index, for both the Bunbury and Dunsborough reefs, reached an asymptote prior to the 60 min mark (Figs. 3.6 to 3.8). Approximately 95% of all taxa, and the Simpson's Index, were recorded on the Dunsborough reef after 40 mins, and after 45 mins at Bunbury (Table 3.2). Similar trends were also found for total MaxN, with ~95% of the total value being recorded after 35 mins in Dunsborough and 50 mins at Bunbury.

Table 3.2. Mean percentage number of taxa (% Taxa), total MaxN (%MaxN) and Simpson's Index (%Simp) recorded after analysing BRUV footage from the (a) Bunbury and (b) Dunsborough artificial reefs with time. Percentage values approximately at/or above 95% are highlighted in grey.

Time	(a) Bunbury			(b) Dunsborough		
(mins)	%Taxa	%MaxN	%Simp	%Taxa	%MaxN	%Simp
5	45.6	47.1	70.5	36.2	41.3	79.5
10	54.4	53.8	76.7	40.6	80.2	75.8
15	59.7	64.8	82.5	55.1	87.5	80.1
20	66.7	72.4	83.3	62.3	89.6	83.9
25	73.7	74.8	87.9	69.6	91.5	88.6
30	77.2	82.4	89.7	78.3	93.1	90.9
35	87.7	87.1	91.3	87.0	94.8	92.8
40	91.2	90.5	95.9	95.7	97.1	96.7
45	94.7	91.4	96.5	97.1	97.9	97.6
50	94.7	94.8	98.0	98.5	99.0	99.3
55	100.0	98.1	99.5	98.5	99.2	99.3
60	100.0	100.0	100.0	100.0	100.0	100.0

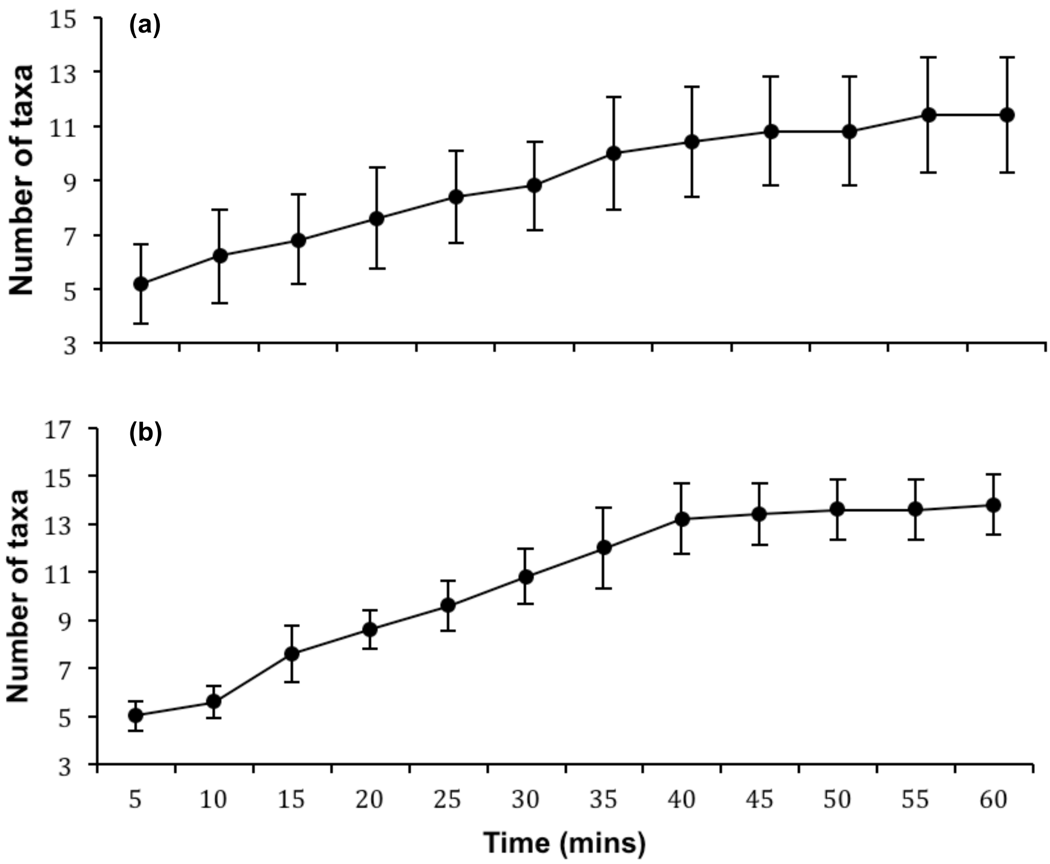


Fig. 3.6. Rarefaction curves for the mean number of taxa *vs* time found on the (a) Bunbury and (b) Dunsborough artificial reefs from BRUV footage. Error bars represent ±1 standard error.

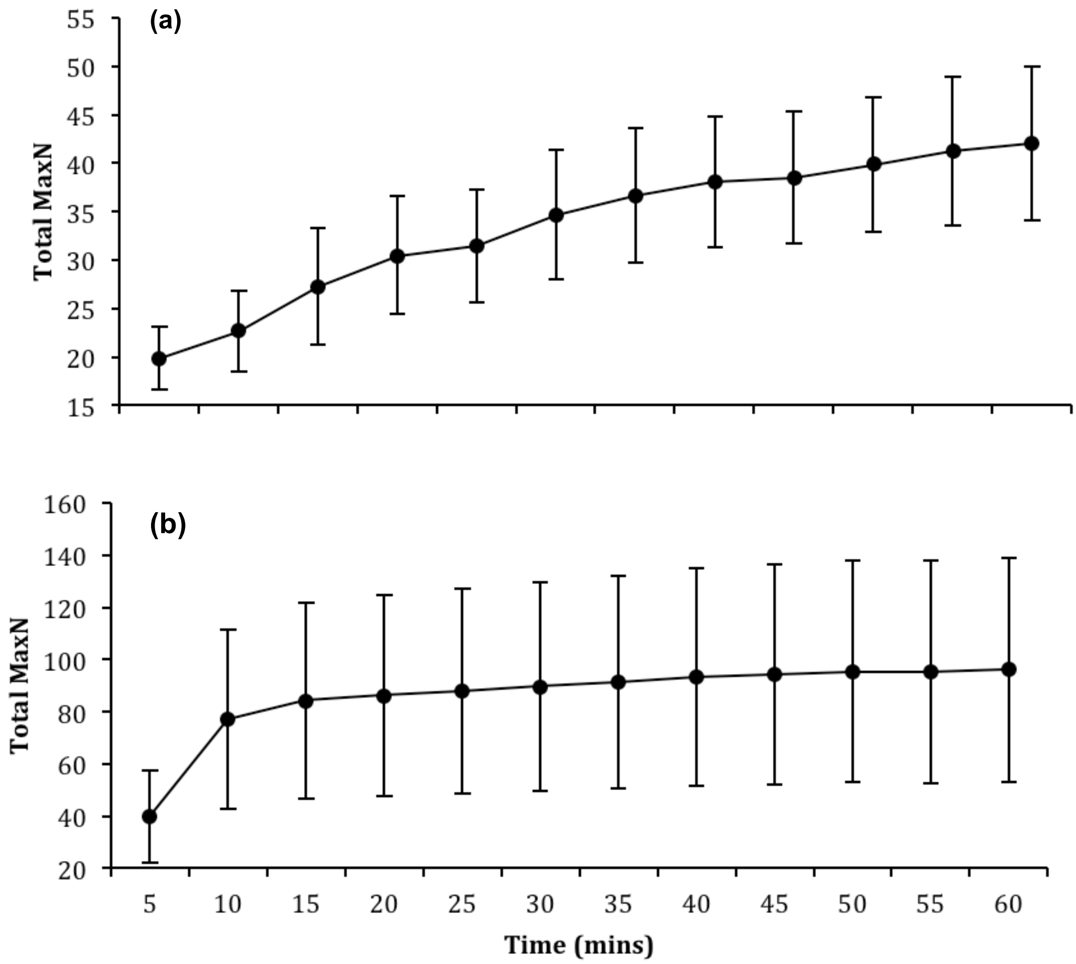


Fig. 3.7. Rarefaction curves for the mean total MaxN vs time found on the (a) Bunbury and (b) Dunsborough artificial reefs from BRUV footage. Error bars represent ±1 standard error.

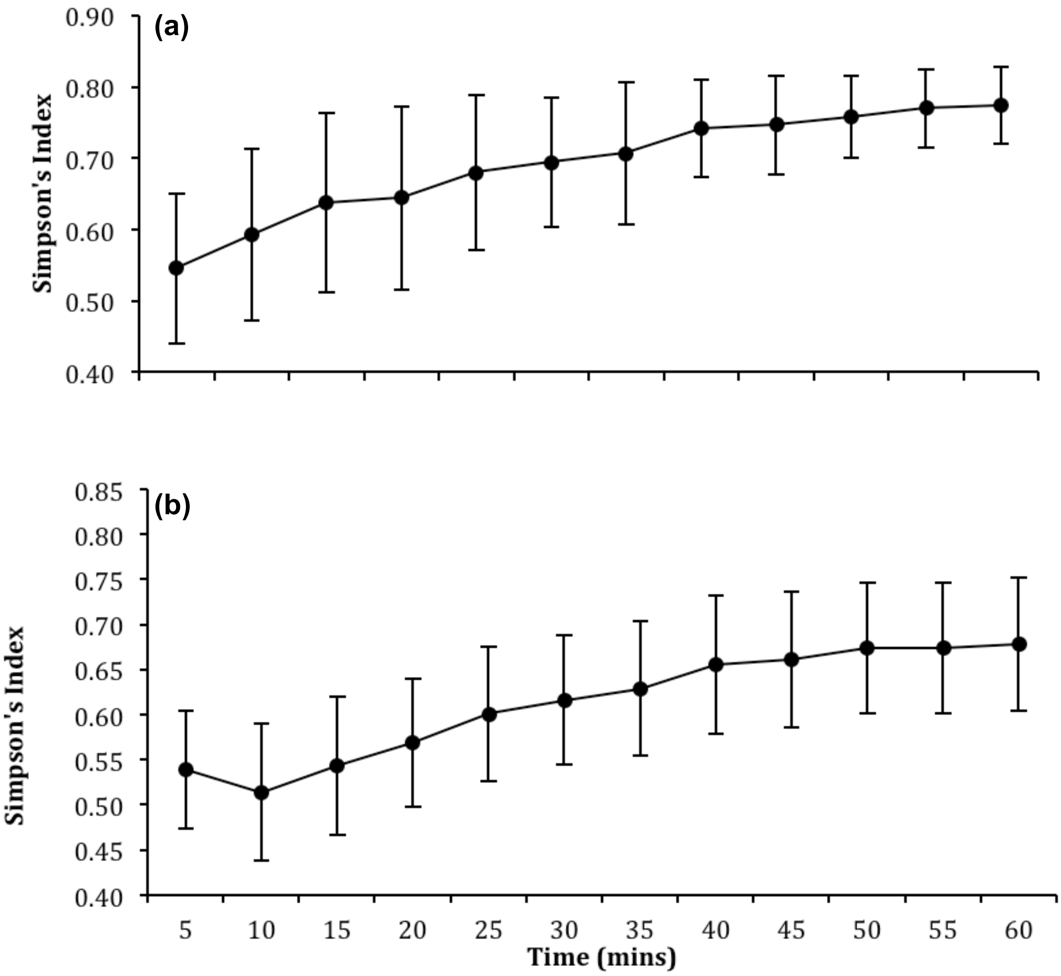


Fig. 3.8. Rarefaction curves for the mean Simpson's Index vs time found on the (a) Bunbury and (b) Dunsborough artificial reefs from BRUV footage. Error bars represent ±1 standard error.

Ordination plots for the square-root transformed fish community data for both reefs showed a sequential progression with time. The lowest amount of time (5 mins) occurred on the left side of the plot, with the largest amount of time (60 mins) on the opposite side (Figs. 3.9a and 3.9b). The distance between pairs of points decreased with time, indicating the faunal composition recorded became more similar as more of the videos were watched and MaxN scored. When circles representing 95% Bray-Curtis similarity were overlain on each of the ordination plots, samples from 35-60 minutes formed a group at the Bunbury reef, and between 40-60 minutes at Dunsborough. Thus, fish fauna composition was 95% similar on both reefs after 40 minutes.

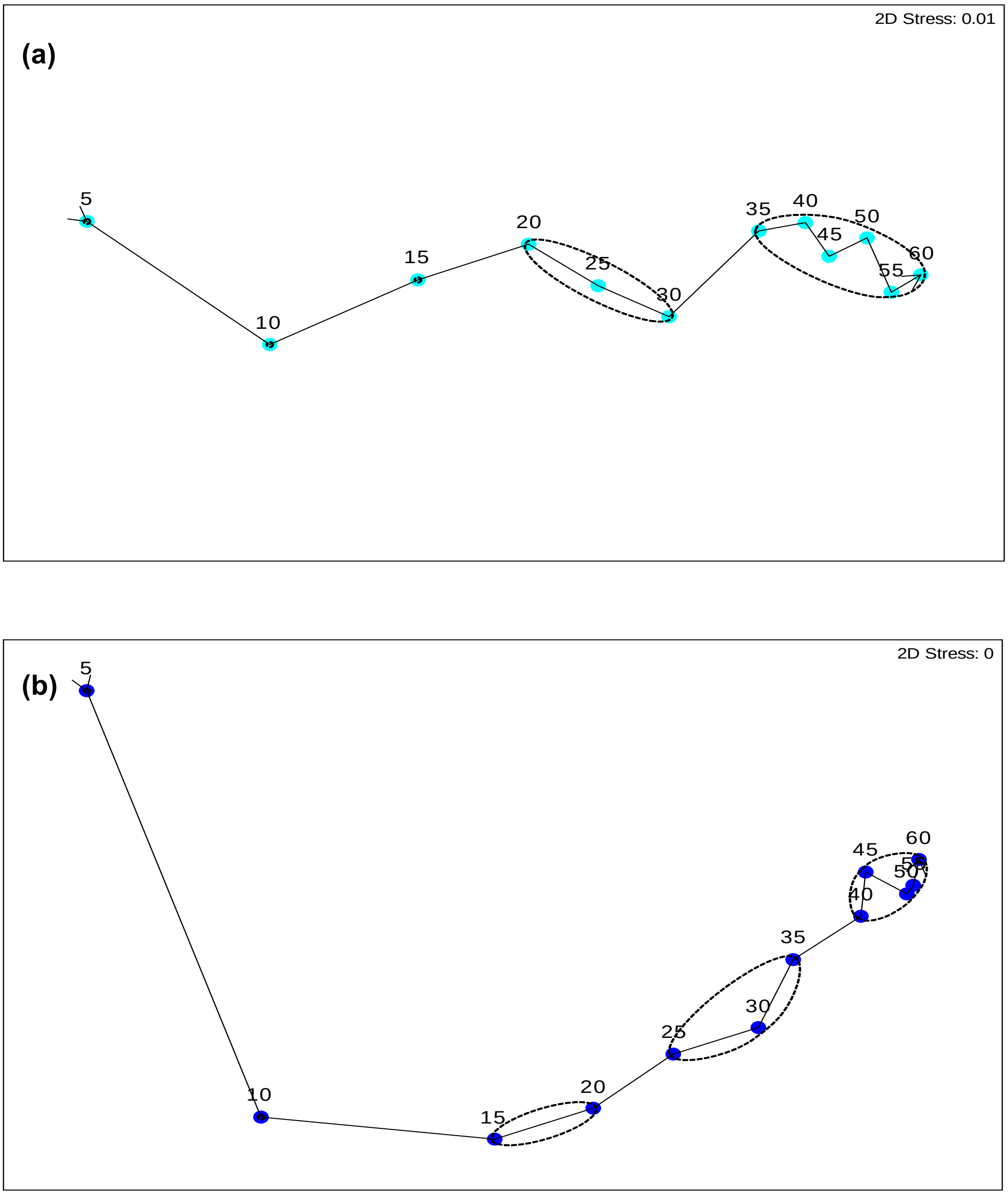


Fig. 3.9. nMDS ordination plots, derived from a Bray-Curtis similarity matrix, constructed from the square-root transformed and averaged MaxN fish community data recorded from consecutive five minute intervals of video footage recorded from the (a) ● Bunbury and (b) ● Dunsborough artificial reefs. Dotted line circles encompass samples that have a Bray-Curtis similarity of ≥ 95%.

The shade plot illustrates that very few new taxa were recorded after 45 minutes and that the MaxN abundance for those taxa that were present typically remained similar (Fig. 3.10). For most taxa, including abundant ones such as the Western Footballer *Neatypus obliquus, C. auricularis* and *T.*

novaezelandiae, their MaxN changed very little over the duration of the video. Moreover, even for those species whose abundance did change with increasing time, *e.g. Pseudocaranx* spp. and Silverbelly *Parequula melbournensis,* these values changed little after 45 minutes on both reefs.

These results demonstrate that it is not necessary to analyse the entirety of a one-hour video to adequately quantify the univariate and multivariate characteristics of the fish fauna of the Bunbury and Dunsborough artificial reefs. As such, only the first 45 minutes of each video will be analysed. This result is supported by the findings of Watson (2006), who conducted a BRUV based study on reef fish communities of the Houtman Abrolhos Islands, Western Australia. She found, from examining the cumulative percentage of species recorded over time, that the majority of species were recorded after 36 minutes of video.

Fig. 3.10. Shade plot, constructed using the square-root transformed and averaged MaxN abundances of each taxa recorded from consecutive five minute intervals of video footage recorded from the recorded in consecutive five minute internals on the ● Bunbury and ● Dunsborough artificial reefs. Numbers above the reef symbols indicate the number of minutes of video that a sample represented. White space denotes the absence of a taxon, with the grey scale represents the transformed and averaged MaxN abundances.

3.4.2. Primary analysis

3.4.2.1. Abundance and frequency of occurrence

Sixty taxa were identified, over the 71 videos analysed, from the Bunbury and Dunsborough artificial reefs, comprising 48 teleosts, nine elasmobranchs and three cephalopods (Table 3.3). Taxa that could not be identified to the species level were either grouped to the family (*i.e.* Pempherididae and Monocanthidae*)* or genus level (*i.e. Pseudocaranx*). The taxa that contributed the highest proportion to the total MaxN were *N. obliquus* (15%), *Pesudocaranx* spp. (14.2%), *C. auricularis* (14.1%) and the Elongate Bullseye *Parapriacanthus elongates* (12.8%), with all others representing < 5% (Table 3.3). Among the 50 taxa recorded on the Bunbury reef *C. auricularis* was by far the most abundant representing 30.4% of the total MaxN, with *N. obliquus* (11.4%), *P. melbournensis* (10.4%) and *Pseudocaranx* spp. (10%) all occurring in substantial numbers (Table 3.3). A total of 49 species were recorded on the Dunsborough reef, with *P. elongatus* being the most abundant (17.5%), closely followed by *N. obliquus* (16.3%) and *Pseudocaranx* spp. (15.8%).

Overall, the top ten most abundant taxa contributed 81% to the total MaxN, with each one being recorded at the Dunsborough reef and collectively contributing 84% to its total, while nine of the ten (*i.e.* all except, *P. elongates*) were found at Bunbury, representing 71% of its total. Among the recreationally targeted species, *C. auratus* and the Tarwhine *Rhabdosargus sarba* were recorded at Dunsborough and not Bunbury, while the reverse was true for Mulloway, *Argyrosomus japonicus*, although none of these species were particularly abundant (< 0.5% of the mean MaxN).

Among the 60 taxa recorded on either artificial reef, only six, *i.e. C. auricularis*, Western Smooth Box Fish *Anoplocapros amygdaloides*, *S. hippos*, *Pseudocaranx* spp., *P. melbournensis* and the Southern Eagle Ray, *Myliobatus australis* were recorded in more the 50% of the videos (Table 3.4). Of these species, *C. auricularis* was the most frequently recorded appearing in >90% of videos, whereas 26 taxa were recorded in <5% of videos. The top ten taxa in terms of overall frequency of occurrence were also those that were most frequently sighted on each reef, although their values sometimes differed. For example, while *Pseudocaranx* spp. were recorded on 94% of videos at Dunsborough, this taxon only occurred in 49% of videos at Bunbury (Table 3.4). Similar, albeit less marked, trends were found for *N. obliquus* (67% vs 31%) and Western Talma *Chelmonops curiosus* (61% vs 34%). Generally, individual taxa were found less frequently on the Bunbury than Dunsborough artificial reefs, although this was not true for both the Western

Butterflyfish *Chaetodon assarius* (17% vs 0%) and Masked Stingaree *Trygonoptera personata* (11% vs 3%; Table 3.4).

Table 3.3. Habitat (HG) and feeding (FG) guilds, rankings (R), MaxN (N) and percentage contribution to total MaxN (%) for each taxon recorded on the Bunbury and Dunsborough reefs combined and individually on BRUV footage between October 2015 and June/July 2016. The total number of taxa and overall MaxN are also provided. Habitat guild: benthic (B), epibenthic (E) and pelagic (P). Feeding guild: zoobenthivore (ZB), zooplanktivore (ZP), piscivore (PV), omnivore (OV) and herbivore (H). Species targeted by recreational fishers are shaded. * denotes cephalopod taxa

			Overall			Bunbury			Dunsborough		
Taxa	**HG**	**FG**	**R**	**N**	**%**	**R**	**N**	**%**	**R**	**N**	**%**
Neatypus obliquus	E	ZP	1	8.40	15.00	2	3.50	11.40	2	13.20	16.30
Pseudocaranx spp.	E	ZB	2	8.00	14.20	4	3.10	10.00	3	12.80	15.80
Coris auricularis	E	ZP	3	7.90	14.10	1	9.40	30.40	4	6.50	8.10
Parapriacanthus elongates	B	ZP	4	7.20	12.80				1	14.10	17.50
Pempherididae spp.	B	ZP	5	3.10	5.50	8	0.80	2.70	5	5.30	6.60
Trachurus novaezelandiae	P	ZB	6	2.90	5.10	13	0.40	1.20	5	5.30	6.60
Parequula melbournensis	E	ZP	7	2.50	4.40	3	3.20	10.40	12	1.80	2.20
Seriola hippos	P	PV	8	2.10	3.70	5	1.40	4.60	9	2.70	3.30
Pempheris klunzingeri	B	ZP	9	1.90	3.40	7	1.10	3.50	8	2.80	3.40
Diodon nicthemerus	B	ZB	10	1.80	3.20	35	0.10	0.20	7	3.40	4.30
Anoplocapros amygdaloides	E	ZB	11	1.70	3.00	6	1.30	4.30	10	2.00	2.50
Austrolabrus maculatus	E	ZB	12	1.30	2.40	9	0.70	2.20	11	1.90	2.40
Chelmonops curiosus	B	ZB	13	0.70	1.20	10	0.50	1.70	13	0.90	1.10
Trygonorrhina dumerilli	B	ZB	14	0.60	1.10	12	0.40	1.40	14	0.80	1.00
Myliobatus australis	B	ZB	15	0.60	1.10	10	0.50	1.70	16	0.70	0.90
Parapercis haackei	B	ZB	16	0.50	0.90	24	0.10	0.50	14	0.80	1.00
Dasyatis brevicaudata	B	ZB	17	0.40	0.70	20	0.20	0.70	17	0.60	0.70
Cheilodactylus gibbosus	E	OV	18	0.30	0.60	24	0.10	0.50	18	0.50	0.60
Monocanthidae spp.	E	OV	19	0.30	0.60	15	0.30	1.10	24	0.30	0.30
Aracana aurita	E	ZB	20	0.30	0.50	18	0.30	0.80	20	0.30	0.40
Pentaceropsis recurvirostris	B	OV	21	0.30	0.50	20	0.20	0.70	20	0.30	0.40
Notolabrus parilus	E	ZB	22	0.30	0.50	16	0.30	0.90	24	0.30	0.30
Upeneichthys vlamingii	E	ZB	23	0.20	0.40	23	0.20	0.60	20	0.30	0.40
Anoplocapros lenticularis	E	ZB	24	0.20	0.40	20	0.20	0.70	24	0.20	0.30
Parapercis ramsayi	B	ZB	25	0.20	0.40	30	0.10	0.30	20	0.30	0.40
Chrysophorus auratus	E	ZB	26	0.20	0.40				19	0.40	0.50
Argyrosomus japonicus	P	PV	27	0.20	0.30	13	0.40	1.20			
Tilodon sexfasciatus	E	ZP	28	0.20	0.30	30	0.10	0.30	24	0.30	0.30
Chaetodon assarius	E	OV	29	0.10	0.30	16	0.30	0.90			
Choerodon rubescens	E	ZB	30	0.10	0.20	24	0.10	0.50	33	0.10	0.10
Apogon victoriae	B	ZP	31	0.10	0.20	18	0.30	0.80			
Glaucosoma hebraicum	E	ZB	32	0.10	0.20	24	0.10	0.50	33	0.10	0.10
Arripis truttaceus	P	PV	33	0.10	0.20	40	0.00	0.10	28	0.20	0.20
Suezichthys cyanolaemus	E	ZB	34	0.10	0.20				28	0.20	0.20
Aptychotrema vincentiana	B	ZB	35	0.10	0.20	40	<0.10	0.10	28	0.20	0.20
Platycephalus speculator	B	ZB	36	0.10	0.20	30	0.10	0.30	33	0.10	0.10
Chromis westaustralis	E	ZP	37	0.10	0.20				28	0.20	0.20
Trygonoptera personata	B	ZP	38	0.10	0.10	28	0.10	0.40			
Platycephalus longispinis	B	ZB	39	0.10	0.10	30	0.10	0.30	33	0.10	0.10
Rhabdosargus sarba	E	ZB	40	0.10	0.10				28	0.10	0.20
Eubalichthys mosaicus	E	OV	41	0.10	0.10	28	0.10	0.40			
Trygonoptera mucosa	B	ZP	42	0.10	0.10	40	<0.10	0.10	33	0.10	0.10
Eupetrichthys angustipes	B	ZB	43	0.10	0.10	30	0.10	0.30			
Orectolobus maculatus	B	ZB	44	0.00	0.10				33	0.10	0.10
Haliocheres brownfieldi	E	ZB	45	0.00	0.10	40	<0.10	0.10	33	0.10	0.10
Mustelus antarcticus	E	ZB	46	0.00	0.10	40	<0.10	0.10	33	0.10	0.10
Scobinichthys granulatus	E	OV	47	0.00	0.10	35	0.10	0.20			
Octopus tetricus *	E	ZB	48	0.00	0.10	40	<0.10	0.10			
*Sepioteuthis australis**	E	ZB	49	0.00	0.10	35	0.10	0.20			
Achoerodus gouldii	E	ZB	50	0.00	0.10	35	0.10	0.20			
Trygonoptera ovalis	B	ZB	51	0.00	0.10	40	<0.10	0.10			
Sepia apama *	E	ZB	52	0.00	0.10	35	0.10	0.20			
Meuschenia venusta	E	OV	53	0.00	0.10				33	0.10	0.10
Ophthalmolepis lineolatus	E	ZB	54	0.00	0.10	40	<0.10	0.10			
Parupeneus chrysopleuron	E	ZB	55	0.00	<0.10	40	<0.10	0.10			
Enoplosus armatus	E	ZB	56	0.00	<0.10	40			34	<0.10	<0.10
Dactylophora nigricans	E	OV	57	0.00	<0.10	40			34	<0.10	<0.10
Hypoplectrodes nigroruber	E	PV	58	0.00	<0.10	40			34	<0.10	<0.10
Siganus fuscescens	E	H	59	0.00	<0.10	40	<0.10	0.10			
Pseudorhombus jenynsii	B	ZB	60	0.00	<0.10	40	<0.10	0.10			
Total number of taxa				**60**			**50**			**49**	
Total mean MaxN				**56.1**			**30.9**			**80.7**	

Table 3.4. Residency guilds (RG), rankings (R) and percentage occurrence (%) for all identified taxa overall, as well as at the Bunbury and Dunsborough reefs individually, between October 2015 and July 2016 inclusive. Residency guilds: transient (T), resident level three (R3), resident level two (R2) and resident level one (R1). Species targeted by recreational fishers are highlighted. * denotes cephalopod taxa.

		Overall		Bunbury		Dunsborough	
Taxa	**RG**	**R**	**%**	**R**	**%**	**R**	**%**
Coris auricularis	R1	1	90.1	1	91.4	2	88.9
Anoplocapros amygdaloides	R1	2	78.9	3	74.3	3	83.3
Seriola hippos	R1	3	74.6	2	77.1	4	72.2
Pseudocaranx spp.	R1	4	71.8	5	48.6	1	94.4
Parequula melbournensis	R1	5	64.8	4	60.0	5	69.4
Myliobatus australis	R1	6	52.1	5	48.6	10	55.6
Neatypus obliquus	R1	7	49.3	9	31.4	6	66.7
Chelmonops curiosus	R1	9	47.9	8	34.3	7	61.1
Austrolabrus maculatus	R1	8	47.9	6	37.1	8	58.3
Trygonorrhina dumerilli	R1	10	47.9	6	37.1	8	58.3
Parapercis haackei	R1	11	33.8	19	11.4	10	55.6
Dasyatis brevicaudata	R1	13	28.2	12	20.0	13	36.1
Aracana aurita	R1	12	28.2	10	25.7	14	30.6
Cheilodactylus gibbosus	R1	14	26.8	19	11.4	12	41.7
Notolabrus parilus	R2	15	23.9	10	25.7	21	22.2
Monocanthidae spp.	R2	16	22.5	12	20.0	18	25.0
Pentaceropsis recurvirostris	R2	17	21.1	15	17.1	18	25.0
Upeneichthys vlamingii	R2	18	21.1	15	17.1	18	25.0
Anoplocapros lenticularis	R1	19	21.1	12	20.0	21	22.2
Parapercis ramsayi	R2	20	19.7	24	8.6	16	30.6
Diodon nicthemerus	R2	21	18.3	37	2.9	14	33.3
Tilodon sexfasciatus	R2	22	18.3	24	8.6	17	27.8
Pempheris klunzingeri	R1	23	12.7	19	11.4	25	13.9
Choerodon rubescens	R2	24	12.7	18	14.3	27	11.1
Chrysophorus auratus	R3	26	9.9			23	19.4
Suezichthys cyanolaemus	R3	27	9.9			23	19.4
Glaucosoma hebraicum	R2	25	9.9	19	11.4	28	8.3
Aptychotrema vincentiana	R3	29	8.5	37	2.9	25	13.9
Chaetodon assarius	T	28	8.5	15	17.1		
Trygonoptera personata	R2	30	7.0	19	11.4	36	2.8
Trygonoptera mucosa	R3	31	5.6	37	2.9	28	8.3
Platycephalus speculator	R3	34	5.6	30	5.7	31	5.6
Platycephalus longispinis	R3	32	5.6	24	8.6	36	2.8
Eupetrichthys angustipes	R3	33	5.6	24	8.6	36	2.8
Orectolobus maculatus	R3	39	4.2			28	8.3
Trachurus novaezelandiae	T	35	4.2	37	2.9	31	5.6
Haliocheres brownfieldi	R3	40	4.2	37	2.9	31	5.6
Pempherididae spp	R3	36	4.2	30	5.7	36	2.8
Apogon victoriae	R2	37	4.2	24	8.6		
Eubalichthys mosaicus	R2	38	4.2	24	8.6		
Parapriacanthus elongatus	R3	41	2.8			31	5.6
Chromis westaustralis	R3	43	2.8			31	5.6
Arripis truttaceus	R2	44	2.8	37	2.9	36	2.8
*Octopus tetricus**	R3	46	2.8	37	2.9	36	2.8
Mustelus antarcticus	T	47	2.8	37	2.9	36	2.8
Trygonoptera ovalis	R3	50	2.8	37	2.9	36	2.8
Ophthalmolepis lineolatus	R3	52	2.8	37	2.9	36	2.8
Argyrosomus japonicus	R2	42	2.8	30	5.7		
Scobinichthys granulatus	R3	45	2.8	30	5.7		
*Sepioteuthis australis**	R3	48	2.8	30	5.7		
Achoerodus gouldii	R3	49	2.8	30	5.7		
*Sepia apama**	R2	51	2.8	30	5.7		
Rhabdosargus sarba	R3	53	1.4			36	2.8
Enoplosus armatus	R3	55	1.4			36	2.8
Dactylophora nigricans	R3	56	1.4			36	2.8
Hypoplectrodes nigroruber	R3	57	1.4			36	2.8
Meuschenia venusta	R3	58	1.4			36	2.8
Parupeneus chrysopleuron	R2	54	1.4	37	2.9		
Siganus fuscescens	R3	59	1.4	37	2.9		
Pseudorhombus jenynsii	R3	60	1.4	37	2.9		

3.4.2.2. Univariate diversity and abundance indices

Two-way ANOVA showed that the number of taxa differed significantly between reefs, among months and with the reef×month interaction (Table 3.5a). The reef main effect explained by far the greatest proportion of the variance (76.1%), with month and the interaction term being relatively minor (11.4% and 8.6%, respectively). The mean number of taxa was significantly higher at Dunsborough than Bunbury in each of the months and particularly so in December (14 *vs* 5) and April (16 *vs* 6, respectively; Fig. 3.11). This difference was far less marked in February (14 *vs* 13.5 in Dunsborough and Bunbury, respectively), which explains the relatively minor interaction between reef and month. The number of taxa displayed a general trend of increasing values over spring and summer months, though in Bunbury these values began to decrease after February, whilst in Dunsborough this began after April, with these differences also contributing to the significant interaction (Fig. 3.11).

Table 3.5. Degrees of freedom (df), mean squares (MS), percentage of variance explained by the mean squares (% var), F-values (F) and significance levels (*p*) from a two-way ANOVA on (a) number of taxa, (b) total MaxN, (c) Simpson's Index and the MaxN of (d) *Chrysophorus auratus*, (e) *Pseudocaranx* spp. and (f) *Seriola hippos*, recorded on the Bunbury and Dunsborough artificial reefs between October 2015 and June/July 2016. Significant results are highlighted in bold (*p*<0.05).

		(a) Number of taxa				**(b) Total MaxN**			
Factors	**df**	**MS**	**% var**	**F**	***p***	**MS**	**% var**	**F**	***p***
Reef	1	**221.090**	**76.10**	**19.600**	**0.001**	**2.400**	**79.50**	**28.010**	**0.001**
Month	8	**33.130**	**11.40**	**2.940**	**0.009**	**0.200**	**6.60**	**2.310**	**0.033**
Reef×Month	8	**24.970**	**8.60**	**2.210**	**0.041**	**0.330**	**11.00**	**3.890**	**0.001**
Residual	53	11.290	3.90			0.090	2.90		

		(c) Simpson's Index				**(d) *Chrysophorus auratus* MaxN**			
Factors	**df**	**MS**	**% var**	**F**	***p***	**MS**	**% var**	**F**	***p***
Reef	1	0.010	12.70	0.560	0.459	**1.357**	**75.50**	**7.020**	**0.011**
Month	8	0.020	32.40	1.370	0.233	0.124	6.90	0.640	0.739
Reef×Month	8	0.020	31.00	1.290	0.267	0.124	6.90	0.640	0.739
Residual	53	0.020	24.00			0.193	10.70		

		(e) *Pseudocaranx* spp. MaxN				**(f) *Seriola hippos* MaxN**			
Factors	**df**	**MS**	**% var**	**F**	***p***	**MS**	**% var**	**F**	***p***
Reef	1	**16.400**	**86.20**	**65.690**	**0.001**	**0.410**	**47.90**	**5.460**	**0.025**
Month	8	**1.250**	**6.60**	**5.020**	**0.001**	**0.240**	**28.10**	**3.190**	**0.008**
Reef×Month	8	**1.110**	**5.90**	**4.450**	**0.001**	0.130	15.10	1.720	0.127
Residual	53	0.250	1.30			0.080	8.80		

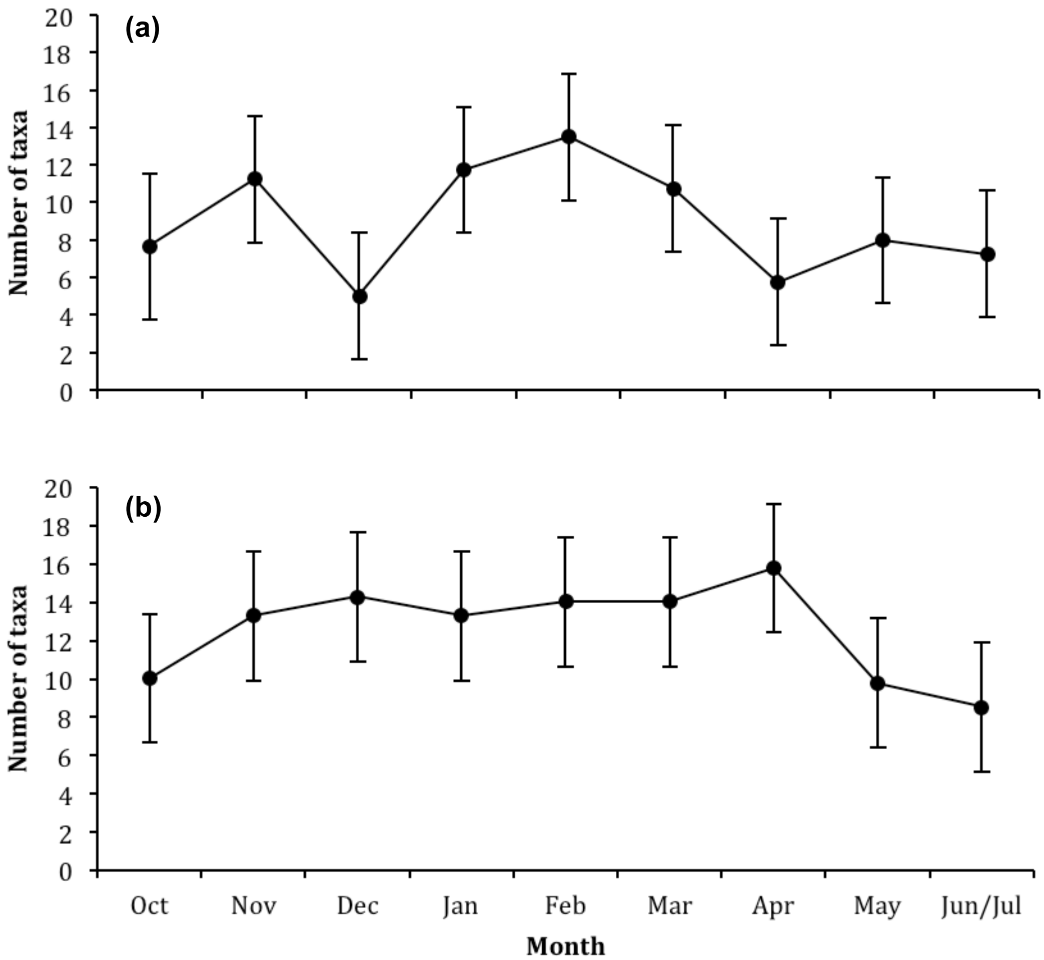


Fig. 3.11. Mean number of taxa recorded on the (a) Bunbury and (b) Dunsborough artificial reefs in each month between October 2015 and June/July 2016. Error bars represent ± 95% confidence intervals.

Significant differences in total MaxN were also recorded between reefs, months and the one-way interaction between these main factors (Table 3.5b). Almost 80% of the variation in this variable was explained by reef, followed by the reef×month interaction and month (11% and 6.6%, respectively). In all months, except October and November, total MaxN was greater on the Dunsborough reef compared to Bunbury (Fig. 3.12). While mean total MaxN was relatively consistent among months at Bunbury ranging from 16 in April to 55 in November, values for this varied far more at Dunsborough (22 in October to 177 in March). Among months at Bunbury, the greater mean total MaxN values were recorded in the spring and summer months, excluding December, compared to the autumn and winter months. At Dunsborough, higher values occurred in summer and autumn (typically >100), compared to winter and spring (<53). These differences in the monthly trends at each reef were, in part, responsible for the significant reef×month interaction.

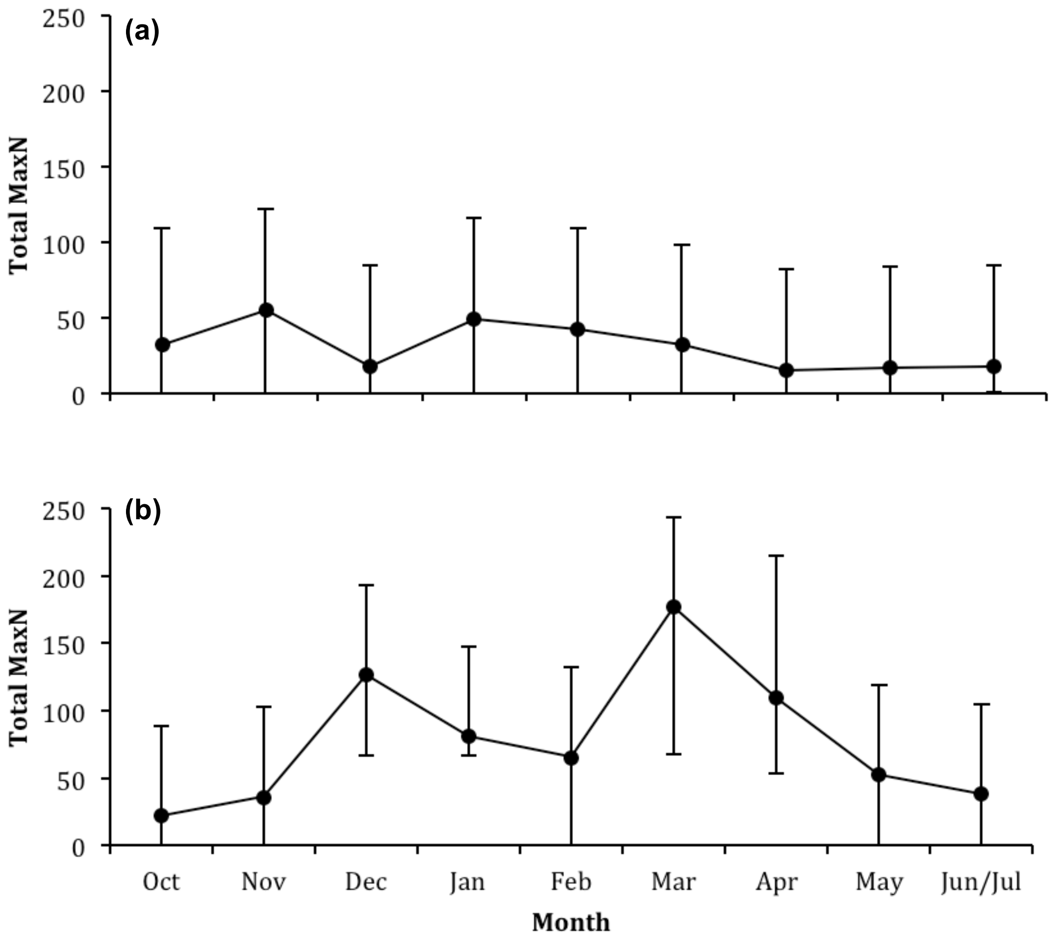


Fig. 3.12. Mean total MaxN recorded on the (a) Bunbury and (b) Dunsborough artificial reefs in each month between October 2015 and June/July 2016. Error bars represent ± 95% confidence intervals.

A two-way ANOVA demonstrated Simpson's Index did not differ significantly among any main effect or interaction (Table 3.5c). Mean values ranged from a low of 0.62 during November at Dunsborough to a high of 0.88 during the following month, on the same reef (data not shown).

The MaxN of *C. auratus* differed significantly among only the reef main effect, which explained 75.5% of the observed variance (Table 3.5d). The average MaxN at Dunsborough was 0.42, while this species was not recorded on the Bunbury artificial reef (Fig. 3.13).

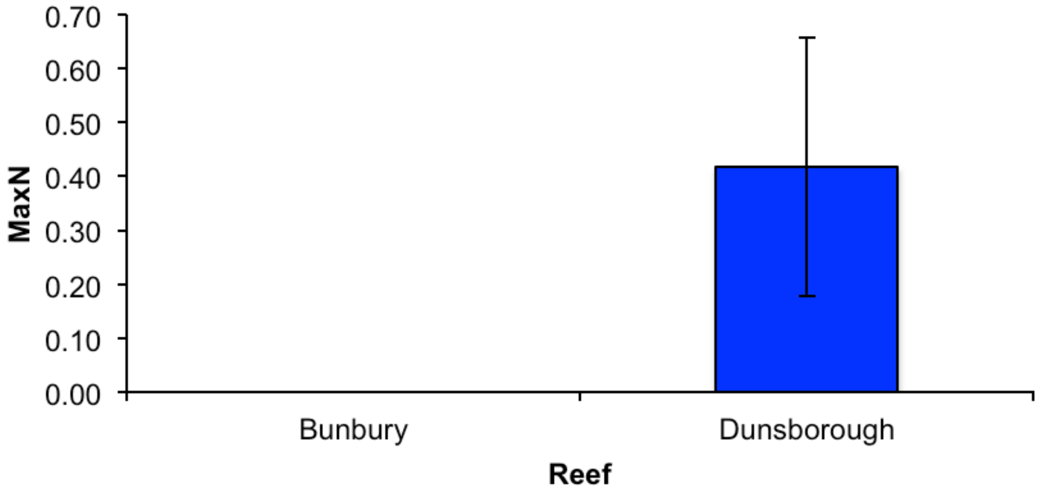


Fig. 3.13. Mean MaxN of *Chrysophorus auratus* recorded on the Bunbury and Dunsborough artificial reefs. Error bars represent ± 95% confidence intervals.

MaxN of *Pseudocaranx* spp. was found to exhibit significant differences with all three factors, *i.e.* reef, month and the reef×month interaction (Table 3.5e). Once again, reef was found to be the most important term in the model, accounting for 86.2% of the variance, with month and the interaction only making minor contributions (6.6% and 5.9%, respectively). In all months except October and November, the MaxN of *Pseudocaranx* spp. was greater on the Dunsborough reef compared to Bunbury (Fig. 3.14). The monthly pattern of abundance differed among reefs, with a pronounced peak occurring at Bunbury in November (16 *vs* 1-3 during the other months), whereas this peak occurred between December and January at Dunsborough (32 and 32, respectively, *vs* 2-13 in the other months). This mismatch in the monthly abundances accounts for the significant result in the reef×month interaction.

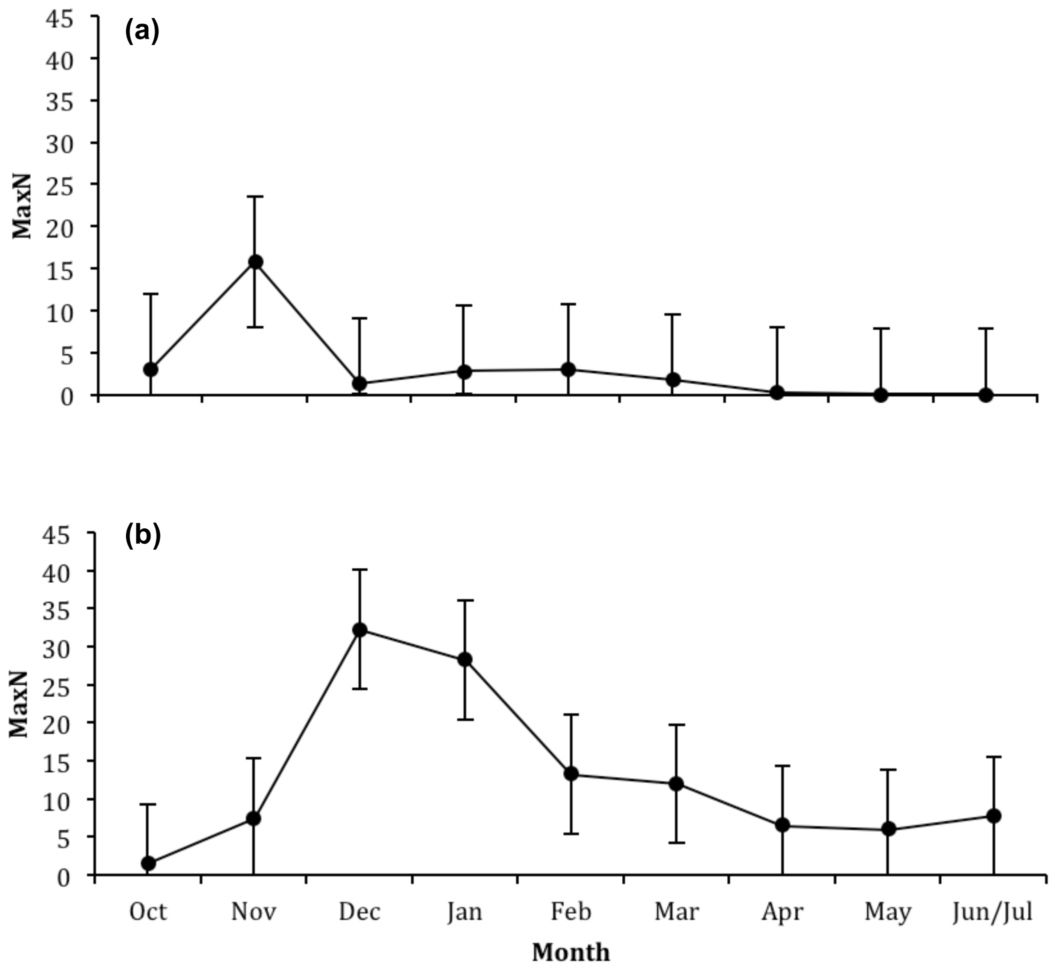


Fig. 3.14. Mean MaxN of *Pseudocaranx* spp. recorded on the (a) Bunbury and (b) Dunsborough artificial reefs in each month between October 2015 and June/July 2016. Error bars represent ± 95% confidence intervals.

A two-way ANOVA detected significant differences in the monthly MaxN of *S. hippos* and among reefs, but not in the interaction between these main effects (Table 3.5f). Reef (47.9%) was also shown to explain a larger proportion of the variance than month (28.1%). The MaxN of *S. hippos* was greater at Dunsborough than Bunbury, *i.e.* 0.387 vs 0.192 individuals per video, respectively (Fig. 3.15). The abundance of *S. hippos* was quite variable with relatively large values in January and June/July (3.9 and 3.6, respectively) and a low of 0.9 individuals per video in April (Fig. 3.16).

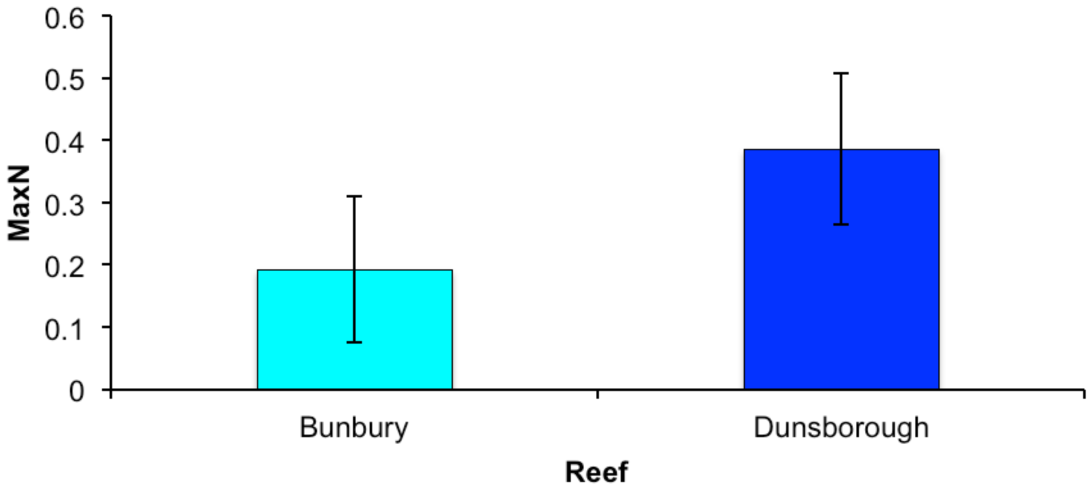


Fig. 3.15. Mean MaxN of *Seriola hippos* recorded on the Bunbury and Dunsborough artificial reefs. Error bars represent ± 95% confidence intervals.

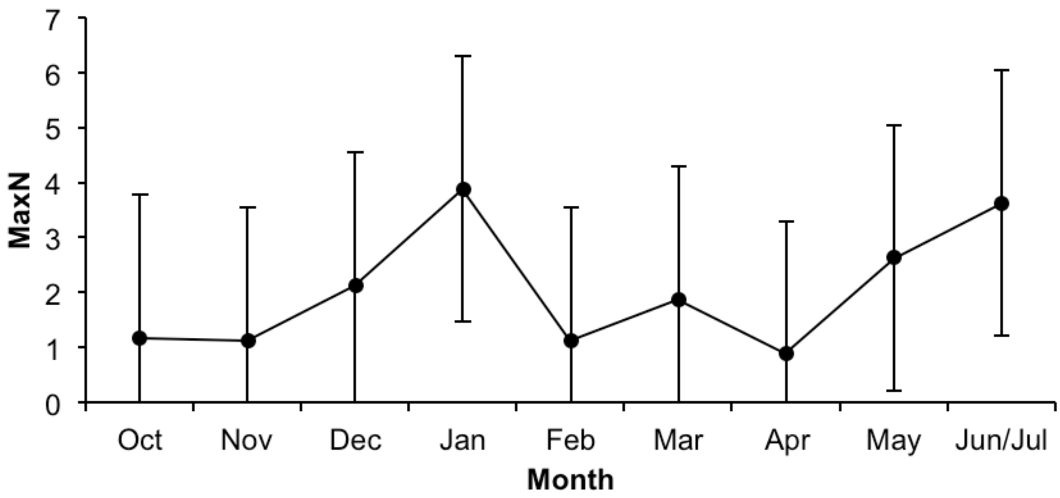


Fig. 3.16. Mean MaxN of *Seriola hippos* recorded on the Bunbury and Dunsborough artificial reefs in each month between October 2015 and June/July 2016. Error bars represent ± 95% confidence intervals.

3.4.2.3. Contribution of taxa and individuals to guilds

Among the 60 taxa recorded, 19 (32%) were classified as transient, meaning they were never present in more than two consecutive months. In contrast, 16 (26%) were classified as resident level 1, i.e. found in ≥ than 87.5% of the months, 15 (25%) were classified as resident level 2, meaning they were found in ≥50% of the months and a further 10 (17%) were resident level 3, i.e. found in two or more consecutive months (Fig. 3.17).

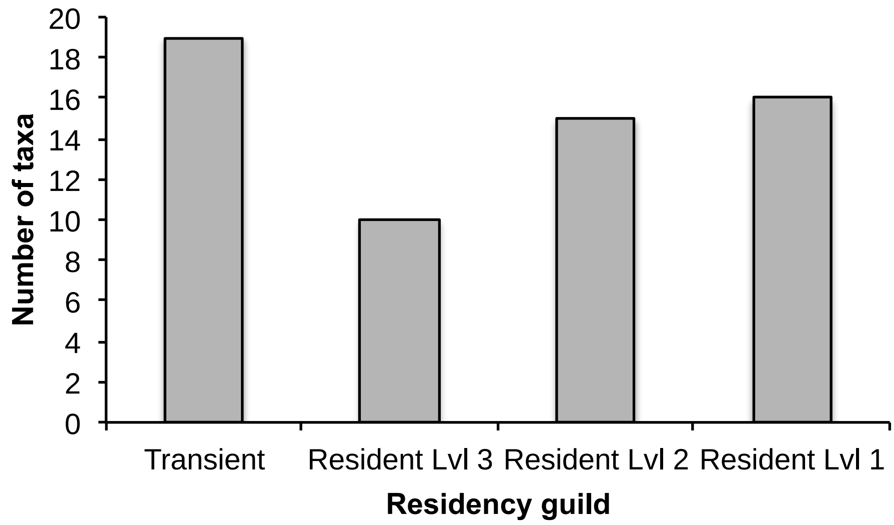


Fig. 3.17. The number of taxa from both reefs in each of the residency guilds.

PERMANOVA found that the percentage contribution of individuals from each of the habitat guilds did not differ significantly among reef, month or the reef×month interaction (Table 3.6a). The overall reef communities were composed of ~23% benthic, ~36% epibenthic and ~41% pelagic taxa.

Table 3.6. Degrees of freedom (df), mean squares (MS), percentage of variance explained by the mean squares (% var), F-values (F) and significance levels (*p*) from a two-way PERMANOVA on the percentage contribution of (a) habitat guilds by individuals, (b) habitat guilds by taxa, (c) feeding guilds by individuals, and (d) feeding guilds by taxa, recorded on the Bunbury and Dunsborough artificial reefs between October 2015 and June/July 2016. Significant results are highlighted in bold ($p \leq 0.05$).

		(a) Habitat guilds by individuals				**(b) Habitat guilds by taxa**			
Factors	**df**	**MS**	**% var**	**F**	***p***	**MS**	**% var**	**F**	***P***
Reef	1	971.05	44.5	1.81	0.17	**514.07**	**6.7**	**3.99**	**0.03**
Month	8	116.13	5.3	0.22	0.99	144.14	1.9	1.12	0.39
Reef×Month	8	559.24	25.6	1.04	0.42	156.37	2.1	1.22	0.29
Residual	53	537.25	24.6			6822.20	89.3		

		(c) Feeding guilds by individuals				**(d) Feeding guilds by taxa**			
Factors	**df**	**MS**	**% var**	**F**	***p***	**MS**	**% var**	**F**	***p***
Reef	1	**1371.43**	**3.8**	**3.34**	**0.04**	407.33	38.9	2.42	0.09
Month	8	366.34	1.0	0.89	0.56	207.98	19.9	1.23	0.25
Reef×Month	8	**873.88**	**2.5**	**2.13**	**0.02**	264.53	25.2	1.58	0.10
Residual	53	33223.55	92.7			168.01	16.0		

When each species was allocated to a habitat guild, PERMANOVA found that the percentage of species in each guild differed significantly for the factor reef, although it should be noted that this factor only explained 6.7% of the variance observed, compared to 89% in the residual (Table 3.6b). Differences in guilds between the reefs were due to the fact that Dunsborough had a higher mean percentage contribution of benthic taxa than Bunbury (32.8% *vs* 23.9%, respectively), while the reverse was true for pelagic taxa (32.6% *vs* 44.1%, respectively; Fig. 3.18).

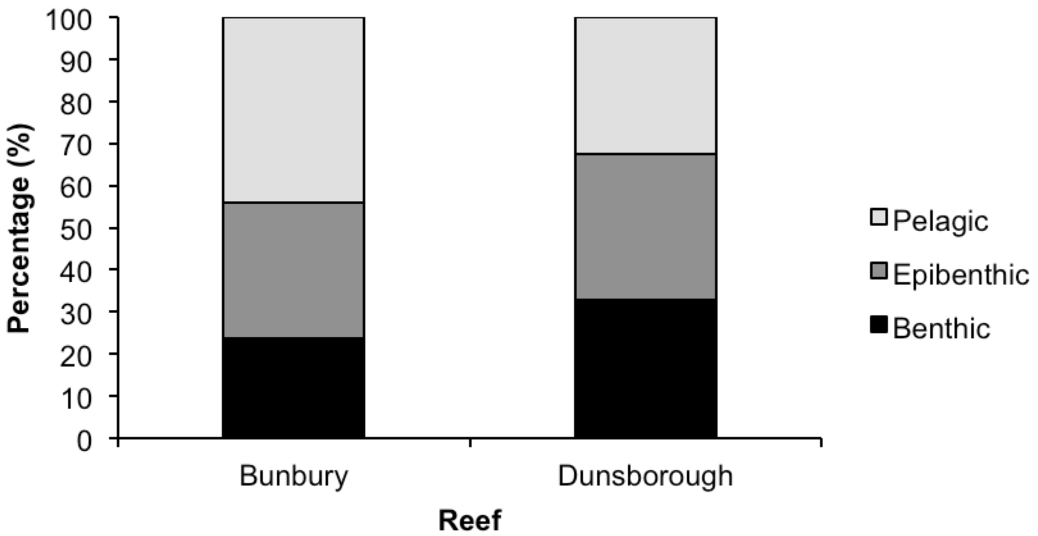


Fig. 3.18. Percentage contribution of taxa to the various habitat guilds at the Bunbury and Dunsborough artificial reefs.

When testing percentage composition of feeding guilds based upon contribution by individuals, significant differences were detected for the reef main effect and the reef×month interaction (Table 3.6c). However, these factors explained relatively small proportions of the variance, with reef contributing 3.8% and the interaction explaining 2.5%. When comparing reefs Bunbury typically had a greater proportion of zooplanktivores and a lower contribution of zoobenthivores, although the contributions were quite variable among months, thus helping to explain the reef×month interaction. The percentage contribution of the remaining guilds was relatively minor and typically variable, although herbivores were exclusively encountered on the Bunbury reef, albeit only in January (Fig. 3.19).

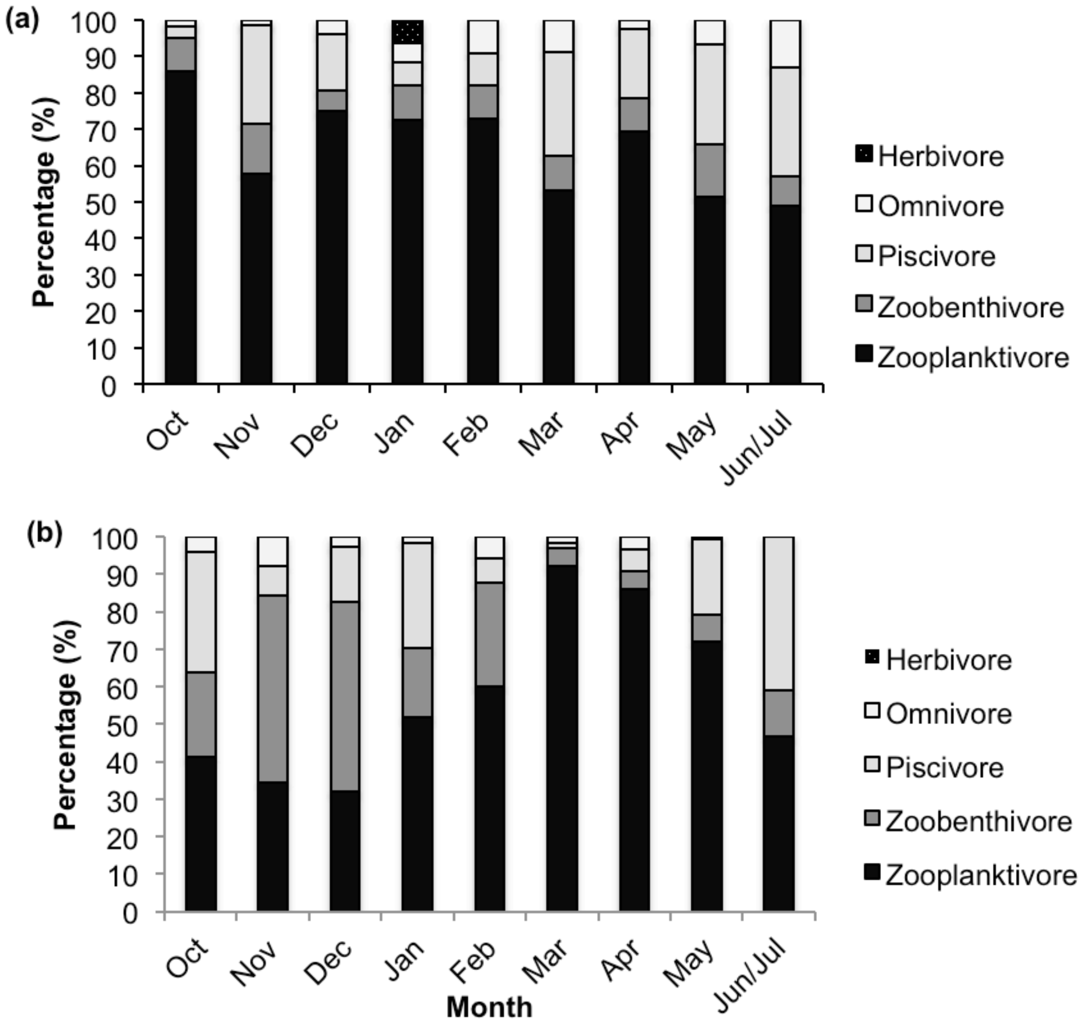


Fig. 3.19. Percentage contribution of individuals to the various feeding guilds at the (a) Bunbury and (b) Dunsborough artificial reefs in each month between October 2015 and June/July 2016.

PERMANOVA demonstrated that the percentage number of species in each feeding guild, did not differ among any of the terms in the model (Table 3.6d). The mean percentage composition of each guild over both reefs was as follows, zooplanktivore ~32%, zoobenthivore ~24%, piscivore ~27%, omnivore ~15% and herbivore ~2%.

3.4.2.4. Fish community composition

A two-way PERMANOVA on the fish community composition detected significant differences among reef, month and the reef×month interaction (Table 3.7). The reef main effect explained around four times more of the variation than either month or the reef×month interaction.

Table 3.7. Degrees of freedom (df), Mean Squares (MS), percentage of variance explained by the means squares (% var), Pseudo-F values (F) and significance levels (*p*) from a PERMANOVA on the fish community composition of the Bunbury and Dunsborough artificial reefs in each month between October 2015 and June/July 2016. Significant results are highlighted in bold (p<0.05).

Factors	df	MS	% var	F	*p*
Reef	1	**11363**	**60.7**	**6.93**	**0.001**
Month	8	**2814**	**15.0**	**1.72**	**0.002**
Reef×Month	8	**2917**	**15.6**	**1.78**	**0.001**
Residual	53	1639	8.7		

The nMDS ordination plot shows a distinct demarcation between reefs, with the point representing the Bunbury reef occurring predominantly to the left of those for the Dunsborough reef. The points for both reefs also show a general clockwise cycling pattern starting from October through to June/July. The interaction between the factors is also apparent with the reefs showing differences in the distances between their monthly samples. For example, the months December and January are located relatively far apart from one another for Bunbury, but are tightly coupled for Dunsborough. This pattern is also repeated with March and April, though to a lesser extent (Fig. 3.20).

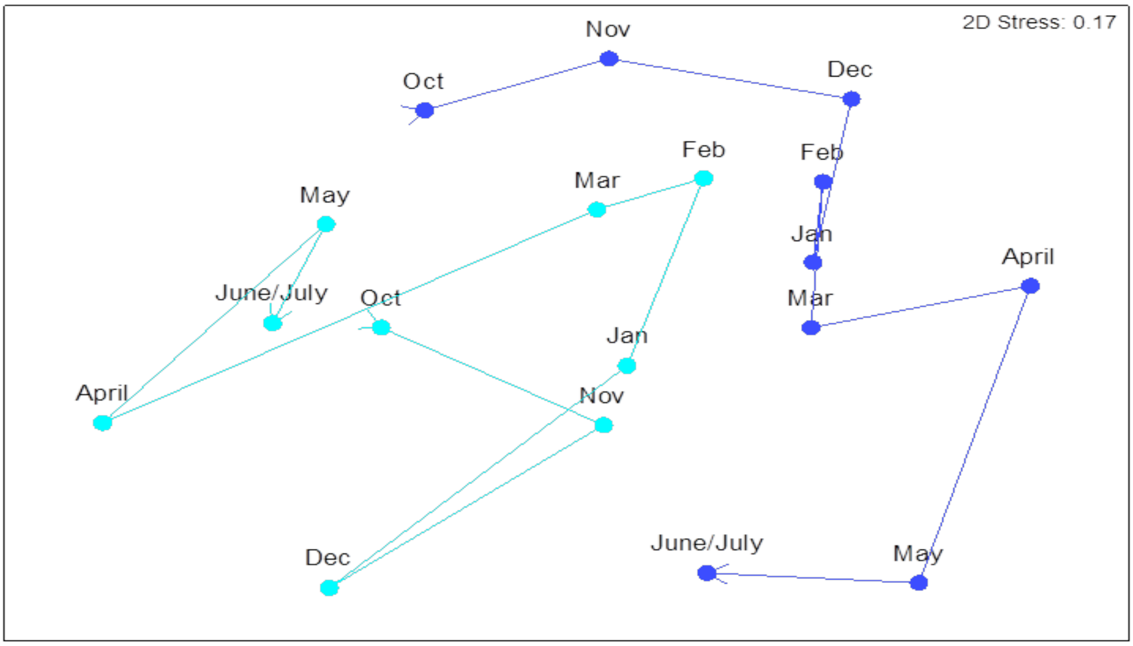


Fig. 3.20. nMDS ordination plot, derived from separate Bray-Curtis similarity matrices, constructed from the square-root transformed and averaged MaxN fish community data recorded on the ● Bunbury and ● Dunsborough artificial reefs between October 2015 and June/July 2016. Separate trajectories for each reef have been plotted to allow tracking of the fish composition of each reef through time.

Among the two artificial reefs, pairwise comparisons generated by PERMANOVA, demonstrated that fish faunal composition differed significantly in November and December, as well as March through May. The biggest differences according to the magnitude of the t-values, were for April, followed closely by May (Table 3.8). From the shade plot it is apparent that the presence of some key species at the Dunsborough reef, and absence or low abundance at the Bunbury reef likely made a large contribution to the differences in overall assemblage seen between reefs. These taxa include the Crested Morwong *Cheilodactylus gibbosus,* Globefish *Diodon nicthemerus,* Spotted Grubfish *Parapercis ramsayi*, Wavy Grubfish *Parapercis haackei, C. auratus,* Bluethroat Rainbow Wrasse *Suezichthys cyanolaemus* and the Moonlighter *Tilodon sexfasciatus.* While the exclusivity, or majority presence, of the West Australian Butterflyfish *Chaetodon assarius*, Longspine Flathead *Platycephalus* *longispinis,* Snakeskin Wrasse *Eupetrichthys angustipes* and the Masked Stingaree *Trygonoptera personata* on the Bunbury reef also likely made a large contribution to the observed differences. Specifically, differences observed between the reefs in April, which had the largest t-value, were driven by *C. auratus*, *C. gibbosus*, *P. haackei* being recorded exclusively on the Bunbury reef. Additionally, Rough Bullseye *Pempheris klunzingeri*, *C. assarius* and *P. longispinis* were noted as absent on the Dunsborough reef, but were recorded on the Bunbury reef (Fig. 3.21).

Table 3.8. T-values derived from a pairwise PERMANOVA test on the reef×month interaction, demonstrating the months in which the fish composition recorded on the Bunbury and Dunsborough artificial reefs differed. Significant pairwise comparisons are highlighted in grey ($p<0.05$).

Month	t-value
Oct	1.287
Nov	1.359
Dec	1.627
Jan	1.117
Feb	1.065
Mar	1.615
Apr	2.074
May	2.068
Jun/Jul	1.333

A pairwise PERMANOVA test between months for each reef revealed that the composition of the fish fauna at Bunbury differed only between April *vs* November, February and March (Table 3.9a). This was due to fewer species being caught during April, with species, such as the Southern Fiddler Ray *Trygonorrhina dumerilli*, *M. australis, C. curiosus* and *N. obliquus,* all absent, but recorded in relatively high abundances in most months (Fig. 3.21). Thus, it was the depauperate nature of April that made it unique. Dunsborough exhibited a greater number of monthly differences, with 20 of the 36 pairwise comparisons being significant and typically only successive months not differing (Table 3.9b). Fish faunal composition was fairly consistent in terms of the presence/absence of species and thus the significant differences are driven by changes in the relative abundance of species such as *Pseudocaranx* spp., *N. obliquus*, *A. amygdaloides* and *S. hippos* (Fig. 3.21).

Table 3.9. T-values derived from a pairwise PERMANOVA test on the reef×month interaction, demonstrating the months in which the fish composition recorded on the (a) Bunbury and (b) Dunsborough artificial reefs differed. Significant pairwise comparisons are highlighted in grey (p<0.05).

(a) Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Nov	1.16							
Dec	1.01	0.97						
Jan	0.99	0.88	0.96					
Feb	1.14	1.43	1.23	1.06				
Mar	1.41	1.23	1.26	1.05	1.24			
Apr	1.18	1.59	0.92	1.31	1.67	1.70		
May	1.05	1.45	1.14	1.22	1.44	1.33	0.79	
Jun/Jul	0.81	1.34	1.2	1.04	1.36	1.30	0.97	0.70

(b) Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Nov	1.24							
Dec	1.62	1.35						
Jan	1.68	1.45	1.13					
Feb	1.47	1.38	0.98	1.16				
Mar	1.63	1.53	1.41	1.22	0.78			
Apr	2.21	2.09	1.76	1.57	0.97	0.71		
May	2.16	2.11	1.86	1.42	1.8	1.65	1.86	
Jun/Jul	1.42	1.38	1.48	1.44	1.49	1.32	1.62	1.17

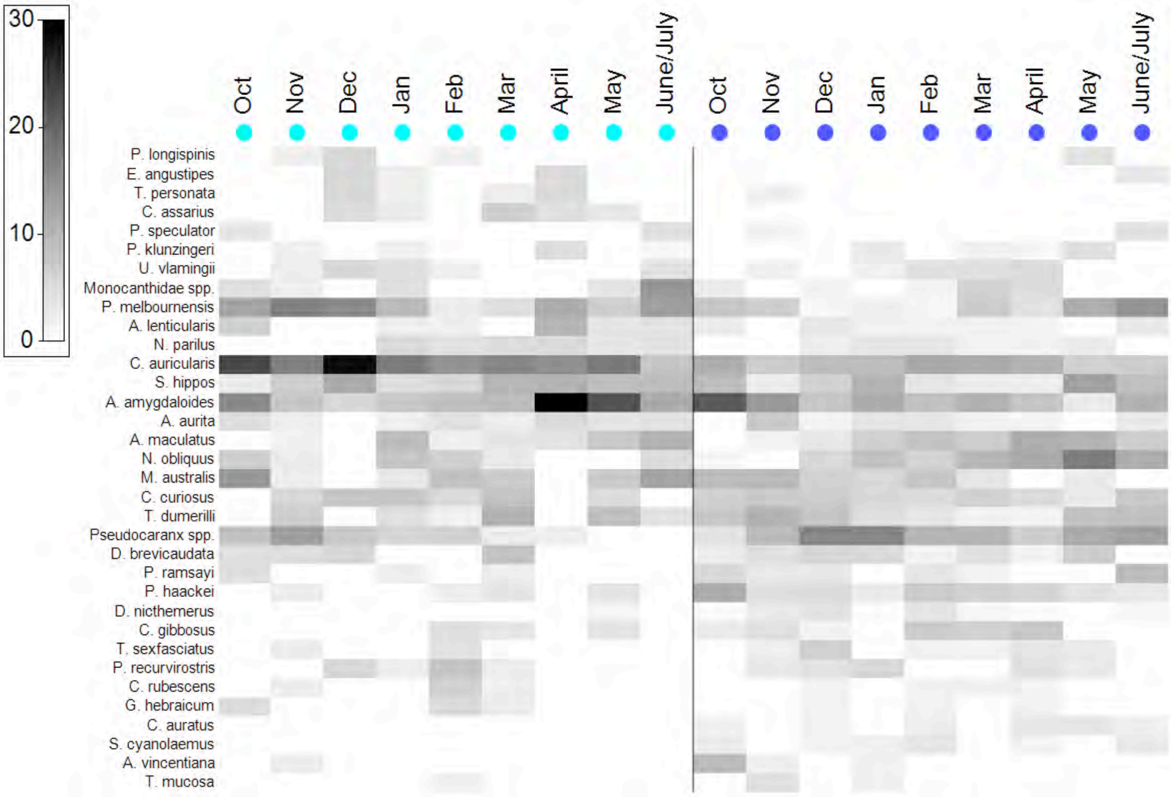


Fig. 3.21. Shade plot, constructed using the square-root transformed and averaged MaxN abundances of each taxon recorded on video footage recorded on the ● Bunbury and ● Dunsborough artificial reefs in each month between October 2015 and June/July 2016. White space denotes the absence of a taxon, with the grey scale representing the transformed and averaged MaxN abundances. Note only species that occurred in ≥5% of the videos from either reef are included.

The segmented bubble plot of key recreational species on the Bunbury artificial reef shows that *S. hippos* was found at a relatively similar abundance in every month, whereas the West Australian Dhufish *Glaucosoma hebraicum* was found only between October and March, although not in every month. Other species, such as *Pseudocaranx* spp. and the Baldchin Groper *Choerodon rubescens,* appeared sporadically (Fig. 3.22a). Although *Pseudocaranx* spp. was found in every month at Dunsborough, the abundances of other species, such as *G. hebraicum*, *S. hippos* and *C. rubescens* were typically restricted to months between January and April (Fig. 3.22b).

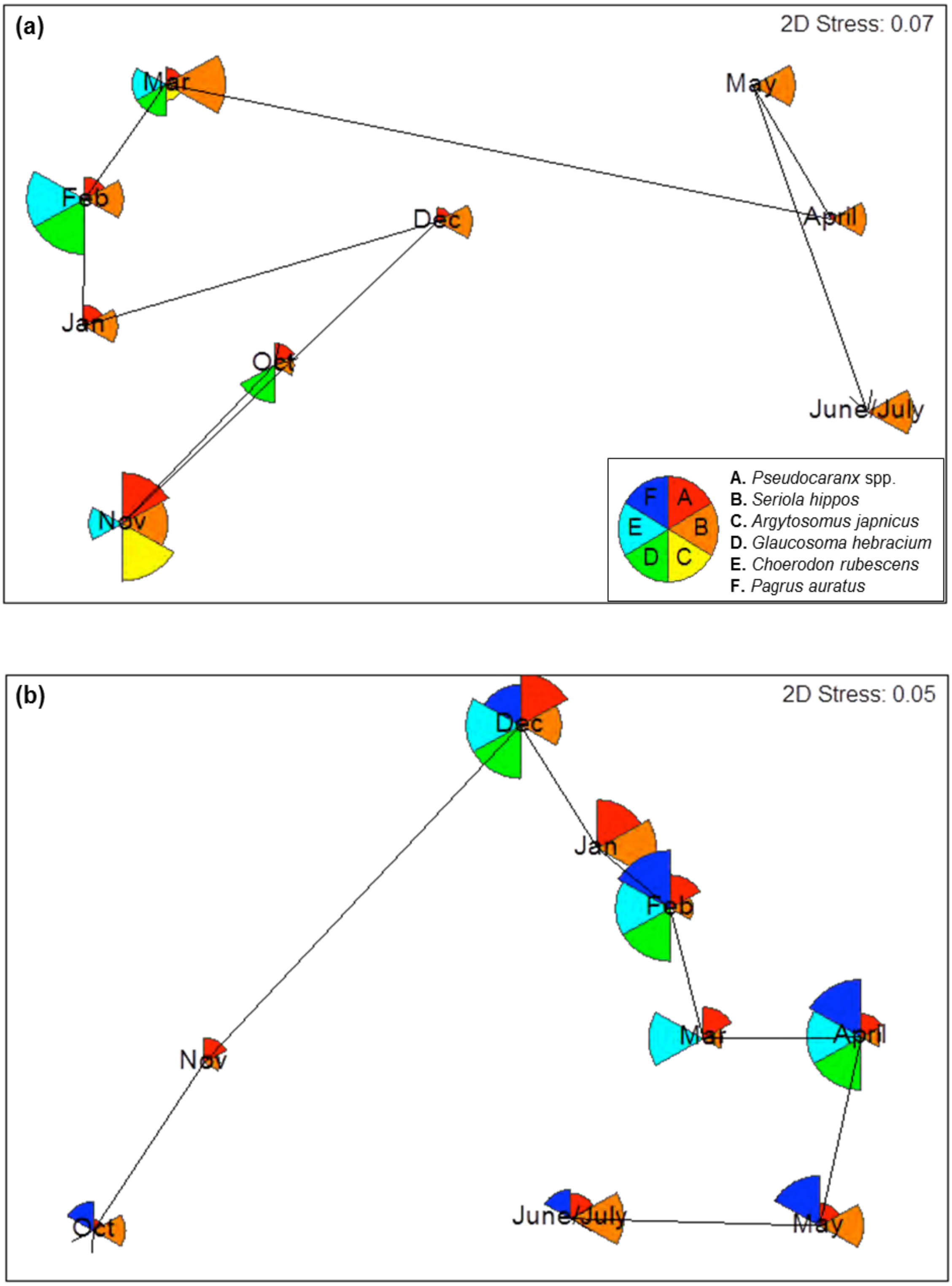


Fig. 3.22. nMDS ordination plots, derived from separate Bray-Curtis similarity matrices, constructed from the square-root transformed and averaged MaxN fish community data recorded on the (a) ●Bunbury and (b) ● Dunsborough artificial reefs in each month between October 2015 and June/July 2016. Segmented bubbles of proportional sizes are overlaid illustrating the relative abundance of six key recreational target species.

3.5. Discussion

This research project utilised BRUV technology, in conjunction with a citizen science based sampling program (Reef Vision), to compare spatial and temporal trends in the fish communities of the artificial reefs of Geographe Bay (*i.e.* Bunbury and Dunsborough) between October 2015 and July 2016 inclusive. A range of statistical tests were undertaken to elucidate whether the number of taxa, total MaxN, the MaxN of a number of recreationally important fish species, fish community composition and the contributions of habitat and feeding guilds differed spatially, *i.e.* between the Bunbury and Dunsborough reefs, and temporally, *i.e.* in months between October and July. The following sections discuss the patterns of variation in (i) the number of taxa and total abundance, (ii) the proportions of species and individuals to the different residency, habitat and feeding guilds and (iii) the faunal community structure, and detail how and why these characteristics changed either spatially and/or temporally.

3.5.1. Number of taxa and total MaxN

3.5.1.1. Differences among reefs

Significant differences in the number of taxa and total MaxN were detected between reef, month and their interaction. The reef main effect accounted for by far the greatest proportion of the variance observed, with the values recorded at Dunsborough typically being larger than the corresponding values at Bunbury. This finding mirrors the work by Bateman (2015), who also found significant differences in the fish communities of the same artificial reefs, in terms of species richness, abundance and composition, with the Dunsborough reef supporting a higher richness and abundance of fish than Bunbury. Despite the relatively small distance between the two artificial reefs (~50 km), their differences in the number of taxa and the abundance of key species could potentially be attributed to their varying levels of connectivity with nearby natural reefs. Distance between reefs is believed to be an important determinant of associated fish communities, with studies finding both an increase (Gascon and Miller, 1981; Walsh, 1985; Bombace et al., 1994) and decrease (Molles, 1978; Bohnsack, 1979; Gladfelter et al., 1980) of diversity and abundance with the factor.

In order to understand how the results from this study fit in with these findings, it is necessary to determine how fish communities utilise natural reefs. Temperate limestone reefs in Western Australia have been found to support higher abundances of fish than either seagrass meadows or bare sand habitats (Howard, 1989), with the increased structural complexity of reef habitats thought to be responsible (Borges-Souza et al., 2013; Graham and Nash, 2013). Moreover, Molles (1978) and Harman and Kendrick (2003) found that natural reefs with higher vertical profiles supported greater numbers of fish species and individuals, which has also been documented on artificial reefs (Strelcheck et al., 2005).

It has been suggested that differences in the diversity and abundance of fish communities between habitats are driven by behavioural preferences. For example, individuals may move to areas with lower population densities to reduce intra- and interspecific competition and predation (Ault and Johnson, 1998). This could potentially explain the observed increase in species richness and abundance with increasing isolation of artificial reefs (Gascon and Miller, 1981; Walsh, 1985; Bombace et al., 1994). However, this phenomenon may also be scale dependent, as some studies that cited this were comparing reefs over much smaller distances than in the current study (Gascon and Miller, 1981; Walsh, 1985).

Despite the preference for fish to move to more isolated habitats, with lower population densities, they are limited in their ability to do so by their vagility. Molles (1978) suggested that pelagic fish with a high vagility may be able to traverse relatively large distances between reefs better than less mobile reef-associated fish. Pelagic species are more able to freely move between habitats, regardless of their isolation, while species with a lower vagility, *e.g.* benthic and epibenthic species, are less able to migrate to isolated habitats. This assertion is supported by Vega Fernández et al. (2007), who found higher fish abundances, particularly of smaller less mobile fish species, on artificial reefs with high reef connectivity, whilst larger mobile species were more likely to be associated with isolated artificial reefs.

The south-west edge of Geographe Bay has a high level of reef connectivity, due to the number of limestone and granite reefs occurring near Cape Naturaliste (Westera et al., 2007; Department of Environment and Conservation, 2013), which are thought to influence nearby fish communities (Westera et al., 2007). The results of a BRUV-based study found the abundance of some reef-associated species to decline with increasing distance from Cape Naturaliste, suggesting sparser reef coverage in the bay moving northerly. Therefore, the Dunsborough artificial reef is likely to have a higher connectivity with natural reefs, than the Bunbury artificial reef. This connectivity of the Dunsborough artificial reef, as opposed to Bunbury’s relative isolation, is likely to have led to its higher observed number of taxa and total MaxN. This is due to the ability and preference of fish, regardless of their vagility, to move between the connected natural reefs and the Dunsborough artificial reef, either temporarily or permanently.

Vagility and habitat connectivity provide possible explanations for the presence and movement of juvenile and adult fish, however, they do not take into consideration larval dispersal. The dispersal of larval propagules is likely to overcome any boundaries present between habitats on small to medium scales, particularly in Geographe Bay where particle retention rates (residence times) are high (Cowen et al., 2006; Feng et al., 2010). With larval propagule dispersal showing variability both between and within species, as well as over space and time, it is difficult to estimate the impact it has upon fish communities as a whole (Kinlan et al., 2005). It is likely that the abundance of reef habitat in the proximity of the Dunsborough reef would make this area more suitable for reef fish communities, resulting in higher survival rates of fish from the larval stage. Therefore, despite larval dispersal overcoming gaps in habitat connectivity present in Geographe Bay, the presence of more suitable habitat around the Dunsborough reef likely contributed to higher survival rates and therefore, a greater abundance and richness of fish at the reef, compared to Bunbury.

Another factor that could have contributed to differences in number of taxa and abundance observed between the reefs could be depth, as the Bunbury and Dunsborough reefs are situated at depths of 17m and 27m, respectively (Government of Western Australia, 2013). Environmental factors, such as water temperature, light and hydrodynamics, are known to change with depth, thus affecting the growth and condition of fish species (Bayle-Sempere et al., 1994). However, given the small difference in depth between the sites and the ability of some species to tolerate a wide depth range, it is unlikely that increasing depth has contributed to large-scale differences in their fish communities (Srinivasan, 2003). Rather, it is more likely to have species-specific impacts, particularly for taxa that can only tolerate a small depth range.

3.5.1.2. Differences among months

The significant difference observed among months, for both the number of taxa and total MaxN, could potentially be attributed to the impact of changing water temperature with season. A number of studies of artificial reefs have found that water temperature influences associated fish communities (Hastings et al., 1976; Sanders Jr et al., 1985; Stephens Jr et al., 1994; Fujita et al., 1996; Bortone et al., 1997). Seasonal changes in water temperature are used as cues for both migration and reproduction, with gonadal development in many fishes being temperature dependent (Ware and Tanasichuk, 1989). Specifically, fish in temperate marine environments generally release their larvae during spring or autumn (Cushing, 1990; Brodersen et al., 2011). A number of studies on artificial reefs have noted a pattern of high fish abundance during the warmer summer and autumn months, compared to the cooler winter and spring months (Hastings et al., 1976; Bohnsack et al., 1994; Relini et al., 1994; Fujita et al., 1996). These differences in abundance have been attributed to the arrival of juveniles during summer (Bohnsack et al., 1994; Relini et al., 1994); however, Burt et al. (2009) found the majority of the change in abundance observed in their study was driven by the arrival of adults. The movement of adults between seasons is primarily due to migrational behaviour to spawn and/or access increased food availability (Hastings et al., 1976; Bohnsack et al., 1994; Fujita et al., 1996; Burt et al., 2009). Thus, the generally higher values of the number of taxa and total MaxN during spring and summer, observed over both reefs, can be attributed to the movement of both juveniles and adults onto the reefs, triggered by changing sea surface temperatures in Geographe Bay (McMahon et al., 1997).

The process by which communities change over time, ecological succession, could also potentially contribute to the differences observed between months. The theory of ecological succession postulates that communities of new, or disturbed, habitats are not static, rather they constantly change until they reach a point of stabilisation (Anderson, 2007). Bohnsack (1991) found artificial reefs to take between one and five years for climax communities to develop depending upon a range of environmental factors. Thus, since the reefs have only been deployed for just over three years, their associated fish communities are potentially still undergoing successional changes. These changes could contribute to differences observed over time, however, given that the monitoring only took place over only ten months it would be difficult to attribute significant monthly differences completely to this.

3.5.1.3. Difference in monthly variation between locations

Like month, the reef×month interaction was significant for the number of taxa and total MaxN, though had a lesser mean squares than the factors reef or month. This effect is likely due to the variability of oceanographic processes between sites, as well as with time. Oceanographic processes are known to play an important role in determining food availability, ultimately helping to shape ecological communities (Vanni, 1987; Mann, 1993). With the considerable variability oceanographic processes show, over both spatial and temporal scales, the artificial reefs are likely to reflect these differences in their fish communities (Taylor et al., 2013).

Between October and April, the poleward flowing Leeuwin Current weakens due to the influence of northerly winds and the mass movement of water northward via the Capes Current (Gersbach et al., 1999; Department of

Environment and Water Resources, 2006). The latter current promotes the equatorward movement of cool water along the inshore of the south-west coast, causing localised upwellings and enhanced nutrient availability, stimulating algal blooms and attracting aggregations of fish to the area (Gersbach et al., 1999; Pearce and Pattiaratchi, 1999; Department of Environment and Water Resources, 2006). Thus, it would be predicted that areas influenced by this current would temporarily experience a greater number of fish species and individuals due to increased food availability over summer, which as a general trend is borne out in this study. Differences within the patterns of diversity and abundance at each reef could be explained by the differential strength of the current, with Dunsborough being located closer to its strongest point (between Cape Leeuwin and Cape Naturaliste), and thus being impacted for a longer period of time than the Bunbury reef (Pearce and Pattiaratchi, 1999). This resulted in the continuation of high numbers of taxa and total MaxN into autumn at Dunsborough, whereas Bunbury began to experience a decrease in these variables during summer.

3.5.1.4. Differences in the abundance of recreationally important species

Given the purpose of the Bunbury and Dunsborough artificial reefs was to increase the abundance of specific targeted recreational species, *i.e.* *C. auratus*, *Pseudocaranx* spp. and *S. hippos* (Department of Fisheries, 2016), it is important to understand the factors influencing their distribution. The first of these, *C. auratus*, is found along the coastline of southern Australia, predominantly occurring on rocky reef to depths of up to 200 m (Moran et al., 1999; Fowler et al., 2004; Edgar, 2008; Parsons et al., 2014). The higher abundance of this species on the Dunsborough reef, compared to Bunbury, is thought to be related to the fact that the former is located in closer proximity to natural reefs. However, it is unlikely that there is a complete lack of individuals on the Bunbury reef, as observed in the current study, as local recreational fishers have noted catching the species in the area (Reef Vision participants 2016, pers. comm., 9 September; Westera et al., 2007; Department of Environment and Conservation, 2013). This recorded absence could be attributed to a variety of factors, including missed observations due to environmental conditions, individuals being recorded on footage that was not analysed and/or a failure in the methodology to record them.

The abundance of *Pseudocaranx* spp. (likely *Pseudocaranx dentex, georgianu*s and *wrighti)* differed both spatially and temporally, with typically greater values recorded on the Dunsborough reef, and both reefs displaying increased MaxN values in spring/summer. Trends in their abundance with reef, month and their interaction are likely driven by the aforementioned factors of habitat connectivity, changes in water temperature and the influence of currents, as their abundance showed similar patterns to those seen overall (Smith-Vainz and Jelks, 2006).

Habitat connectivity is also considered responsible for the increased abundance of *S. hippos* at Dunsborough as this species typically inhabits inshore waters with structured habitat, such as reefs (Rowland, 2009). This species spawns in late spring and throughout summer in Western Australia, with individuals forming spawning aggregations to the west of Rottnest Island (Rowland, 2009). Their observed pattern of abundance on the Geographe Bay artificial reef, *i.e.* typically being low over summer and increasing in late autumn/winter, could be explained by their migration away from the reefs to spawn.

3.5.2. Residency, habitat and feeding guilds

A number of studies on artificial reefs have found wide-ranging results when assigning fish to residency guilds. For example, the percentage of species classified as non-residents ranges between 35% and 90% depending on the study (Relini et al., 1994; Stephens Jr et al., 1994; Santos et al., 2005; Gül et al., 2011). These wide ranging results, particularly when compared to this study, show that without a clear definition of what constitutes ‘resident’ or ‘transient’ species comparisons between studies are difficult, even when using a tiered system as employed here (Boisnier et al., 2010). Therefore, no meaningful conclusion can be drawn as to how the fish community use the Geographe Bay artificial reefs, in terms of residency, compared to other deployments.

Differences in the proportion of taxa representing the various habitat guilds, provides more evidence to support the assertion that habitat connectivity plays a key role in determining the fish assemblages present on the artificial reefs. Due to the isolation of the Bunbury reef, it would be more difficult for species with low vagility to immigrate there, thus explaining why highly mobile, pelagic taxa predominate. The closer location of the Dunsborough reef to natural reefs has meant that benthic taxa with low vagility, are able to move between the habitats and hence, make up a greater proportion of the total population.

When classifying individual fish into feeding guilds, significant reef and reefxmonth differences were detected, with the former explaining a far greater proportion of the variance. When comparing reefs, greater proportions of zooplanktivores and zoobenthivores were found on the Bunbury and Dunsborough reefs, respectively. The greater abundance of zooplanktivores in Bunbury is likely related to the presence of strong currents year round. South of Perth, the Leeuwin Current moves into an offshore position, except for an arm that penetrates into Geographe Bay, in the general proximity of Bunbury. This, and the presence of the Capes Current during summer, means that the Bunbury reef is likely to be affected by relatively high current speeds year round, while the Dunsborough reef is likely only affected by large scale currents when the Capes Current moves in during summer (Cresswell and Vaudrey, 1977; Pearce and Pattiaratchi, 1999; Smale, 2012). With the presence of these currents, zooplanktivorous fish are able to increase their feeding rates, making the Bunbury reef an advantageous location to inhabit year round, while the Dunsborough reef is a beneficial site only between late spring and early autumn (Stevenson, 1972; de Boer, 1978; Gersbach et al., 1999; Pearce and Pattiaratchi, 1999). These observations are reflected in the reef×month interaction results, with the Dunsborough reef showing a general increase in the proportion of zooplanktivores in summer and early autumn, while Bunbury shows a more consistent proportion of zooplanktivores year round.

The difference in the proportion of zoobenthivores between the two reefs could be due to the greater provision of structured habitat surrounding the Dunsborough reef. In their work, comparing invertebrate abundances between habitats, Nakamura and Sano (2005) found a greater biomass of invertebrates in reef habitats compared to seagrass meadows, due to the tendency for larger invertebrates to occupy reefs. With the Dunsborough reef likely having greater connectivity with natural reefs, this area may support a greater biomass of invertebrates for zoobenthivores to feed upon, leading to them making up a larger proportion of the community compared to Bunbury (Westera et al., 2007; Department of Environment and Conservation, 2013).

3.5.3. Fish community composition

The significant differences detected in the composition of the fish fauna among reef, month and the reefxmonth interaction is likely due to a variety of factors. These include the aforementioned changes in the overall number of taxa and total MaxN, as well as differences in the abundance of key recreational species and the composition of habitat and feeding guilds.

In an attempt to explain how the overall fish communities differ, pairwise PERMANOVA tests were carried out between months on each reef, and between reefs with month. Beyond the general contribution of the previously covered univariate measures, the shade plot and pairwise tests revealed a number of different fish as having contributed to these differences. Some of these highlighted species were found to occur exclusively, or primarily, on the Dunsborough reef, in a sporadic fashion, including *C. gibbosus, D. nicthemerus, P. ramsayi*, *P. haackei, C. auratus, S. cyanolaemus* and *T. sexfasciatus*. Their abundance at the Dunsborough reef can likely be attributed to their preference for structured habitat, particularly reefs, which have a greater coverage in the vicinity of the site (Hutchins and Thompson, 1983; Moran et al., 1999; Fowler et al., 2004; Westera et al., 2007; Edgar, 2008; Department of Environment and Conservation, 2013; Parsons et al., 2014). However, their absence at the Bunbury reef could also be contributed to a failure in the method to record their occurrence. This is likely to have occurred with *S. cyanolaemus, P. ramsayi* and *P. haackei* due to their colouration and small size, which makes identification difficult, as well as the schooling behaviour of *D. nicthemerus*, which could have caused the patchy abundance recorded (Florisson 2016, pers. comm., 20 April; Edgar, 2008).

The distribution of *C. gibbosus* primarily on the Dunsborough reef appears anomalous, as they are known to occur over both reef and sand habitat, meaning habitat connectivity cannot explain their distribution (Hutchins and Thompson, 1983). This species has been little studied but others in the genus *Cheilodactylus* are noted to occur in patchy aggregations or display territorial behaviour, limiting their densities (McCormick, 1989; Lowry and Suthers, 1998). Thus, the recorded distribution of *C. gibbosus* could potentially be attributed to the low densities in which it occurs, causing missed observations (Edgar, 2008). Furthermore, the zero recorded abundance of *C. auratus* at the Bunbury reef found in this study, as noted earlier, is in contrast to their recorded occurrence in the vicinity of the reef and highlights the potential for the method to fail to record some species (Reef Vision participants 2016, pers. comm., 9 September). Furthermore, the observed differences in water clarity between the sites, over winter could impact the ability to observe small and cryptic species. Bunbury experienced a considerable reduction in water clarity over winter, while Dunsborough also experienced this, but for a shorter duration.

A number of other species displayed the opposite trend, occurring exclusively, or primarily, on the Bunbury reef. These included *C. assarius*, *P. longispinis, E. angustipes* and *T. personata.* The recorded absence of *C. assarius* at the Dunsborough reef is likely linked to its infrequent occurrence on the south-west coast of Australia, as it is found in a greater abundance at higher latitudes within its home range (Hutchins and Thompson, 1983). The abundance of *E. angustipes* and *P. longispinis* at the Bunbury reef could be due to its preference for sandy habitats, which are likely to cover a greater area near the Bunbury reef (Hutchins and Thompson, 1983; Edgar, 2008). Though the small size, colouring and cryptic behaviour of *E. angustipes*

(Gomon et al., 2008) may have caused missed observations on the Dunsborough reef. The greater abundance of *T. personata* at the Bunbury reef is difficult to explain as the species has been found to occur in low densities typical at the depth of this reef (Platell et al., 1998). However, this species has been little studied and its distribution is yet to be fully understood.

The centroid plot, showing the occurrence of the six most abundant recreationally targeted species, reveals that each reef supports a different suite of recreational species. While the patterns of abundance of *S. hippos, Pseudocaranx* spp. and *C. auratus* are discussed above, the appearance of the Western Australian Dhufish *Glaucosoma hebraicum* and Baldchin Groper *Choerodon rubescens* between November and April on the reefs warrants discussion. Mature *G. hebraicum* are known to spawn on reefs between December and March (Hesp et al., 2002; Edgar, 2008). Its appearance on the reefs during these months could be a result of its migration to the area to spawn, while the presence of *C. rubescens* is likely linked to the appearance of new recruits, which generally appear in reef and sand habitats during late summer (Hutchins and Thompson, 1983; Fairclough, 2005).

The characteristics of the fish fauna of the artificial reefs of Geographe Bay differ, both spatially and temporally. Habitat connectivity with adjacent natural reef systems is likely to be largely responsible for structuring the fish communities of the artificial reefs. However, both water temperature and the influence of the Leeuwin and Capes Currents are likely to play a subsidiary, but significant role.

3.5.4. Study limitations and scope for future work

Having evaluated a range of methods for monitoring the faunas of artificial reefs (Chapter 2), this section firstly provides an evaluation of the BRUV methodology and its application in the current study. Secondly, it details ideas for future research on the Geographe Bay artificial reefs, as well as the application of the method to monitor the fauna of other artificial reef deployments.

3.5.4.1. Critical evaluation of the use of BRUVs

Although based on limited data, the results of Florisson (2015) indicated that the placement of the BRUV, *i.e.* facing towards or away from the artificial reef modules, has the potential to influence the types of fish recorded. However, Bateman (2015), using a more comprehensive data set found this factor did not significantly impact the composition recorded. Moreover, the distance of the camera from the reef module likely influences the types of species recorded. Thus, on the few occasions that cameras were placed within the module itself, species not previously observed, such as *Apogon victoriae* and Pempherididae spp., were identified. The identification of cryptic species, such as these, has been noted to show high levels of variability in video footage (Williams et al., 2006). Therefore, the positioning of the BRUV units on the reefs could impact the fish community composition recorded and thus needs to be controlled.

The introduction of sampling bias, both temporally and spatially, by volunteers has been noted as a significant risk within citizen science based monitoring programs (Dickinson et al., 2010). Such biases could have been introduced into this study as sampling dates were not kept consistent and sampling locations were not randomised. Volunteers were allowed to choose the timing of their sampling resulting in some videos, which occurred in different months, being only separated by a few days, while others were more than a month apart. Furthermore, when the timing of diurnal sampling is not consistent (or even randomised) it has the potential to confuse patterns of difference/similarity observed over large time scales (Birt et al., 2012; Harvey et al., 2012a). In regards to spatial biases participants were allowed to choose their sample sites, within each reef, potentially favouring specific sites. This could be problematic due to ‘edge effects’, where a species abundance will vary along the boundary between specific habitats (Ries and Sisk, 2004). With habitat fidelity varying among species it is likely that the over representation of specific clusters will introduce biases, depending on the type of surrounding habitat (Dorenbosch et al., 2005).

A variety of methodology issues relating to the BRUV itself may have also introduced biases into the study. These include potential misidentifications of organisms due to the reduction of light with depth, distance of organisms from the camera and low water quality, making differentiation between morphological characteristics difficult (Kingsford and Battershill, 2000; Widder, 2004). Additionally, the count of individuals may be underestimated when observing high densities of fish, as there is a limit to the number of individuals that can be counted simultaneously (Wraith, 2007). BRUVs have also been noted to underrepresent cryptic species (Watson et al., 2005), site attached fish and those not attracted to bait (Watson et al., 2010). There is also the potential for BRUVs to introduce biases by attracting carnivorous species, influencing the abundance of species that display avoidance behaviour towards large predators (Watson et al., 2010), though this is debated (Willis et al., 2000; Watson et al., 2005; Langlois et al., 2010). As a result, these issues could have potentially introduced bias into the fish community composition recorded, though this would likely be the case regardless of the methodology chosen.

A systemic limitation of the BRUV method is its inability to provide accurate densities, due to difficulties in determining the area sampled by the bait plume (Priede and Merrett, 1996). BRUVs provide relative densities and replicate samples based upon a standardised unit of time, assuming that each deployment is sampling a similar area per unit of time (Taylor et al., 2013). Considering the variable nature of water movements, both between and within the artificial reefs, it can be assumed that bait plume dispersal will change depending on the environmental conditions, resulting in different areas sampled between and within studies (Taylor et al., 2013). To standardise sampling in the method would require the ability to calculate bait plume dispersal, however, given the number of different parameters involved this would be extremely difficult (Harvey et al., 2011). Taylor et al. (2013) showed that when accounting for bait plume dispersal, with rudimentary calculations, community composition results could vary significantly compared to unstandardised results. Therefore, it is likely that each sample within this study is sampling different sized areas, potentially obscuring differences observed.

The methodology used in this study of BRUV based sampling, run through citizen science, has been shown to provide useful monitoring data on the fish communities of artificial reefs in a cost effective manner. Further to that, the results appear to reinforce trends observed over both artificial and natural reefs, indicating that the method has provided relatively accurate results. However, as previously noted, the method is likely to only record a subset of the fish communities present on the artificial reefs. Therefore, it is important that if this methodology is to be utilised in future studies that this limitation is acknowledged or addressed by supplementing the program with additional monitoring through other methods. This approach has been adopted by the Department of Fisheries (Western Australia) who have conducted BRUV based sampling whilst also utilising Diver Operated Video (DOV) when monitoring the fauna of the Geographe Bay artificial reefs (Appendices 1).

Despite the methodologies limitations, which are inherent in any monitoring method, the Reef Vision program has generated a large and useful data set that would prove to be cost-prohibitive to collect through other means. Therefore, utilising BRUV based sampling, deployed through citizen science, should be considered an option for monitoring the fish communities of artificial reefs in the future.

3.5.4.2. Future work

Due to time constraints, only nine months of data could be analysed in the current study. Thus, the first step in furthering the work presented here would be to analyse data collected for August and September. This analysis would allow for the determination of whether the patterns observed during the winter months are typical or driven by short-term events. This is particularly important as, due to poor weather and thus a lack of videos, June and July had to be merged into a single sample, potentially obscuring subtle trends between these months and winter in general.

While the methodology employed here resulted in the collection of sufficient data, developing a more regimented approach to the citizen science monitoring program would help to remove some temporal and spatial biases. However, it was noted by Florisson (2015) that increased requirements placed upon participants, *i.e.* sampling a natural reef in addition to the artificial reefs, resulted in low volunteer participation and thus limited quantities of data being collected. This is supported by the literature with highly regimented citizen science programs being found to result in low recruitment and retention rates of volunteers (Dickinson et al., 2010). One modification to reduce spatial bias in data collection, without increasing regulation significantly, could be to have participants deploy their BRUVs on specific clusters. Although controlling the timing of sampling, *i.e.* asking volunteers to all sample on specific days, may make the program too regimented and lower participation rates.

While this study has investigated the characteristics of the fish communities of the artificial reefs in Geographe Bay, it provides no comparison with adjacent natural reefs or sand/seagrass areas. This could be used to assess how effectively the reefs mimic nearby natural reefs, provide further investigation into the effect of habitat connectivity, as well as helping to determine whether the fish communities of these artificial reefs are influenced by 'attraction' and/or 'production'. Ultimately, these investigations would allow for an evaluation of the performance of the reef against its stated goals and contribute to the broader scientific literature on artificial reefs. To achieve this, utilising the current methodology, would require significant alteration of the current program and again may hinder participation rates. Alternatively, a concurrent BRUV based citizen science program, or another program utilising different methodology, could be created to solely sample natural reefs.

Standardising sampling among videos by calculating the area of the bait plume would also provide a significant improvement to the current methodology. The addition of a current meter to the BRUV frame would allow for the measurement of the strength and direction of currents on each deployment to be recorded, providing a rough estimation of the area covered by the plume and thus enabling the standardisation of each video drop (Harvey et al., 2011).

Furthermore, with the limitations inherent to BRUVs (see Chapter 2), it is likely that the monitoring program utilised only recorded a subset of the fish communities present on the reefs. A more accurate representation of the fish fauna could be recorded with the addition of another technique, such as an underwater visual census method. Given that the current monitoring program was developed to be cost-effective, the second method could be employed less regularly (*e.g.* seasonally or annually) and/or deployed/conducted using citizen science.

Chapter 4: General conclusion

Over the past five years the number of artificial reefs in Australia has expanded greatly, with the majority being deployed to increase the localised abundance of fish (Bateman, 2015). This increase is believed to be due to the provision of additional habitat, which results in their increased production and/or attraction and concentration from the wider environment (Bohnsack and Sutherland, 1985; Baine, 2001; Simon et al., 2011). It is this alteration of the surrounding environment that has led to legislation potentially requiring the biological monitoring of artificial reef deployments to ensure any negative impacts are identified and ameliorated (Department of Fisheries, 2012; Department of the Environment, 2016b).

With a number of artificial reef deployments planned around Western Australia, as well as those already underway, it is essential that cost-effective faunal monitoring programs be developed (Recfishwest, 2016). As such, Recfishwest, through funding from the FRDC, has instigated a number of research projects on artificial reefs, including the development of cost-effective methods for their monitoring. As part of this research, this thesis has reviewed a range of techniques for monitoring the fauna of artificial reefs and applied one of these, the BRUV system, in a citizen science program (Reef Vision) to monitor the characteristics of the Bunbury and Dunsborough artificial reefs.

Firstly, a critical review of a wide variety of methods for monitoring the faunas of artificial reefs, from traditional underwater visual census techniques to rapidly emerging fields such as environmental DNA analysis, was conducted (Chapter 2). Each method was assessed against five criteria; deployment, accuracy, precision, time and cost. The review found that the effectiveness of each monitoring method was dependant on a number of factors including, the type of fauna targeted, the type of artificial reef being monitored, the spatial scale of monitoring required and other considerations, such as logistics, budget and the timeframe of the monitoring program. Therefore, the type of monitoring method chosen should be based upon the objectives and logistical considerations of each study. One technique that scored well was the remotely operated underwater video method, which includes BRUV. This method was found to be relatively inexpensive and easy to deploy, whilst providing a moderate level of species richness and abundance accuracy of mobile fauna. Furthermore, the method was found to be effective for use with citizen science (Bear, 2016; Raoult et al., 2016).

Building on the earlier work by Florisson (2015) and Bateman (2015), this study investigated whether the characteristics of the fish faunas of the Bunbury and Dunsborough artificial reefs differed both spatially and temporally by utilising BRUV (Chapter 3). Local recreational fishers were recruited to deploy the BRUV units on the artificial reefs providing samples from October 2015 to July 2016. The results of this project found that the reefs showed significant differences geographically, as well as temporally, with a number of variables. The factor reef was found to have the most influence within these variables, indicating that habitat connectivity played a large part in determining the associated fish communities of the reefs. Significant results were also found with the factors month and the interaction between the main effects, suggesting that changes in temperature, as well as oceanographic processes, also contribute to shaping the reefs fish communities. Therefore, from these results it can be understood that the fish communities of the artificial reefs of Geographe Bay differ geographically and show temporal variations.

Furthermore, this study has demonstrated that the BRUV technique, deployed through citizen science, can be used successfully for monitoring the fish faunas of artificial reefs. With future deployments of artificial reefs, both planned and already underway around Western Australia, this program would be able to provide cost-effective monitoring for their faunas, particularly in regional areas where Government and tertiary institution based work can be financially prohibitive (Recfishwest, 2016).

To summarise, this thesis has provided an evaluation of the various fauna monitoring techniques available for artificial reefs, and then used one of these techniques, BRUV, to study the fish faunas of the artificial reefs of Geographe Bay. Ultimately, it has shown these fish communities to differ both geographically, and temporally, highlighting the usefulness of the technique in monitoring artificial reefs.

Appendices

Appendices 1. Fish species recorded over different studies of the Bunbury and Dunsborough artificial reefs in Geographe Bay. Studies include: this thesis which utilised Baited Remote Underwater Video (BRUV), deployed through citizen science, between October 2015 and June/July 2016; BRUV and Diver Operated Video monitoring by the Department of Fisheries (Western Australia) over six surveys between April 2013 to October 2014; and studies by Bateman (2015), utilising BRUV across three sampling dates in March and May 2015, and Florisson (2015), using BRUV between November 2014 and April 2015. A tick indicates that the species was found in these studies.

Taxa	Thesis	Department of Fisheries	Bateman (2015) and Florisson (2015)
Achoerodus gouldii	✔	✔	✔
Anoplocapros amygdaloides	✔	✔	✔
Anoplocapros lenticularis	✔	✔	✔
Apogon victoriae	✔	✔	
Aptychotrema vincentiana	✔	✔	✔
Aracana aurita	✔	✔	✔
Argyrosomus japonicus	✔		
Arripis truttaceus	✔		
Aulohalaelurus labiosus		✔	
Austrolabrus maculatus	✔	✔	✔
Chaetodon assarius	✔		
Caesioscorpis theagenes		✔	
Cheilodactylus gibbosus	✔	✔	✔
Cheiodactylus nigripes			✔
Chelmonops curiosus	✔	✔	✔
Choerodon rubescens	✔	✔	✔
Chromis klunzingeri		✔	✔
Chromis westaustralis	✔		
Coris auricularis	✔	✔	✔
Dactylophora nigricans	✔	✔	
Dasyatis brevicaudata	✔	✔	✔
Diodon nicthemerus	✔	✔	✔
Enoplosus armatus	✔		
Eubalichthys mosaicus	✔	✔	✔
Glaucosoma hebraicum	✔	✔	✔
Haliocheres brownfieldi	✔	✔	
Hypoplectrodes nigroruber	✔		
Haliochoeres brownfieldii		✔	
Helcogramma decurrens		✔	
Heniochus acuminatus		✔	
Hypoplectrodes nigroruber		✔	
Meuschenia freycineti		✔	✔
Meuschenia venusta	✔		
Monocanthidae spp.	✔		
Mustelus antarcticus	✔	✔	
Myliobatus antarcticus		✔	
Myliobatus australis	✔	✔	✔
Neatypus obliquus	✔	✔	✔
Neosebastes pandus		✔	✔
Eupetrichthys angustipes	✔	✔	
Notolabrus parilus	✔	✔	
Octopus tetricus	✔		
Ophthalmolepis lineolatus	✔	✔	
Orectolobus maculatus	✔		
Chrysophorus auratus	✔	✔	✔
Parapercis haackei	✔	✔	✔
Parapercis ramsayi	✔		
Paraplotosus albilabris		✔	
Parapriacanthus elongatus	✔	✔	
Parequula melbournensis	✔	✔	✔
Paristiopterus gallipavo		✔	
Parma mccullochi		✔	
Parupeneus chrysopleuron	✔	✔	
Pempherididae spp.	✔	✔	✔
Pentapodus vittae		✔	
Pempheris klunzingeri	✔	✔	✔
Pentaceropsis recurvirostris	✔		✔
Platycephalus longispinis	✔	✔	

Taxa	Thesis	Department of Fisheries	Bateman (2015) and Florisson (2015)
Platycephalus sp.		✔	
Platycephalus speculator	✔	✔	
Pseudocaranx spp	✔	✔	
Pseudolabrus biserialis		✔	✔
Pseudorhombus jenynsii	✔	✔	
Rhabdosargus sarba	✔		
Scobinichthys granulatus	✔		
Sepia apama	✔		
Sepioteuthis australis	✔		
Seriola hippos	✔	✔	✔
Siganus fuscescens	✔		✔
Siganus sp.		✔	
Suezichthys cyanolaemus	✔		
Tilodon sexfasciatus	✔	✔	✔
Trachinops noarlungae		✔	✔
Trachurus novaezelandiae	✔	✔	✔
Trygonoptera mucosa	✔		
Trygonoptera ovalis	✔		
Trygonoptera personata	✔	✔	✔
Trygonorrhina dumerilli	✔	✔	✔
Upeneichthys vlamingii	✔	✔	✔
Urolophus sp.		✔	✔
Total no. of taxa detected	**60**	**59**	**36**

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Appendix IV. Habitat Enhancement Structures (HES) or Artificial Reefs: a Review of design, application and deployment for Australian Waters

Habitat Enhancement Structures (HES) or Artificial Reefs: a Review of design, application and deployment for Australian Waters.

DRAFT FINAL Report: September 2015

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Document Status

Version	Purpose of Document	Orig	Review	Review Date	Issue Date
Rev A	Draft for Issue	Chris Surman	L Nicholson	12/09/2015	14/09/2015

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Contents

Abstract

Habitat Enhancement Structures (also known as FADs and Artificial Reefs) have been utilised for many hundreds of years. Recently, however, as a result primarily from overfishing pressures, some nations have implemented regulated and systematic installation of HES to increase the availability of both recreational and commercial fishes. In the past 40 years, millions of cubic metres of artificial reefs have been installed.

A wide variety of materials and designs have been utilised over the past 40 years, with a shift recently (due to community concerns) from materials of convenience (i.e. tyres, building rubble, cars, ships, telegraph poles etc.) to purpose designed and built structures. In Japan at least 130 different reef modules have been designed. Favoured construction materials are concrete and steel.

In contrast Australia has only a small number of artificial reefs, many of these constructed using old car tyres, particularly in South Australia. More recently, two purpose-built AR of concrete modules were installed in Geographe Bay, and a high profile steel structure off Sydney.

The purposes of artificial reefs are manyfold: Principally they are used to attract fishes for either commercial or more recently recreational purposes; reefs also are playing an increasingly important role in tourism associated with recreational diving. However the construction of ARs around the globe adhere to a few main outcomes; Preservation or protection of coastline, enhancement of fisheries, conservation of marine flora and fauna o prevention of trawling in sensitive areas.

The literature indicates several consistent requirements in the design and deployment of ARs. These include the use of stable materials, non – toxic material , complexity of structure rugosity (roughness of surface) and the provision of shelter, refuge, settlement areas and feeding areas all increase the biodiversity of and therefore success of HES.

Much has been written of whether such structures actually increase fish production, or merely act as attraction device thereby making fish extraction easier for users. The careful design and implementation of guidelines for any ARs can lead to a well-balanced design that incorporates all biotic trophic levels thereby increasing feeding opportunities not only for predatory fishes but for grazing animals.

The use of ARs is generally an expensive process – however the socio economic benefits of a well-designed reefal system will in the longer term contribute to the community.

1 Introduction

1.1 What are HES's

Habitat Enhancement Structures (HES) encompass a wide range of structures and materials placed deliberately in the aquatic environment for various purposes, but usually associated with increasing fishing success. More widely referred to as Artificial Reefs (AR), HES have been crudely defined as the development of any productive habitat in an otherwise unproductive location (Brock 1985). However, this has been further refined by the European Artificial Reef Research Network (EARRN) as *"submerged structures placed on the substratum (seabed) deliberately, to mimic some characteristics of a natural reef"* (Baine, 2001, Jensen 1998). However to incorporate a broader range of uses, Sutton and Bushnell 2007 defined HES's as *"one or more objects of natural or human origin deployed purposefully on the seafloor to influence physical, biological or socioeconomic processes related to living marine resources"*.

HES come in many forms, ranging from waste or surplus materials to sophisticated, specifically designed pre-fabricated units ranging from old car tyres, shopping trolleys, and building rubble to plastic reinforced concrete or moulded ceramic reef modules. Similarly, the purposes and acceptance of HES and their construction material has evolved from one of the creation of fish habitat through the disposal of waste materials to the development of artificial reef modules capable of mimicking natural ecosystems

The aim of this document is to review the types and uses of HES both within Australia and around the world with the aim of providing an overview and guide that may aid in the decision process when developing the concept of a new HES or AR.

2 The History of Habitat Enhancement Structures

Indigenous cultures have used artificial reefs for thousands of years to harvest both marine and freshwater food supplies (Kerr 1992). In the Mediterranean, ancient tuna fishermen from Sicily cut ballast stones free from their nets, the accumulation of these ballast stones provided fish habitat for the fishermen to exploit between tuna seasons, and eventually they added to the sites with wrecks. Similarly, the disposal of ancient Greek temple stones during harbour construction created new artificial reefs about 3000BC (Riggio 2000).

Elsewhere, particularly Japan, ad hoc use of artificial fishing reefs constructed of trees, rocks and sand-filled straw sacks were commonly used in the 17th century (Sato 1985). However, specific documented creation of an artificial reef in Japan occurred in 1795 when a local fisherman noted elevated fish catches over a sunken vessel. When the vessel deteriorated, the local fishing community constructed gabion baskets of bamboo and rocks in an effort to replicate the effects of the vessel. Elevated catches were recorded during the next summer, and hundreds more such reefs were developed over the next 10 years (Ino 1974).

Japan became the first nation to systematically develop HES for increased fisheries production. By 1930 the Japanese Government was subsidising the development of artificial reefs through the ministry of Agriculture and Forestry, and by 1954 regulation on the design and placement of HES was in place (Thierry 1988).

HES or AR development has increased rapidly in the past 40 years. The USA, Taiwan, Korea and Europe started developed AR programs in the early 1960's and the first Australian AR were placed in 1965 (Kerr 1992, Kim *et al.* 1994, Sheehy 1982). However, unlike Japan, most other countries initially constructed artificial reefs with waste materials, or Materials of Opportunity (MOP), such as tyres, car bodies, culvert pipes and building rubble. Led by Japan and the USA, by the 1980's most HES were being constructed of pre-fabricated concrete. Today more than 50 countries have deployed HES (Frijlink 2012).

3 Types of HES – Materials.

HES fall into two main categories of construction, those constructed from Materials of Opportunity (MOP, Harris 1995) and those that are Purpose Built to task. The types of construction material utilised since HES became more widespread has evolved in line with both experience and environmental, community and design concerns. More recently however, materials have become more sophisticated as tolerance for waste materials declines. Manufactured reef modules can range in shape, size, function and materials, with most constructed of reinforced concrete often stabilised to provide a neutral surface.

3.1 Materials of Opportunity

Early HES were principally constructed of readily available materials that could be used to create bulk whilst at the same time disposing of unwanted waste material. Common materials used to generate many reefs worldwide included tyres (Kerr 1992, Tessier *et al*. 2015, Downing *et al*. 1985, Campos and Gamboa 1989, Ferrer 2015), car bodies (Brown 2014, Kerr 1992, Fitzhardinge and Bailey-Brock 1989, Barnabe *et al*. 2000), concrete rubble (Kerr 1992) and vessels (dos Santos 2012, MMCS 2012) and discarded oil and gas platforms (Jorgensen *et al.* 2002). However, a myriad of materials have been utilised to create reefs either for recreational fishing or diving and range from shopping trolleys (QLD Govt. 2015), trolley cars (Lukens *et al.* 2004, Urbina 2008), tanks, armoured personnel carriers, drones and aircraft (Lukens *et al*. 2004) white goods (Brown 2014) and telegraph poles (Chuang *et al.* 2008).

Whilst some materials of opportunity such as scuttled vessels have proved successful both environmentally and socio-economically (see Brock 1994, Cole and Abbs 2012), others have provided both important lessons in the design and application of HES in the marine environment. For example, environmental concern of the impacts that tyres may have on the marine environment has led France to commence removal of 25, 000 tyres in the Mediterranean. Part of the issue for materials such as car tyres is that whilst readily available, they may leach toxins in to the environment (Collins *et al.* 2002), move across the sea floor destroying habitat (Ferrer 2015, Sherman and Spieler 2006) and are not suitable substrate for many benthic species due to the flexibility of the rubber (Fitzharding 1989, Barnabe *et al.* 2000). Tyre reefs in many cases have broken up and washed ashore after storms, or weighted tyres have fragmented, depositing rubber fragments onto beaches (Ferrer 2015, Skoloff 2007).

In Florida, at Osborne Reef, nearly 2 million tyres were dumped at sea in a community effort to create an artificial reef. After the reef broke up and dispersed, and tyres repeatedly washed ashore, the state government decided to remove the reef. Currently the government contributes $US3.4 million annually in an effort to remove the tyres. It is estimated that there are 200 reefs worldwide constructed of tyres with at least 20 million m^3 of AR (Ferrer 2015).

It is beyond the scope of this review to detail each type of HES created by MOP. However, it does appear that the costs associated with this type of habitat creation in the maritime environment presents long-term socio economic issues, including costs to local, state or federal government in clean-ups, damage and loss of marine habitat or leaching of material into the sea.

Figure 1: Recycled car tyres at Osborne Reef, Florida. The reef has broken up and dispersed (Lukens *et al.* 2004).

Whilst scuttled vessels must also be cleaned and prepared extensively prior to deployment, it appears that the costs involved may be offset by increased annual returns, especially from tourism-based activities, and especially diving (see dos Santos 2012, Brock 1994). In Hawaii a vessel that cost $US1 million to prepare and scuttle currently generates revenues in excess of $8 million a year for three operators, including an annual profit (after costs) of $1.3million (Brock 1994). The scenario is similar in Australia. The HMAS Brisbane has generated revenue of $AUD18 million since its scuttling four years ago (Sundstrom 2015). The HMAS Adelaide after costing $AUD5.8 million to prepare and deploy, currently generates an estimated $AUD4.5 million of dive revenue per year (Cole and Abbs 2012).

Some often overlooked environmental impacts form MOP are entrapment. Fish and sea turtles are known to have died as a result of disorientation in newly deployed vessels and aircraft in the USA due to inadequate planning and escape hatches (Lukens *et al.* 2004).

The convenience and availability of many MOP no longer exists. International Marine Pollution laws prohibit dumping of certain products at sea, requiring the cleaning and removal of hydrocarbons from car bodies prior to deployment. Scrap materials previously available to be used as MOPs for artificial reef projects are often recycled. Tyre recycling rates in the USA have increased from 10-70% in the past 15 years (Lukens *et al*. 2004). Yipp (1998) listed the longevity and suitability of MOP for artificial reefs and concluded that many materials do not last as long as previously expected (Table 1).

Table 1. Materials used for construction of artificial reefs, degradation lifespan and suitability for use as an artificial reef (adapted from Brown 2014 & Yip 1998).

Type	Life time (years)	Recommended
Cars and buses	<8	No, they are subject to corrosion
Wooden materials	< 1-6	No, they collapse even sooner from wave surge and destruction by marine borers.
Household appliances	< 6	No, polluting
Tyres	Indefinite	No, difficult to keep in place
Concrete/rock rubble	Indefinite	Yes, but transport costs excessive.
Boxcars	2-14	Debateable, breakup quickly
Subway cars	25-30	Yes
Tanks	>30	Yes, but preparation expensive.
Aircraft	>15	Yes, but preparation expensive.
Vessels (Navy ships, barges, ferry's)	>30	Yes, preparation expensive.

3.2 Purpose Built

The goals or objectives of many HES are to increase the productivity of specific target fishes, principally fish with intrinsic commercial or recreational value. The effectiveness of HES increasing productivity of any particular target species largely depends upon the design of the reef structure to be used (Pickering and Whitemarch 1997).

The development of pre-fabricated reef structures or HES has largely been driven by a renewed focus upon clear HES objectives and target species. The need to design HES that target particular species has been extensively developed in Japan, where over 130 different reef module designs targeting particular species have been constructed since 1952 (Thierry 1988, Polovina and Sakai 1989). Many authors have agreed that to achieve the desired objectives from the installation of an HES, integrating specific biological requirements of target species with engineering components will often lead to a more successful outcome (Diplock 2010, Seaman *et al*., 1989, Seaman 2008, Koeck *et al*. 2014, Fabi et al. 2011, Guner *et al.* 2009, Sato 1985, Sheehy 1982).

Japan has been at the forefront of the development of pre-fabricated HES, with reef modules specifically designed for increasing the production of pelagic and demersal fisheries, abalone (Okamoto 2002), sea cucumber, sea urchin, octopus (Polovina and Sakai 1989), marine algae culture, oysters and squid (Barnabe and Barnabe-Quet 2000). Extensive biological and engineering studies conducted by the Japanese, reflected in specifically designed reef material, allow for greater certainty that the reef will stay in place and provide the proper conditions for the particular species desired (Stone 1982, Thierry 1988).

In Japan, Korea, Taiwan and some states of the USA there are various government regulations stipulating the types of materials as well as the design and durability of new HES (Diplock 2010, Chuang *et al*. 2008, Thierry 1988, Lindberg and Seaman 2011, Murray 1994).

Purpose built HES take many forms, and may be constructed of;

- Reinforced Concrete or limestone
- Plastic Injected Concrete

- Fibre reinforced plastic
- Steel
- Ceramics
- Polypropylene (artificial seagrass)
- Geotextile bags
- Recycled shells
- Electrical current $CaCO_3$ deposition
- Recycled nylon fishing line
- Waste bivalve shells in cages or bags

Some HES may utilise a combination of the above materials in a composite design. For example, the Shell Nurse utilises discarded oyster or scallop shells embedded within a steel framework creating a "nursery-like" HES that recruits spawning invertebrates up to 80 times faster than standard concrete (JF Group 2008). Each material or composite has its benefits to allow the exact fabrication and manufacture of the engineered designs.

To date the most practicable material found to meet the growing requirements of HES is high strength marine-grade concrete. The advantages of concrete is that it can be manufactured in a wide range of shapes and sizes to suit specific requirements of individual reefs, and that they are non-toxic, pH balanced and may be altered to provide more suitable surface textures to encourage benthic settlement (Baine 2001, Lukens *et al*. 2004, Perkol-Finkel and Sella 2014). An added benefit is that the material is universal and easily applied by community groups in developing countries wishing to utilise designs such as Reef Balls (ReefBalls 2015). The Reef Ball Foundation estimates Reef Ball™ life expectancy to be 500 years or more. Steel, however, is used in pre-fabricated units for high profile type reefs (see below) where weight precludes the use or transportation of concrete equivalents.

Government-set manufacturing standards in Japan have allowed the development of far more sophisticate, longer-lasting designed HES. Japanese Government approved designed units must meet specific criteria, including durability/stability (minimum of 30 years' service, ability to withstand handling/placement rigors, resistant to burial/movement); safety (non-toxic, handling safety); functionality/biological effectiveness (proven and tested record of fish aggregation, attraction/production of targeted species, creation of desired habitat, biotic diversity); and economy (Grove and Sonu 1985).

4 Geographical Evolution of HES

Habitat Enhancement Structures, in the form of artificial reefs, have been utilised for many centuries. However, more recently many countries have adopted a regulated approach to installing HES, and consequently there is an increase in the sophistication of design and deployment of these structures, which then equates to more effective uses of materials and a more productive output. The development of HES has occurred principally in regions where fisheries production is paramount – either economically or socially. Hence it is no surprise that Japan leads in both the deployment and design in HES in the world, followed closely by Taiwan, Korea and the USA. The sections below outline the history of the use of HES in each of these regions.

4.1 Japan

HES's in Japan having been installed for several hundred years. The first records date to 1650 however regular use of intensive bamboo structures between 1789-1801 was initiated after artisanal fishermen noticed increased fish catches over old wrecks (Ino 1974). Fishermen had placed over 2000 cubic feet of stones creating two reefs. Fish catches where larger than expected for 4-5 years after deployment. By 1906 the first disused naval vessel was scuttled deliberately as an artificial reef. In 1930 the Japanese Ministry for Agriculture and Forestry had commenced subsidizing the construction of artificial reefs (Ino 1974). Since 1952 construction has intensified with estimates that the Japanese Government invests billions of dollars into enhancing fishing in both shallow and deep waters (Stone 1982). Japan is almost unique in that its HES are developed to enhance not only fin fish, but also commercial algae, lobsters, sea cucumbers, octopus and sea urchins.

The first generation of prefabricated artificial reef units were deployed in 1950, and were simple concrete cubes/boxes with windows (voids) which could be stacked to increase the height of reefs. By 1954 the Japanese government had regulations stipulating that only designed units could be deployed, and more recently that pre-fabricated units or reefs must pass stringent design protocols of longevity (Sheehy 1982). There are 6400 HES sites and approximately 20 million m^3 (1800 km^2) of artificial reefs in Japan (Barnabe and Barnabe-Quet 2000).

4.2 USA

The first use of reefs in the USA were small log huts (1.2m x 1.2m) immersed to attract table fish in Carolina during the 1830's (Lukens *et al.* 2004). Most artificial reefs in the USA were comprised of rocks, logs, ships or tyres, using waste material disposal as a secondary objective of the use of artificial reefs (Sheehy 1982). However, the cost effectiveness of such materials (it was cheaper to dispose of such materials in land fill) and inherent issues with tyres scouring bottom, and dislodging and becoming washed onto beaches, prompted both California and Florida to ban their use (Lukens *et al*. 2004). Since the 1980's, artificial reef development has been led by Japanese inspired design. A set of three study reefs as early as 1960 compared four materials, including street cars, vehicles, building rubble and prefabricated Japanese modules – the results found that both streetcars and vehicles lasted only 3-4 years whilst the rubble and prefab units lasted greater than 15 years (Sheehy 1982). In the USA approximately 1 million m^3 of reef exists, much of this along the Florida coastline where over 1500 artificial reefs have been deployed (Sutton and Bushnell 2007, Barnabe and Barnabe-Quet. 2000).

4.3 Philippines

Thousands of small reef modules have been deployed as part of aid programs sponsored by the federal government, and through Japanese and USA aid programs. Between 1977-1995, an estimated 70,541 reef modules were deployed, each module comprising either bamboo pyramids, clusters of four tyres, or a single concrete block (Munro and Balgos 1995).

Since 1991, 174 artificial reefs have been deployed in 75 sites in Negros Oriental, Central Visayas, Philippines (Munro and Balgos 1995). It was estimated that the annual harvest from these artificial reefs is 3.0 $kg.m^2$ which can be about 150 times higher than the yield from natural coral reefs. In this area, and elsewhere in the Philippines, artificial reefs are popular because they attract a great abundance of fish and enable Fishers to reduce fishing effort. However, it appears that they can contribute severely to overfishing if the catches exceed the maximum potential new production (Waltemath and Schirm 1995).

4.4 Korea

The government started subsidising and coordinating the placement of artificial reefs in 1971 using prefabricated concrete structures, which by 2011 had become a $55 million a year project (Kim *et al*. 1994, DoF 2010). Approximately $885 million has been spent on developing the South Korean artificial reef program over the past 40 years (DoF 2010). The total area of ARs now installed exceeds 207,000 hectares.

The South Korean Government applies a strict approvals process which takes 2 - 3 years. During the approvals process, each design is assessed on the basis of cost, economic efficiency and quality. An HES design has to demonstrate to be the equivalent or greater at generating productivity and effectiveness than any surrounding natural reef systems.

There are two basic types of HES deployed in South Korea, reinforced concrete structures designed for shellfish, crustacean and seaweed cultivation in shallow waters and larger concrete or steel structures used for finfish production in deeper waters (DoF 2010, Kim *et al.* 1994).

4.5 Taiwan

The first reef sets were small 1m^3 concrete blocks installed in 1957 (Chuang *et al*. 2008). Whilst a more recent participant in artificial reefs, the Taiwan Government commenced a coordinated approach in 1974 (Sheehy 1982, Chuang *et al* 2008) as part of their national fishery policy. By 1996 reefs designed to promote abalone, lobsters and fish had been installed using a variety of materials including fly ash, tyres, ships and concrete (Lin and Wang 2006). By 2008, an estimated 88 AR sites containing 180 000 modules and creating 2.2 million m^3 of reef had been deployed (Chuang *et al* 2008).

4.6 Europe

The first reefs are thought to have been deployed 3000 years ago when fishing nets were left amongst boulders to enhance fish catches in the next season (Riggio *et al*. 2000). In the last 40 years HES development has increased rapidly. For example in France, up until the 1980's there were 30000m^3 of reefs installed compared to at least 90000 m^3 at 33 sites presently. Europe, unlike other locations, has developed prefabricated modules to restrict illegal trawling and protect adjacent habits (Fabi *et al*. 2011).

The design of many European artificial reefs has experimented with a wide variety of forms of modules. These include Bonna (4 x 6m rectangular concrete matrixes), Alveolar Pyramids (2.5x2.5x2.9m concrete/steel pyramids), Comin (2.3 x 2.3m soccer ball like concrete frames), various cubic reefs (hollow cube concrete with various windows), Fakir electric piles (7 concrete pillars 1.6m on a concrete base), Floating ropes suspended in a cube frame 6x6m, the very strange prefabricated Kheops (concrete modules) and Thalame (Igloo-like concrete structures 1x3m). (Tessier *et al.* 2015, Figure 2)

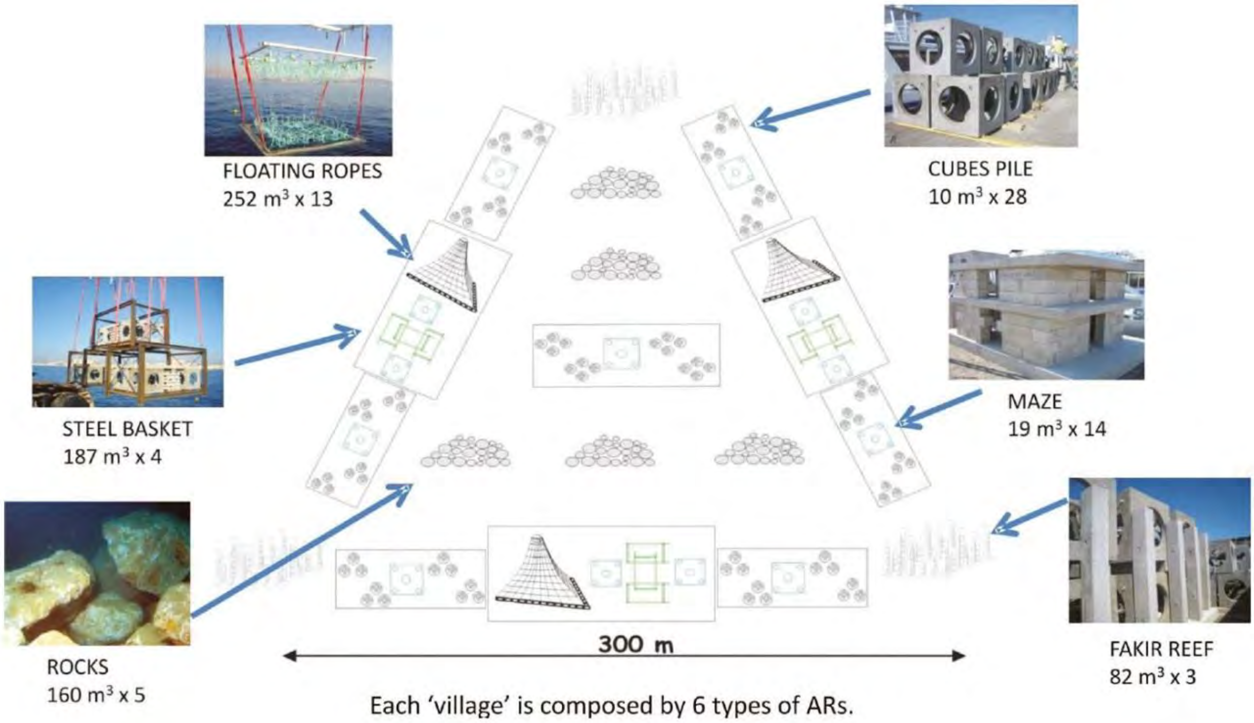
In addition, several structures have been deployed specifically to prevent trawling to protect habitats, these are concrete Tripods, Negris (three large columns on concrete base), Fakir electric piles and hexapods constructed of electricity poles (Tessier *et al.* 2015). The designs are based upon weighty structures with devices for snagging nets, thereby providing a disincentive to illegal trawling in the region. Often they are deployed in sets, and adjacent sensitive seagrass beds (Charbonnel *et al*. 2011, Tessier *et al*. 2015).

The French no longer utilise materials of opportunity, and have moved to prefabricated and designed structures almost exclusively manufactured form concrete. In addition, over the past ten years most HES have been planned, designed and subjected to environmental impact assessments and monitoring, with few negative impacts now being observed.

Eight percent (80%) of reefs in France have the primary objective of protecting artisanal fisheries, but also the protection of habitat from illegal trawling. HES modules must be stable and have design attributes to provide suitable habitat for a variety of organisms, not just fish. The European use of "Reef Villages" is extensive, where reefs systems are composed of a designed arrangement containing different reef modules with connectivity between each area (see Tessier *et al*. 2015, Fabi *et al.* 2011). This type of reef increases the structural complexity overall in order to suit a larger variety of organisms in a sustainable manner.

In contrast to both the USA and Australia, over half of the artificial reefs in France prohibit fishing, anchoring, dredging, trawling and diving.

Figure 2: The European example; a "Reef Village" in the French Mediterranean (after Tessier *et al.* 2015).



4.7 Australia

In Australia, aboriginals utilised artificial reefs as far back as 2000BC (Carstairs 1988 in Kerr 1992). Non-indigenous development of artificial reefs in Australia did not commence until the 1960's. Of the 72 reefs reviewed in Kerr (1992), 29 were constructed of recycled car tyres and 22 of vessels. Interestingly, at the same time that Japan was heavily regulating the use of artificial reefs and had moved away from adhoc materials, Australia continued to deploy tyre-based reefs. Similarly, by 1982 several North American states had banned the use of tyres due to pollution concerns (Sheehy 1982) and in the Mediterranean France have begun to remove tyre reefs (Ferrer 2015).

More recent artificial reefs include several surfing reefs (Rocks-Cable Stations and Geotextile - Narrowneck Reef, Frijlink 2012), several ReefBall-based reefs in QLD

(Moreton Bay) and NSW (Botany Bay), and several larger scale prefabricated concrete Fish Box (Haejoo Pty Ltd, Geographe Bay, W.A. – DoF 2013) and steel Fish Cave (Haejoo Pty Ltd) units (Sydney, NSW – Frijlink 2012).

Unlike European and Asian HES, Australian installations are primarily focussed upon recreational activities such as fishing or diving, rather than on artisanal or commercial fisheries.

5 The Purposes of Habitat Enhancement Structures

Habitat Enhancement Structures may be defined by their functionality according to the outcomes that each HES aims to achieve. Originally HES's, principally in the form of artificial reefs composed of materials of opportunity (tyres- i.e. Philippines Munro and Balgos 1995) or of more durable pre-fabricated concrete structures (see i.e. Japan, Korea - Kim *et al*. 1994, Thierry 1988) had the sole purpose to enhance commercial fin fish catches. In contrast, during the early development of HES in the USA and Australia, extensive use of waste tyres, vehicles (cars, buses, railway carriages, tanks) or building rubble was primarily aimed to increase benefits for recreation fishers and SCUBA divers (Kerr 1992, Lukens *et al.* 2004, Grossman *et al.* 1997, Boshnack *et al.* 1991).

More recently, HES take many physical forms, ranging from small, plastic artificial seagrass units (100cm^2) to massive rock breakwaters (1000's m^3, Dyson 2009, Bartholomew 2002, Virnstein and Curran 1986). There may be physical (coastal processes, coastal defence) biological (conservation, enhancement, protection) or socio-economic (recreational fishing, surfing and diving) factors in determining both the siting and structural attributes of HES. They may be designed to mitigate for loss of fish habitat during the construction of marinas (Davis 1984), to rehabilitate or stabilise habitat for fish and dolphins (Mikkelsen *et al*. 2013), to attract or encourage commercial fish species (Nakamura 1985), to protect sensitive marine areas from trawling (Tessier *et al.* 2015), to develop a commercial tourism industry (Brock 1994), to prevent coastal erosion (Kliucininkaite and Ahrendt 2011) for surfing (Tomlinson *et al.* 2007) or habitat rehabilitation after coral mining (Clark and Edwards 1994).

The primary purposes of HES may be categorised as;

- Conservation
- Recreation
- Restoration
- Prevention
- Attraction

However this list can be expanded to include specific purposes of HES;

- Restoration of habitat- rehabilitate habitat perceived to have been impacted by some process (i.e. trawling, fishing, storms).
- Creation of Protection Zones – install HES to create a barrier to entry to an area.
- Reduce fishing on stock
- Prevention of trawling – install HES to prevent fishing trawlers damaging habitat.
- Control of erosion – install HES to deflect waves, accrete sand, and protect coasts.
- Creation of breakwaters- shelter harbours dissipates waves.
- Increase fishery catches- attraction of commercial fish species to artificial reefs.
- Create Spawning grounds-creation of designed micro niches suitable for breeding.
- Create Recreational Fishing grounds-utilisation of artificial reefs targeting favoured table fish species.
- Create Diving areas-Design of aesthetically pleasing structures or vessels to attract marine life.
- For Scientific Research- Experimental assessment of HES.
- For Mariculture – Designed HES for abalone, oyster, lobster culture.

HES in Japan have been almost exclusively designed to enhance commercial fisheries production. There are numerous designed structures that have been approved by the government, ranging from small-scale modules developed for abalone (Cultivar Base- Kaiyo Doboku 2010), octopus (Octopus Home- Kaiyo Doboku 2010), and Shell Nurses (JF Group 2008) to promote the spawning of and settlement of fish and cephalopods. Rectangular, modular low profile concrete units have been developed to encourage algal growth (Kanakura Block Reef-JAFRA 2011), which in turn enhances production of crustaceans, molluscs and fishes. In contrast, large, multi-faceted steel or concrete, high profile reefs have been specifically designed to provide habitat for benthic fishes but also create upwelling and favourable current profiles for pelagic fishes (i.e. the 30m tall Uni-tower Series, the triangular JUMBO Reef, or the pyramidal Truss Reef, JAFRA 2011). A large range of cubic concrete modules are also produced which may be arranged together if necessary (i.e. the Tetra Reef TR3, Fish Paradise Reef, JAFRA 2011) which are very similar to the Haejoo designed Fish Box reef module deployed recently in Western Australia (DoF 2013).

The Norwegian-designed SeaCult Habitat (SeaCult AS 2015), comprises a central concrete cylinder filled with stones and surrounded by numerous polyethylene pipes creating fish habitat and seabed stability. This unit provides 300m2 of growing surfaces and the equivalent of 100 tons of rock in a unit weighing only 7.5 tons (SeaCult AS 2015).

At a much smaller scale, Diplock (2011) reviewed numerous structures and construction techniques designed to retrofit microhabitat for fishes along defensive structures (such as riverside rock revetments), below pontoons or jetties in marinas or anchored between jetty pylons or secured to pylons. One particular module called FishHab are made from recycled plastic (including old fishing line), which provides a durable and environmentally friendly structure. The prefabricated slats join together to form crate-like modules of 1.2 m^2 that provide additional fish habitat (Barwick *et al.* 2004).

Reef Balls are one of the most extensively utilised designed HES, with over 500 000 deployed. The designs range from 3kg-5000kg, and can be manufactured on site using moulds provided by the ReefBall foundation (see ReefBalls 2015, Lennon 2003). They are comprised of a rough-textured hollow concrete dome with numerous holes.

Figure 3: ReefBalls™ in situ.

6 Habitat Enhancement Structure Design and Construction

Prior to the adoption of Japanese-inspired designed structures, many artificial reefs deployed from the 1960's to the 1980's considered only the availability of cheap materials and a site to dump them. More recently, HES design focussed on structural integrity and stability (Bohnsack *et al*. 1994, Brickhill *et al*. 2005). However, current consensus is that the design process must consider an array of factors in order to better meet the objectives of any HES (Barnabe and Barnabe-Quet 2000, Spieler *et al*. 2001, Dyson 2009, Kliucininkaite and Ahrendt 2011, Chuang *et al.* 2008, Baine and Side 2003).

The architecture of any HES should consider biological, physical factors and socio-economic and engineering concerns during the design stage (see Figure 4). Thorough assessment and community stakeholder consultation will increase the likelihood of a successful outcome.

6.1 Reef Design and Complexity

Many authors have reviewed the influence upon HES structure and its effectiveness at meeting the reefs objectives. For example, in Europe, and particularly in Spain and France, some reef designs are predominately aimed at reducing the levels of illegal trawling in shallow waters in order to protect important fisheries nursery grounds of *Posidonia oceanica* (Barnabe *et al*. 2000, Bombace 1989, Charbonnel and Bachet 2010, Fabi *et al*. 2011). Such designs utilise heavy, concrete-based structures with protuberances that may catch or destroy nets. In Malaysia, the use of ReefBalls was in part to reduce bycatch of turtles by trawlers, which reduced from 100 to 20 pa, Bali (2004). These reefs are less effective at providing new habitat complexity for colonisation by different species, however provide both protection (from trawlers) at the same time as providing habitat for fishes.

As many HES/AR's are focused upon the enhancement or recovery of commercially or recreationally important fishes, their design is orientated to this end. Of the 72 AR's reviewed by Kerr (1992), 61 (85%) were placed to attract fish. Most of these reefs were constructed of tyres, and had little habitat complexity.

However, more recently, HES have multiple objectives that must be met. An assessment of the importance of the structural complexity of HES was undertaken in 2007 at a new "village" style HES placed in shallow water off of Marseille (see Rouanet *et al*. 2015). The relationship between habitat complexity and species diversity has been demonstrated (Charbonnel *et al.* 2011, Moura *et al.* 2007, Rilov and Benayahu 1998, Diplock 2011, Perkel-Finkel and Sella 2011, Le Direach *et al*. 2015).

Spieler *et al*. (2001) review of artificial reefs concluded that there is a long list of design attributes, i.e. Structure, texture, colour, substrate composition, leaching toxins, chemistry (i.e. wettability), that should be considered before construction. Design elements such as vertical profiles and shelter to reduce predation and increase settlement as well as increase diversity will all impact upon the numbers and diversity of species attracted to any structure, and ultimately to its overriding ecological success.

6.2 Biological Considerations

The design of any HES must include careful assessment of the biological attributes of the target species or community, as well as the existing environment. Milon (1989) summarised the biological objectives of HES as:

- attraction effects-the recruitment and concentration of species from an existing stock,
- productivity effects-an increase in the number and density of habitat-limited species due to greater food resources, reproductive habitat, and/or protection from predators, and
- Diversity effects-the attraction or development of new species in particular areas.

One of the central arguments surrounding HES is whether they simply aggregate fish from surrounding waters or other natural reefs (a FAD effect) or whether they actually contribute to the production of target species and biomass in a potentially resource-limited ecosystem. Many authors have discussed the ability of HES, particularly AR's to attract fishes, and particularly pelagic fishes (Brickhill *et al*. 2005, Koeck *et al.* 2014, Powers *et al.* 2003, Bohnsack 1989, Polovina 1989, Pitcher and Seaman 2000, Grossman *et al*. 1997). In fact, the potential for increased catches of fish encouraged the early development of the first artificial reefs by the Japanese artisanal fishers in the 1700's (Ino 1974). Newly placed HES are often rapidly colonised by adult and juvenile fishes, and are often characterised by higher diversity and biomass when compared to adjacent natural reef systems (Charbonnel *et al.* 2002, Gratwicke and Speight 2005, Willis *et al*. 2005, Folpp *et al*. 2011, Bohnsack *et al.* 1994). However there is scant data on the whether HES actually contribute to the production of biomass.

Pickering and Whitmarsh (1997) outlined four main pathways for increase in production;

- Increase in growth through prey availability at the HES
- Reduction in mortality through refuges provided by the HES
- Increase in recruitment of larval/juveniles by provision of suitable settlement habitat
- Reduction of harvesting pressure on adjacent natural reefs.

Very few papers have been able to demonstrate recruitment of fishes through production, although Feigernbaun *et al.* (1989) recorded spawning and recruitment of juvenile fish at a reef in Chesapeake Bay effectively demonstrating production within that site. In a study based at assessing the production vs attraction debate, Cresson *et al*. (2014) assessed trophic relationships on the largest artificial reef installed offshore of Marseille, France. Their results found two pathways, one based on the consumption of organic matter of pelagic origin and the benthic pathway based on local production. The reef system at Marseille was shown to increase the amount of organic matter produced which in turn led to an increase in secondary biomass production, perhaps representing that AR's can enhance the biomass of commercial fishes outside of the influence of attraction (Cresson *et al*. 2014).

HES may represent an effective management tool by increasing fish productivity at the HES whilst redirecting potentially harmful human activities away from natural reefs (Ambrose and Swarbrick 1989, Osenberg *et al.* 2002). However most studies on artificial reefs have focused monitoring at the HES rather than on nearby natural reefs or habitats. Osenberg *et al.* (2002) argues that whilst artificial reefs and HES present apparently attractive cure-alls for declining recreational fish takes, or increased recreational fishing effort, the risks are that HES may simply redistribute fishes away from natural habitats to the HES, and if exposed to fishing effort, increased catch rates (which are perceived as successful outcomes for HES) may actually lead to longer term declines in fish stocks (see also Milon 1989, Brock 1994, Bohnsack 1989).

6.3 Attraction versus production

It is widely accepted that many fish species rapidly colonise HES within the first months of deployment (Charbonnel *et al.* 2002, Cresson *et al*. 2014, Terashima *et al.* 2007). However, does attraction and production interact through density dependence (the provision of new habitat) or simply redistribute existing fishes? Some argue that it is possible that attraction of adults and juveniles (particularly of benthic species) away from natural reefs reduces the density of these species at those reefs, thereby providing settlement opportunities for larval fishes (Wilson *et al*. 2001, Osenberg *et al*. 2002). However these arguments suggest that HES present similar attributes to existing habitat, when many HES are installed over sea beds largely devoid of reefs.

In summary the attraction debate suggests that net production will not increase but that fish will aggregate towards either the natural reef or artificial reef depending upon the quality of the tow habitats, thus if the HES installed presents as preferred habitat, recruitment to the HES will be seen as a reduction in the density of the same species at nearby natural reefs. The production debate argues that any neighbouring natural reefs will be unaffected by HES, as larval fishes that could not settle or recruit on existing reefs due to competition for space, could do so at the HES, thereby increasing production (Polovina and Sakai 1989, Osenberg *et al.* 2002).

Brock (1994) suggests that AR's may aggregate the last remaining fishes in a local population and make them more vulnerable to exploitation from fishing, contributing to their decline or collapse from fishing. Similarly, Milon (1989) suggests that developing HES in support of commercial fishery may lead to a reduction in catches through congestion at sites, gear loss, fish take exceeding production or recruitment rates leading to declining returns to the fishery. This argument can equally be applied to HES development to encourage recreational fishing.

When assessing the objectives of any HES Milon (1989) suggests considering several key factors;

- What is the target species?
- What are the expected harvest levels?
- What potential impacts can be expected to background stocks?
- What expected impacts are there on any non-users of the proposed HES?

Prior to the deployment or design of any such structure, planners of HES should consider the levels of activity of potential users in the area before the HES are installed. This can then be assessed compared to post deployment activity levels and an assessment of cost-benefits be made. Coupled with this, during the consultation and through to the design stage, the focus user groups or stakeholders should be consulted to determine what the preferred target species are and design the HES to enhance the availability of these species.

In Hong Kong, Wilson *et al.* (2002) found that whilst the AR installed had rapid recruitment of both adult fish and settlement of small fry, careful management of fishing effort would be required for the AR to be successful in improve habitat, physically prevent bottom trawling, and enhance nursery areas

Biological or Ecological requirements to be considered prior to the design of any HES include:

- What species are being targeted
- What are the habitat requirements of target species (Pelagic/benthic, temperature, visibility)
- What are the food requirements?
- What are the shelter requirements (Refuges, surfaces, lighting)
- What are the life-history traits of the target species?
- Seasonality (Timing of larval settlement of prey or habitat species i.e. weed, coral, crustaceans)

6.4 Life History

All life forms that potentially may be targeted for any HES exhibit vastly different life history traits. For example, pelagic fishes are likely to be attracted to high profile reefs that generate favourable water currents, whereas demersal species will be more dependent upon the structure and configuration of HES. Incorporating micro habitats within a high profile reef may help attract both, and in some areas artificial reefs are comprised of networks of different structures designed for different target species (see Barnabe and Barnabe-Quet 2000, Tessier *et al*. 2015).

6.5 Seasonality

There are seasonal differences in the distribution and abundance of larvae of marine fauna and in the presence of mobile adult pelagic species. The sequence of larval settlement upon new HES may impact upon the later colonisation of higher trophic levels (Spieler *et al.* 2001) impacting upon target species. Assessing seasonal trends at the chosen site may facilitate recruitment to the HES.

6.6 Shelter and Habitat

Different species require different depth, light and temperature regimes, with some requiring shadowed areas for shelter. Some coral species recruit best to vertical surfaces, and others like gorgonia require dark overhangs. Similarly the complexity of the habitat and the range of shelter provided will ultimately determine what species of demersal fishes are able to successfully recruit to the HES.

6.7 Physical Characteristics

The physical attributes of HES that will contribute to its design and function include;

- surface texture, colour and chemistry;
- reef profile,
- shelter, and shading,
- reef size and configuration,
- Stability
- Substrate
- Hydrodynamics (currents, waves, tides)

Benthic assemblages (algae and invertebrates) are more abundant and diverse on textured surfaces, and texture increases the diversity of grazing fish. The impact of this upon the ability of different species to colonise HES will impact upon larger, predatory species of fishes that are often the target of recreational fishers (Spieler *et al.* 2001). As concrete is able to be manipulated to produce a desirable rugosity, and with the addition of micro silica can have a neutral pH, it has a prominent role in design of HES (Frijlink 2012, ReefBall 2015).

Once a HES is immersed its surface will rapidly acquires a biofilm. Studies have demonstrated that the type of biofilm will influence the succession of epibiota, and in turn influence higher trophic levels, including fishes (Fitzhardinge and Bailey-Brock, 1989). Incorporating design features that include the provision of shelter or refuges of different types will also influence settlement onto HES. Some fish species prefer blind-ended holes, others open ended void spaces that are shaded. A variety of void spaces or refuges will influence the ability of both small fishes or different life-stages of fishes to settle on HES. One study observed that increases in large void spaces reduced the number of smaller fish species likely due to predation pressure (Hixon and Beets 1989). Habitat complexity too increases diversity and biomass in fishes on HES. For example (Charbonnel *et al*. 2002, Baine 2001 and Sherman *et al.* 2002) found that increasing the number of small void spaces by adding concrete blocks into ReefBalls provided increased habitat for small fishes, crustaceans and other taxa, which appeared to have the added benefit of providing prey for larger fishes that used the reef.

These physical attributes provide a feed-back loop into the engineering considerations for HES during the development stage and will likely influence the end design.

6.8 Engineering Characteristics

Engineering considerations for HES include attributes of the structure, quality of the construction material as well as the attributes included in the design to facilitate recruitment (Dyson 2009).

Depending upon the purpose of the HES, engineering considerations will vary. For example an HES with the sole purpose of attracting fish for fishermen will not need to consider any visual or aesthetic qualities like one that is designed for both attracting fishers and recreation divers.

The most important attributes, apart from those design elements discussed above, is to provide an economical structure that is readily manufactured and transported to site that will also remain in situ without impacting the environment under a range of sea conditions. Thus it is essential that a design will not subside or sink into the substrate (Chuang *et al.* 2008), or be dispersed by storm events like tyre reefs or aircraft reefs (Lukens *et al.* 2004, Ferrer 2015).

Hydrodynamic features of the site also influence the construction and design, with many reef modules currently in use designed to produce upwelling effects to encourage fish attraction (see JAFRA 2011, JF Group 2008, Kaiyo Doboku 2010).

Figure 4 shows a flow diagram illustrating the factors influencing HES design. A combination of biological and physical characteristics of the site and target species along with engineering and socio-economic concerns will determine the siting, size and type of HES deployed.

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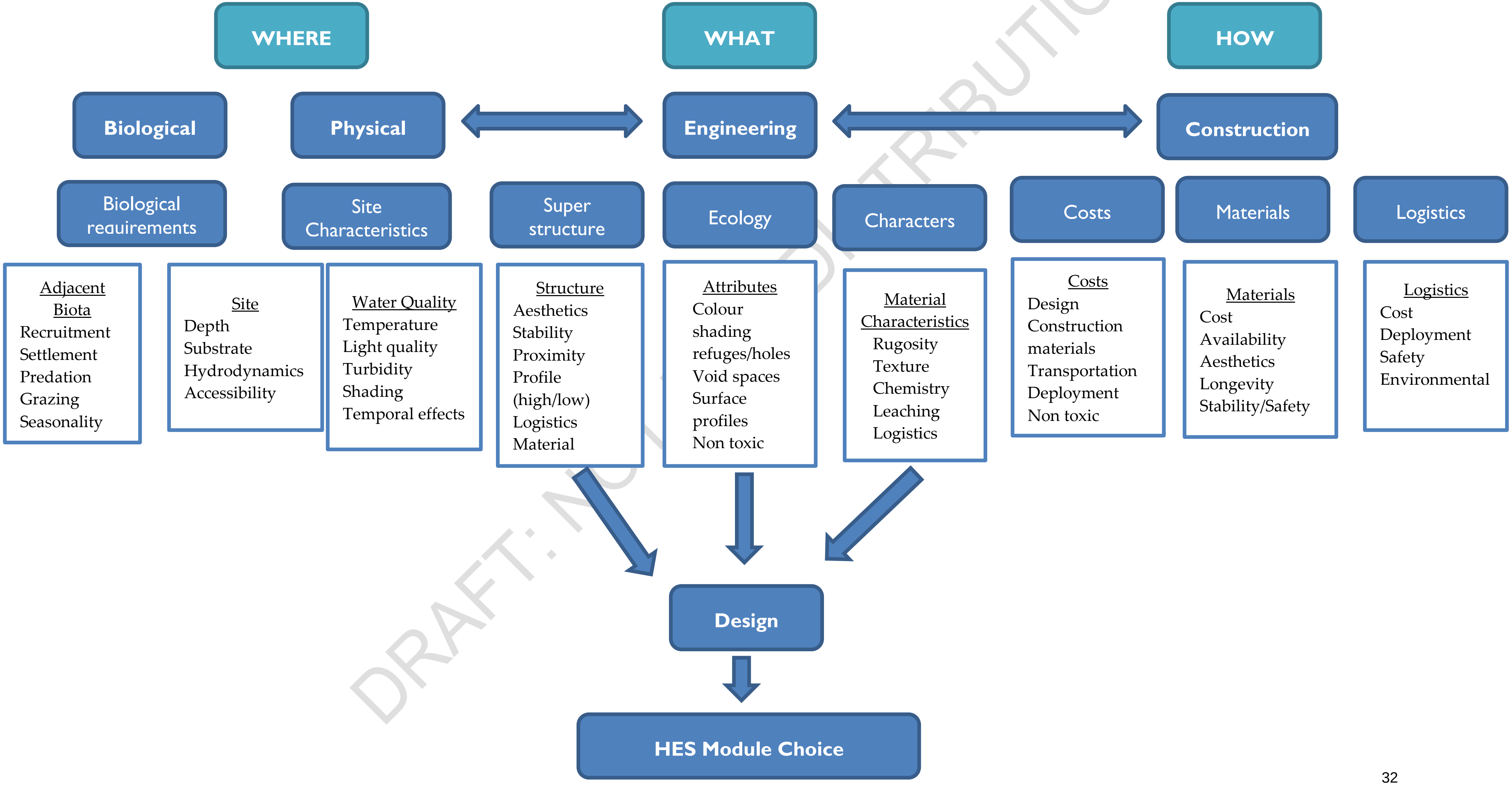
Figure 4: Diagram illustrating the factors influencing HES design. A combination of biological and physical characteristics of the site and target species along with engineering and socio-economic concerns will determine the siting, size and type of HES deployed.



7 The Design and Management Process

In Baine's (2001) extensive review of 249 reefs, over half failed to adequately meet the objectives originally set out for each HES. Most of the issues encountered revolved around poor planning and management in the early stages (1960-1980's outside of Japan) of the deployment of artificial reefs. Issues arose through;

- Poor site selection
- Size, stability and structure of HES
- Cost of the development
- Poor monitoring
- Illegal fishing/take
- Impacts of local climatic factors

Baines found that there was no single approach to managing an HES, but that it was dependent upon historical, social, economic and political factors unique to the site and objectives, all of which benefit from extensive planning and stakeholder consultation. Of the most critical factors to be considered during the process of managing an HES are socio-economics, economic evaluation, potential assessment of conflict, location of HES, and design.

7.1 Need/Objectives/Goals

Before the development of any HES the need to identify the objectives to be fulfilled by any installation needs to be established (Dyson 2009). Is the HES necessary and the most appropriate solution for the objectives and goals set?

As discussed above, there are many reasons or demands for HES/AR. The development of HES in the form of artificial reefs in Australia has primary focussed upon the demand created from recreational fishing or diving groups (Kerr 1992).

However, when considering any HES, the managers of such deployments must consider the implications of production or aggregation of various species on existing management policies (Guner *et al*. 2009), as well as a complex array of reef variables in order to produce the most cost effective outcome for the user group being targeted.

7.2 Site Identification

Perhaps the most significant contributor to the failure of HES is poor site selection (Baine 2001, Lowry *et al.* 2010). Selection of an appropriate site must consider ecological characteristics as well as physical and social-economic factors.

Site selection must consider areas with appropriate sea bed characteristics to deploy a HES (see Figure 4) whilst at the same time considering the proximity of suitable sites for end users of the HES. Folpp and Lowry (2013) recommend the development of Constraint Mapping, where limiting factors such as user conflict, environmental constraints or engineering constraints pose potential limitations on the potential location for any HES. Constraint mapping was used extensively in Bahrain to select suitable sites for artificial reefs (Edwards and Arora 2013).

Farina-Franco *et al.* (2013) considered the following aspects to increase the success of a new mussel reef;

- targeted species historically known form the area populations historically existed;
- Sea bed characteristics are adequate for the proposed HES
- Natural recruitment is likely to occur;

- Hydrodynamics of the site suitable for biological and engineering considerations.
- It is protected from human activities.

Each of these factors is equally important for any target taxa, although there may be some community resistance to limiting access to potential HES.

7.3 Material Selection.

The development of modern HES has moved away from the use of materials of opportunity that were often utilised in the past. The increased cost of utilising purpose-built structures is likely to be more cost effective as designed HES may be;

- engineered to suit specific objectives such as target specific species, user groups and fishing gear;
- manufactured to suit a chosen location in terms of depth, oceanographic conditions and substratum type;
- designed to maximise the duration, durability and compatibility of the structure to avoid problems associated with material toxicity;
- considered to yield comparatively greater cost-benefits than the use of materials of opportunity;
- improved ability to assess reef performance against set objectives

7.4 Reef Design – Layout

The structure and layout or site plan of any HES will determine the effectiveness of the HES to meet its objectives as well as the type and diversity of species utilising the HES (Folpp and Lowry 2013). The principal factors have been discussed in Section **X** above but include biological (habitat availability, habitat complexity, refuge availability, texture), physical (reef profile, module layout, size stability and strength) and socio-economic (community use, economic benefits, social benefits to perceived end user groups or stakeholders).

7.5 EIA

Prior to the deployment of any reef, once a design has been agreed upon through the above processes and community consultation has taken place, an Environmental Impact Assessment should be undertaken.

An EIA will assess the impacts to the existing environment, for example from scouring around structures from changes to existing habitat and communities as well as social impacts to the community including existing user groups be they commercial or recreational.

7.6 Evaluation of effectiveness/monitoring

The success of any HES can only be assessed through a managed monitoring program designed with the original objectives in mind.

8 Examples of HES

Appendix 1 lists a review of 224 Habitat Enhancement Structures and Artificial Reef, assessing the location, depth, material, size, cost and success. Examples of the main types of HES are described below.

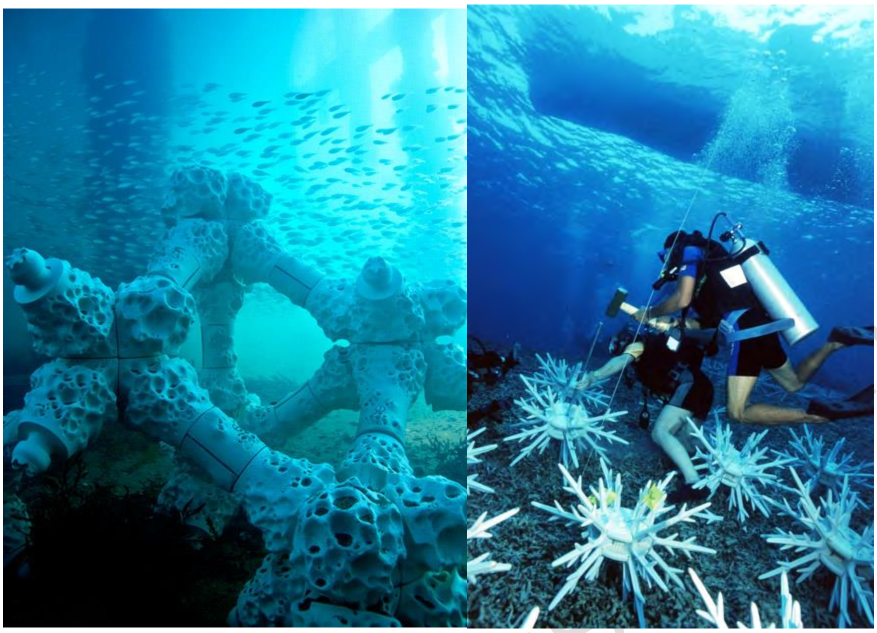
8.1 Ceramic based reef modules

Several relatively small sized, low profile reef modules have been produced in using a ceramic-based material. EcoReef (Ecoreef 2015) and Alex Goad's Modular Artificial Reef Structure (MARS - Goad 2015) use novel, small scale interlocking ceramic modules to create HES. The benefit of both the MARs and EcoReefs are that the modules are made from ceramic, an ideal material because it is pH neutral, non-toxic and chemically inert in seawater. The modules function to create suitable settlement or transplanting options for coral reefs and other epibenthos, as well as creating matrices of interlocking interstitial spaces suitable to a range of marine fauna. Ecoreefs have been utilised to rehabilitate reef areas damaged by dynamite fishing in the Caribbean (Pappagallo 2012). Cost benefits of Ecoreef is that it is estimated that the cost per organism settled was estimated at $2 compared with tyre reefs at $32.

8.2 Geotextile

Geotextiles are often constructed as large sausages or bags that may be deployed and filled in situ with local materials such as sand. Large Geotextile Reefs are beneficial as they are relatively easy to deploy, utilise local sand as fill, and if used as recreational reefs, provide a soft substrate to reduce potential injury from users.

Figure 5: MARS (Left) and Ecoreef ceramic modules.



Several multi-purpose reefs have been established using geotextiles. Two, one at Narrowneck reef QLD, and another in India were both designed to act as coastal protection reefs to reduce erosion of the shoreline, but also as recreational surfing reefs. In both cases, the deployment has proven very successful in terms of coastal erosion prevention, and somewhat successful at providing regular surf breaks. Jackson *et al*. 2007, Tomlinson *et al*. 2007. The Narrowneck (QLD), Boscombe (UK), Kovalam (India) and Mount (NZ) reefs have all experienced extensive colonisation by epifauna. In the case of the Narrowneck reef, its role as a multi-function reef includes dive trails and as a popular fishing spot. Both the fishing and diving activities do not conflict with the reefs surfing role as a large swell precludes the former activities (Edwards and Smith 2005, Kurian 1995).

There have been few reefs developed principally for surfing, however nearly all suffer from cost blowouts. The Boscombe Artificial Reef in Bournemouth, UK cost nearly £3 million and currently does not produce any surf (Bloxham 2010).

A surfing reef installed in California as compensation for the loss of surfing amenity through the construction of a nearby rock groyne by Chevron, resulted in poor surf conditions largely due to poor planning and the size of geotextile bags deployed. The bags were removed in 2008 after 24 years (Fontaine 2008).

A successful surfing reef, designed by ASR at Mount Maunganui in New Zealand, utilised long geotextile bags in an A frame shape. The project has been successful in meeting its prime objective as a surfing reef (http://www.asrltd.com/media/project-pdf/mount-maunganui.pdf).

Similarly, at Kovalam, India a Multi-Purpose Reef was designed to direct the region's powerful waves to break offshore, thereby minimizing the erosive effects of those waves on the beach. The outcomes included rapid restoration of the beach width as well as a consistent surfing reef, again constructed of geotextile sand filled bags.

8.3 Rigs to Reefs

Decommissioned offshore oil and gas production platforms (rigs) are known to attract large and diverse fish communities (Seaman *et al.* 1989, Rooker *et al.* 1997, Love *et al.* 1994). Rigs-to-Reefs (RTR) are the practice of converting decommissioned offshore rigs platforms so that it can continue to support marine life as an artificial reef. Through this decommissioning process, the oil well is capped and the upper 25 m of the platform is towed, toppled in place, or removed. The platform structure is removed at the expense of the oil company, leaving the remaining structure in place so that is can continue to support marine life. The oil company then donates the underwater platform to the state to manage as an artificial reef. (Rig2Reef 2015, Twomey 2010).

Ajemian *et al*. (2015) surveyed 15 artificial reefs in the Gulf of Mexico ranging from vessels to cut-off oil rigs. Their findings were that ambient water depth influenced fish assemblages, and that vertical structures situated in 50m of water were best suited for both fisheries enhancement and recreational diving opportunities. They also observed that a reefed platform deck provided more productive material for fish communities, although environmental considerations precludes leaving rig decks in place due to the risk of hydrocarbons.

8.4 Shell/ shell bags

Several artificial reefs utilise waste bivalve shells as either a part of a composite reef unit (see ShellNurse) or as stand-alone material for a low-profile reef. Bivalve shells incorporated into concrete or steel structures assist in the settlement of algae and other epibenthos (See JF Group 2008, Nestlerode *et al.* 2007, Fariñas-Franco *et al.* 2013). In Ireland, several experimental artificial reefs constructed of 16 tons of bagged scallops were very successful at re-establishing the existing benthic community (Fariñas-Franco *et al.* 2013)

8.5 Rock and rubble

Natural quarried rocks or rubble from construction have been widely used to create HES. Aggregations of rocks were used in the 17th century in Japan to encourage kelp growth (Nakame 1991), and ballast rocks from tuna nets were known to be functional fish attracting reefs in the Mediterranean (Riggio *et al*. 2000). Large rock seawalls, revetments and breakwaters are regularly used as coastal defensive structures are also known to provide large surface areas and refuge spaces between rocks that encourage fish settlement (Lukens *et al*. 2004, Bulleri and Chapman 2010, Bohnsack and Sutherland 1985). Pastor *et al.* (2013) reported that one coastal defence structure in the south of France had juvenile fish densities 30-109 times greater than adjacent natural habitats. A Californian study comparing reef substrates found that whilst prefabricated concrete shelters were more successful in attracting fish, quarried rocks were the material of choice due the availability, cost and ease of handling and deployment when compared to other materials (Turner *et al.* 1969). However the use of quarried rock and associated transport and deployment costs must be shown to be significantly more cost effective than purpose-built designed concrete structures.

Recently, Mikkelsen *et al*.(2013) reported on a project where 100 000 tonnes of boulders quarried from a harbour area were redeployed to create a stable reef system to prevent further erosion, create cavernous rock areas and restoring the original vertical profile of the reef . The key target species was to re-establish habitat for commercially important species such as Atlantic cod and Atlantic lobster *Homarus gammarus* and increase the use of the area by porpoises. The project was successful, increasing the frequency of porpoises feeding in the area over time.

8.6 Electrodeposition

Electrodeposition uses a low-voltage current to encourage the deposition of calcium carbonate (Arogonite) on the cathode to produce a biorock very similar in composition to natural coral skeletal material (Hilbertz 1977, Goreau 2012). The use of creating coral reefs utilising electrolysis has proven to be successful in providing a stable substrate for transplanting coral nubbins and encouraging epibenthos growth (van Treek and Schumacher 1998). In experiments conducted in Corsica, within 2 months of deployment approximately 5-10mm of aragonite was deposited upon the experimental mesh. Elsewhere it was found that corals and other benthic organisms spontaneously settle upon the produced substrate (Schumacher and Schillak 1994). The advantages to the system were found to be;

- Little alien material is required
- Not necessary to transport large amounts of material
- Can create any shape of foundation by bending cathode
- Substrate produced is like natural coral rock
- Materials can be recycled

Many projects are currently using the process in Indonesia (Goreau 2014), where power supplies are fed directly to developing reef areas close to shore. While the process is limited due to the nature of the power supply, the survival of transplanted coral and the speed of growth onto the substrate are far greater than on conventional substrates.

8.7 Artificial Seagrass

Artificial seagrass has been used extensively in seagrass community research, as the artificial beds can be placed next to natural meadows and easily sampled without damaging the natural seagrass (Bartholomew 2002, Virnstein and Curran 1986). Artificial seagrass has also been widely used as a soft engineering method to protect shorelines from erosion and as an alternative habitat for various marine organisms (Shahbudin *et al.* 2011). Artificial seagrass beds can be made from a range of materials and customized to mimic the target seagrass species.

Studies by Virnstein and Curran (1986) on artificial seagrass made from green polypropylene ribbons designed to mimic *Thalassia testudinum* (Turtle grass) showed extremely rapid colonization by seagrass-associated epifauna. The colonisation of artificial seagrass by epifauna was remarkably quick, with experiments showing peaks in abundance and species diversity after just 4-8 days. The growth of bacterial or diatom film on the seagrass blades was very rapid with evidence of colonisation within hours of deployment (Virnstein and Curran 1986). In another experiment, Shahbudin *et al.* (2011) constructed seagrass beds of $3m^2$ with seagrass manufactured from rubber. They recorded over 490 fishes around the installed modules illustrating the effectiveness of artificial seagrasses as a habitat and refuge.

Most artificial seagrass beds are small, and thus susceptible to being displaced by storm events. However the inclusion of seagrass habitat adjacent to larger HES perhaps as part of a multi-functional HES habitat could significantly increase the diversity of fauna.

9 Assessment of existing HES

Table 5 provides a summary of the costs and benefits of deploying different types of artificial reefs based upon data collected and presented in Appendix 1.

Scales for each category assessed with enough data are cumulative, that is the higher the score the less effective or attractive the HES is perceived to be based on the materials used, deployment techniques, outcomes achieved and impacts to the environment. Every care has been made when compiling this data, however it must be understood that there are overlaps between categories. Three categories were able to be scored;

- Cost
- Success
- Materials used

9.1 Cost

I have assigned an arbitrary cost scale to standardise information from numerous sources where often no cost is documented. Costs include the acquisition of materials (MOP, purpose built, community manufactured), transport (terrestrial and marine), deployment platform (small vessel, large barge, large barge with crane), labour source (volunteer groups, government agencies, private contractors). After considering the range of published costs for particular projects (see Appendix 1), a scale was developed where 1 = cheapest known method of installing reef, and 10 = most expensive documented reef (approx. 7 million Euros).

Table 2: Cost scales assigned to each HES reviewed in Appendix 1

	Scale	Description
Inexpensive	1	Very inexpensive, use of recycled or natural materials of opportunity, volunteer groups, simple deployment.
	2	Medium sized volunteer-driven reefs using MOP, very small research reefs.
	3	Large volunteer driven MOP reefs, small scale HES modules (i.e. FishHab modules) under jetty's, or ReefBall type projects in developing countries.
Moderately Expensive	4	Small scale designed HES or larger scale ReefBall type project in developing country
	5	Small –medium scale designed HES (i.e. reefballs), commercial construction, government funded or small vessels.
	6	Medium scale designed HES (composite reefs) funded by Government
Expensive	7	Designed HES or MOP (i.e. Tanks, trams, aircraft or oil rigs) cleaned and modified for deployment, deployed via barge with crane.
	8	Sophisticate designed or quarried rock on a medium to large scale government run with barge and crane.
	9	Sophisticated design, med-large scale HES or large ex-military vessels, cleaned & deployed with contract labour and barges with cranes.
	10	Sophisticated designed, large-scale HES deployed with contract labour and large barges and cranes.

9.2 Success

The success of any HES is whether it meets the original objectives set for the HES. In many early cases of artificial reefs using materials of opportunity there is little evidence of whether a reef was successful or not. In these cases a neutral value is assigned. Success scores are based on a scale outlined in Chuang *et al*. (2008).

Table 3. Matrix used to evaluate reef performance of case studies.

	Scale	Reef Performance
Successful	1	The reef has successfully met all of its objectives. There are no social or ecological concerns; research is fair enough and conclusive; the management is considered very well so it does not require any change.
	2	The reef has succeeded in meeting its objectives. It also shows positive effects over the local environment or sea users. Research is fair enough and conclusive and has good management but still needs improvement.
	3	The reef has only succeeded in meeting its objectives with limited success. Beneficial effects are recognizable. Research is fair enough to determine their performance; management has been good but needed to be improved.
Neutral	4	The reef has had inappropriate location, but it exhibits some achievement of objectives and also other beneficial effects in terms of the local environment or sea users. Some research has been done but is poor and not conclusive.
Unsuccessful	4	The reef's performance in terms of its objectives is inconclusive. Some positive aspects are identifiable but the overall success of the reef is indeterminable. The reef has had poor management.
	5	The reef has had inappropriate location; It does not exhibit any achievement of objectives nor any effect in terms of the local environment or sea users; poor or none research has been done.
	6	The reef has failed in its objectives and has negatively impacted the local environment or sea users.

9.3 Materials

A scale based upon the material used has been assigned to each reef based upon aesthetics and environmental attributes for each material. Therefore, purpose built designs score better (lower score) than materials of opportunity. Some MOP score better than others (i.e. waste quarry stones score better than used tyres).

Table 4: Scale of HES materials

Scale	Material
1	Purpose built – Ceramic modules
2	Purpose Built – Plastic/rubber Seagrass modules or waste shell reefs
3	Purpose Built – Pre-fab concrete modules
4	Purpose Built – Steel frames, geotextile bags, composite reefs
5	Materials of Opportunity – Waste quarry rock
6	Materials of Opportunity – Building rubble, concrete rubble
7	Materials of Opportunity – Ships (stripped and cleaned)
8	Materials of Opportunity – Dismantled Oil platforms
9	Materials of Opportunity – Car bodies, white goods
10	Materials of Opportunity - Tyres

Table 5: Average rankings of the main materials utilised in HES as summarised in Appendix 1.

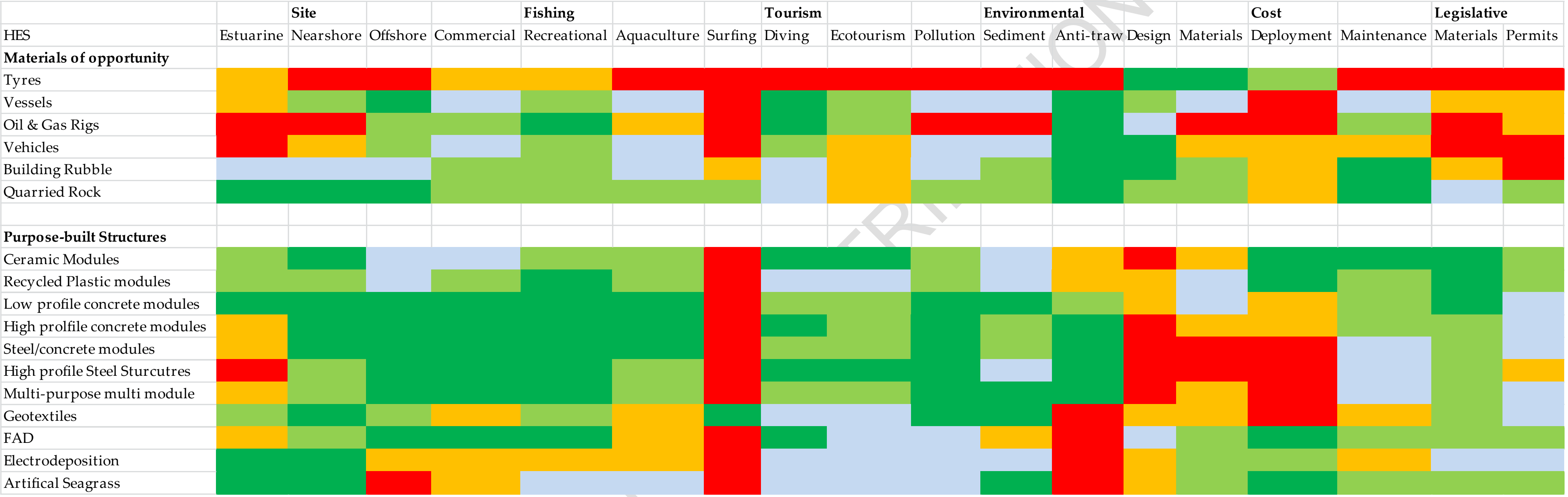
HES Types	Type	N	Material	Cost	Success	Total
Purpose Built - Bagged Shell	B	1	2.0	4.0	2.0	8.0
Purpose Built - Concrete	C	48	3.2	5.0	3.3	11.4
Purpose built - Geotextile	G	5	4.0	7.6	4.4	16.0
Purpose built - Mixed	MPB	22	3.8	6.1	2.9	12.8
Purpose built - Steel	I	1	4.0	9.0	4.0	17.0
Purpose built - Rocks	R	8	5.5	6.0	3.4	14.9
Purpose built - Seagrass	SG	2	2.0	1.0	2.0	5.0
Purpose Built - Natural	N	1	1	1	2	4
Total		**88**	**3.5**	**5.4**	**3.2**	**12.1**
Material of opportunity - Mixed	MW	23	8.8	3.4	3.5	15.7
Material of opportunity - Oil Rigs	O	13	8.0	7.0	3.0	18.0
Material of opportunity - Vessels	S	51	6.1	4.6	3.1	13.8
Material of opportunity - Tyres	T	35	10.0	2.8	3.6	16.4
Material of opportunity - Vehicles	V	14	8.1	5.5	4.1	17.6
Total		**136**	**7.9**	**4.2**	**3.4**	**15.6**
		224				

The results of assessing 224 HES from around the world are presented in Table 5 above. In general, purpose-built HES performed better than those using materials of opportunity in all categories except cost. MOP were on average ranked as 4.2 for costs (this would be lower if we excluded disused oil rigs, the preparation of oil rigs is considerably more expensive than the acquiring of waste materials) compared with 5.4 for purpose built HES. However purpose built HES outperformed MOP HES in both Material ranks and success. Material utilised in the construction of purpose built HES are invariably higher quality, designed for purpose and constructed of non-toxic materials. MOP generally still have some risk of being toxic, or polluting the environment through degradation. Whilst there is little difference in the rank success of both HES types, this is largely due to the paucity of data assessing the ability of HES to meet their original objectives in full or in part. Appendix 1 has an extensive assessment of the 224 reefs, but of these 94 (41.9%) do not include any qualitative or quantitative assessment of the success of the deployment.

Also missing from the assessment of HES, are results of the deployment on HES in Japan. Whilst there are numerous brochures and some references to Japanese development of artificial reefs and HES, none contained detailed descriptions of deployed reefs.

A heatmap (Figure 6) is presented showing a colour-coded scaling of the various characteristics of each type of Habitat Enhancement Structure reviewed. Codes were assigned based upon scores as outlined in the above tables, where the more desirable HES for a particular factor will be bright green, a mid-range HES will be pale blue and a highly undesirable HES will be bright red.

Figure 6: Heat map highlighting the various characteristics of Habitat Enhancement Structures.



Key: The likelihood that HES will be suitable for a particular suite of situations.

Very Suitable	Suitable	Neutral	Unsuitable	Very Unsuitable

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Appendix 1: A summary of Habitat Enhancement Structures (HES) and Artificial Reefs (AR) deployed around the world. HES are arranged according to country and year of deployment. HES codes; C = prefabricated concrete modules, B= bags of bivalve shells, G = geotextile bags, I = Prefabricated Steel, MW = Multipurpose Materials of opportunity, MPB = Multi-Purpose Built, N = Natural products, O = Oil Platforms, R = Natural Rock, S = Ships/Vessels, SG = Sea grass, T = Tyres, V = Vehicles (cars, trams, trains, tanks, planes). Function Codes; F = fishing, D= Diving, T = Anti-trawling, C= Conservation, S = Surfing, R = Research.

Country	Year	HES Code	HES Description	No. of Modules	Size	Agency	Depth (m)	Functions F	D	T	C	S	R	Outcome Met?	Notes	Source
Australia	1965	MW	Vessel/concrete/rubble	-	400 t	GOVT	20	x						No	Sunk into silt	1
Australia	1966	MW	Tyres/car	250/1	-	VOL	8	x	x					No	Dispersed due to corrosion of bindings.	1
Australia	1968	MW	Tyres/cars/rubble/vessels	10000/250/400t	-	VOL	18	x			x			YES		1
Australia	1968	MW	Tyres/cars/rubble/vessels/tram	500/60/70/11/1	-	VOL	20		x		x			YES		1
Australia	1969	V	Cars	-	-	VOL	10	x						No		1
Australia	1970	T	Tyres	2400	-	GOVT	10	x						YES	Too turbid to survey	1
Australia	1970	T	Tyres	15000	-	GOVT	10	x						No	Broke up in storm	1
Australia	1971	C	Concrete Modules	-	-	GOVT	4.5	x					x	YES	Lobster research	1
Australia	1971	C	Concrete Modules	8	-	VOL	3-5						x	YES		1
Australia	1971	T	Tyres	80	-	VOL	ND	x						-		1
Australia	1971	T	Tyres	5000	-	VOL	10	x						-		1
Australia	1972	M	Tyres/cars/rubble/vessels	-	-	VOL	5		x					-		1
Australia	1972	T	Tyres	-	-	VOL	-	x						-		1
Australia	1972	T	Tyres	2000	-	VOL	-	x						-		1
Australia	1972	T	Tyres	700	-	VOL	8	x						NO	Broke up in storm	1
Australia	1973	MPB	Tyres/concrete mods/steel frames	1000/100m3/4	-	COMM	10	x						YES	Attracted small no. fish	1
Australia	1973	MPB	Tyres/concrete mods/steel frames	1000/100m3/4	-	COMM	10	x						YES	Attracted small no. fish	1
Australia	1973	MPB	Tyres/concrete mods/steel frames	1000/100m3/4	-	COMM	10	x						YES	Attracted small no. fish	1
Australia	1973	T	Tyres	2000	-	VOL	10		x					-		1
Australia	1973	T	Tyres	25000	-	GOVT	18	x						NO	Broke up in storm	1

Country	Year	HES Code	HES Description	No. of Modules	Size	Agency	Depth (m)	Functions						Outcome Met?	Notes	Source
								F	D	T	C	S	R			
Australia	1975	MW	Composite waste Harry Atkinson	1	-	GOVT	-	x						-		2
Australia	1975	T	Tyres	-	-	-	3	x						-		1
Australia	1976	S	Vessels (multi)	10	76m	-	45	x	x					YES		1
Australia	1976	S	Vessels	1	74m	-	20	x	x					-		1
Australia	1976	T	Tyres	-	-	-	25		x					-		1
Australia	1977	T	Tyres	-	-	-	25	x						NO	Too deep to work	1
Australia	1978	MW	Rubble/machinery	-	-	-	9							-		1
Australia	1978	T	Tyres	-	-	-	12	x						-		1
Australia	1982	S	Vessels	1	18	-	12	x						YES	attracts fish	1
Australia	1982	S	Vessels (2)	2	39	-	16	x						YES	attracts fish	1
Australia	1983	T	Tyres/ pipe	50t/10t	-	-	15	x						-		1
Australia	1983	T	Tyres	1400	-	-	-	x						-		1
Australia	1984	S	Vessel	1	-	GOVT	20	x						YES	attracts fish	1
Australia	1984	S	Vessel	1	-	GOVT	20	x						YES	attracts fish	1
Australia	1984	T	Tyres	1000	-	VOL	5-10	x						-		1
Australia	1984	T	Tyres	33600	-	GOVT	18	x						YES		1
Australia	1985	S	Vessel	1	-	COMM	22	x						-		1
Australia	1985	T	Tyres	25200	-	GOVT	18	x						YES		1
Australia	1985	T	Tyres	18200	-	GOVT	20	x						YES		1
Australia	1986	S	Vessel	1	-	COMM	66	x						-		1
Australia	1986	T	Tyres	11200	-	GOVT	18	x						YES		1
Australia	1986	T	Tyres	12600	-	GOVT	18	x						YES		1
Australia	1986	T	Tyres	33600	-	GOVT	18	x						YES		1
Australia	1986	T	Tyres	28000	-	GOVT	18	x						YES		1
Australia	1986	T	Tyres	28000	-	GOVT	18	x						YES		1
Australia	1987	MW	Steel flotation tanks	2	-	COMM	20	x						-		1
Australia	1987	S	Vessel	3	-	GOVT	33	x						-		1
Australia	1987	S	Vessel	1	-	GOVT	25	x	x					-		1
Australia	1987	S	Tyres	33600	-	GOVT	20	x						YES	good fishing	1
Australia	1988	C	Concrete pontoons	20	-	COMM	20	x						-		1

Country	Year	HES Code	HES Description	No. of Modules	Size	Agency	Depth (m)	Functions F	D	T	C	S	R	Outcome Met?	Notes	Source
Australia	1988	S	Vessel	1	-	GOVT	20	x						YES	attracts fish	1
Australia	1988	S	Vessel	2	-	VOL	18	x	x					YES	attracts fish	1
Australia	1988	S	Vessel	1	-	VOL	20	x						-		1
Australia	1988	S	Vessel	1	-	VOL	20	x						-		1
Australia	1989	S	Derrick Barge	1	-	COMM	50	x						-		1
Australia	1989	V	cars/vessel	50/1	-	VOL	9	x						-		1
Australia	1990	IW	Port load facility	1	-	COMM	9-17	x						-		1
Australia	1990	R	Boulders	50000t	-	COMM	10-20	x						-		1
Australia	1990	S	Vessel	1	-	VOL	15	x						YES	rapid colonisation by flora & fauna	1
Australia	1990	S	Vessel	1	-	VOL	20-24		x					-		1
Australia	1990	S	Vessel	1	-	VOL	11	x						-		1
Australia	1990	S	Vessel	1	-	GOVT	200	x						-	too deep to be use	1
Australia	1991	C	Concrete pontoons	1	-	GOVT	45		x					-		1
Australia	1991	MW	Tyres/pontoons/bus shelters/vessel	45/6/3/1	-	GOVT	20	x						YES	attracts fish	1
Australia	1991	R	Rubble	1	-	VOL	5	x						-		1
Australia	1991	S	Vessel	1	-	VOL	13	x						YES	attracts fish	1
Australia	1991	S	Vessel	1	-	VOL	5-30		x					-		1
Australia	1991	S	Vessel	1	-	VOL	22		x					-		1
Australia	1991	T	Tyres	2800	-	GOVT	9	x						YES	good fishing	1
Australia	1991	T	Tyres	2800	-	GOVT	15	x						YES	good fishing	1
Australia	1999	G	Geotextile bags	400	70000m3	GOVT	-				x	x		YES		45
Australia	1999	R	Granite boulders	-	3500m3	GOVT	-					x		YES		45
Australia	2000	G	Geotextile bags	1	45000m3	GOVT	2-10					x		YES		3
Australia	2001	C	Reef Balls	50	-	VOL	20		x					YES	fish attracted to site	2
Australia	2002	C	Reef Balls	5	2500m2	GOVT	-	x						YES		2
Australia	2005	C	Reef Balls	180	-	GOVT	20	x						-	barge, small crane, contractors for 14d	4
Australia	2006	C	Reef Balls	180	-	GOVT	20	x						-		4
Australia	2007	C	Reef Balls	180	-	GOVT	20	x						-		4

Country	Year	HES Code	HES Description	No. of Modules	Size	Agency	Depth (m)	Functions F	D	T	C	S	R	Outcome Met?	Notes	Source
Australia	2007	S	Vessel	-	-	GOVT	-	x	x					-		2
Australia	2008	C	Reef Balls	3	2500m2	GOVT	11	x						YES	high satisfaction from surveys	2
Australia	2008	C	Reef Balls	2	-	GOVT	-	x						-		2
Australia	2008	C	Reef Balls	400	-	GOVT	20	x						-		4
Australia	2008	C	Fish Boxes	2	200ha	GOVT	14	x						-	large, concrete structures on barge crane	2
Australia	2008	C	Fish Caves	2	175ha	GOVT	35	x						-	large, concrete structures on barge crane	2
Australia	2009	C	Reef Balls	400	-	GOVT	20	x						-		4
Australia	2010	C	2 reefs of reefballs	224	65ha	GOVT	14.5	x						YES	$265000 for 224 balls	5
Australia	2011	I	Steel pre fab unit 12m high	1	700m3	GOVT	38	x						-		2
Australia	2012	C	Fish Boxes	20	208ha	GOVT	22	x						-	large, concrete structures on barge crane	46
Australia	2013	C	30 x 10t prefab in groups of 5	30	4ha	GOVT	27	x	x					YES	Very expensive, large structures	6
Australia	2013	C	3o x 10t prefab in groups of 5	30	4ha	GOVT	17	x	x					YES		6
Bahrain	2012	MPB	Reef Complex, reefballs, antitrawl, wind tower	2620	-	GOVT	6-15	x	x	x				YES		7
Canary Is.	1990	MPB	Multi-purpose concrete modules	52	15000m2	GOVT	18-26	x		x				YES		8
Canary Is.	1991	C	concrete rectangle	84	24000m2	GOVT	18-26	x		x				YES		8
Canary Is.	1993	C	alveolar type	35	9800m2	GOVT	18-26	x						YES		8
Canary Is.	1993	C	alveolar type	34	9800m2	GOVT	18-26	x						YES		8
Costa Rica	1987	T	Tyres	5000	1000m2	GOVT	10				x			YES		9
Cyprus	1990	S	Zenobia - 178m ship	1	178m	WRECK	>30		x					YES	Accidental sinking full of cars trucks, 57000 divers a year	10
Cyprus	2012	S	Nemesis 3- Vessel, plus 2 others	1	25m	GOVT	25		x					YES	1800 divers on first day, Lots of fish, octopus, inverts.	10

Country	Year	HES Code	HES Description	No. of Modules	Size	Agency	Depth (m)	F	D	T	C	S	R	Outcome Met?	Notes	Source
Denmark	2008	R	Large stones to create cavern reef	-	45000m2	GOVT	4-18				x		x	-		11
Denmark	2014	S	Ferry	1	55m	GOVT	19		x					YES		12
France	1968	MW	Pipes, tyres, cars, rocks	15/7ton/100/50	400m3	GOVT	20-23	x						-		13
France	1970	MW	Tyres, rocks	-	200m3	GOVT	-						x	-		13
France	1971	V	Cars	26	-	GOVT	12-18	x						NO		14
France	1972	V	Vehicles	26	-	GOVT	12-18						x	-		13
France	1975	T	Ballasted Tyres	>170	-	GOVT	12	x						NO		14
France	1979	MW	Tyres and breeze blocks	20000/47	3856m3	GOVT	15-30			x				-		13
France	1980	C	Breeze blocks x 6 modules	1	48m3	GOVT	22-39	x						-		13
France	1980	C	Breeze block modules	36	288m3	GOVT	22-39	x						-		13
France	1983	MPB	36 Alveolar pyramids	36	225m3	GOVT	15-23			x				-	Alveolar are 2.5x2.5x2.9 concrete/steel pyramids	13
France	1985	MPB	Bonnas, nine heaps of 14 Comins	4/126	1942m3	GOVT	17-30			x				-		13
France	1985	MPB	Concrete modules 15 x Bonna type	15	4208m3	GOVT	22-39	x						-	Bonnas are 4x6m concrete matrix rectangle	13
France	1986	MPB	Bonnas/cube reefs(2m3)	3/190	856m3	GOVT	33			x				-		13
France	1988	T	Tyres	-	-	GOVT	12-25	x						YES		14
France	1989	MPB	3 Thalames, 2 x bonnas	3/3	127m3	GOVT	15-30						x	-		13
France	1989	MPB	Sea rocks	440	654m3	GOVT	-			x				-	Searocks are 2m2 base concrete with a 1.2m high concrete spike	13
France	1989	MPB	Concrete reef modules 1.92m3	125	240m3	GOVT	33	x						-		13
France	1990	MPB	3 Thalames, 2 x bonnas	1	81m3	GOVT	15-30	x						-	Thalames are 3 x 1m domes like igloos	13
France	1992	C	Pipes	60	426m3	GOVT	7-23			x				-		13
France	1993	S	Vessel	1	250m3	GOVT	31				x			-		13
France	1996	C	Pipes	45	319m3	GOVT	30-35	x						-		13
France	1996	S	Vessel	1	140m3	GOVT	36				x			-		13
France	1999	C	Bonna pipes	800	2400m3	GOVT	18-20	x						-		13

Country	Year	HES Code	HES Description	No. of Modules	Size	Agency	Depth (m)	F	D	T	C	S	R	Outcome Met?	Notes	Source
France	1999	MPB	Pipes, Sabla in 25 piles of 20	109/500	1623m3	GOVT	7-22			x				-	Sabla are a 1.2m3 concrete block with round windows and catching protrubances on each top corner	13
France	1999	S	Vessel	1	-	GOVT	-		x					-		13
France	2000	MPB	40 negri, tripods, kheops	40/12/6	734m3	GOVT	15-25						x	-	Tripod like spikes, negri column on base, kheops weird prefab	13
France	2002	MPB	rocks, steel plates, concrete, float ropes	3/18/2	1048m3	GOVT	20-30	x						-		13
France	2002	MW	Dalots, telegraph poles, spiral staircases, chaotic haps	2/9/12/2	4250m3	GOVT	10-25	x						-		13
France	2003	MPB	Bonna x 3 heaps	600	600m3	GOVT	20	x						-		13
France	2004	CW	Concrete culverts, concrete heaps	28	12ha	UNI	10-30	x						YES	rapidly colonised	15
France	2004	MW	pipes, chaotic heaps, dalots	60/36/72	2200m3	GOVT	15-30			x				-		13
France	2006	MPB	Pipes, Sabla in 80 piles of 20	144/1600	2400m3	GOVT	15-20	x						-		13
France	2007	MPB	cube reef/mazes/baskets/ropes/fakir	168/78/18/18/18	27300m2	GOVT	18-33	x						-	maintain fishing, experimental and enhance biodiversity	13
France	2009	MPB	pipes, steel baskets and eco reefs	99/10/2	1083m3	GOVT	9-32	x						-		13
France	2009	MPB	Multi prefab domes/plate steel/ropes	6	850m3	GOVT	6-12	x						-		13
Indonesia	1999	C	Reef Ball	3000	-	COMM	-				x			YES	increase mar habitat, counter reef bombing	16
Iran	2012	MPB	reef complex, reef ball, lameh mahi etc.	64	100m2	GOVT	10-15						x	YES		17
Ireland	2012	B	Bags filled with scallops, 0.5-1tonne bags	16	16t	GOVT	17				x			YES		18
Israel	1982	S	barge	1	80x30m	GOVT	32	x	x				x	YES		19

Country	Year	HES Code	HES Description	No. of Modules	Size	Agency	Depth (m)	F	D	T	C	S	R	Outcome Met?	Notes	Source
Israel	1982	T	tyre modules ballasted	1	27m3	GOVT	26	x					x	NO		19
Italy	1974	MPB	composite e pre fab to encourage mussel oyster anti trawl	168	3ha	GOVT	13	x		x	x		x	YES		20
Italy	1989	C	cub pre fab blocks	191	1.8ha	GOVT	10	x		x	x		x	NO		20
Korea	1983	C	Reef sets of 4 prefabricated modules - turtle/cube/cylinder/jumbo	-	800m3	UNI	20-40	x						YES		21
Kuwait	1981	T	Tyres	-	25m2	GOVT	10	x						YES		22
Malaysia	1998	C	Reef Ball	1500	-	GOVT	-				x			YES	reef ball a suitable tool to ripping the trawler nets that entangled on it	23
Malaysia	2006	SG	Artificial Seagrass modules	-	3m2	UNI	6-10	x						YES		24
Mauritius	1980	S	Vessel	1	-	VOL	24	x	x		x			YES		25
Mauritius	1981	S	Vessel	1	-	VOL	20	x	x		x			YES		25
Mauritius	1986	S	Vessel	1	-	VOL	12	x	x		x			NO		25
Mauritius	1987	S	Vessel	1	-	VOL	38	x	x		x			YES		25
Mauritius	1987	S	Vessel	1	-	VOL	36	x	x		x			YES		25
Mauritius	1987	S	Vessel	1	-	VOL	22	x	x		x			YES		25
Mauritius	1989	S	Vessel	1	-	VOL	71	x	x		x			YES		25
Mauritius	1991	S	Vessel	1	-	VOL	39	x	x		x			YES		25
Mauritius	1992	S	Vessel	1	-	VOL	45	x	x		x			YES		25
Mauritius	1996	S	Vessel	1	-	VOL	29	x	x		x			YES		25
Mauritius	1996	S	Vessel	1	-	VOL	29	x	x		x			YES		25
Mauritius	1998	S	Vessel	1	-	VOL	19	x	x		x			YES		25
Mauritius	1998	S	Vessel	1	-	VOL	30	x	x		x			YES		25
Mauritius	2003	S	Vessel	1	-	VOL	27	x	x		x			NO		25
Monaco	1977	R	rock	1	300t	GOVT	28-30	x						NO	too deep and incorrect material	26
Monaco	2007	C	1.2t breeze block slab pyramid	1	1.2t	GOVT	-						x	YES		26
Netherlands	1992	R	basalt rock	4	500t	GOVT	18				x		x	YES		27
North Sea		O	Decommissioned Oil Rig	1	182360m3		70	x						-		28

Country	Year	HES Code	HES Description	No. of Modules	Size	Agency	Depth (m)	F	D	T	C	S	R	Outcome Met?	Notes	Source
								Functions								
Norway	2006	C	Rundel reefs Each with 12 modules	2	3.5m2	GOVT	10-20			x	x			YES	Rehab KELP after grazing by sea urchin, encourage fish	12
Norway		C	Rundle reefs (spindle type) 9t Seacult	2	250m2		-	x			x			YES	lots of cavities and Area for size, 7.5t product equivalent to 100t habitat	26
NZ	2006	G	Geotextile bags	-	5000m3	GOVT	10					x		NO		45
Philippines	1977	T	low profile tyre	-	small	GOVT	15-18	x						YES		29
Philippines	1978	T	low profile tyre	-	small	GOVT	4	x						YES		29
Philippines	1984	N	Pyramid Bamboo	-	small	GOVT	12	x						YES		29
Philippines	1989	C	Concrete cube	-	small	GOVT	11-12	x						YES		29
Philippines	1991	C	Concrete tent	-	small	GOVT	4-6	x						YES		29
Philippines	2009	MPB	concrete steel wheel 4x21m	1	med	GOVT	-	x	x					-		30
Portugal	1998	MPB	Massive each with 2940 protect mods/36 exploit modules	21500	43km2		20	x		x				YES	massive system of 6 reefs totalling 21 500 modules covering 43km2, Fisheries recovery, new habitats, manager of fisheries	26
Portugal	2012	S	4 massive ships	4	102m	GOVT	26-32	x	x				x	YES	7000 divers, lots of benthic/pelagic fish, 150 sp inverts; recreation, research, fish, diving	31
Scotland	2006	C	Each 4000 breeze blocks	12000	6000t each	GOVT	12-30						x	YES	loss of o2 near edges	12
Senegal	2004	C	400 gabions/75 concrete cubes	475	570m2	AID	12-16	x						YES	Cost v.low used local labour. Materials, local rafts to deploy	32
Spain	2005	C	369 x 5t modules, 3x3m	569	4818ha	GOVT	15-40			x	x			YES	Prevent illegal trawling/ Artisanal fishing increased/trawling stopped	12
St Helena	2014	MW	Cars, Bakery equip, vessels	13	-		8-27	x						-		33
Sth Africa	2008	S	Large Barge	1	128m	GOVT	20		x					YES		34

Country	Year	HES Code	HES Description	No. of Modules	Size	Agency	Depth (m)	F	D	T	C	S	R	Outcome Met?	Notes	Source
Sth Africa	2008	S	Large Barge	1	128m	GOVT	40		x					YES		34
Sweden	2003	R	Large rock reef	7	800000m3	GOVT	20-37				x			YES	Compensation for habitat loss dt harbour/lobster, brown crab, cod, saithe, pollack and whiting	12
Thailand	2010	V	Tanks, trucks, trains	27/273/198	-	GOVT	-	x						-		35
UK	2001	MW	Tyre and concrete	500	900	GOVT	12						x	YES		36
UK	2004	S	Vessel	1	113m	GOVT	23-28		x					YES	Research recreation dive centre,	12
UK	2009	G	Geotextile bags	1	13000m3	GOVT	10		x			x		NO	Failed to get useable surf	26
USA	1960	MW	Streetcar, cars, prefab concrete, rock	1/14/44/333t each	409m3	GOVT	18	x						YES	tested longevity, prefab most effective	37
USA	1965	C	Prefab concrete boxes, 2.4x1.2x1m each	75	-	GOVT	?	x						NO	only 20 remained close together, rest displaced dt bad logistics	37
USA	1965	C	Prefab concrete boxes, 2.4x1.2x1m each	125	-	GOVT	?	x						NO	20 remaining effective after 17yrs	37
USA	1965	C	Prefab concrete round	100	-	GOVT	?	x						NO	site lost completely	37
USA	1975	C	Concrete blocks	150	-	GOVT	2	x						YES		38
USA	1980	C	Fibre reinforced concrete prefab modules from Japan	3	-	GOVT	<20	x						YES	vol. labour supervised by manufactures easy to put together, tow , no cranes	37
USA	1983	MW	Tyres embedded in concrete, concrete igloos	103	-	GOVT	-	x						YES		39
USA	1985	SG	Artificial Seagrass modules	>10	1000cm2	UNI	0.5						x	YES	Very quick colonisation by invertebrates	40
USA	1985	V	railroad cars various states	210	-	GOVT	24	x						YES		41
USA	1986	V	DC3	4	30m	GOVT	10	x	x					NO		41
USA	1987	V	boxcars in sets 6	48	-	GOVT	22	x						NO		41
USA	1993	V	Boeing 727	1	50m	GOVT	24	x	x					YES		41
USA	1994	V	F4 Aircraft ballasted	2	100m2	GOVT	20	x	x					YES		41

Country	Year	HES Code	HES Description	No. of Modules	Size	Agency	Depth (m)	Functions F	D	T	C	S	R	Outcome Met?	Notes	Source
USA	1995	V	F106 Drone	2	20m	GOVT	35	x	x					YES		41
USA	2000	G	Geotextile bags	175	1400m3	GOVT	-					x		NO		45
USA	2003	C	Reef Ball	2000	-	GOVT	-				x			YES		23
USA	2006	V	Armoured Personnel carriers	-	-	GOVT	-	x	x					YES		41
USA	2008	V	Subway Cars	48	912t	GOVT	25	x						Yes	subway cars provided free, lots of conflict with fishing/lobsters	47
USA	?	C	Reef Ball	800	-	VOL	-	x						YES		23
USA	?	O	Rig deck	3		GOVT	40	x						-		42
USA	?	O	standing platform	1		GOVT	40	x						-		42
USA	?	O	standing platform	1		GOVT	67	x						-		42
USA	?	O	standing platform	1		GOVT	79	x						-		42
USA	?	O	toppled platform	8		GOVT	50	x						-		42
USA	?	O	cut-off platform	12		GOVT	60	x						-		42
USA	?	O	toppled platform	6		GOVT	83	x						-		42
USA	?	O	cut-off platform	3		GOVT	84	x						-		42
USA	?	O	toppled platform	4		GOVT	46	x						-		42
USA	?	O	toppled platform	2		GOVT	36	x						-		42
USA	?	O	cut-off platform	2		GOVT	75	x						-		42
USA	?	O	cut-off platform	2		GOVT	71	x						-		42
USA	?	S	Vessel	1		GOVT	34	x						-		42
USA	1970's	C	Prefabricated boxes for lobsters	?		GOVT	-	x						YES	research suggests useful	37
USA-Hawaii	1963	V	cars			GOVT	20	x						NO		43
USA-Hawaii	1982	S	vessel			GOVT	20-25	x						YES		43
USA-Hawaii	1985	C	Reef modules concrete			GOVT	20	x						-		43
USA-Hawaii	1985	T	Tyres			GOVT	10-15	x						NO		43
USA-Hawaii	1989	S	Vessel, concrete prefabricated modules	53m/6x/4x	1.85ha	GOVT	24-36		x					YES		44
Denmark	2007	R	boulders 1-6t	1	60000m3	GOVT	-			x	x			YES		26

Sources: 1. Kerr 1992, 2. Frijlink 2012, 3. Jackson *et al.* 2007, 4. Maunsell 2009, 5. Kerr 2013, DoF 2013, 7. Edwards and Arora 2013 , 8. Haroun and Herrera 2000, 9. Campos and Gamboa 1989, 10. Olsson 2014, 11. Mikkelsen *et al*. 2013, 12. OSPAR 2009, 13. Tessier *et al.* 2015, 14. Barnabe *et al* 2000, 15. Koeck *et al*. 2011, 16. Newmont Mining 2003, 17. Azhdari *et al.* 2012, 18. Farinos-Franco *et al*. 2013, 19. Spanier 2000, 20. Bombace *et al.* 2000, 21. Kim *et al.* 1994, 22. Downing *et al.* 1985, 23 ReefBall Foundation, 24. Shahbudin *et al.* 2011, 25. MMCS 2012, 26. Fabi *et al*. 2011, 27. Leewis and Hallie 2000, 28. Jorgensen *et al*. 2002, 29. Munro and Balgos 1995, 30. Rotary Philippines, 31. dos Santos 2012, 32. Terashima *et al.* 2007, 33. Brown 2014, 34. Gotz *et al.* 2015, 35. Heimbuch, J. (2010). 36. Collins *et al.* 2002 37. Sheehy 1982, 38. Davis 1985, 39. Feigenbaum *et al.* 1989, 40. Virnstein and Curran 1986, 41. Lukens *et al.* 2004, 42. Ajemian *et al*. 2015, 43. Fitzhardinge and Bailey-Brock 1989, 44. Brock 1994, 45. Wikipedia, 46. http://www.nprsr.qld.gov.au/parks/moreton-bay/zoning/trial_artificial_reef_program.html, 47. Urbina 2008.

Appendix V. The application, needs, costs and benefits of Habitat Enhancement Structures in Western Australia: Trends in artificial reef construction, design and management in Australia

The application, needs, costs and benefits of habitat enhancement structures in Western Australia:

II Trends in artificial reef construction, design and management in Australia

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November 2015

Cover photo: One of 140 1 tonne concrete cubes deployed in three sites around Koh Tao, Thailand by the Department of Marine and Coastal Resources and the Prince of Songkla University. Photo Andreas Fiskeseth.

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Non-technical summary

Although the first modern habitat enhancement structure was deployed in Australian waters in 1965, the total count of artificial reefs now stands at 121. The prevalence of such structures varies between states, with relatively large numbers in Victoria (28), South Australia (26), Queensland (22) and New South Wales (21), with lower numbers in Western Australia (11), Northern Territory (9) and Tasmania (4). Unsurprisingly, the highest concentrations of artificial reefs are found close to major cities and/or within sheltered bays, such as the Gulf of St Vincent and Moreton Bay. The rates of deployment of these structures have changed overtime, with the trends also differing among states, however, it is relevant that 29 of the 121 reefs (24%) have been deployed since 2010 reflecting a change in government policy and demand from particular public sectors. To date, 65% of artificial reefs in Australia are composed from materials of opportunity (i.e. cheap and easily accessible waste items), with decommissioned steel vessels and used tyres the most commonly employed constituents. However, there has been a clear shift in materials used to construct artificial reefs in Australia over the 50 years. For example, most reefs constructed between 1965 and 1978, were comprised of used tyres, with this material of opportunity being used less frequently compared to scuttled steel vessels between 1982 and 1994. Whereas, since 2001 almost all the artificial reef deployed around the country were constructed from purpose-built pre-fabricated concrete and steel modules. While artificial reefs in countries such as Japan and South Korea have been deployed to enhance commercial fisheries and most of those in France used to prevent illegal trawling, the vast majority of reefs in Australia were deployed for recreational activities. Thus, 96 of the 121 artificial reefs were constructed for the primary purpose of enhancing fishing activities, with a further 19 and 2 for designed to facilitate SCUBA diver and generate waves for surfers, respectively.

Introduction

There has and will always be a need for food and the realisation that placing objects into waterbodies attracted fish, and other potential food sources, resulted in the creation the first habitat enhancement structures (HES). In the Mediterranean Sea, the use of such structures dates back 3,000 years, with the disposal of ancient Greek temple stones during harbour construction (Riggio et al., 2000). Furthermore, Sicilian tuna fishermen cut ballast stones free from their nets at the end of the fishing season, which, over time, provided fish habitat and thus stocks for the fishermen to exploit (Riggio et al., 2000). In Australia, however, there is archaeological evidence that indigenous groups employed artificial reefs much earlier from about 2,000 B.C. to 200 years ago to grow both marine and freshwater food (Carstairs 1988), with some of those structures still present in some south-western Australian estuaries today (Dix and Meagher, 1976; Dortch, 1997).

Initially HES were used to attract fishes for commercial exploitation and, such was the success of these structures that, by 1930, the Japanese Government was subsidising the development of artificial reefs (Thierry, 1988). The earliest reefs were made from natural, locally abundant materials, such as rocks, logs and bamboo, referred to as "Materials of Opportunity" (Harris 1995, Harris et al. 1996). By 1954, Japan had established a national program to undertake research and development on HES and specifically purpose-built designs (Nakamae, 1991; Grove et al., 1994; Jensen, 2002; Bortone et al., 2011). The increase in functionally and range of purpose-built designs led to the realisation that HES could not only increase commercial fishery yields, but could also enhance recreational fisheries and provide opportunities for aquaculture and sea ranching (Nakamae 1991, Grove et al. 1994, Fabi and Fiorentini 1996) and tourism, particularly SCUBA diving (Branden et al. 1994). Moreover, these structures could aid in species conservation (Pickering et al. 1999, Claudet and Pelletier 2004), the provision of additional specific types of habitat (Spanier and

Almog-Shtayer 1992), illegal fishing mitigation (Ramos-Esplá et al. 2000), habitat restoration (Clark and Edwards 1994) and habitat protection (Jensen 2002).

Despite the proliferation of HES around the world, the first modern artificial reef was not deployed in Australia waters until 1965 (Kerr, 1992). Since then more reefs have been deployed and reviews undertaken by Pollard and Matthews (1985), Kerr (1992), Branden et al. (1994) and Coutin (2001) have provided information on trends in early reef developments. However, unlike countries like Japan and South Korea, which deploy specifically designed pre-fabricated HES, as of 2001, the majority of artificial reefs within Australia were still made up of material of opportunity such as tyres (37%) or ships (22%) with only a small portion made from concrete (6%; Coutin, 2001). In recent times, states such as New South Wales and Western Australia have developed policy statements and guidelines on the design, location and use, environmental impacts and monitoring (Department of Fisheries Western Australia, 2012; New South Wales Government, 2015). Moreover, a number of artificial reef programs have been developed, aimed at improving the quality and management of artificial reefs and which have resulted in the deployment of numerous HES (Department of Fisheries Western Australia 2015, Fisheries Victoria 2015, New South Wales Department of Primary Industries 2015).

In light of the above, the aim of this study is to undertake a literature search to identify trends in artificial reef construction within Australia, since the deployment of the first artificial reef in 1965 to the present day. The chapter considers where and when artificial reefs were deployed, what the reefs were constructed from, and their primary purpose. It identifies trends in artificial reef design, location and purpose, and assesses how these patterns have changed over the past 50 years.

Materials and methods

This work builds directly on to earlier analyses of artificial reefs in Australia conducted by Pollard & Matthews (1985), Kerr (1992), Branden et al. (1994) and Coutin (2001). It thus combines the data presented in those documents with those obtained during contemporary literature searches. These searches were conducted in search engines (*e.g.* Google and Google Scholar) and documents indexed in scientific databases (*e.g.* Scopus and Web of Science). Keywords employed as search terms included artificial reefs and habitat enhancement structures, with additional words such as Australia and the names of the various states and territories. Once a habitat enhancement structure was detected in the literature, information for the following metrics, i.e. location, year of deployment, materials of construction, primary purpose and builder/funder were obtained and stored in a database.

To allow comparison of different reefs in different spatial locations (states and territories) and over time, the information was condensed into several broad categories. For example, the materials of construction were categorised as either being 'materials of opportunity' (MOP) or 'purpose-built' and then subdivided further based on the material (see Table 1). Similar the data for the reef purpose and the builder/funder for that structure were also categorised.

Note that the literature search was limited to purposely-placed benthic artificial reefs and thus both accidental shipwrecks or floating Fish Aggregation Devices (FAD) have been excluded from this meta-analysis.

Table 1: Classification and description of materials used in the construction of artificial reefs. Photographs of each of the various types of artificial reefs are provided in Plate 1 and 2 below.

Materials of opportunity (MOP)	
Category	**Description**
Tyres	Used vehicles tyres of any size (Plate 1).
Steel vessels	Steel hulled ships and other steel vessels that have been purposely scuttled for the creation of an artificial reef (Plate 1).
Rubble	Quarry rock and concrete rubble/waste (Plate1).
Mixed MOP	Combination of two or more materials of opportunity at a single reef.

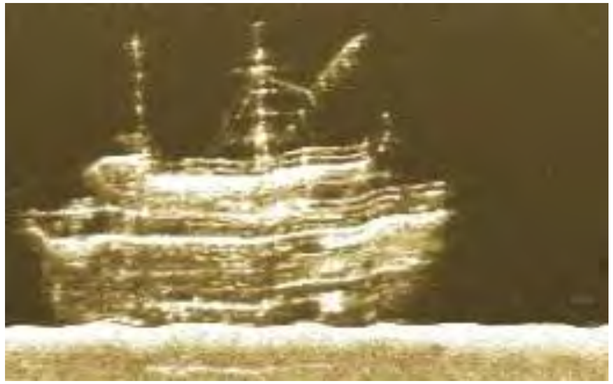
Purpose-built	
Category	Description
Concrete modules	Concrete modules of any size built specifically for use in the construction of an artificial reef e.g. concrete fish boxes and Reef Balls (Plate 2).
Steel modules	Steel modules of any size built specifically for use in the construction of an artificial reef, e.g. steel fish caves (Plate 2).
Geotextile bags	Geotextile bags, which can be filled with material such as sand, that have been specifically designed for use in artificial reef construction (Plate 2).
Mixed	Mixture of materials of opportunity and purpose-built modules at a single reef. Generally this occurs when a reef is added to over multiple years.

Plate 1: Examples of artificial reefs constructed from various materials of opportunity (see Table 1).

Osborne Tyre Reef, USA. Photos from http://fishwrecked.com/forum/reef-or and http://www.projectbaseline.org/gulfstream/

Deploying a rubble reef, USA.

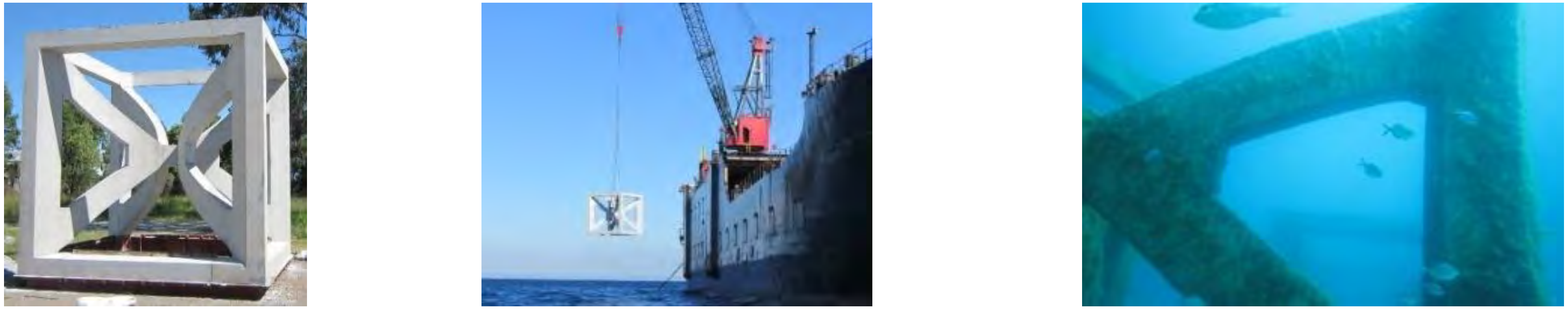
Photo from http://www.mymanatee.org/



Tiwi Pearl, part of the Harry Atkinson artificial reef in Queensland

Photos from http://www.nprsr.qld.gov.au/parks/moreton-bay/zoning/trial_artificial_reef_program.html

Plate 2: Examples of various purpose-built artificial reefs (see Table 1).

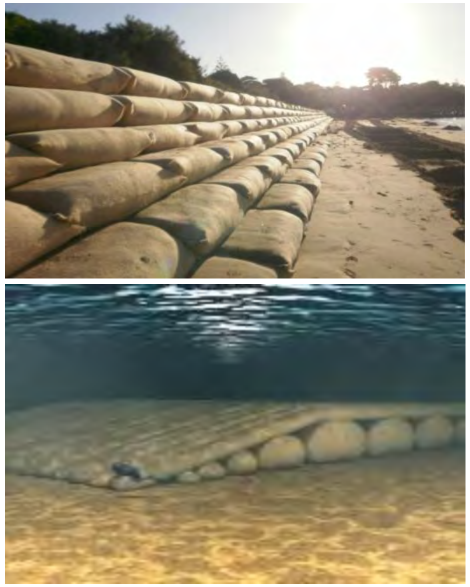


Concrete fish boxes made by Hae Joo. Boxes are 4 m^3 and weigh 14.4 T.

Photos from http://haejoo.com.au/qld-moreton-bay-artificial-reef-program/ and http://www.nprsr.qld.gov.au/parks/moreton-bay/zoning/trial_artificial_reef_program.html

Reef Ball
Photos from http://www.reefball.org

Steel fish cave made by Hae Joo, 11m tall & 14.4 T.
Photos from http://haejoo.com.au/qld-moreton-bay-artificial-reef-program/ and https://www.youtube.com/watch?v=63xSeBSoGx0



Geotextile bag.
Photos from http://www.elcorock.com/ and https://secure.ifai.com/geo/articles/0610_up1_reef.html

Results and discussion

To date, 121 artificial reefs were found in this study to have been deployed in Australian waters (Fig.1). While artificial reefs were present in each state and territory with a coastline (*i.e.* excluding the Australian Capital Territory), the numbers recorded in each location differed markedly. For example, relatively large numbers of artificial reefs were found in Victoria (28), South Australia (26), Queensland (22) and New South Wales (21), while lower numbers are present in Western Australia (11), Northern Territory (9) and Tasmania (4). Unsurprisingly, the highest densities of artificial reefs are found close to major cities and/or within sheltered bays, such as the Gulf of St Vincent and Moreton Bay. In contrast, remote coastlines, such as those in the Kimberley in Western Australia and the Great Australian Bight, do not contain artificial reefs and there is only one in the Gulf of Carpentaria.

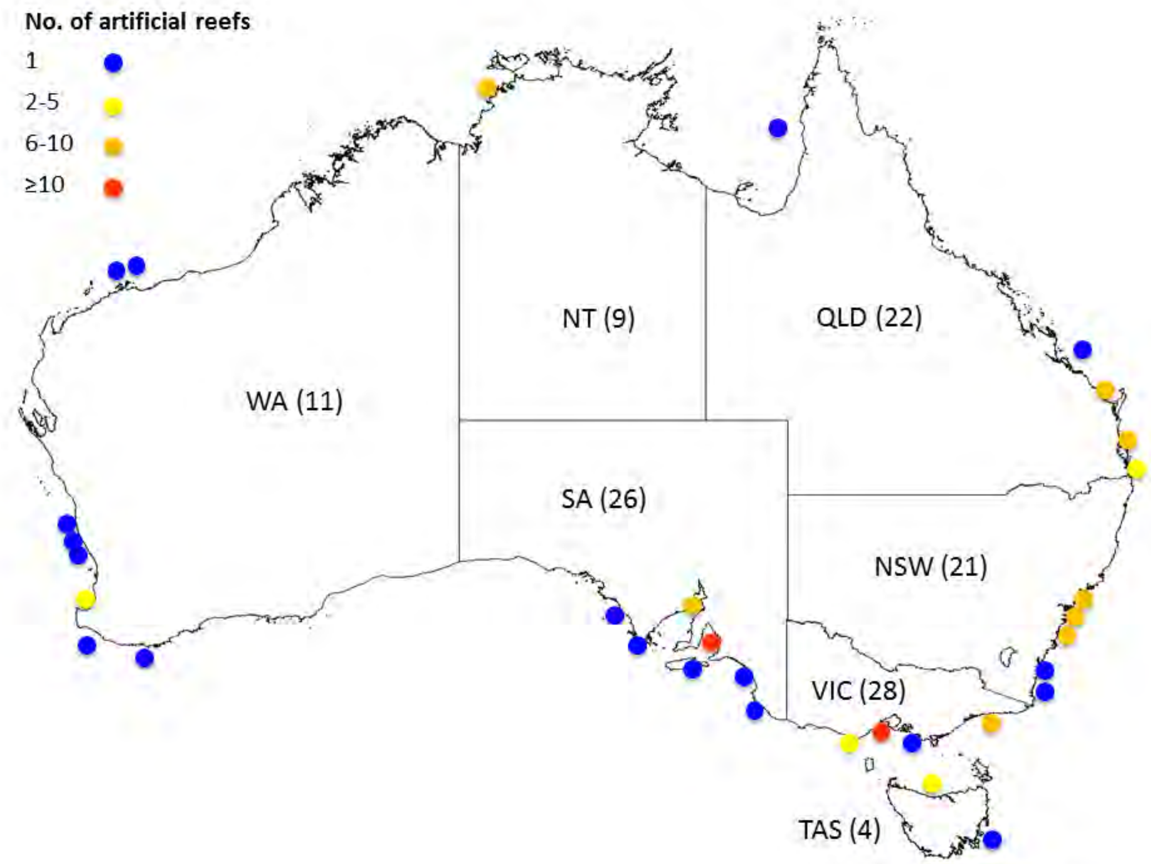


Figure 1. Geographical distribution of artificial reefs in Australian waters. Colour coding reflects the number of artificial reefs in a given area. The numbers of artificial reefs in the waters of each state and territory are given in brackets after the name of that state/territory.

Currently, 65% of artificial reefs in Australia are composed from materials of opportunity (see Table 1 for a definition). Indeed, for some locations, such as South Australia and the Northern Territory, all artificial reefs deployed to date have been constructed from materials of opportunity (Fig. 2). Victoria is the only location where the proportion of purpose-built reefs is greater than those constructed from materials of opportunity, although the ratio between these two 'types' is almost equal in Queensland.

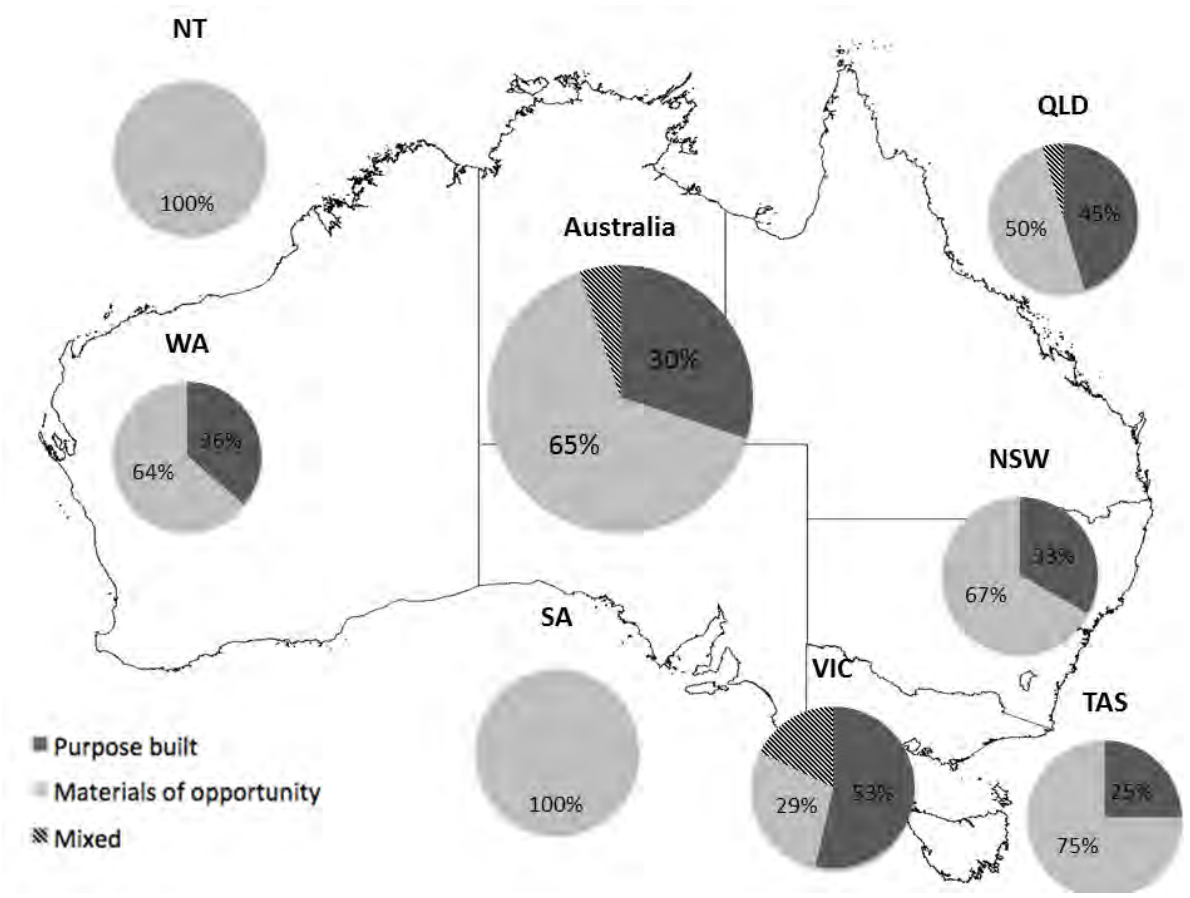


Figure 2. The contribution of artificial reefs constructed from purpose-built material, materials of opportunity or both broad types of material to the total number of artificial reefs in each state and territory and to Australia as a whole.

Among the purpose-built artificial reefs in Australia, the vast majority (34 out of 43) are constructed from concrete modules, with only two and one reefs comprising steel modules and geotextile bags, respectively (Fig. 3). The constituency of reefs constructed from materials of opportunity was more diverse and included scuttled steel vessels (32), such as old warships, used tyres (28) and mixed materials (13). While rubble has been used, it has only been so sparingly, with only five reefs constructed from this material of opportunity.

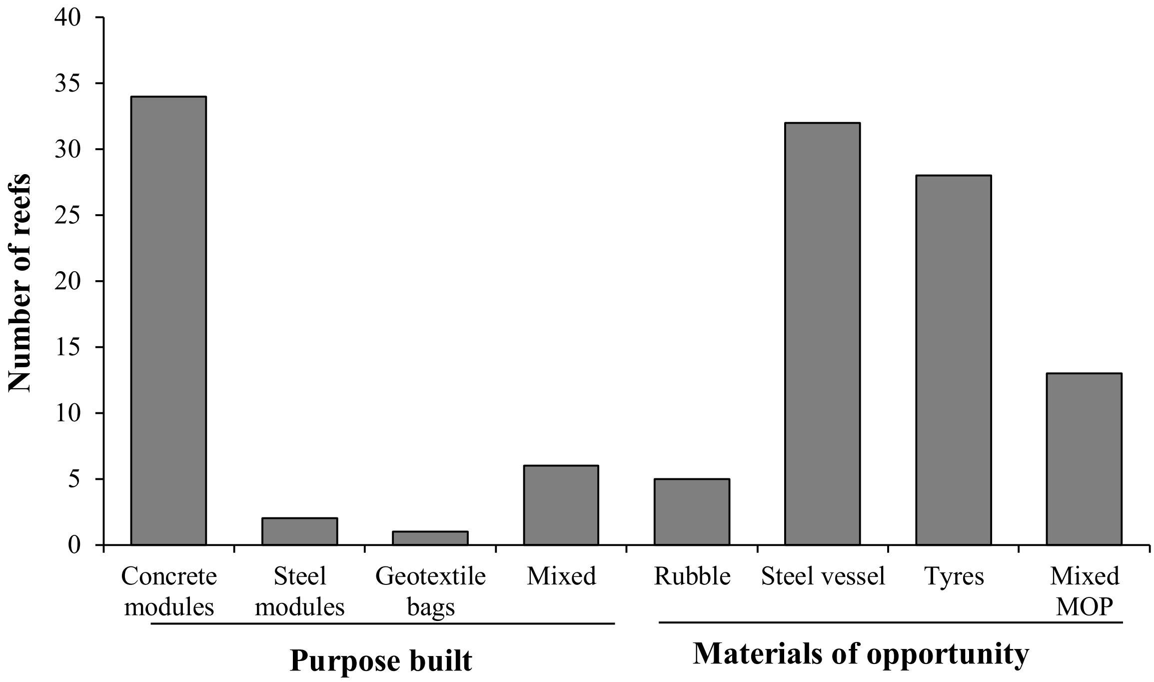


Figure 3. The number of artificial reefs in Australia constructed from different materials.

Since the first artificial reef was deployed in Victoria in 1965, another 120 reefs have been constructed (Fig. 4). In each of almost all the last 50 years at least one artificial reef has been deployed, with a relatively large number of reefs (2-8) being deployed in some periods, *i.e.* 1968-1973, 1982-1991 and 2009-2015. While the construction of artificial reefs in some states, such as Victoria, New South Wales and Western Australia, was spread out across the last 50 years, in South Australia and the Northern Territory construction occurred in distinct periods (Fig. 4). In the case of South Australia, deployment occurred almost exclusively between 1969 and 1973 and between 1983 and 1991, whereas construction in the Northern Territory occurred between 1982 and 1991, and 2011 and 2012.

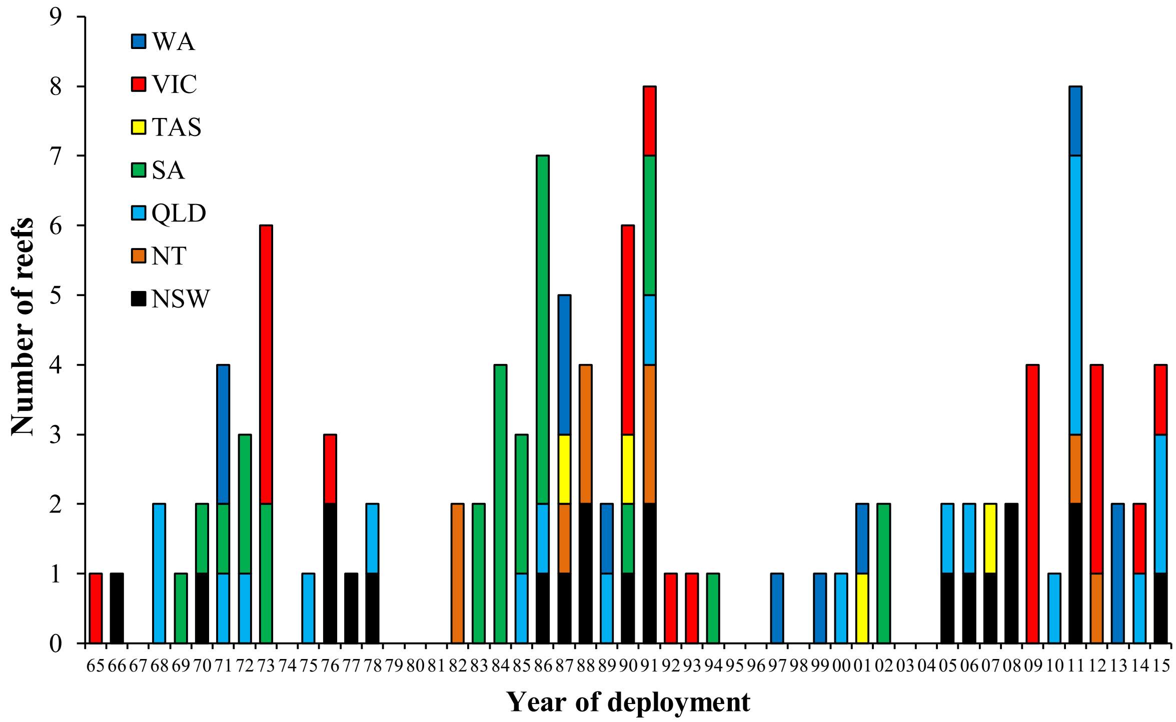


Figure 4. The number of artificial reefs deployed between 1965 and 2015, and the state or territory in which they were deployed.

The materials used to construct the various artificial reefs found in Australian waters differ among states and territories (Fig. 5). Tyres, for example, are the primary constituent of artificial reefs in South Australia, representing 18 out of 26 reefs, but were not used to construct any of the artificial reefs in the Northern Territory or Tasmania and only comprised a limited number of reefs in Victoria, Queensland and Western Australia. Instead, these last three states employed a mixture of reef materials, most notably concrete modules and steel vessels.

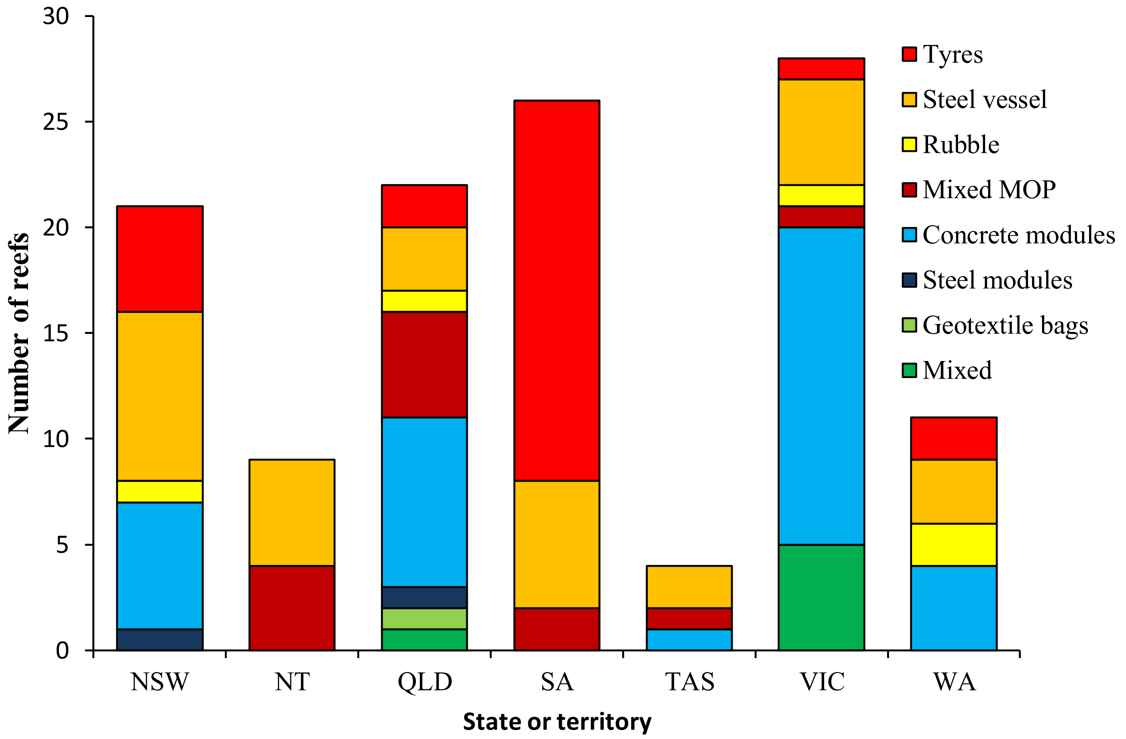


Figure 5. The number of artificial reefs in each state and territory and the materials used to construct them.

There has been a clear shift in materials used to construct artificial reefs in Australia over the 50 years. The 'early' reefs (*i.e.* 1965-1978) were most commonly constructed from materials of opportunity, predominantly used tyres (Fig. 6). The trend of using materials of opportunity also extended into the 'middle' period (*i.e.* 1982-1994). During these years the relative proportion of reefs constructed from tyres decreased, albeit they were still heavily used, and there was a switch to primarily the sinking of steel vessels. As with the early period, very few purpose-built reefs were deployed, however, this changed in the 'modern' period (*i.e.* 2001-2015), where the majority of reefs were constructed from purpose-built concrete and steel modules (Fig. 6).

In terms of the individual materials used to construct artificial reefs, tyres were widely used from 1966 through to 1991. This likely reflects the readily availability of this material and the view that utilising this material as a habitat enhancement structure constituted recycling, which would also benefit fish and invertebrate communities. However, in many cases around the world, tyre reefs have broken up with tyre(s) moving across the sea floor destroying habitat and/or washing ashore after storms (Skoloff 2007, Ferrer 2015). These environmental impacts led France to commence removal of 25,000 tyres in the Mediterranean in 2015, while in Florida US$3.4 million is spent annually in an effort to remove the tyres that wash up from a nearby reef (Ferrer, 2015).

From the mid-1970s onwards, steel vessels became a popular construction material, with the first steel vessel being sunk to form a reef in 1976. This material continues to be used, with the last reef of this type deployed in Australian waters in 2011 (HMAS Adelaide). These types of reef are popular with scuba divers and provide tourism opportunities and, as such, have been funded by diving clubs. For example, Ex-HMAS Brisbane has generated revenue of AU$18 million since its scuttling four years ago off the Sunshine Coast (Sundstrom, 2015) and Ex-HMAS Adelaide, after costing AU$5.8 million to prepare and deploy in 2011, currently generates an estimated AU$4.5 million of dive revenue per year (Cole and Abbs, 2012). Due to legalisation, such as the London Convention on the prevention of marine pollution by dumping of wastes and other material, and state, national and international guidelines pertaining to the construction and deployment of artificial reefs, the methods for deploying them has changed significantly since the 1970s. Thus, there are now more stringent clean up and safety requirements for scuttling of decommission vessels as HES (see Worley Parsons, 2009 for information pertaining to the preparation and environmental considerations for the sinking of Ex-HMAS Adelaide as a SCUBA diving reef).

Although the first reef built from purpose-built concrete modules was deployed in Australian waters in 1971, it was not until the 2000s, and particularly post 2010, that this type of material was been widely used. Today it constitutes the dominant construction for contemporary artificial reefs and is more widely used than other purpose-built materials, such as steel modules and geotextile bags. Such a trend reflects the awareness of the artificial reef technology (e.g. Department of Fisheries Western Australia, 2010), the research and development of state policies on HES and artificial reefs (e.g. Department of Fisheries Western Australia, 2012; New South Wales Government 2015) and the availability of funds collected through recreational fishing licences fees. As such, it is not surprisingly that the majority of these reefs have been deployed to improve recreational fishing experiences (see below).

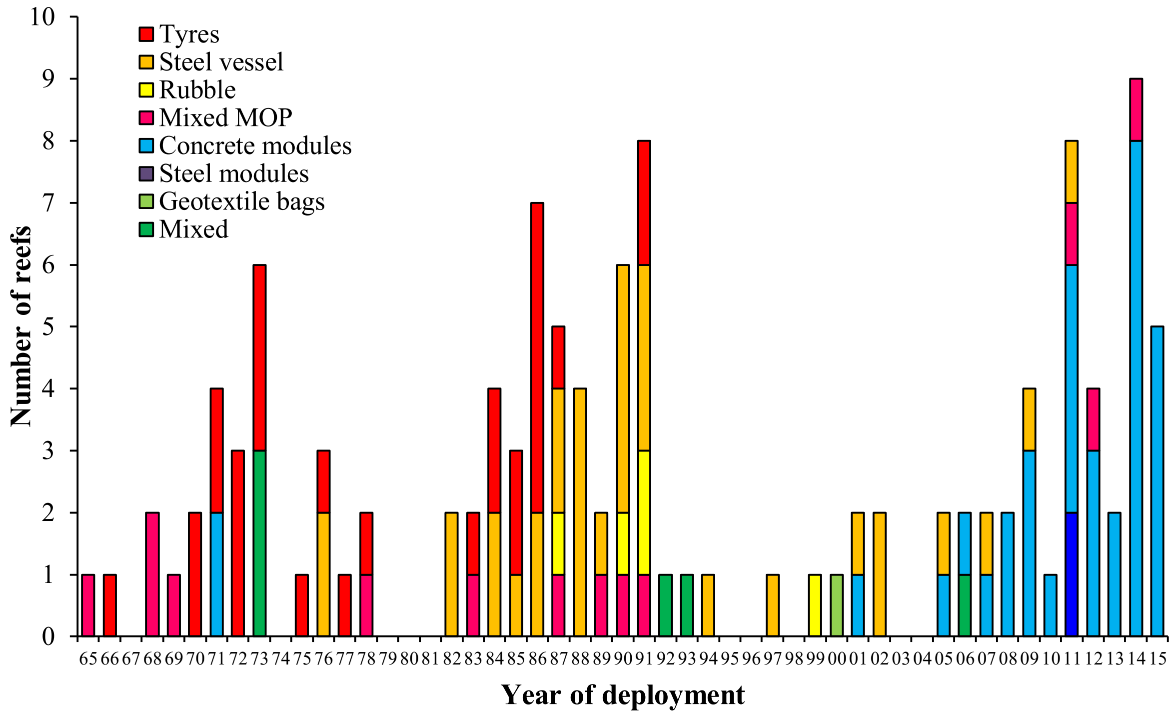


Figure 6. The number of artificial reefs deployed in each year between 1965 and 2015 and the materials used to construct them.

The vast majority of artificial reefs currently deployed in Australian waters (*i.e.* 96 out of 121) have been constructed for the primary purpose of enhancing fishing activities (Fig. 7). While these structures have been deployed by a wide range of organisations, including community groups, fishing and diving clubs, most were installed by state (or territory) fisheries departments. The next most common purpose for artificial reef deployment was for SCUBA divers, with 19 such reefs present in Australia. Many of these were organised by diving clubs themselves or state fishery departments. Small numbers of reefs were also deployed by scientists and industrial partners for research (4) and two reefs where also deployed for surfing purposes.

The provision of artificial reefs in Australia, for recreational purposes mirrors that of the USA, where most of the reefs are utilised for recreational fishing and SCUBA diving (Boshnack et al., 1991; Kerr 1992; Grossman et al., 1997; Lukens et al., 2004). However, this is in marked contrast to Japan and South Korea where such structures have the sole purpose to enhance commercial fin fish and invertebrates catches (Thierry 1988; Kim et al., 1994). Trends of artificial reef usage are different again in Europe where, in France, many HES designs are based upon the principle of a weighty structure/base with devices for snagging nets and 80% of the reefs are deployed to prevent illegal trawling of sensitive seagrass beds and other fish nursery habitats (Charbonnel et al., 2011, Tessier et al., 2015).

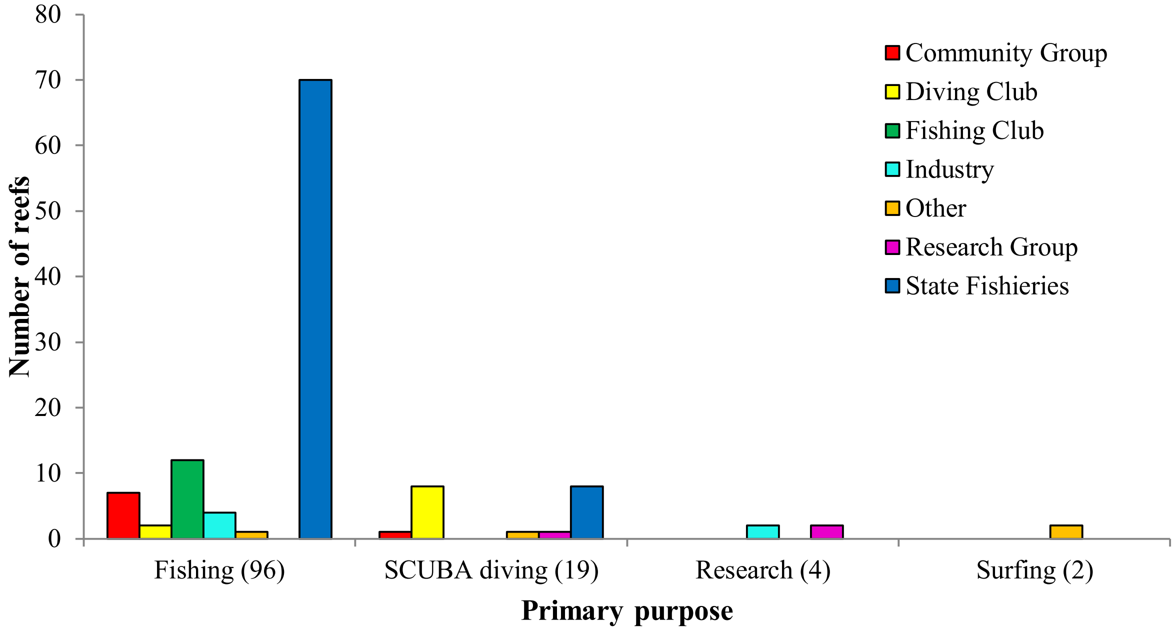


Figure 7. Histogram on the number of artificial reefs categorised by their primary purpose (noting that many have multiple purposes) and the group that deployed the reef. The number in parentheses on the x axis refers to the total count of artificial reefs constructed for that primary purpose.

Conclusion

Whilst Australia's artificial reef developments have previously been behind those of other countries, the past 10 years has seen a surge in interest in the use of modern purpose-built artificial reefs (Pitcher and Seaman 2000, Coutin 2001, Diplock 2010). These purpose-built reef modules offer significant benefits over materials of opportunity, and the availability of additional funds through recreational fishing licence fees has been successfully used in New South Wales, Victoria, and Western Australia to fund artificial reef programs and reduce pressure on natural reefs and could potentially be utilized by other states in the future. As the vast majority of Australia's artificial reefs have been deployed primarily for the purpose of enhancing recreational fishing, reefs have been deployed close to major cities and generally within popular fishing regions. Although this makes the reefs easily accessible, it also creates the potential for overfishing of target species. Future research should also aim to incorporate the socio-economic impacts of these structures and factors, such as reef visitation levels and catch rates, which have not been discussed in detail within this review. With the number of artificial reefs in Australia set to increase over the coming years, dedicated management and monitoring of these structures is essential (Carr and Hixon, 1997; Pickering and Whitmarsh, 1997).

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Appendix: Table showing each of the 121 artificial reefs in Australian waters identified during this study and its location, year of deployment, construction materials, primary purpose, who is was deployed by and a reference for the source information. Reefs ordered chronically within each state/territory. NSW = New South Wales; NT = Northern Territory; QLD = Queensland; SA = South Australia; TAS; Tasmania; VIC = Victoria and WA = Western Australia.

Reef #	State	Year	Depth (m)	Specific construction materials	Materials	Purpose	Deployed by	Reference
1	NSW	1966	8	250 tyres	Tyres	Research	Research Group	Kerr 1992
2	NSW	1970	10	4,660 tyres	Tyres	Fishing	State Fisheries	Kerr 1992
3	NSW	1976	25		Tyres	Fishing	Diving Club	Kerr 1992
4	NSW	1976	45	Sydney Harbour Ferry and 11 other vessels	Steel vessel	Fishing	State Fisheries	Kerr 1992
5	NSW	1977	25		Tyres	Diving	State Fisheries	Kerr 1992
6	NSW	1978	12		Tyres	Fishing	State Fisheries	Kerr 1992
7	NSW	1986	33		Steel vessel	Fishing	State Fisheries	Kerr 1992
8	NSW	1987	20		Steel vessel	Fishing	Community Group	Kerr 1992
9	NSW	1988	20		Steel vessel	Fishing	Community Group	Kerr 1992
10	NSW	1988	20		Steel vessel	Fishing	Community Group	Kerr 1992
11	NSW	1990	200		Steel vessel	Fishing	Other	Kerr 1992
12	NSW	1991	45		Rubble	Diving	Other	Kerr 1992
13	NSW	1991	30		Steel vessel	Diving	Research Group	Kerr 1992
14	NSW	2005	5	Reef Balls	Concrete modules	Fishing	State Fisheries	State Fisheries
15	NSW	2006	10	180 Reef Balls	Concrete modules	Fishing	State Fisheries	State Fisheries
16	NSW	2007	2	210 Reef Balls	Concrete modules	Fishing	State Fisheries	State Fisheries
17	NSW	2008	8	400 Reef Balls	Concrete modules	Fishing	State Fisheries	State Fisheries
18	NSW	2008	8	400 Reef Balls	Concrete modules	Fishing	State Fisheries	State Fisheries
19	NSW	2011	38	Fish Cave, 12 by 15 metres in length, has two 12 metre high masts and is anchored at each corner by a chain and a 60 tonne concrete block	Steel modules	Fishing	State Fisheries	State Fisheries
20	NSW	2011	32	Navy ship	Steel vessel	Diving	State Fisheries	State Fisheries
21	NSW	2015	30	20 concrete modules	Concrete modules	Fishing	State Fisheries	State Fisheries
22	NT	1982	12		Steel vessel	Fishing	Fishing Club	Kerr 1992
23	NT	1982	16		Steel vessel	Fishing	Fishing Club	Kerr 1992
24	NT	1987	25		Mixed MOP	Fishing	State Fisheries	NT Fisheries
25	NT	1988	18		Steel vessel	Diving	Diving Club	Kerr 1992
26	NT	1988	20		Steel vessel	Fishing	State Fisheries	Kerr 1992
27	NT	1991	13		Steel vessel	Fishing	Fishing Club	Kerr 1992

Reef #	State	Year	Depth (m)	Specific construction materials	Materials	Purpose	Deployed by	Reference
28	NT	1991	20		Mixed MOP	Diving	State Fisheries	Kerr 1992
29	NT	2011	15	Steel vessels, concrete	Mixed MOP	Fishing	State Fisheries	State Fisheries
30	NT	2012		Steel vessels, concrete	Mixed MOP	Fishing	State Fisheries	State Fisheries
31	QLD	1968	18	Car bodies, tyres, concrete rubble	Mixed MOP	Fishing	Fishing Club	Kerr 1992
32	QLD	1968	20	Car bodies, tyres, concrete rubble	Mixed MOP	Research	Research Group	Kerr 1992
33	QLD	1971	5	28 Concrete modules	Concrete modules	Fishing	State Fisheries	Kerr 1992
34	QLD	1972	5	Concrete shelters	Tyres	Fishing	State Fisheries	Kerr 1992
35	QLD	1975	3	Tyres	Tyres	Fishing	Fishing Club	Kerr 1992
36	QLD	1978	9		Mixed MOP	Fishing	Community Group	Kerr 1992
37	QLD	1985	22	Steel vessel	Steel vessel	Fishing	Industry	Kerr 1992
38	QLD	1986	66	Steel vessel	Steel vessel	Fishing	State Fisheries	Kerr 1992
39	QLD	1989	9	Car bodies	Mixed MOP	Fishing	Community Group	Kerr 1992
40	QLD	1991	5	Concrete pipes and rubble	Rubble	Fishing	Community Group	Kerr 1992
41	QLD	2000	5	Geotextile bags filled with sand	Geotextile bags	Surfing	Other	State Fisheries
42	QLD	2005	28	Former warship	Steel vessel	Diving	State Fisheries	State Fisheries
43	QLD	2006	15	Steel vessels and concrete pipes, some concrete and steel modules	Mixed	Diving	State Fisheries	State Fisheries
44	QLD	2010	10	117 Reef Balls	Concrete modules	Fishing	State Fisheries	State Fisheries
45	QLD	2011	15	78 Reef Balls	Concrete modules	Fishing	State Fisheries	State Fisheries
46	QLD	2011	14	25 Fish Boxes	Concrete modules	Fishing	State Fisheries	State Fisheries
47	QLD	2011	22	20 Fish Boxes	Concrete modules	Fishing	State Fisheries	State Fisheries
48	QLD	2011	35	3 Steel Fish Caves	Steel modules	Fishing	State Fisheries	State Fisheries
49	QLD	2014	21	1975-2014	Mixed MOP	Fishing	State Fisheries	State Fisheries
50	QLD	2015	16	30 reef temple modules	Concrete modules	Fishing	State Fisheries	State Fisheries
51	QLD	2015	10	30 reef temple modules	Concrete modules	Fishing	State Fisheries	State Fisheries
52	QLD	2015		6 cluster of concrete modules	Concrete modules	Fishing	State Fisheries	State Fisheries
53	SA	1969	10	Car bodies	Mixed MOP	Fishing	Fishing Club	Kerr 1992
54	SA	1970	10	15000 tyres	Tyres	Fishing	State Fisheries	Kerr 1992
55	SA	1971	10	5000 tyres	Tyres	Fishing	State Fisheries	Kerr 1992
56	SA	1972	8	2000 tyres	Tyres	Fishing	Fishing Club	Kerr 1992
57	SA	1972		Vessels and tyres	Tyres	Fishing	State Fisheries	Kerr 1992
58	SA	1973	10	Tyres	Tyres	Fishing	Fishing Club	Kerr 1992
59	SA	1973	18	25000 tyres	Tyres	Fishing	State Fisheries	Kerr 1992
60	SA	1983	15	50 tonnes of tyres, 10 tonnes of concrete pipes	Mixed MOP	Fishing	Fishing Club	Kerr 1992

Reef #	State	Year	Depth (m)	Specific construction materials	Materials	Purpose	Deployed by	Reference
61	SA	1983		14,000 tyres	Tyres	Fishing	Fishing Club	Kerr 1992
62	SA	1984	10	1,000 tyres	Tyres	Fishing	Fishing Club	Kerr 1992
63	SA	1984	20		Steel vessel	Fishing	State Fisheries	Kerr 1992
64	SA	1984	20		Steel vessel	Fishing	State Fisheries	Kerr 1992
65	SA	1984	18	Tyres	Tyres	Fishing	State Fisheries	Kerr 1992
66	SA	1985	18	Tyres	Tyres	Fishing	State Fisheries	Kerr 1992
67	SA	1985	20	Tyres	Tyres	Fishing	State Fisheries	Kerr 1992
68	SA	1986	18	Tyres	Tyres	Fishing	State Fisheries	Kerr 1992
69	SA	1986	18	1,200 tyres	Tyres	Fishing	State Fisheries	Kerr 1992
70	SA	1986	18	400 tyres	Tyres	Fishing	State Fisheries	Kerr 1992
71	SA	1986	18	1,000 tyres	Tyres	Fishing	State Fisheries	Kerr 1992
72	SA	1986	18	1,000 tyres	Tyres	Fishing	State Fisheries	Kerr 1992
73	SA	1990	15		Steel vessel	Fishing	Fishing Club	Kerr 1992
74	SA	1991	9		Tyres	Fishing	State Fisheries	Kerr 1992
75	SA	1991	15		Tyres	Fishing	State Fisheries	Kerr 1992
76	SA	1994	20		Steel vessel	Diving	Diving Club	http://www.sdfsa.net/adelaide_metro.htm
77	SA	2002	20	Fishing boat	Steel vessel	Diving	Diving Club	State Fisheries
78	SA	2002	30	Navy ship	Steel vessel	Diving	State Fisheries	State Fisheries
79	TAS	1987	25		Steel vessel	Fishing	Industry	Kerr 1992
80	TAS	1990	17	Loading facility	Mixed MOP	Fishing	Industry	Kerr 1992
81	TAS	2001	20	50 Reef Balls	Concrete modules	Fishing	Diving Club	State Fisheries
82	TAS	2007	27	55 m hopper barge	Steel vessel	Fishing	State Fisheries	State Fisheries
83	VIC	1965	20	440 tonnes of concrete pipes and two vessels	Mixed MOP	Fishing	State Fisheries	Kerr 1992
84	VIC	1973	10	2000 tyres	Tyres	Diving	Diving Club	Kerr 1992
85	VIC	1973	10	Quary rock, steel frames, cube modules and tyres	Mixed	Fishing	State Fisheries	Kerr 1992
86	VIC	1973	10	Quary rock, steel frames, cube modules and tyres	Mixed	Fishing	State Fisheries	Kerr 1992
87	VIC	1973	10	Quary rock, steel frames, cube modules and tyres	Mixed	Fishing	State Fisheries	Kerr 1992
88	VIC	1976	20	74 m bucket dredge	Steel vessel	Fishing	State Fisheries	Kerr 1992
89	VIC	1990	12		Steel vessel	Diving	Diving Club	Kerr 1992
90	VIC	1990	24		Steel vessel	Diving	Diving Club	Kerr 1992
91	VIC	1990	20		Rubble	Research	Industry	Kerr 1992
92	VIC	1991	22		Steel vessel	Diving	Diving Club	Kerr 1992
93	VIC	1992	20	150 tetrahedron shaped units with a base of 9 tyres (3 x 3) bound together with industrial straps that were fastened with stainless steel crimps	Mixed	Fishing	State Fisheries	Coutin 2001

Reef #	State	Year	Depth (m)	Specific construction materials	Materials	Purpose	Deployed by	Reference
94	VIC	1993	20	150 tetrahedron shaped units with a base of 9 tyres (3 x 3) bound together with industrial straps that were fastened with stainless steel crimps	Mixed	Fishing	State Fisheries	Coutin 2001
95	VIC	2009	11	100 Reef Balls	Concrete modules	Fishing	State Fisheries	State Fisheries
96	VIC	2009	11	100 Reef Balls	Concrete modules	Fishing	State Fisheries	State Fisheries
97	VIC	2009	11	100 Reef Balls	Concrete modules	Fishing	State Fisheries	State Fisheries
98	VIC	2009	28	Navy ship	Steel vessel	Diving	State Fisheries	State Fisheries
99	VIC	2012	4	99 concrete dome modules	Concrete modules	Fishing	State Fisheries	State Fisheries
100	VIC	2012	4	99 concrete dome modules	Concrete modules	Fishing	State Fisheries	State Fisheries
101	VIC	2012	4	99 concrete dome modules	Concrete modules	Fishing	State Fisheries	State Fisheries
102	VIC	2014	5	Reef Balls, 8 small reefs all together, made from 15 modules	Concrete modules	Fishing	State Fisheries	State Fisheries
103	VIC	2014	5	Reef Balls, 8 small reefs all together, made from 15 modules	Concrete modules	Fishing	State Fisheries	State Fisheries
104	VIC	2014	5	Reef Balls, 8 small reefs all together, made from 15 modules	Concrete modules	Fishing	State Fisheries	State Fisheries
105	VIC	2014	5	Reef Balls, 8 small reefs all together, made from 15 modules	Concrete modules	Fishing	State Fisheries	State Fisheries
106	VIC	2014	5	Reef Balls, 8 small reefs all together, made from 15 modules	Concrete modules	Fishing	State Fisheries	State Fisheries
107	VIC	2014	5	Reef Balls, 8 small reefs all together, made from 15 modules	Concrete modules	Fishing	State Fisheries	State Fisheries
108	VIC	2014	5	Reef Balls, 8 small reefs all together, made from 15 modules	Concrete modules	Fishing	State Fisheries	State Fisheries
109	VIC	2014	5	Reef Balls, 8 small reefs all together, made from 15 modules	Concrete modules	Fishing	State Fisheries	State Fisheries
110	VIC	2015	25	25 Fish Box modules	Concrete modules	Fishing	State Fisheries	State Fisheries
111	WA	1971	4.5	8 concrete module reefs	Concrete modules	Fishing	State Fisheries	Kerr 1992
112	WA	1971		80 tyres	Tyres	Fishing	State Fisheries	Kerr 1992
113	WA	1987	20		Tyres	Fishing	Community Group	Kerr 1992
114	WA	1987	20		Rubble	Fishing	Industry	Kerr 1992
115	WA	1989	50		Steel vessel	Diving	Diving Club	Kerr 1992
116	WA	1997	30	Navy ship	Steel vessel	Diving	Community Group	State Fisheries
117	WA	1999	4	Rock	Rubble	Surfing	Other	State Fisheries
118	WA	2001	35	Navy ship	Steel vessel	Diving	State Fisheries	State Fisheries
119	WA	2011	19	700 concrete units	Concrete modules	Research	Industry	State Fisheries
120	WA	2013	27	30 ten-tonne concrete modules	Concrete modules	Fishing	State Fisheries	State Fisheries
121	WA	2013	17	30 ten-tonne concrete modules	Concrete modules	Fishing	State Fisheries	State Fisheries

Appendix VI. The application, needs, costs and benefits of Habitat Enhancement Structures in Western Australia: Bibliographic analyses of scientific literature on Habitat Enhancement Structures

The application, needs, costs and benefits of habitat enhancement structures in Western Australia:

III Bibliographic analyses of scientific literature on habitat enhancement structures

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November 2015

Cover photo: A fish aggregation device deployed in the Aldabra atoll (Seychelles).

Photo Thomas Peschak.

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Non-technical summary

Habitat enhancement structures have been used for over 3,000 years for a range of purposes and have been deployed in over 50 countries around the world. A literature search of the Scopus and Web of Science databases was conducted using the terms habitat enhancement structure, artificial reef and fish aggregation device and >3,500 citations than employed these terms were exported and the citations presented. Bibliographic analyses indicated that among these three terms, artificial reef was the most widely used in the literature comprising ~76% of all references. The fact that this term is the most widely used reflects the fact that it was first used in 1968 and thus well before fish aggregation device (1975) and habitat enhancement structure (1982). The use of all terms, and particularly that for fish aggregation device, has increased markedly post 2000, reflecting the increased levels of interest and research in this field. Researchers from the USA were the most prolific publishers, together with those from Australia, UK and, to a lesser extent, France and Canada. In fact, >96% of all documents found in the two databases were written in English, which may explain the relatively low contribution by researchers from Japan, China and South Korea, all of which have long histories of research and development in this area. In terms of the research areas, the majority of document were focused on the biology and ecology of faunal communities In contrast, documents focusing on the design of these structures and of their social and economic implications received little attention.

Introduction

Habitat enhancement structures (HES) are thought to have been employed for at least 3,000 years to help increase catches of target fish species (Riggio, 2000), with the first documented creation of a dedicated artificial reef in Japan in 1795 using a sunken vessel. After elevated catches of fish were recorded during the next summer, hundreds more artificial reefs were developed over the next 10 years using scuttled vessels and other materials of opportunity (Ino, 1974). Such was the success of these structures that, by 1930, the Japanese Government began subsidising the research and development of artificial reefs and designing purpose-built structures in 1952 (Thierry 1988, Grove et al., 1994). Regulations stipulating that only those HES which pass stringent design protocols to ensure longevity were passed and, as of 2000, there were 6,400 HES sites in Japanese waters, which cumulatively covered an area of ~20 million m^3 (1,800 km^2) (Sheehy, 1982; Barnabe and Barnabe-Quet, 2000).

During the last 60 years there has been a marked increase in the number of HES around the world, with more than 50 countries have deployed these structures (Fabi et al., 2011). For example, there is approximately 1 million m^3 of artificial reef habitat in the USA along, with over 1,500 artificial reefs in Florida alone (Barnabe and Barnabe-Quet, 2000; Sutton and Bushnell, 2007) and South Korea has invested almost AU$ 1 billion in HES over the last 40 years, creating 2,070 km^2 of artificial reef habitat (DoF,2010).

Despite the success of HES around the world, the first artificial reef was not deployed in Australian waters until 1965 and, to date, only 121 reefs have been constructed using the wide range of available materials (both materials of opportunity and purpose-built modules; Bateman et al., 2015). However, the use of HES in Australia is gaining popularity, with 29 reefs comprising such structures (i.e. 24% of all Australian artificial reefs) being deployed since 2010 and with many more in the planning process. Moreover, a policy shift by the

Western Australian government towards facilitating the deployment of HES has created the need understanding of what peer-reviewed research has been conducted on HES, where the work took place.

In light of the above, the aim of this bibliographic study was to search major databases of scientific publications for publications that used key words relating to HES and i) describe broad trends in the usage of these terms in the scientific literature and ii) compile a reference lists of documents using these terms that can be used by scientists and managers to find relevant information quickly and easily.

Materials and methods

Habitat Enhancement Structures (HES) comprise a wide range of structures and materials placed deliberately in the aquatic environment. As this term is designed to encompass a range of structures, including Artificial Reefs (AR) and Fish Aggregation Devices (FAD) each of the above three terms was used in content analysis. Scientific publications containing any of these terms in either the title, abstract or list of keywords were identified using search functions in two large databases of scientific documents, namely Scopus and Web of Science (WoS). Scopus (http://www.scopus.com/) contains 22,000 documents (55 million records) dating back to 1966 and Web of Science (http://wokinfo.com/) contains more than 50,000 books, 12,000 journals and 160,000 conference proceedings (90 million records). These databases were employed in this study because unlike some others, *e.g.* Google Scholar, they are able to analyses and export large quantities of bibliographic information, including the citations for each document (year or publication, type of document, journal title), location and institution of the lead author, research area and language.

Trends in the bibliographic data for year of publication, location and research area calculated and graphed using Microsoft Excel. The resultant bibliographic information, together with the abstract for each publication, from each database was exported, combined and used to create a separate Endnote library for i) habitat enhancement structure, ii) artificial reef and iii) fish aggregation device. Duplicate records were identified by the Endnote X7.4 and deleted, visual analyses was also employed to delete records that were similar and highly likely to be recorded of the same publication, but whose character strings for each field were not identical e.g. Smith, A.B vs Alan B. Smith. A reference list for each of the library has been published in this report. Note that, while the individual publications recorded have been reported in a consistent ‘output’ style, the information in the records has not been altered to correct any errors e.g. erroneous capitals and incorrect use of italics.

Results and Discussion

The total number of documents recorded in the Scopus and WoF databases using any one of the terms HES, AR or FAD was 2,475 and 2,541, respectively. Of those documents, 83% were journal articles and 13% conference proceedings, while the remainder were book, trade publications and reports. Among the three terms, AR (*i.e.* 1,896 and 1,949 in Scopus and WoS, respectively) was the most recorded, compared to 390 and 370, respectively for HES and 189 and 222, respectively, for FAD.

While the first document containing the phrase AR was published in 1968, it was not until 1975 and 1982, respectively, that the terms FAD and HES were employed in the scientific literature. The use of all terms, and particularly FAD, has increased markedly post 2000. As implied above, for each search term, the number of documents published per year has tended to progressively increase each year after the date in which that term was first used (Fig. 1). There are, however, noticeable peaks in the number of documents produced in particular years, most notably in the case of AR (Fig. 1a). These peak years, *i.e.* 1985, 1989, 1994 and 2002, coincided with international conferences on artificial habitats and reefs and thus special issues of the Bulletin of Marine Science and ICES Journal of Marine Science were published comprising papers presented at those meetings. This also explains why these two journals ranked first and third in terms of the highest number of papers on artificial reefs (*i.e.* 185 and 68, respectively; data not shown).

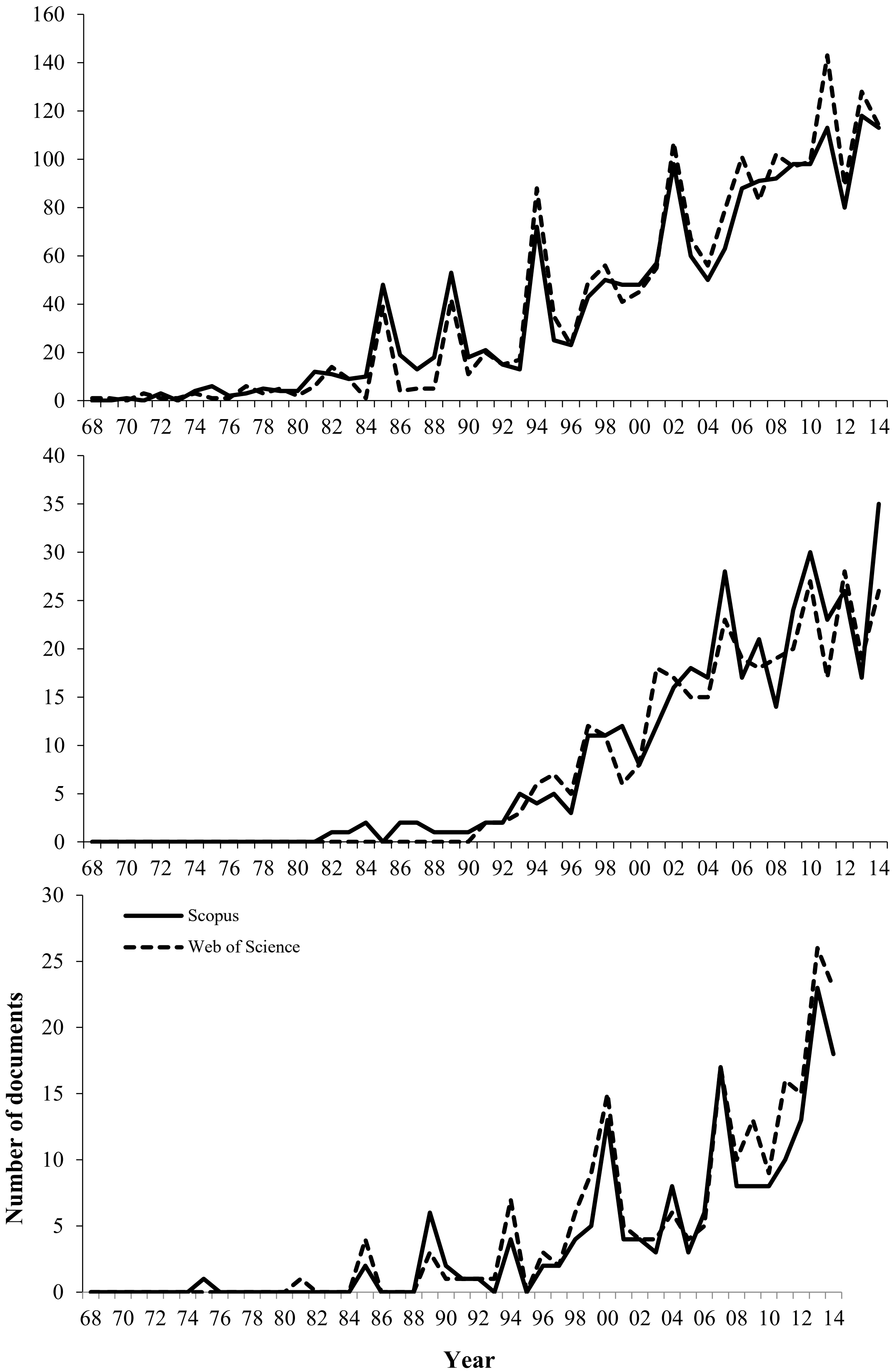

Figure 1. Number of documents listed in the Scopus and Web of Science databases in each year using the words a) artificial reef, b) habitat enhancement structure and c) fish aggregating device.

The lead authors of much of the research on AR (*i.e.* 25 and 35% in Scopus and WoS, respectively) and HES (38 and 45%) and, to a lesser extent, FADs (17 and 18%) were based in the USA (Table 1). Australian authors have been productive in each of the three areas, producing the second most number of documents on AR and fifth and sixth on HES and FADs, respectively. The relatively small number of documents produced by workers from several Asian countries with a strong history in habitat enhancement *e.g.* Japan, China and South Korea (Table 1) may reflect the fact that both Scopus and WoS predominately search databases containing records of documents written in English and thus undoubtedly would have underestimated the contribution made by research workers from these countries. For example, 1,800 of the 1,896 AR documents found by Scopus were written in English, with only 26 and 14 written in Chinese and Japanese, respectively and the same was true for HES (387 out of 390) and FAD (183 out of 192). These trends are mirrored by the work of Baine (2001) who reviewed 249 abstracts from six volumes of published papers on global artificial reef research (usually those associated with special editions of journals following international conferences) and found that although acknowledged as a world leader in artificial reef research, particularly in terms of HES design, only 29 of the 249 papers (12%) were written by Japanese authors.

Table 1. The percentage contribution made by research workers in different countries to documents with Artificial Reef (AR), Habitat Enhancement Structure (HES) or Fish Aggregating Devices (FAD) in the title, abstract and/or keywords. Countries making a large contribution (>~5%) are highlighted in grey. Note that for brevity, only the countries the produced the ten greatest percentage contributions for each keyword in each database have been included in the table.

	AR		**HES**		**FAD**	
Database	Scopus	WoS	Scopus	WoS	Scopus	WoS
Number of documents	1,896	1,949	390	370	189	222
Country						
Australia	***10.34***	***11.65***	***3.30***	***4.87***	***4.36***	***4.67***
Belgium					2.01	
Brazil	2.77					
Canada		3.28	5.49	8.92		
China	3.94		2.42			
Finland			2.20	3.51		
France	2.72	4.46	2.86		21.14	19.51
Germany	3.14		2.20			
Ireland				2.97		
Israel		3.59				
Italy	3.78	5.70	2.86	4.05	5.03	4.67
Japan	5.70	5.64	3.52	5.14	3.69	4.40
Netherlands				2.97		
Philippines					2.01	2.20
Portugal		3.23				
Reunion Island						2.20
Seychelles					8.39	7.14
South Africa					2.35	2.20
Spain	2.82	3.18		2.97	7.05	6.87
United Kingdom	6.29	4.87	9.67	12.16		
USA	25.20	35.40	38.02	44.87	16.78	18.68
Other	***33.30***	***18.98***	***27.47***	***7.57***	***27.18***	***27.47***

While the geographic distribution of documents was similar for AR and HES, *i.e.* mainly produced by workers from USA, UK, Australia and Japan, the countries responsible for much of the research into FADs differed. Specifically, many of the 'FAD documents' were produced by workers from France (principally the Institut de Recherche pour le Développement and the Institut Francais de Recherche pour l'Exploitation de la Mer rather than Universities), Italy, the Seychelles and Spain. Interestingly, researchers from Canada produced more documents in the HES area than all other countries except the USA and UK, but rarely published on AR or FAD. Such a trend likely reflects the fact their research has focused on habitat modifications that enhancing salmonid fisheries in freshwater rivers and lakes.

In terms of the research areas of documents on AR, HES and FAD, the majority were focused on the biology and ecology of faunal communities (Fig. 2). For example, between 8 and 32% of the documents that used each term were classified as belonging to *Marine & Freshwater Biology* or *Environmental Science* areas. The percentage contribution of documents in the *Fisheries* area varied among terms, representing 8 and 11% for HES and AR, respectively, but 30% for FAD. This presumably reflects the fact that FADs are usually employed for the sole purpose of attracting fish, rather that the often multipurpose nature of artificial reefs and habitat enhancement structures. Documents focusing on the *Engineering* of AR, HES and FAD made up only a small proportion of the total number of documents (<~4%). Little attention was also given to the social and economic research.

While, at a broad level, the percentage contribution of documents produced on AR and HES were similar, there were a few subtle differences. For example, documents on *Oceanography* were far more prevalent in AR than HES (17 vs 6%, respectively) whereas the reverse was true for *Biodiversity Conservation* (<1 vs 5%, respectively), which again reflects the purpose of the structures. Thus, while artificial reef may have been deployed for a number of reasons, some of which do not relate to fisheries or faunal communities, these structures may be deployed to protect eroding coastlines and/or create favourable surfing conditions.

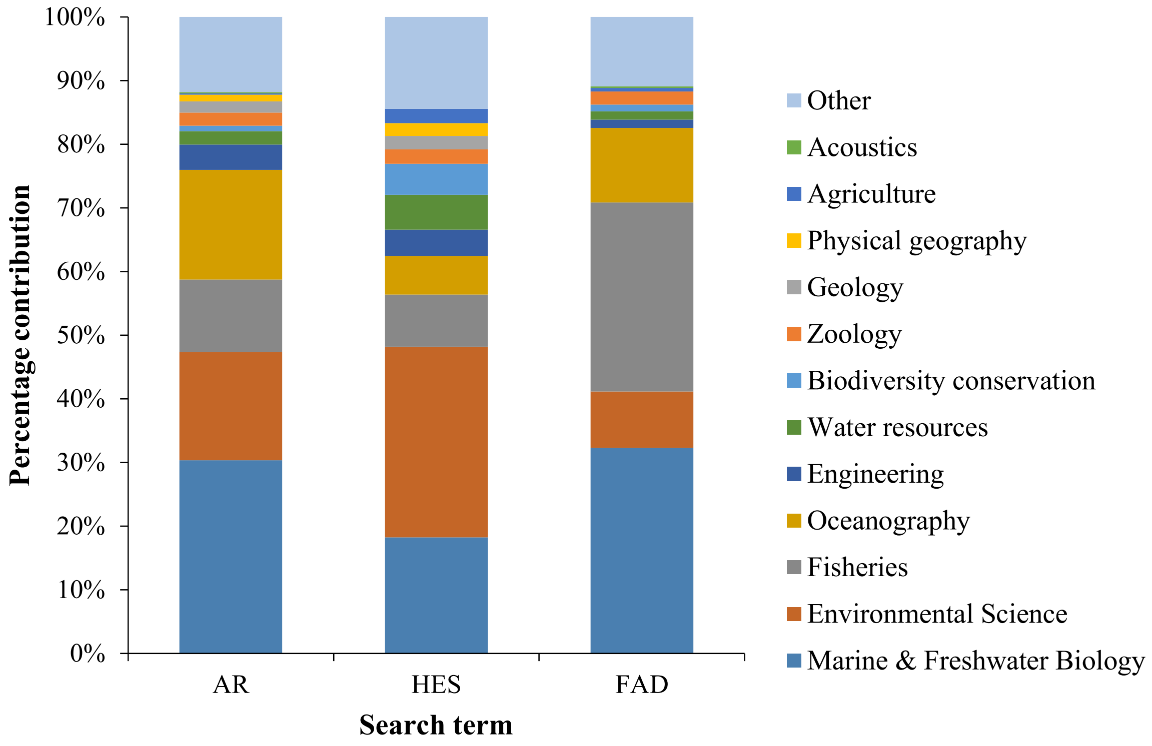

Figure 2. Stacked histogram of the percentage contribution of documents in the various field of research categories used by Web of Science. Note, for clarity only fields making a sufficiently large contribution were included as categories. The contributions made by those 68 other fields were combined into the '*Other*' category.

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Bibilographic data

Note that these citations remain in their original state following export from Scopus and/or Web of Science.

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Appendix VII. ASFB – Newsletter – 214 – 12 – 17

Lateral Lines

AUSTRALIAN SOCIETY FOR FISH BIOLOGY NEWSLETTER

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VOL 47: (2) December 2017

ISSN 2208-7028

ASFB Executive 2017-18

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Lateral Lines is the Newsletter style journal for the Australian Society for Fish Biology (ASFB), published twice a year. It welcomes contributions from all its members. The ASFB was founded in 1971 with the aim of 'promoting research, education and management of fish and fisheries and providing a forum for the exchange of information'.

Contributing to this issue ...

Dr Sean Tracey is a Senior Research Fellow at IMAS in the University of Tasmania. His portfolio is diverse, with interests in fisheries and marine ecosystems science. He conducts innovative research across multiple disciplines to address critical ecological questions and facilitate sustainable management of marine resources.

Dr Alistair Hobday leads the Marine Climate Impact and Adaptation area at CSIRO. His research spans a range of topics including spatial management and migration of large pelagic species, environmental influences on marine species, climate change impacts on marine resources, and the development of adaptation options for marine conservation, fisheries and aquaculture.

Michael "Tropi" Tropiano is the Habitat Officer at Recfishwest, the peak body for recreational fishing in Western Australia. He has been working with fishers to increase awareness around the importance of healthy fish habitats to healthy fisheries, and looking for opportunities to get fishers involved in fish habitat restoration activities in Western Australia.

ON THE COVER: Sean Tracey and his team capture and place a satellite tag on swordfish *Xiphias gladius* off the coast of Tasmania

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Editorial

I am stepping in this year as the newsletter editor for the ASFB, following in the awesome footsteps of Michelle Treloar, who kept us well informed and entertained for seven years in a row.

My first aim has been to give the publication a fresh look and to that attempt the ASFB ran a competition for a new name. Cheers to Chris Fulton, our former president, for his winner entry.

A new introduction which I hope you all like is an "Arts and Science" column that for it's first voyage features an interview with South Australian artist Janet Ayliffe, along with her nature inspired work. In the future, I hope to see many submissions from all the fish artists out there!

Thank you to everyone who contributed to this year's newsletter, in particular our three feature stories which showcase three different angles of some of the work done by our members around the country. Sean Tracey shares his work looking at the impacts and management of a new fishery for swordfish in Tassie, Alistair Hobday showcases how habitat modelling can be used to improve fisheries management, and Michael Tropiano brings us the people angle with his story on how he has gotten fishos in WA to go sciency.

Enjoy everyone, and hope to see you all at the next conference in Melbourne, which promises to be another epic fish-a-thon.

Katherine Cure
Editor, Lateral Lines

President's Preamble

The end of the year, Christmas parties about to hit, and the December newsletter, time for reflection past and future. Firstly, to the recent past, many thanks to our immediate past-president Chris Fulton, what a sterling job he has done, continuing the modernisation of our society and putting gender equality and diversity at the forefront. I look forward to continuing on from Chris (and don't go anywhere because I will have plenty of jobs for you). Others passing the baton include Heather Patterson who worked tirelessly as our treasurer for the last 2 years and Michelle Treloar our long-serving newsletter editor. So welcome to our new Vice-President Alison King, Treasurer Lenore Litherland and Newsletter Editor Katherine Cure. Thanks to the outgoing State/Student reps, welcome to our new ones and thankyou to all continuing Executive members.

This has been another great year for ASFB, highlighted by our Albany conference, it was such a nice sea-change to attend a cosy country conference (and gain further appreciation of how much effort it is for our WA members to regularly fly great distances to attend such events). The conference: "Turning Points in Fish & Fisheries" had some great keynote presentations, supported *by 14 special sessions spanning a wide-array of topics. This was a great theme for us to reflect upon the factors that have taken us in our field to where we are now, but also a chance to discuss with our ECR members some key learnings from our careers. The focus session on career development and support of postgraduate students in fish and fisheries science and management set the scene for the whole conference. The student talks were a highlight, they seem to get better every year. We were lucky enough to have some great talks presented by Albany High School students studying the local marine environment (see Conference report for a full rundown), hopefully all will become future members. Congratulations to the conference organisers for a great conference.*

Our society continues to grow with 412 members, with 129 of these being students, this growth has been assisted by strong management over many years with an increased focus on our students via significant investment in our various awards. This support will continue and grow into the future as part of our Financial Plan (2017-2021) presented at our 2017 AGM. Adopting this plan will be one of our key tasks over the next 4 years to ensure we have sufficient balances to cover any unexpected budget emergencies, maintain strategic savings (e.g. for key events) and spend-down some of our surplus for increased student grants and ASFB-wide competitive grants.

Our social media presence continues to grow thanks to the efforts of Andrew Katsis (and Di Bray and Sarah Hearne at the Albany Conference until Andrew arrived). Our tweets in July received 91600 impressions, and almost 450 reads from our three blog posts. Our facebook has now more than 4700 likes with a strongly increasing trend since commencing in 2015. This number tops other similar Australian Scientific Societies. Very impressive, and an important outcome given the challenges we are facing managing our natural resources in the current political and social climate.
Some of the issues we will be focussing on as an executive in the near future will be to get Fisheries Managers back into the ASFB via a sub-committee, continue to work towards better indigenous partnerships/engagement with ASFB, re-structuring executive election processes and investigating potential refinements to the Kay Radway Allan award.

Looking ahead we have some great events upcoming starting with the Melbourne Conference ("Science into Practice, Practice into Science"), on October 7-11, 2018. The draft program is currently being developed, but it will be a fantastic event with a very stimulating theme. Keep an eye out for emails and our website for further information. We will also be hosting two international conferences into the future with the World Fisheries Conference in Adelaide 2020 and the Indo-Pacific Fish Conference in Auckland 2022. More information will follow as these programs are developed.

Finally, congratulations to all members on their achievements in the last year, it is a great field we are in and we should be proud of what we do. I wish everyone and their friends and families a wonderful Christmas and New Year.

Harry Balcombe
President

Above *Swordfish Xiphias gladius*

Recreational fishing for Swordfish in Australia – Opportunities and knowledge gaps

By Sean Tracey

It is a rare occurrence in this day and age that a new fishery develops; however, this was recently the case off the cool temperate waters of the east coast of Tasmania. A particularly driven recreational fisher had spent years investigating methods used in the United States and New Zealand to target swordfish during the daytime. Swordfish display regular crepuscular behaviour where they spend the night in shallower depths, where commercial fisheries using longlines most commonly target them. At dawn however, swordfish migrate to depths between 400 and 800m, and if they are in the vicinity of the continental shelf, they may associate with bathymetric features like seamounts or canyon edges.

Targeting swordfish at this depth provides many challenges for a recreational fisher. Firstly, fishers need to travel out to the shelf break - along the east coast of Tasmania the break is closer than many others areas in Australia, but still involves at least a 15-nautical mile run to sea. They then need to send a large bait of either fish or squid down to the seafloor approximately 500 meters below. Finally, they need to have exceptional patience and a keen eye on the rod to identify a swordfish bite that can be very subtle when there is over 500 meters of fishing line in the water.

Despite these challenges the fisher persisted and after several unsuccessful trips finally hit pay dirt - landing a large swordfish. This capture got the recreational fishing community talking, as swordfish are considered globally as the pinnacle of game fishing. Although much of the talk was suggesting this was a fluke – there has been the odd swordfish caught over the years by recreational fishers often as bycatch to other target species. But he pushed on and over the next three trips he caught a fish each time. Now the recreational fishing community were definitely paying attention. This led to several other fishers in Tasmania gearing up and trying their luck. During

2014, there were a few other boats that had success, but by 2015 a number of keen game fishers were catching fish off Tasmania, and a few key fishers from the mainland made the trip south to hone their skills and try their hand at catching the gladiator of the sea. They then took this knowledge back to Victoria and in 2016 several Victorian anglers were reporting catching swordfish along the continental shelf break along the southeast coast.

“ the fisher persisted and after several unsuccessful trips finally hit pay dirt - landing a large swordfish ”

An interesting point here, is that this new fishery was occurring in the cool temperate waters of Tasmania, albeit it in the summer and autumn months when the water temperatures are at their warmest. The commercial fishery for swordfish in Australia occurs in the warmer waters from the central Queensland coast and extends down the NSW coast, but swordfish are known globally to spend most of their time in warmer waters, with only the larger females venturing poleward into cooler waters.

The concept of the bulk of the population inhabiting the more northern waters of the EEZ on the east coast of Australia was supported by satellite tagging work conducted by CSIRO in conjunction with the commercial fishery from 2004 to 2008. With 29 fish tagged and only two fish moving south of Sydney. So, while it is not unexpected to find swordfish in the cooler southern waters, several questions were raised: how many of these fish are in southern waters, are they resident or migratory, are they all going to be large fish, and so on.

These questions are obviously not only of interest to the fishers but also important from a fisheries science and fisheries management perspective. A new fishery is not only an opportunity for recreational fishers, but also researchers to understand more about a species in an area where it has not been studied previously. Alongside these opportunities, however, are challenges for resource managers on needing to rapidly respond to a new fishery with little information on what is actually occurring.

For the new swordfish fishery occurring off Tasmania, two of the fundamental questions that arose were: “What is the post-release rate”, and “Are these fish residents and potentially susceptible to localised depletion”. These questions were of interest to both the recreational fishers and also resource managers, as robust knowledge of these two factors will guide management strategies in regard to regulatory catch limits.

“ Two fundamental questions that arose were: -What is the post-release rate-, and -Are these fish residents and potentially susceptible to localised depletion- ”

In 2014, IMAS received funding for a pilot study to determine whether satellite tags would be an effective method to assess post-release survival rates and further understand the movement and migration of these fish in southeast Australia.

During the 2015 season, which ran from February to July in Tasmania, we worked closely with the recreational sector where we caught swordfish mirroring the techniques they were using and in some cases joining the fishers on their boats to deploy tags on fish that they had caught. As each fish was caught, the time from hook-up to landing was recorded and then when the fish was boatside a Wildlife Computers MiniPAT tag was attached and the fish’s weight estimated. Immediately following this a rapid physiological assessment of the fish was conducted. The method used for the assessment was modified from the work of Dr David Kerstetter out of Florida who bases his method (ACESS) on the same philosophies of an APGAR test used to provide a rapid assessment of babies after birth. The assessment uses a three-point

Captured swordfish undergoing a rapid physiological assessment via the ACESS three-point score system

score for a range of criteria that include an assessment of physical damage (i.e. hook damage and barotrauma) as well as an assessment of physiological conditions that inform on the state of health of the fish, including body colour, eye response status and general physical activity. If the fish was assessed as in a good condition, it was released. If it was not in a condition for release the boat was driven slowly forward with the fish held boatside to allow water to flow over its gills to facilitate resuscitation. After a period of time the fish was re-assessed and either released or humanely dispatched.

The most common physical impairment that was identified through the assessment was barotrauma, most obviously a swelling of the belly. In some cases, the barotrauma hindered the fish's ability to dive, even after boatside resuscitation.
In these cases, the fish were dispatched. In other cases, the barotrauma was not as severe and the fish was able to descend where the gases could be recompressed. The satellite tags indicated that in all these cases the fish went on to survive post-release. The second most common physical damage that was identified was hooking damage, specifically deep hooking in the stomach or the gills. This led to a rapid deterioration in the condition of the fish and in these cases the fish was dispatched.

For fish that had barotrauma or hook damage the signs of deterioration were distinctive. This is a useful finding that allows recreational fishers to make an informed decision on whether or not the fish is likely to survive release, improving responsible fishing practices and improving animal welfare. In each case so far, the fish either recovered or deteriorated within a few minutes of resuscitation.

Seven of the satellite tagged fish survived post-release and went on to provide some interesting information on the movement and migration of swordfish tagged well south of where previous tagging studies had been conducted. For three of the fish the tags stayed on for the programmed duration (250 days). For the other four fish the tags shed early, which is not uncommon when using satellite tags, but all stayed on for between 127 and 200 days, plenty of time to see if the fish were staying resident in southeast Australia or migrating north to the Coral Sea to spawn.

" Seven of the satellite tagged fish survived post-release and went on to provide information on movement and migration."

Two of the fish left the temperate waters of Tasmania soon after being tagged and moved in a direct fashion up into tropical waters over the period of approximately two months. They then both changed their behaviour to meander for a period of time, before again resuming directed behaviour, one moving south, back towards the east coast of Australia – covering a total distance of 7568 km over 196 days (Fig. 1). The other fish made a very different move, heading due east before the tag detached after 186 days, a journey of 5817 km (Fig. 2).

There was also evidence of residency in southeast Australia with five fish remaining in the area for at least several months. Two fish remained in the area until their tags detached spending at least 127 and 164 days in the region respectively. It is possible they may have left the area after the tags detached but for the latter it has stayed in cool temperate waters for almost half a year. The remaining three fish migrated north after a period of time, not as far north as the fish described previously, but again changed their behaviour from direct travel to a period of meandering before continuing directed movement. It is possible that this change in behaviour is related to spawning as all fish began their meandering behaviour in temperatures above 24C, where swordfish are thought to spawn, and the timing was also consistent with the known spawning season for the species.

One particularly interesting migration occurred for a fish that remained resident adjacent to Tasmania for four months prior to directed movement until it was roughly adjacent to Brisbane but outside the

Australia EEZ. Here, it displayed the meandering behaviour for almost a month, before a directed migration back to the east coast from where it travelled south along the coast until it returned back to Tasmanian waters (Fig. 3). This was considered strong evidence of philopatry and raises concerns about the potential for localised depletion, on what is considered the range edge of the species.

So, in summary working with the recreational fishery in southeast Australia has led to a greater understanding of the behaviour of swordfish in the Tasman and Coral Seas. The opportunity to begin research on a species at the inception of a new fishery has begun to fill in some of the knowledge gaps around post-release survival so fisheries managers can make informed decisions on whether catch limits are an effective management strategy, and has also provided insight into signs of trauma that the recreational fishers can consider when making decisions on whether to retain or release a swordfish after capture, improving responsible fishing practices.

" working with the recreational fishery in southeast Australia has led to a greater understanding of the behaviour of swordfish in the Tasman and Coral Sea"

While the satellite tags provide a wealth of information the results also raise many questions. IMAS will continue to deploy satellite tags on swordfish in 2018, this time in the waters off southeast Victoria. With each tag providing new insight into best fishing practices but also the behaviour of these enigmatic fish.

**** This work has been funded by the Fisheries Research and Development Corporation, the Tasmanian State Government, the Game Fishing Association of Australia, TarFish and the Victorian Recreational Fishing Trust.*

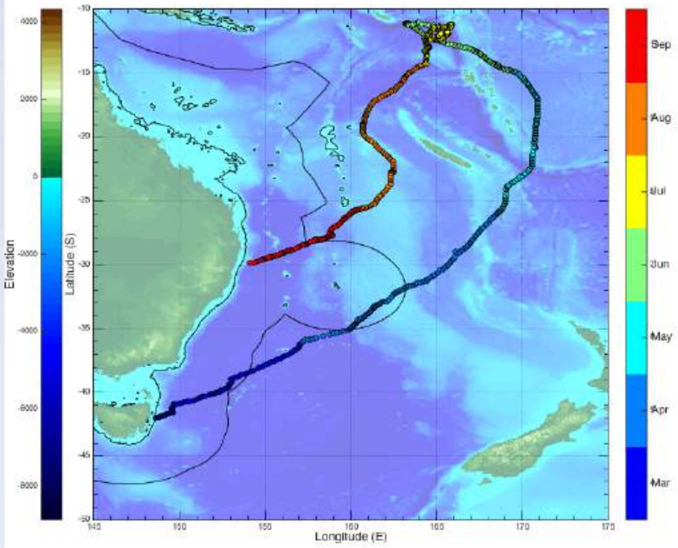

FIGURE 1. JOURNEY OF A SATELLITE-TAGGED SWORDFISH ALONG EAST THE COAST OF TASMANIA, HEADING NORTH INTO TROPICAL SEAS AND RETURNING TO THE EAST COAST OF AUSTRALIA.

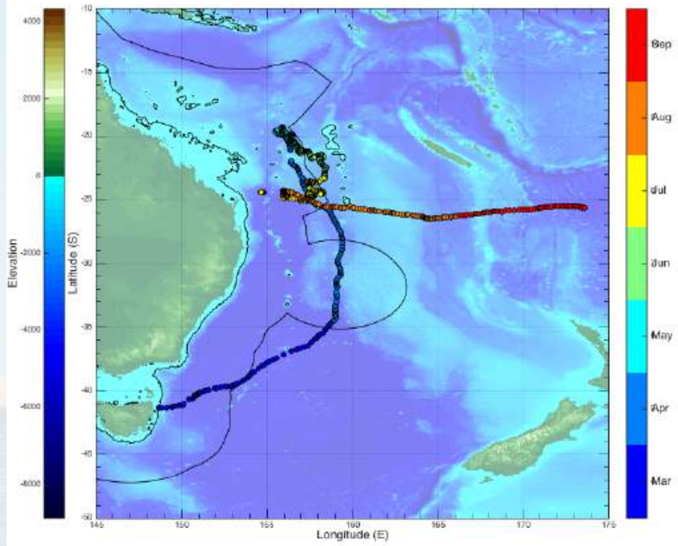

FIGURE 2. NORTH-EAST JOURNEY OF A SECOND TAGGED SWORDFISH BEFORE TAG DETACHMENT AT 186 DAYS.

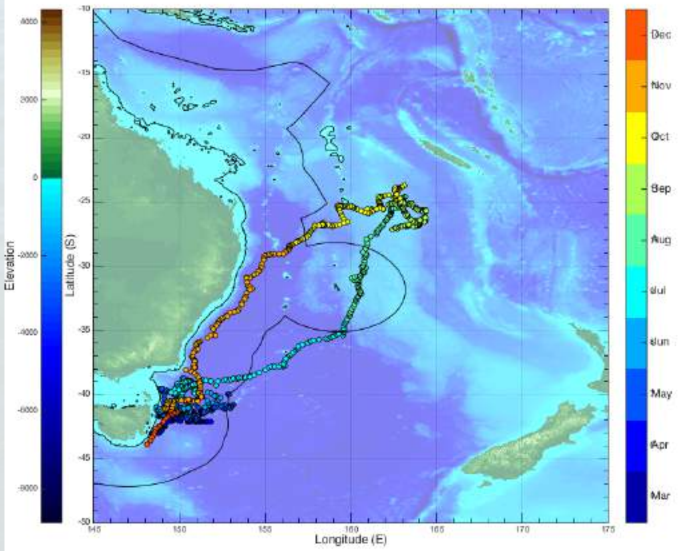

FIGURE 3. SWORDFISH JOURNEY BACK TO TAGGING SITE ALONG THE EAST COAST OF TASMANIA.

Above *Swordfish held boat side to allow recovery via water flow through the gills*

By ALISTAIR HOBDAY

Habitat modelling, dynamic ocean management, and seasonal forecasting to support fisheries management in Australia

Habitat modelling, estimating the distribution of a species based on environmental preferences has important uses in, for example, marine spatial planning, and has also facilitated the development of dynamic ocean management and seasonal forecasting applications. In this overview, Alistair Hobday provides examples of how these approaches have been used in Australian marine fisheries applications.

Fisheries in Australia

The majority of fisheries in Australia are now well managed, with fishing effort actually in decline in many regions. Stock assessments, harvest strategies and ecological risk assessments for developed and data-poor fisheries provide managers with an excellent suite of tools for assessing and managing population abundance. In addition to abundance, a second important element in sustainable fisheries is an understanding of species distribution patterns. These distribution patterns influence the location of management zones, interactions with non-target species or other non-consumptive uses of the ocean, and obviously, the distribution of fishing effort. Historical understanding of species distribution was obtained through direct observation – fish captured as part of commercial or recreational fishing activities, scientific surveys, and reports from the general public. The advent of synoptic ocean data products beginning in the early 1990's has seen a rise in habitat modelling, which has subsequently facilitated the development of dynamic ocean management, and the use of both approaches in seasonal forecasting of marine habitats. Economic efficiency is considered as important as obtaining maximum sustainable yield, and in quota-based fisheries approaches that can reduce the fishing costs and limit interactions with non-target species are in demand. Habitat modelling, dynamic ocean management, and seasonal forecasting all help in this regard.

Habitat modelling for fisheries

The first use of real time habitat modelling for fisheries management in Australia was initiated in 2003 (Hobday and Hartmann 2006) – at the same time as a similar approach was independently being developed to avoid turtle bycatch in the Hawaiian longline fishery (Howell et al 2008).

Box 1. Definitions

Habitat modelling: An approach that uses the association between a species and its preferred environmental conditions to make predictions of distribution.

Dynamic Ocean Management: Management that changes rapidly in space and time in response to the shifting nature of the ocean and its users based on the integration of new biological, oceanographic, social and/or economic data in near real-time (Maxwell et al. 2016).

Seasonal forecasting: aims to deliver information at a timescale of weeks to months ahead of the present.

The management challenge that precipitated the need for habitat models was the unwanted capture of southern bluefin tuna (SBT, *Thunnus maccoyii*) in the eastern Australia longline fishery (Eastern Tuna and Billfish Fishery, ETBF). Prior to the use of habitat models, ETBF managers sought to minimise the bycatch of quota-limited SBT by commercial ETBF longline fishers with limited or no SBT quota through spatial restrictions. Access to areas where SBT were believed to be present was restricted to fishers holding SBT quota, using a fixed closed area for the season.

Hobday and Hartmann (2006) developed a temperature-based SBT habitat model to provide managers with a real time estimate of tuna distribution. Adult SBT temperature preferences were determined using pop-up satellite archival tags and the near real-time predicted location of SBT was determined by matching temperature preferences to satellite sea surface temperature data and vertical temperature data from an oceanographic model. Three zones based on probability of occurrence of SBT were created (**Figure 1).** The habitat model was updated every two weeks, and managers then used this information to inform placement of management boundaries, which were also adjusted every two weeks – the first application of dynamic ocean management for fisheries in Australia and perhaps the world. Since that time, habitat modelling and dynamic management for fisheries has garnered increased attention, and is now a mainstream part of fisheries oceanography.

Dynamic ocean management

Habitat descriptions allow a range of spatial marine management techniques (e.g., marine protected areas), however, these were historically based on stationary boundaries applied to mobile marine features, animals, or resource users (Hobday et al 2015). While these approaches can work for relatively stationary marine resources, to be most effective marine management must be as fluid in space and time as the resources and users under management. As described above, the early applications were delivery of real time maps of distribution to managers (Hobday and Hartmann 2006) and fishers (Howell et al. 2008), and this area has evolved into a field known as dynamic ocean management.

Dynamic ocean management (DOM, **Box 1**) is defined as management that rapidly changes in space and time in response to changes in the ocean and its users through the integration of near real-time biological, oceanographic, social and/or economic data. DOM techniques have been applied in a limited number of situations around the world, notably for fisheries, to regulate or restrict the capture of a particular marine species, beginning with tuna (Hobday and Hartmann 2006) and turtles (Howell et al. 2008). In work since, Hobday et al (2014) argue that DOM requires seven elements: (1) tools and data collection, (2) data upload and management, (3) data processing, (4) data delivery, (5) decision-making, (6) implementation, and (7) enforcement. The first four have been technically possible for some time, the latter three remain challenging in many jurisdictions and applications.

It is clear that DOM can refine the temporal and spatial scale of managed areas, thereby better balancing ecological and economic objectives. For example, Maxwell et al (2016) simulated the efficiency of dynamic management for a hypothetical mobile marine species and showed that 82.0 to 34.2 % less area needs to be managed using a dynamic approach. With advances in data collection and sharing, particularly in remote sensing, animal tracking, and mobile technology, DOM is now being used in a range of marine sectors, although most are in fisheries (Lewison et al 2015). Existing examples demonstrate that dynamic management can successfully allow managers to respond rapidly to changes on-the-water, however to implement DOM widely, several gaps must be filled. These include enhancing legal instruments (Hobday et al 2014), incorporating ecological and socioeconomic considerations simultaneously (Lewison et al 2015), and developing platforms to serve dynamic management data to users (Hazen et al 2016).

Seasonal forecasting

Once habitat models are developed, and managers are willing to use dynamic approaches, it is a small step to project these habitats into the future. Contemporary environmental variables used in the habitat models are replaced with forecast environmental variables, from a seasonal forecast model, such as the Bureau of Meteorology's POAMA model. Sometimes only a subset of variables used in a contemporary model can be used in a forecast model, as not all variables are forecast.

Seasonal forecasts provide insight into upcoming environmental conditions, and thus allow proactive rather than reactive decision making (Hobday et al 2016). Forecasts based on dynamic ocean models offer improved performance relative to statistical forecasts, particularly given baseline shifts in the environment as a result of climate change. Seasonal forecasting is being used in marine farming and

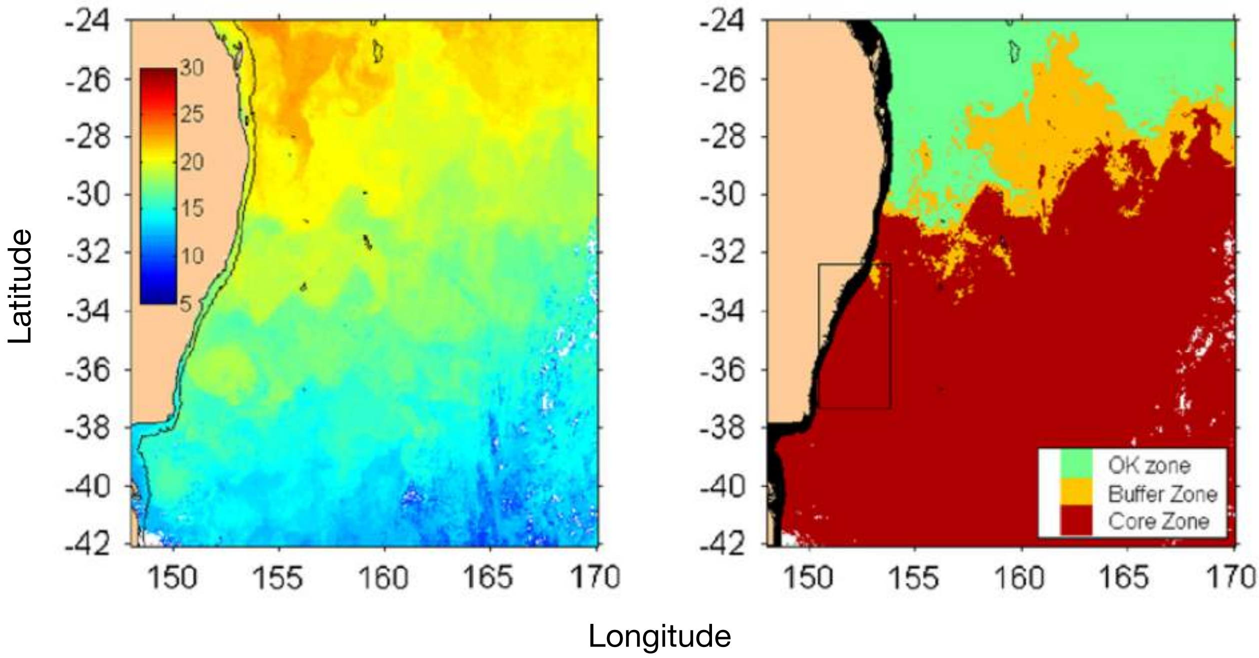

FIGURE 1. EXAMPLE OUTPUT FROM THE SOUTHERN BLUEFIN TUNA (SBT) HABITAT MODEL FOR THE EAST COAST OF AUSTRALIA, SHOWING SEA SURFACE TEMPERATURE (LEFT) AND THREE ZONES OF SBT OCCURRENCE. SEE HOBDAY ET AL (2011) FOR DETAILS.

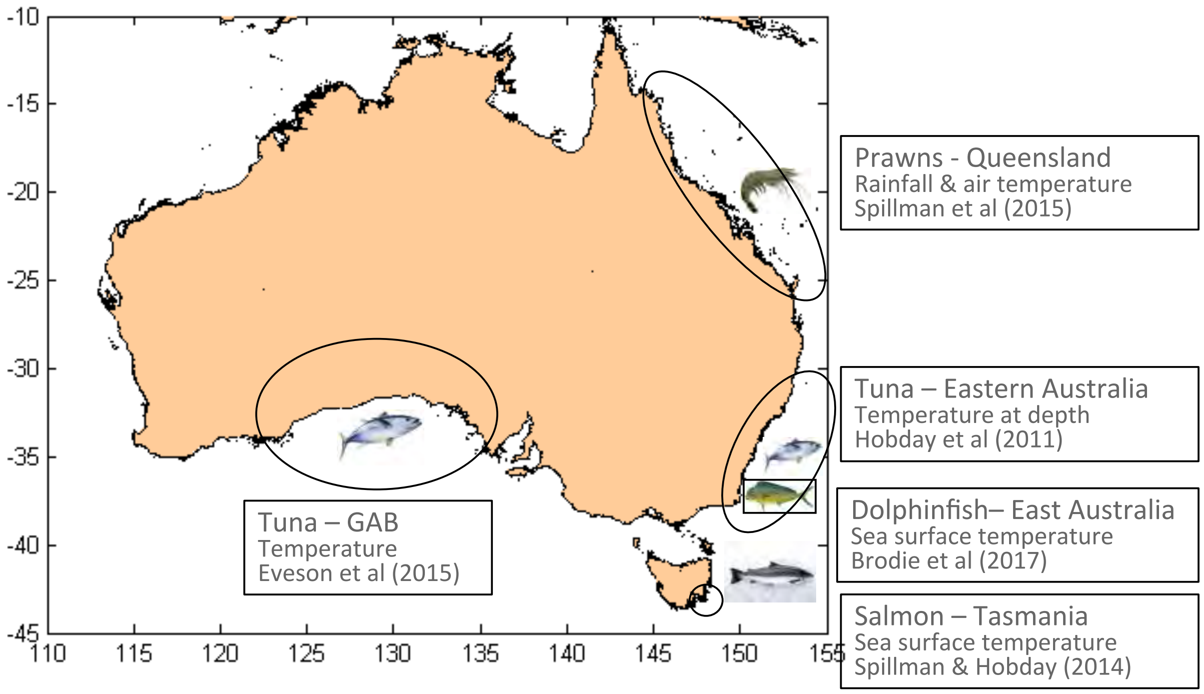

FIGURE 2. SUMMARY OF SEASONAL FORECASTING APPLICATIONS FOR MARINE FISHERIES AND AQUACULTURE. THE KEY ENVIRONMENTAL VARIABLE AND REFERENCE IS ALSO PROVIDED.

fishing operations in Australia, including wild tuna and farmed salmon and prawns (**Figure 2**), to reduce uncertainty and manage business risks. Forecast variables include water temperature, rainfall and air temperature, and are considered useful up to approximately four months into the future, depending on the region and season of interest (Hobday et al 2016). Species-specific habitat forecasts can also be made by combining these environment forecasts with biological habitat preference data, as for tuna (Hobday et al 2011; Eveson et al 2015).

Seasonal forecasts are useful when a range of options are available for implementation in response to the forecasts. The use of seasonal forecasts in supporting effective marine management may also represent a useful stepping stone to improved decision making and industry resilience at longer timescales, including the next horizon – decadal forecasting (Tommasi et al 2017). Collectively these approaches can facilitate improved decision making by fishers and managers and complement the tools available for estimating and managing fish abundance.

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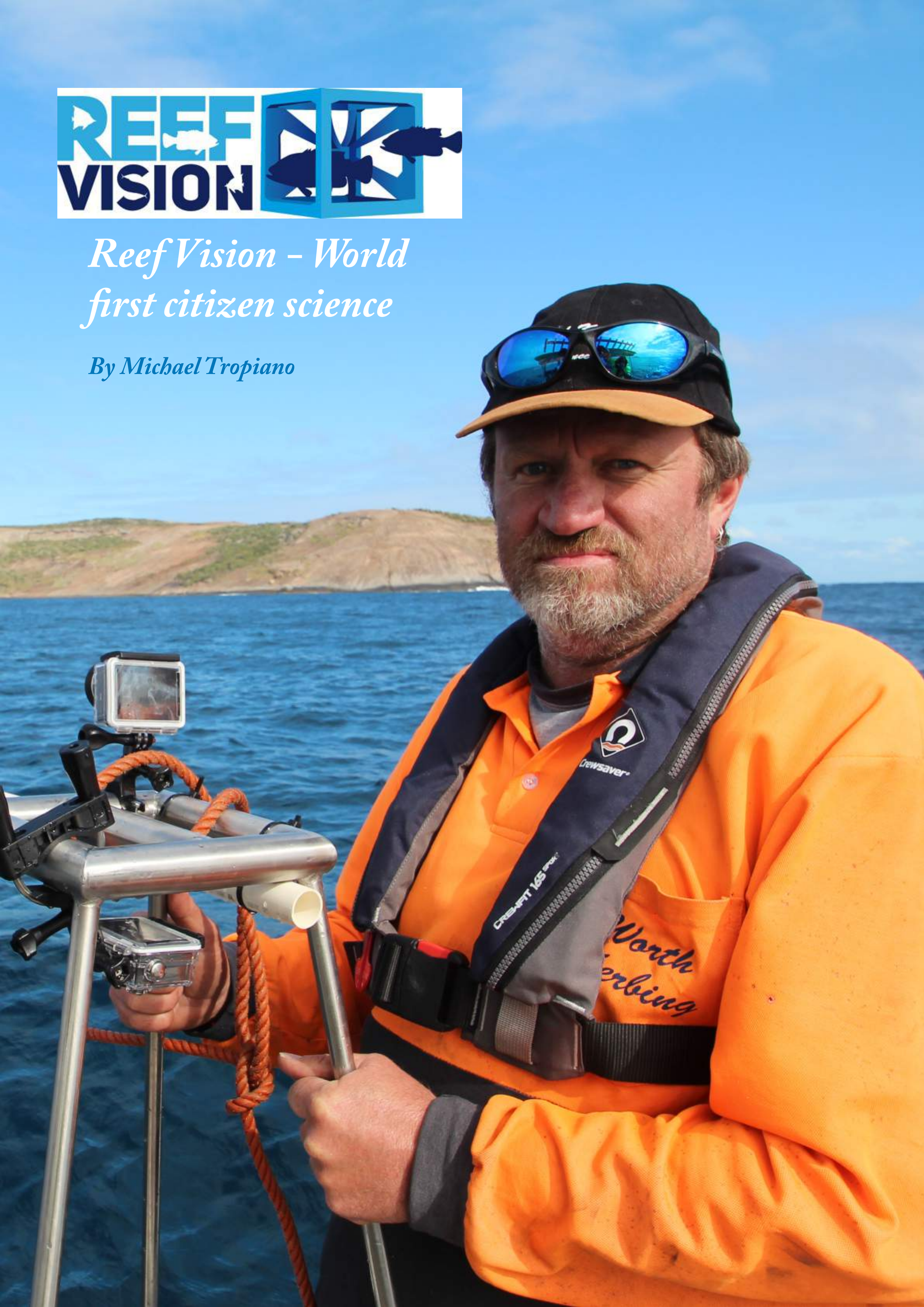
REEF VISION

Reef Vision - World first citizen science

By Michael Tropiano



Artificial reefs have the potential to change barren areas into complex biodiverse ecosystems full of life. This transformation creates a sense of awe and fascination for people around these structures. Whether it's a World War II wreck that captures a unique glimpse at history or a modern purpose-built fishing reef, this ability to transform undervalued marine environments into highly valued areas captures the imagination of anyone who has a connection to the ocean.

For fishers and divers, artificial reefs represent a unique recreational opportunity that is often likened to building a basketball court on the ocean floor. They create community owned underwater infrastructure that allows people to connect with marine areas in a new way. Modern purpose-built artificial reefs are designed to create maximum benefits to the surrounding ecosystem and promote productivity. The variations in their shape and layout, influences water movement while their design and construction material can help drive the growth of new marine life, creating many unique niches, complex voids and crypts for a wide variety of species.

With all this potential, there has been an exciting expansion of artificial reefs across Australia. WA alone has had four new purpose built artificial reefs deployed in the last four years, with three more recently announced in late 2016. With this new progress for artificial reefs it's crucial that they continue to be deployed in locations where they provide maximum social, economic and environmental benefits. To ensure this, there are strict State and Commonwealth regulations around their deployment, one of which involves a commitment for the long term monitoring of any new reefs post deployment. Historically, monitoring programs can be cost prohibitive, which for an already expensive project such as the

Main *Esperance recreational fisher Nigel Worth collecting baseline data before the deployment of the upcoming Esperance artificial reef* **Left** *Before (top panel) and after (bottom panel), transformations like this highlight exactly why artificial reefs create such excitement amongst marine users.*

installation of an artificial reef, can create an added financial burden that has the potential to hold back exciting new projects. A world first citizen science project is changing this.

Reef Vision

In WA, Reef Vision is actively involving the end users -recreational fishers- in monitoring their own reefs.

Previously, Baited Remote Underwater Video systems (BRUVs) have been the domain of scientists, however Reef Vision gives local fishers a simplified citizen science style BRUV that they can take out and drop on the artificial reefs on their way to their fishing spot. The program was originally developed by Recfishwest Research Officer James Florisson through a Fisheries Research and Development Corporation funded project that investigated cost effective monitoring options for artificial reefs. Reef Vision now has 40 volunteers and has collected over 400 hours of video footage with over 34,000 individual fish being counted from 82 different species. The sampling methodology and technology utilised ensures that the data collected by volunteers is of a high quality enabling it to be analysed by scientists to produce robust and rigorous science. To date data collected has been used for spatial and temporal comparisons of the fish faunal assemblages as well as for studying habitat, feeding and residency guilds. The hard work of the volunteers involved in the program has recently been recognised by the Commonwealth Department of Environment with *Reef Vision* being accepted as an approved monitoring method for artificial reefs, meaning that the project was successful in its aim in creating a new cost-effective method for monitoring artificial reefs.

Above *The Reef Vision volunteer starter pack*

Right *Reef Vision volunteer training days*

Below right *The original Reef Vision volunteers and their citizen science BRUVs.*

Above *One species picked up by the volunteers which surprised even some of the most experienced local fishers, a Saw Shark!*

More than monitoring – the bigger picture

As with all citizen science projects, Reef Vision's success is due to the incredible commitment and hard work put in by volunteers. Fishers are increasingly looking for opportunities to be able to give back to their marine environment and are eager to be involved in community-based projects such as this. As well as creating a cost effective monitoring option, Reef Vision has provided a unique way for volunteers and the wider community to connect with their local marine environment. For many of the volunteers, firing up the computer to check out their latest footage is the first activity to do as soon as they get home (and not just because it's easy to make up excuses to not clean the boat). For some of these guys who may have never been scuba diving, in the 50 or 60 years they have been living and fishing in the area, this is the first glimpse they have ever had as to what fish and marine life is really down there.

Seeing schools of huge pink snapper tearing apart bait bags and experiencing unique encounters with creatures like saw sharks appearing from the depths are things that many of the volunteers had previously only ever dreamt of, or in the case of the saw shark, didn't even know existed! It's these experiences which give the volunteers immediate value from being involved and keep them heading out each fortnight to the reef.

One of the most fascinating and beneficial things to come out of the back of the program has been the way in which sharing this footage has enabled so many people to connect with their local marine environment in a new way. As soon as the volunteers see something new and exciting in their footage, they go straight onto Facebook, sharing it with the rest of their community. This has two great benefits: Firstly, the likes, comments and views these videos receive provides immediate positive reinforcement for volunteers, giving them encouragement to get back on the water and collect more data. Secondly, once its shared online, it is quickly picked up by local tourism and media pages and shared so that everyone in the southwest of WA soon gets the chance to see it.

Recently, one of the volunteers collected footage of a green turtle swimming through one of the artificial reefs. This footage was shared and quickly went viral, reaching almost 30,000 people in the first few weeks. And it wasn't the number of people that were viewing the video that was so interesting, it was the surprising diversity of the different groups outside of recreational fishers who were viewing it. By sharing their footage, volunteers have inadvertently have managed to connect people of all likes with their local marine environment. Reef Vision has been an incredible tool for sharing the story of artificial reefs and increasing the local communities' custodianship over local marine resources.

The keys to the success of this program have been its simplicity (keep it easy and enjoyable), the self-fulfilling role social media has played in providing volunteers with encouragement to go out and get more videos (data) and the ability to quickly and easily share the journey with local community through Facebook.

With new artificial reefs planned for WA in the coming years, there are plans to expand Reef Vision state-wide. This method has many potential applications for community monitoring of not only artificial reefs, but other marine systems around Australia such as shellfish reefs, marine parks, marine infrastructure, seagrass beds and natural reefs. The framework has recently begun to be used by The Nature Conservancy to monitor restored oyster reefs in Port Phillip Bay, Victoria and there has also been interest from south east Asia. We would be more than happy to share our learnings and methods with those interested in setting up a similar program elsewhere in Australia.

For more information please email, michael@recfishwest.org.au.

Arts & Science

Featuring Janet Ayliffe

Interview by Katherine Cure

Although these two concepts appear separate today, arts and science were not seen as mutually exclusive polarities six centuries ago. During the time of the illustrious Leonardo da Vinci, observation and curiosity were clearly understood as the basis of both disciplines.

Modern scientists are slowly coming back to that concept, involving arts into their science, acknowledging the creative process behind the scientific question, and letting curiosity drive at least some of their research. Artists are also acknowledging the science behind their art, engaging in close relationships with scientists and producing collaborations that allow all people to better understand scientific outputs.

Janet Ayliffe is a perfect example of humanity in the time of da Vinci. She has cultivated her curiosity, dedicated herself to the observation of nature, paid attention to the most minute of details, and researched available scientific literature to better understand the world around her. I am a big admirer of her art and thought she would be perfect to get this column started. Janet is based in the Adelaide Hills, where she lives together with her husband Glenn, her dog Milly and a myriad of chooks. You can learn more about her and her art by visiting her webpage http://www.janetayliffe.com.au

Your work is dominated by the natural landscape and animals, why does this inspire you?
I think it is because of the world I grew up in as a small child with my family. I was raised in Kangaroo Island and remain emotionally tied to its landscape and environment.

My parents were second-generation farmers on the island and many of their practices were conservative in how farming might affect the waterways and scrublands. They were very concerned about preservation of the ancient water 'soaks' near our beach. We would sit and look together at these freshwater ponds, only metres from the sea, and watch the tiny fresh water creatures and the birds. My father had never been to school but was taught by his mother who gave him Darwin's books, *'The voyage of the Beagle'* and *'The origin of species'*. He loved to read these to me and I loved to hear them.

I was allowed to walk over our farm from when I was about four years old, and got to know the tracks and signs of insects, reptiles, animals and birds. And at the beach, both freshwater and saltwater creatures. My mother knitted really thick socks so I wouldn't be bitten by a snake, which was good of her. When I learned to count and write, I made and kept records.

Our parents also let me and my brothers stay home from school whenever we wanted, believing there were too

Top *Etching 'A walk of snipe and a lean of sandpipers'*

Above *Janet in her studio at Kangarilla, SA*

Above *Janet's travel pack for recording nature's wonders*

many hours spent behind desks. I think we were a bit feral as children, but we did say please and thank you, which meant we could often go out on fishing boats to watch and help. The main rules for that, was not watching when the fisherman lined up land marks to arrive at the perfect fishing spot, as these were of course secret. From the boats, we were allowed to swim out and that was my first time seeing deeper waters with vast sea meadows and different fish. My friend had goggles and it was a wonder to see underwater with those. Later I had my own, a complete revelation.

From my parents I always had the idea to be careful of our scrubland and beach, that we should all be 'tiny' grains of sand in the whole scheme of things. In hindsight, I was being taught perhaps that we should not dominate this earth and take great care of it. So in summary, my inspiration comes from a respectful observation of the natural world and is linked to memories and experiences with my family.

What do you admire about fish and fish biology?

About fish, how they look of course! How they move, the immense variation of shapes, sizes, behaviours and colours determined by the environment they live in. Each type is remarkable in how it has been formed by often unimaginable extremes of temperature, water pressures, water movements and qualities. I grew up without electricity, so no television, and only a few books. But I did have my Weetbix card collections, and a whole beach to examine, and fresh water creeks on the farm. I was also able to see amazing fish dissections because my best friend's father was a fisherman. We were allowed to collect the intestines and all the insides of the fish he caught, and made a fish insides museum on my parents' front room mantle piece! We liked to see the different sizes, what they had been eating. Later I saw brilliant diagrams of fish in cross section, and marveled at those.

What's your favourite fish and ecosystem?

It is hard to say which one. I like the very strange fishes that live on the weeds like perches, sharp-nosed weed fish, and wrasses with pretend eye shapes. I could make a long list of favourite fish as they are all interesting to me. My favourite ecosystems are the ones I know well from my early days: the estuarine regions and the wide bay of Western cove on Kangaroo Island. As with fish, it's hard to come up with a favourite. I really like the way whole systems can happen around jetties, on submerged timbers and sunken boats. It is difficult to exclude the reefs of the southern ocean, which I also know, and I have yet to see the coasts of the tropical lands, which I know I would admire very much.

How do you get the context and details right for your fish drawings?

I now have lots of books; the main one I use is *'Sea Fishes of Southern Australia'*, by Roger Swainston and Barry Hutchins. It has excellent drawings and good information. I also have two photographic fish/marine books, Graham Edgar's *'Australian marine life'*, and Rudie Kuiter's *'Guide to sea fishes of Australia'*. I also go to museums and libraries, use the giant internet library, and as I used to do when I was small, I go to the sea and draw.

What do you think art can get from science and vice versa?

Art can gain so much from the collected observations of science, both the theoretical and visual evidence. I am reliant on some of this for my own work. Through science I learn more about how systems link and work together, or what difficulties and problems there might be. I think there are many parallels in art and scientific practice: the studied gathering of ideas and information, and the path of hypothesis setting and working to see what might be shown.

In my life I have had close friends who have worked in entomology, plant physiology, pathology, medicine, biochemistry, geology, archaeology and marine sciences, and I have often thought as I scratch away at my pictures, that we use similar methodologies in almost every way, except artists may not have such peer structures on how we proceed. In most science, the world of the humanities is often present, especially in the realm of ethics and considerations of the larger picture, of how we all live in this world. Perhaps then the artist might contribute a wide view of how things can be seen; maybe a surprising angle, the tricky area of feelings and emotion, to balance and counter 'plain' reason.

With my own pictures, I show layers of life, ecosystems of different places and with references to other times, through use of sea charts and written passages from journals. I don't know or assume there is a dominant message. I am interested in mystery and wonder, which I know can be a starting point in the sciences, although one that can probably make a serious thesis a bit wobbly!

How do you approach the concept for a drawing/picture?

I make drawings and paintings in small books, taking them with me in one of our boys' old school backpack when I go out and about. I have many of these books and with real objects I find along the way, I start to work out an idea I have. I do diagrammatic drawings, which I call my flea drawings, because aside from myself only a flea might know what I'm doing. I may then need to gather more information so I go to my books, the library, and the museum. I ask people who might know, I hunt out my collections of seaweeds, shells, dried fishes. I think about my ideas as I walk out on the hills where I live, and then see more things I would like to draw. I realise I have many years of pictures I haven't quite done. I listen to the dear old ABC radio, which is my ongoing education. I am

Above *Etching 'A crèche of stilts and a toggle of toadfish'* especially grateful to the Science show and Robin Williams. I am often inspired to make a picture about what I have heard, and I do; the crèche of stilts etching started from hearing how the stilts float the babies on currents to feeding grounds.

Did you ever consider a science degree?
I did, and I nearly started microbiology but changed my mind at the eleventh hour. I would have liked to study both art and microbiology. But double degrees weren't an option then. But in my own way, as my father did with his life, I have kept studying, not formally, but for how I want to know my world.

When did you start drawing?
I think it was before I had memory! I was born in 1950 and because of the war years, there was a paper shortage, so our mother gave my brothers and me a wall each to draw upon. My wall was the bathroom wall and it lasted until I was four when an earthquake brought it down. Mother then gave me the front room wall and the entire side veranda. I was so happy!

Do you think art has a place in fish management and conservation?
I think it really does. On a small scale, I have realised with my own pictures, that they do link people who may have little contact with what might be happening in our fisheries and sea conservation issues. Also, when I can get the compositions with their underlying thoughts working, the pictures can shine a bright light into dark corners. I hope for this very much, for I am deeply concerned for the health of our oceans. I know that just hard slogans and unsubtle imagery often closes people and organisations out. I wish then for good strong science and good strong art, to meet with and inspire the every person to be absolutely responsible for consequences in how lives are lived. The answer then is I wish for yes!

Above *Janet's notebooks showing her creative process from start to finish*

General News and Information

Australian Society for Fish Biology Information

The Australian Society for Fish Biology was founded in 1971 with the intention of promoting fish studies and the interchange of information between fish biologists in a relaxed but effective manner. Annual Conferences have been held once every year since the Society's inception. They are now the highlight of the Society's calendar, providing a forum for members around Australia to meet and discuss their work.

Since the first conference conducted by the Society in its own right, at Port Stephens in 1975, succeeding conferences have continued to be conducted most successfully, and in a relatively informal atmosphere despite consistent growth in both attendances and programs.

To enhance it's contribution to research, conservation and management of fish and their habitats in Australia, the Society decided to organise and hold workshops on specific topics in conjunction with it's annual conferences. The first such workshop, a two-day event on *Australian Threatened Fishes*, was held at the Arthur Rylah Institute, Melbourne, immediately prior to the Society's annual conference held in that city in 1985.

In addition to these major workshops, another series of workshops on fish collection management, organised independently by museum-affiliated members but held under the auspices of the Society, was initiated with a one-day program immediately after the 1985 Melbourne conference.

The Society now publishes a bi-annual newsletter, which was recently baptised "Lateral Lines" after a naming competition ran with all ASFB members and which was won by Christopher Fulton, ASFB President from 2015 to 2017. The newsletter contains information of interest to the Society membership, including notices and information on Society activities, and a bibliography of publications by Society members. The proceedings of Society-held workshops are usually produced separately as special publications, often with the assistance of other government and non-government organisations.

Please check our frequently updated website for any news or current job positions http://www.asfb.org.au/, and follow us on social media via our Facebook and Twitter accounts.

The Society membership has expanded from 79 members in 1971 to 438 members currently.

Membership

Applications for membership are invited from any person interested in the aims of the Society (as set out in the constitution) or any institution wishing to receive the Society's newsletter and other publications. The membership application is through the website (https://members.asnevents.com.au/login/) with credit card online payment options.

Membership of the Society entitles all members to discounts for conference registrations and access to download the newsletter and conference proceedings from the website. Members who are non-financial for more than 12 months will forfeit the benefits of membership and be removed from the membership database.

There are three membership categories:

Student Member:

One Year	$30.00
Three Years	Not avail.

Ordinary Member:

One Year	$60.00
Three Years	$150.00

Retired Member:

One Year	$30.00

Institutional Memberships are also available by contacting the Membership Secretariat at: http://www.asfb.org.au/contact-us/

Office bearers and half of the Executive Council are elected from the membership at the Annual General Meeting, held during the Annual Conference.

Pay Your Membership & Update your Membership details

The Society requires your details to be registered online. We must have your current contact details and e-mail address in order to send out ASFB communications. Please make sure you pay your subscriptions promptly and contact the Membership Secretariat at: http://www.asfb.org.au/contact-us/.

The ASFB continues its participation in the planning of the upcoming World Fisheries Congress, to be held in Adelaide during October 2020. The conference's motto 'SHARING OUR OCEANS AND RIVERS: A 2020 VISION FOR THE WORLD'S FISHERIES', summarises the event's general aim which is to explore the challenges of fishing sustainably and maintaining prosperous fishing communities in our oceans and rivers. Australia, New Zealand, and the broader Pacific region will be the focus. Look our for updates on the event's website http://wfc2020.com

Science & Technology Australia 2017 Highlights

Worrying estimates predict big cuts to STEM at unis

Science, technology, engineering and maths courses – crucial for future skills and economic growth – would be hardest hit by the Government's proposed cuts to university funding. New analysis by Universities Australia has confirmed the STEM disciplines will take the biggest hit of any field of study if the legislation passes, bearing 35% of the brunt of the $1.2 billion in cuts.

And while Government funding for each student place in a STEM course would be cut, STEM students would have to pay higher fees for those places – even though the Government's own figures show that STEM degrees make a vast contribution to the public good.
"As Australia's economy transitions into a new high-tech era, scientific skills and literacy are going to be foundational for many more future careers," said Universities Australia Chief Executive Belinda Robinson.
"In the next five years alone, there are expected to be an extra 126,000 scientific and technical jobs that will need higher qualifications."
"If we want Australia to be a STEM powerhouse, we can't afford to cut public funding to train future scientists while also making science students pay more," Ms Robinson said.
"This also runs counter to the Government's own science and innovation agenda, which recognises the need for STEM skills more broadly across our economy."

A report to Government prior to this year's Budget showed that STEM graduates delivered a high spillover benefit to Australian society, as well as strong benefits for individual graduates. For engineering graduates, the benefits of their degrees were analysed to have a 61% to 39% split of public and private benefit. For science graduates, 59% of the benefit of their degree was deemed to be public benefit – and 41% private benefit.
"The Government's own analysis shows that these are precisely the kinds of graduates that we need in our economy and for our broader Australian society," Ms Robinson said.
"If properly supported, their knowledge and skills will help to drive improvements in living standards and support technical innovation."
"Against a background of economic and technological change, increasing global competition, and a threat of widening disparity in opportunity – including between regional and metropolitan areas – university education is a way to bridge the gaps, shape our future and transform lives," she said.

Superstars to smash science gender stereotypes

Thirty female scientists and technologists have been named the first Superstars of STEM – ready to smash stereotypes and forge a new generation of role models for young women and girls.

More than 300 applicants vied for a spot to be a Superstar, with the successful 30 candidates to receive training and development to use social media, TV, radio and public speaking opportunities to carve out a more diverse face for science, technology, engineering and mathematics (STEM).
Selected candidates will learn how to speak about their science and inspire others to consider a career in STEM.

Science & Technology Australia President-Elect, Professor Emma Johnston, said studies in the USA and other countries similar to Australia had shown female STEM professionals were significantly under-represented.
"Superstars of STEM is the first program of its kind and will prove vital for the future of STEM in Australia," Professor Johnston said.
"Often when you ask someone to picture or draw a scientist, they will immediately think of an old man with white hair and a lab coat.
"We want Australian girls to realise that there are some amazing, capable and impressive women working as scientists and technologists too, and that they work in and out of the lab in places you might not expect," she said.

Professor Johnston said the participants in this world-first program hailed from nearly every state and territory; from the public, academic and private sectors; and from all sorts of scientific and technological backgrounds.
"Participants are working in archaeology, robotics, medicine, cider research, pregnancy health, education, psychology and so much more," she said.

The Superstars of STEM program will also include a mentoring component, designed to link participants with inspiring women in their sector who can provide insights into leadership in their field. Participants will also be required to share their stories at local High Schools to ensure they are connecting with young Australian women with an interest in STEM.

Of the final 30 women, 8 are from Victoria, 8 from New South Wales, 5 from South Australia, 5 from Queensland, 2 from Tasmania and 2 from the ACT. You can meet them by heading to the Superstars of STEM page.

Above *Dr Kate Grarock, one of the STEM superstars, and a wildlife sanctuary ecologist*

"Superstars of STEM will smash society's gender assumptions about scientists and increase the public visibility of women in STEM."

Ichthyology Hall of Fame

Professor Michael John Kingsford

2017 K Radway Allen Award Recipient

By Prof. Bronwyn Gillanders (U Adelaide), Assoc. Prof. Chris Fulton (ANU) and Dr. Heather Patterson (ABARES)

Born in New Zealand, Mike graduated with a PhD from the University of Auckland in 1986 after completing his research at Leigh Marine Laboratory. After a brief stint working with the NZ Ministry of Agriculture & Fisheries, Mike took up a post-doctoral fellowship at the University of Sydney (1987-1988), where he became a tenured academic, before taking up the role of Head of the School of Marine Biology and Aquaculture at James Cook University in 2001, where he is currently a Distinguished Professor in Marine Biology.

Prof. Kingsford's extensive portfolio of 185+ publications (with 8,000+ citations) reveals a great depth and diversity of topics that he has explored in his research, including: population and community ecology of reef-associated and pelagic fishes; the importance of oceanographic features for larval fish dispersal; how otolith microstructure and elemental chemical tags in fishes can be used to elucidate patterns of connectivity and recruitment; the importance of sensory cues for larval fish settlement; and the consequences of climate change for marine ecosystems.

Mike has been well known for showing an incredible commitment and vigour in the field, and stints with him to various research stations on the Great Barrier Reef were always very productive, with never a dull moment. Besides numerous dives for the day, catching newly recruited fish and the general chores that go along with living at a research station for weeks or months, Mike always made time for a few antics, like repeatedly throwing his students into the water, and on one occasion temporarily relocating the outboard motor off a tinny while the occupants were diving underwater. They returned to the boat to find themselves with no motor, and set to paddling their way back across One Tree lagoon, to the delight of everyone waiting on the beach who watched a 'gondola' slowly make its way back. Mike was also well known for belting out a few songs while driving to and from dive sites and there was often much debate about the origin of these songs or whether Mike had just made them up.

Prof. Kingsford has also shown an exceptional commitment to student-led science education. Mike has authored several textbooks, and has dedicated almost three decades to excellence in higher education through undergraduate courses in marine science, biological oceanography, invertebrate biology and marine ecology, as well as his development of degree-level programs among multiple institutions. Mike's incredible love of science and fish in particular has no doubt encouraged many students into careers in marine biology. He has mentored over 80 students in the art and science of ichthyology, many of whom are now prominent members of the global community of fish and fisheries scientists and managers. Many a student will remember Mike not only coming into the field with them – he loved to shoot a fish or two whether with a camera or spear gun – but also the office meetings where he'd often say "Haven't we talked about this before". Moreover, Mike has contributed exceptional energy to institutional leadership via his roles in various government, museum and NGO advisory committees, as Director of One Tree Island Research Station and the Coral Reef Research Institute, and academic roles such as the Head of School, Dean, and Pro-Vice Chancellor. Mike has also contributed to fish-related science in Australia as lead organiser of the following major conferences: The International Larval Fish Conference, Sydney 1995; the Australian Society for Fish Biology, Sydney 1995; Australian Coral Reef Society 2003, Townsville; the Australian Society for Fish Biology, Townsville, 2011.

For his outstanding contributions to ichthyology, Professor Michael Kingsford was awarded the 2017 K. Radway Allen Award by the ASFB.

Selected Publications:

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Brierley AS, Kingsford MJ (2009) Impacts of climate change on marine organisms and ecosystems. *Curr Biol* **19,** R602-R614.

Gerlach G, Atema J, Kingsford MJ, Black KP, Miller-Sims V (2007) Smelling home can prevent dispersal of reef fish larvae. *Proc Nat Acad Sci USA* **104,** 858-863.

Kingsford MJ, Leis JM, Shanks A, Lindeman KC, Morgan SC, Pineda J (2002) Sensory environments, larval abilities and local self-recruitment. *Bull Mar Sci* **70,** 309-340.

Atema J, Kingsford MJ, Gerlach G (2002) Larval reef fish could use odour for detection of lagoonal waters. *Mar Ecol Prog Ser* **241,** 151-160.

Kingsford MJ, Battershill CN (1998) *Studying temperate marine environments: a handbook for ecologists.* University of Canterbury Press, Christchurch.

Gillanders BM, Kingsford MJ (1996) Elements elucidate the contribution of estuarine recruitment to sustaining populations of reef fish. *Mar Ecol Prog Ser* **114,** 13-20.

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2017 ASFB Conference

Turning Points in Fish and Fisheries, 20-24 July, Albany Entertainment Centre, WA

By Emily Fisher and Chris Fulton

Top *Conference publicity*
Centre *Albany Entertainment Centre*
Bottom *Albany town centre*

For the last weekend of July this year, a collection of Australia's finest fish biology enthusiasts descended on the beautiful coastal town of Albany on the south coast of Western Australia for the 2017 ASFB conference. This was the first stand-alone ASFB conference since 2011 and despite initial concern that the distance to Albany may deter some ASFB members from attending, reports from many of those who completed the migration indicate that the journey was very worthwhile. With the overarching theme *'Turning Points in Fish and Fisheries'*, the conference organising committee aimed to get the 170 delegates thinking about all those influential moments or developments that have changed the way we go about our research. There were also plenty of opportunities for networking during the well-attended evening social functions.

After a Friday night welcome sundowner at the Due South Restaurant and Bar, the conference was formally opened on the Saturday morning by Conference Chair Gary Jackson, followed by a welcome to sea country by Traditional Owner Aunty Avril. The opening address from ASFB President Chris Fulton welcomed several distinguished guests, including the American Fisheries Society President-elect Steve McMullin. The day progressed with five outstanding keynote presentations provided by speakers spanning industry, government and academia. These discussed dynamic ocean management of fish and fisheries (Stephanie Brodie, UC Santa Cruz), industry perspectives on science-based management (David Carter, CEO Austral Fisheries), the utility of sclerochronologies in fish and fisheries (Bronwyn Gillanders, University of Adelaide), positive psychology and work-life balance (Hugh Kearns, Flinders University), and the movement physiology and ecology of inland fishes (Jason Thiem, NSW DPI).

For one of the Saturday morning sessions, the focus was turned to the many student and early career members of the society as Education Committee Chair Stephen Beatty presented one of the highlights of the conference; the '*Nurturing Fish Scientists*' session. It took delegates on a journey from the post-graduate (larval) phase to fully-recruited fish scientists, with several guest speakers at various stages of their careers sharing their personal stories and experiences that helped them land a PhD or employment in this competitive field. The session included panel discussions focused on how to navigate the 'PhD rollercoaster' and what range of employment opportunities are available to newly recruited scientists in academia, Government, industry and consulting. This was followed by the popular rapid fire student talk competition, which gave students the opportunity to take to the stage for three minutes to spruik their research. Students from Albany Senior High School also wowed the audience with five fantastic presentations on their marine research projects spanning biodegradability of soft plastic lures to jig colour preferences of squid!

Top *Conference opening by Gary Jackson*
Centre *Nurturing Fish Scientists session*
Bottom *Rapid students talks*

Over the next few days, the conference delegates delivered a total of 137 oral presentations in three concurrent sessions that showcased recent endeavours and achievements in fish and fisheries science and management. The 14 special and themed sessions spanned advances in stock assessment and management, social and economic dimensions of fisheries, environmental stress and its effects on fish, threats to key biomes supporting fish biodiversity and fisheries, artificial reefs, and a range of other topics in fish biology and ecology. Instead of trying to fit both marine and freshwater contributions in as many sessions as possible, the conference organisers mixed it up (or rather un-mixed it) for the second full day of proceedings when two of the concurrent sessions focused specifically on marine habitat-based topics and freshwater-related issues. On the Sunday evening the Auditorium was opened up to the public, with 90+ attendees enjoying five short talks on key topics from the conference, followed by a Q&A session. The Albany locals then had the opportunity to mingle with conference delegates and speakers while enjoying some drinks and food.

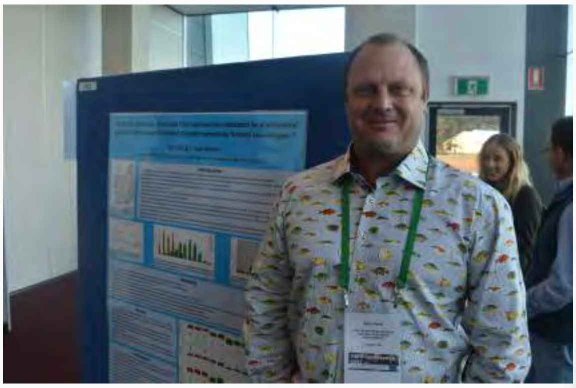
After the Monday afternoon AGM and an

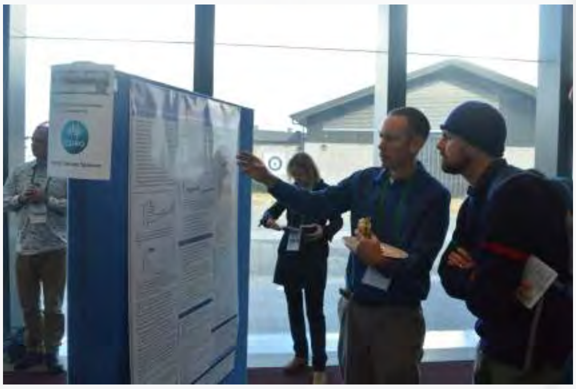
entertaining debate that wrapped up the conference, delegates gathered in the nearby Albany boatshed for the end of conference 'bash'. As part of the registration for the conference, everyone was treated to an abundance of delicious wood-fired treats (including some amazing locally-caught seafood pizzas and tacos) and drinks sourced from an Albany brewery and winery. As the jazz band took a short break, the many different awards offered by the society were handed out to well-deserved winners and the traditional kicking of the duck to the organisers of the next conference in Melbourne was successfully completed. The music resumed and many delegates continued mingling and dancing until the early hours of the Tuesday morning.

Top and Centre *Mingling during tea time*
Bottom right *A captive crowd during one of the sessions*

2017 ASFB Conference Photo Selection - By Andrew Katsis

Can you find yourself in here? Andrew really managed to capture the vibe of the event, and provided some great shots of this year's social events, poster sessions and presentations. A few of them are shared in the following section.





2018 ASFB Conference

"Science into Practice, Practice into Science", Melbourne, VIC

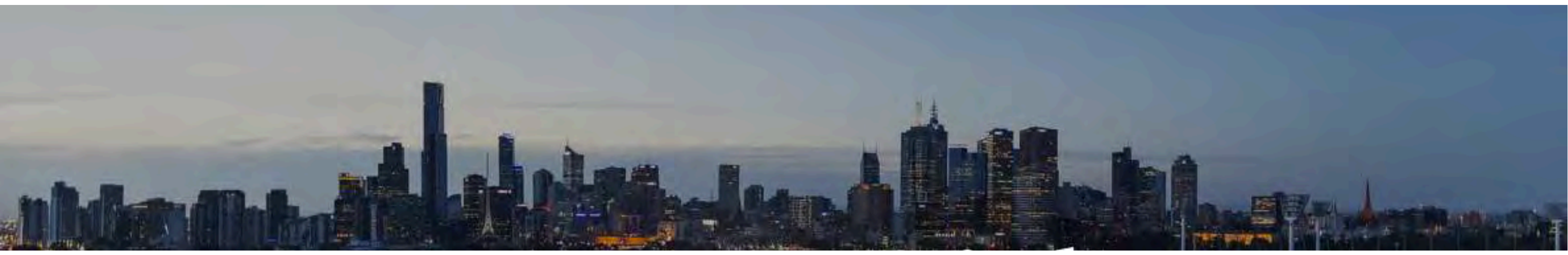
The 2018 ASFB conference will, over four days, challenge and engage delegates by exploring the relationships between scientific research, natural resource management and policy formulation. Scientists, industry, and government share many goals and together we have made major advances in managing freshwater and marine environments and resources. The 2018 conference will celebrate our successes at the science-practice nexus. Through sharing experiences, priorities, skills and new ideas, we will inspire delegates to forge even stronger and more productive relationships with other stakeholders in their field. We want delegates to think in new ways about how we can integrate science with management, and how management can effectively guide science to collectively address the key issues in fish and fisheries management.

A range of special conference sessions will reflect the broad base of the delegates' scientific interests, including:

- *Exploring the science-management-policy interface*
- *Climate change and our aquatic environments*
- *Citizen science- how do we better engage the public?*
- *Fisheries management in our rivers and seas*
- *A review of the Murray Darling Basin Plan*
- *Fish ethics and welfare- promoting industry best practice*
- *Advancing education in the aquatic sciences*

Please join us for a stimulating week, on October 7-11 2018, at the Rydges on Swanston, Carlton.

For more information head to the ASFB conference website; registrations open early February
http://asfb2018.org.au



State Reports

Australian Capital Territory- ACT

Compiled by Matthew Beitzel

ACT Government

Fish work in the ACT continues with a number of new projects:

- ACT Government is expanding the fish habitats in the Murrumbidgee River at Tharwa with at least four more engineered log Jams (ELJ) to begin construction in early 2018. The existing ELJs constructed in 2013 have been successful in scouring the channel from <0.2 m to more than 3 m deep in the sand slug and providing habitat for juvenile and adult Murray Cod, *Maccullochella peelii*.

- A genetic rescue of Macquarie Perch *Macquaria australasica* in association with an ARC project led by Monash University was undertaken with the University of Canberra and ACT government. The rescue consisted of the collection 31 Macquarie Perch from Cataract Dam which were released into the Cotter River. Additional translocation and collection of samples for the ARC project will be undertaken to determine if the introduction of new genetic stock is successful in improving the genetic health of the Cotter River Macquarie perch population.

- In April 2017 the ACT Government Conservation Research Unit undertook the removal of carp from two urban ponds. The ponds were being drained as part of the 'Healthy Waterways Isabella Weir and Wetlands' project to upgrade the weir and construct wetlands at Isabella Pond and the

Top *Macquarie Perch being released into the Cotter River*
Centre and bottom *Carp cleanup in ACT ponds*

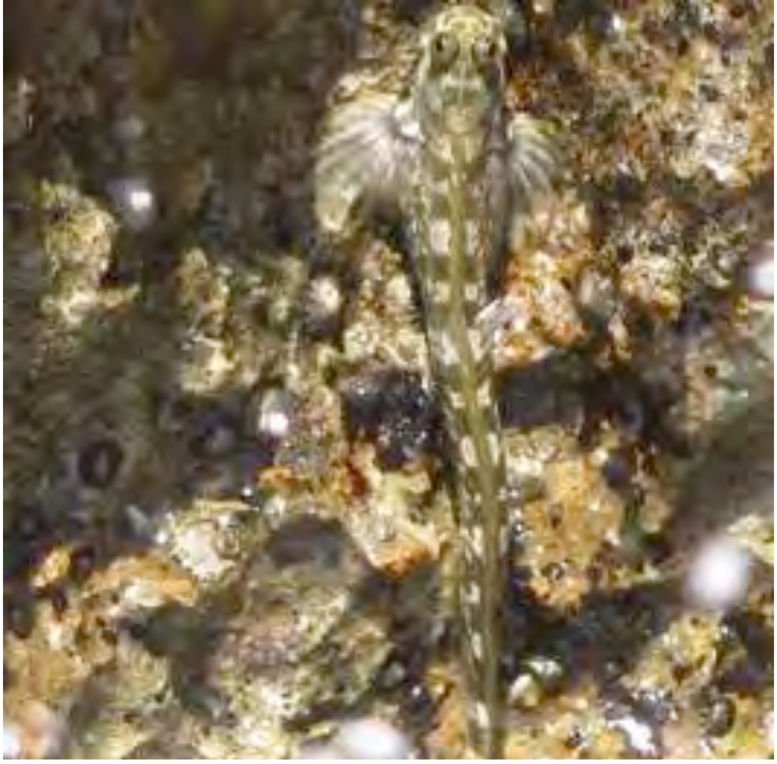
Lake Tuggeranong catchment. A total of 5 tonnes of carp were removed from these two ponds. The work was very messy with deep sediment hampering the removal. Data for the removal will be made available to the National Carp Control Plan and the ponds will be restocked with native fish once the works are complete.

- Changes to the fishing act were implemented in 2017 to bring the ACT size limits for Murray Cod in line with those of NSW and also to reduce the bag limit in the Murrumbidgee River to one fish per day.

- Members of the public and researchers in the Canberra Region can now log fish and crayfish sightings on Canberra Nature Map. The online mapping tool which is run by volunteers, allows members of the public to submit photos of plants, invertebrate, birds, reptiles, fungi and mammals for expert identification and discussion. The verified identifications and locations are available to the ACT Government and Atlas of Living Australia to improve on ground management. The tool has had over 1 million sightings from over 4000 species and has increased the knowledge on the distribution of a number of rare and threatened terrestrial species in the Canberra Region; we hoped it will do the same for aquatic species. For more information please visit: http://canberra.naturemapr.org/.

Australian National University

In 2017, fishes have been as always, a source of fun and amazement for people at the ANU Research School of Biology. Chris Fulton has had the pleasure of finding out why some blennies may forgo life in the water to live on land (Ord et al. 2017, see pic), and has been continuing his collaborative work on habitat as a mediator



Top *An Alticus sp. (Blennidae) nibbling on turfing algae at Rarotonga*
Bottom *Sargassum fields important for fish recruitment*

of fish recruitment at Ningaloo with colleagues based in WA (e.g. Wilson et al. 2017). Having established the importance of soft canopy habitats for reef fishes (van Lier et al. 2017), PhD student Josh van Lier has been finding out some cool stuff about the seascape ecology of *Sargassum* meadows at Ningaloo. Josh has revealed that the position of a *Sargassum* meadows relative to adjacent habitat types (e.g. coral reef) interacts with local habitat structure (e.g. canopy height, substratum complexity) to shape the diversity and relative abundance of fishes occupying the Ningaloo seascape.

We convened a special session on the importance of macroalgae habitats for fish diversity and replenishment at the 10th Indo-Pacific Fish Conference in October, which brought together 11 teams working across the Atlantic, Indian and Pacific Oceans. A unifying outcome of this session was that *Sargassum* meadows facilitate the recruitment of many fish species of ecological and commercial importance around the world, including those typically thought of as "coral reef" fishes during their adult life history phase. Chris and his co-conveners Shaun Wilson (WA DBCA) and Charlotte Berkstrom (Stockholm University) are assembling a meta-analysis on this topic, so if you think you may have data of relevance (i.e. fish and habitat surveys within *Sargassum* meadows), please do get in touch.

References:
Wilson SK, Depczynski M, Holmes TH, Radford B, Tinkler P, Fulton CJ (2017) Climatic conditions and nursery habitat quality provide indicators of reef fish recruitment strength. *Limnology & Oceanography* **62,** 1868-1880.

Ord TJ, Summers TC, Noble MM, Fulton CJ (2017) Ecological release from aquatic predation is associated with the emergence of marine blenny fishes onto land. *American Naturalist* **189,** 570-579.

van Lier JR, Harasti D, Laird R, Noble MM, Fulton CJ (2017) Importance of soft canopy structure for labrid fish communities in estuarine mesohabitats. *Marine Biology* **164,** 45.

2017 Murray-Darling Basin Native Fish Forum

The 2017 Murray-Darling Basin Native Fish Forum was a great success! Over 200 people from across the Murray-Darling Basin came together in Canberra to hear from over 30 presenters about Fish, Flows, Habitat and Heroes.

Keynote talks focused on 'What fish need to thrive', water for the environment, blackwater, basin-scale connectivity and the National Carp Control Plan. Another highlight was the recreational fishers' round table where fishers told the audience about how habitat rehabilitation has enhanced their fishery and how they can help by being involved in decision making processes.
The key messages to come out of the Forum were:

(1) Connectivity across the Basin through addressing fish passage at weirs and other barriers is critical to the recovery of native fish populations
(2) Recreational fishers want to know more about native fish and want to be involved in making decisions that are impacting them
(3) Environmental water is being used in a strategic way to help native fish
(4) Complementary actions such as addressing fishways, cold water pollution, pump screening and riparian rehabilitation will further help native fish recover

Above *Silver Perch from the Murray-Darling Basin*

State Reports

We would like to thank our sponsors (MDBA, NSW DPI Fisheries, VEWH, DELWP, NSW OEH) and all of the attendees, presenters and organisers for making the forum such a great event.

Congratulations to Rod Price (NSW DPI Fisheries) and Kate Scanlon (MDBA) on their excellent coordination of the forum.

Videos of all presentations and new stories and links to native fish info from around the Basin are online at https://www.youtube.com/playlist?list=PLG4856nlXnJ5IadZX3H6zmVYspawT7WlM and https://getinvolved.mdba.gov.au/Nativefishforum2017. Keep the conversations going by using #mdbnativefish and sharing information with others.

New South Wales- NSW

Compiled by Keller Kopf and David Harasti

Australian museum

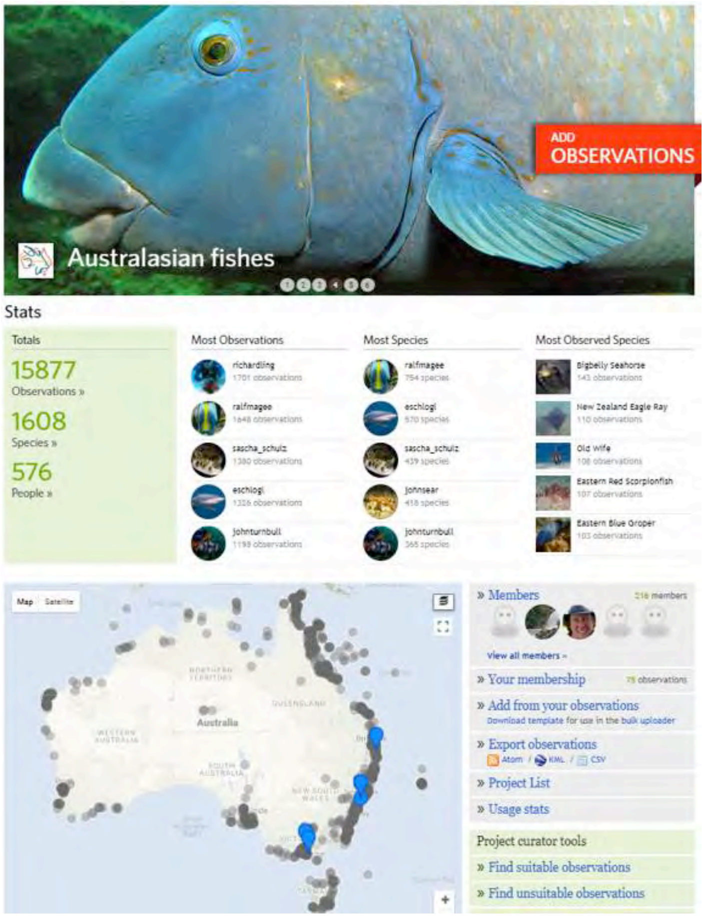
Australasian fishes – a new web resource

By Mark Mcgrouther

mark.mcgrouther@austmus.gov.au

Would you like to have an online expert who will identify your fish sightings/catches? How do you feel about keeping a personal online record of fishes caught over time? What about contributing to knowledge of Australia's fish fauna? All these things are free and available to you right now.

Australasian Fishes is a repository of thousands of observations of Australian and New Zealand fishes, both freshwater and marine, all submitted by professional fish workers and members of the public. The site went online in October 2016 and since then has amassed well over 15000 images of fishes, and it's growing rapidly.



Above *Australasian Fishes homepage*

Some of the terrific features of the site include mapping your sightings/catches and comparing your fish with similar looking species from the same locality. You have unlimited storage space and access to your personal 'life list' that provides a species summary of all your catches. Your images will be identified, often by experts, and each observation can be commented on, sometimes leading to considerable discussion within the community.

I invite you to have a look at the site, and if you like what you see, join the Australasian Fishes community. http://www.inaturalist.org/projects/australasian-fishes. To find out more about the site and watch a how-to video, go to https://www.australianmuseum.net.au/australasian-fishes-project.

Macquarie University

Shark movements and networks, fish welfare/ethics, stress and cognition-Culum Brown fish lab

culumbrown@gmail.com

State Reports

2017 has been another big year for the fish lab at Macquarie University. We have published 13 papers so far on a few key subject areas: Shark movements and networks, fish welfare/ethics, stress and cognition. The largest project in the lab centres on the movement and behaviour of Port Jackson sharks. Nathan Bass and co have shown that PJs in Jervis Bay migrate south to eastern side of Bass Strait. They return year after year to exactly the same rocky reef. While on the breeding reefs they form social groups which are characterised by structured social networks. Social interactions at a meaningful scale can only be detected by sampling acoustic tags at less than 60m diameter. Standard VR2Ws are not sufficient. Jenna Clark developed genetic markers to examine population structure and estimate dispersal. On a similar subject, Johann Mourier and co have shown that learning and redundancy in shark social networks make them more resilient to fishing pressure.

Loiuse Tosetto showed that despite trophic transfer of microplastics up the food chain, there seemed to be little impact on the behaviour of intertidal fish. Continuing with the pollution theme, Navid examined the effect of Prozac on the behaviour of Siamese fighters. Vincent finally published the last paper from his honours showing that stress profiles influences learning in mulloway. Catarina Villa Pouca has been busy writing reviews of fish cognition and Michelle Jerry has been looking at sexual harassment in guppies.

On the animal welfare front, we continue to fight a front-line battle with the fish pain non-believers. An international collaboration, including Lynne Sneddon is emerging on that front. I have recently published a commentary outlining the application of the precautionary principal to animal welfare, particularly fish. This will be a major topic in the next ASFB meeting in Melbourne.

Finally, we have lots of new PhD students: Julianna Kadar working with accelerometers in PJs, Rob Perryman working on social behaviour in Mantas and Joni Pini-Fitzsimons working on provisioning in smooth sting rays. Julianna and Joni won various presentation awards at the last ASFB meeting.

To keep up to date with the current research team be sure to check out our web page (www.thefishlab.com) and follow us on Twitter and Facebook.

Sydney University

Make skates great again!

By Marcelo Reis

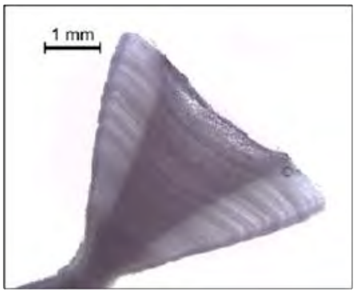
Marcelo Reis is currently in the last year of his PhD in the Coastal and Marine Ecosystems Group – CMEg at Sydney University. He is investigating interactions between fishing operations and Elasmobranch species distribution and identifying spatio-temporal patterns in Elasmobranchs by-catch. One of the project's main concerns is how to address dynamic conservation efforts for threatened species and to understand multi-species reports because catch-aggregated records using generic categories in landings may underestimate changes in community structure and mask reductions in populations.

Moreover, it compiles species with different IUCN Conservation Status in complex individual groups. Simultaneously, with the support of the NSW DPI he's conducting reproductive biology, age, growth and diet study of the Eastern Fiddler Ray (*Trygonorrhina fasciata*) and the Sydney Skate (*Dipturus australis*) at the Sydney Institute of Marine Science – SIMS (Mosman). Both species have uncertain population status and are part of the problem with reports in generic categories landings.

Charles Sturt University

Spotted a mounted cod?

Charles Sturt University, PhD student and ASFB member Matt O'Connell is exploring



Above *Section of a Eastern Fiddler Ray Vertebrae* **Right** *Eastern Fiddler Rays for dissections at Sydney Institute of Marine Science*

the ecological, social and cultural heritage knowledge that can be gained from fish trophies. Matt is compiling information and samples from mounted Murray cod for his PhD project, which has secured a top-up scholarship from the Murray-Darling Basin Authority.

In line with the project's strong community engagement aspect, Matt is collaborating with the Museum of the Riverina, Wagga Wagga and its plans for a Murray cod exhibition in 2020.

Since starting his PhD in early 2017, Matt's initial supervisory team of Drs Paul Humphries, Keller Kopf, Nicole McCasker has been expanded to include Dr Jennifer Bond and Associate Professor Dirk Spennemann.

If you want to help get the word out, contribute to the research or follow the project he's set up a website - codspot.com.au. You can also join the conversation on Facebook - Spotting Murray Cod Mounts, or contact him directly for more information moconnell@csu.edu.au

Carpageddon

The proposed release of koi herpes virus to control common carp in Australia continues to make news around the world. Many scientists and managers suggest great potential benefits to native fish, ecosystems and the economy. In 2018, the government is expected to make a decision about whether or not it will proceed with releasing koi herpes virus to control common carp. Attempts to control and eradicate invasive species have become common, generally with positive outcomes. However, in a paper written by ASFB members Keller Kopf, Lee Baumgartner, Alison King and 10 co-authors

Above *Murray cod mounts – trophies, dusty relics, icons of interest and an environmental indicator from the past. Credit - Museum of the Riverina Collection* from 4 countries published in [Nature Ecology and Evolution](), they highlight the importance of scientific evidence and independent assessment when deciding whether and how to proceed with controlling invasive species across large areas—including the proposed release of koi herpes virus in Australia.

Maggie Watson (Charles Sturt University) and collaborator Marty Asmus (DPI Fisheries NSW) are investigating the physiological stress responses of Murray crayfish by measuring phenoloxidase levels in haemolymph. Phenoloxidase activity and melanisation are part of the invertebrate immune defense against microbial infections, and while well-studied in aquaculture production in prawns and lobsters, has never been considered as a tool for monitoring wild freshwater crustaceans. In addition to this,

Above *Carp; photo by C. Sharpe*

Maggie and collaborator Tommy Leung (University of New England) are examining the costs and benefits of Temnocephala worms to their hosts, freshwater crayfish.

Daniel Svozil, a PhD candidate (supervised by Keller Kopf and Lee Baumgartner) at Charles Sturt University submitted his thesis focused on trait divergence in river and reservoir populations of Australian smelt. Daniel discovered that Australian smelt in reservoirs had different morphological traits and were poorer swimmers with a lower physiological scope than populations inhabiting rivers. His thesis provides some of the first evidence in Australia pointing toward rapid evolution of fish in response to the construction of dams and novel reservoir ecosystems.

NSW Fisheries Research Project Updates

Performance of industry-developed escape gaps in Australian Portunus pelagicus traps

By Matt Broadhurst

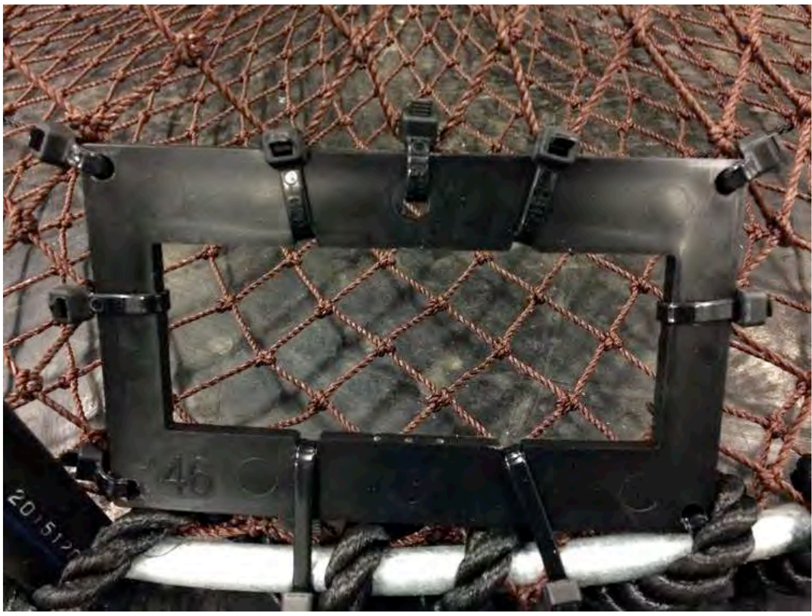
Giant mud and blue swimmer crabs are popular throughout Australia and form the basis of important commercial and recreational fisheries. Until recently in NSW, all fishers mostly targeted both species using large, hand-made wire-meshed (minimum 50-mm square) baited traps. More recently, prefabricated (off-the-shelf) collapsible, netted round traps have become popular. These latter designs comprise smaller mesh (50-mm diamond-shaped) and consequently often retain undersized individuals of both species (<85 and 60 mm carapace-length, respectively) and also small fish—all of which are discarded.

While previous studies suggest that most trapped and released small crabs and fish survive, in an attempt to minimise unwanted catches, Wallis Lake commercial fishers have voluntarily tested various designs of so-called 'escape gaps'. Some of these escape-gap designs reportedly have been effective, but there are few formal data supporting their performances. This study aimed to obtain this information for traps when targeting blue swimmer crabs.

The work was done with three Wallis Lake fishers over three consecutive weeks in May 2016. Conventional round traps without any escape gaps (termed 'controls') were fished against others (during 17–72 h soaks) that had one of five escape-gap designs, and with combinations of one, two or three per trap.

Compared to controls, all traps with escape gaps maintained catches of legal-sized blue swimmer crabs, but caught 51–100% fewer undersized individuals and up to 50% less unwanted fish. Generally, rectangular escape gaps, and especially multiple configurations, were the most effective.

Further work needs to be done to promote using escape gaps among both recreational and commercial trappers targeting blue swimmer crabs, and also to identify an optimal configuration for giant mud crabs. As part of this work, ideally, an interchangeable escape-gap might be developed for use when targeting either species.



Top *Installed escape gap in a crab trap*
Bottom *Mud crab*

Utility of multiple escape gaps in Australian Scylla serrata traps
By Matt Broadhurst

Mud and blue swimmer crabs are economically important estuarine species throughout NSW. Most of these crabs are caught in baited traps and especially collapsible netted round designs (with 50–60 mm stretched mesh opening).

None of the traps used to target crabs only catch the minimum legal sizes (currently 85 and 60 mm carapace length for mud and blue swimmer crabs), which means large numbers of undersized individuals are released. The aim of this study was to assess the effects of single and multiple escape gaps (46 × 120 mm) on catches of traps when targeting mud crabs. During summer 2016/17, twenty-five collapsible netted round traps comprising four replicates of those with zero (control), one, two, three or four escape gaps positioned at the base were fished over several weeks in the Coolongolook and Clarence rivers by three commercial fishers.

Compared to the control (in which 46% of mud crabs were undersized), and irrespective of the river, all traps with escape gaps similarly maintained catches of legal-sized mud crabs while reducing undersize numbers by 85–93%. This result implied no benefit of multiple escape gaps for excluding undersized mud crabs (one escape gap worked as well as four). In the Coolongolook River, 21% of the crab catches included blue swimmer crabs (mostly legal sized)—large numbers (73 to 96%) of which escaped, and (unlike mud crabs) more from traps with multiple escape gaps.

The results further support the utility of escape gaps in NSW crab traps, but there is one important consideration. Because of the size difference between mud and blue swimmer crabs, no single size of escape gap will be suitable for both species. A 46-mm high gap is required for mud crabs (≥85 mm CL), vs a 33-mm high gap for blue swimmer crabs (≥60 mm CL).

To address this issue, it might be possible to regulate the size of the escape gap based on the estuary being fished and the key species encountered. Alternatively, commercial and recreational fishers might be encouraged to always use a 33 mm gap (any mud crabs <62 mm CL will also escape) and simply substitute for the larger escape gap when targeting mud crabs. As part of the research, escape gaps of different sizes have been designed to fit over each other to facilitate easy exchange. These escape gaps have been distributed among commercial fishers for further testing.

Small threatened fish

By Luke Pearce

Funding provided by Murray Local Land Services has allowed DPI Fisheries to team up with Charles Sturt University (led by Lee Baumgartner) in a project targeted at determining the current population status and distribution of three key threatened species in the Murray Catchment and develop management plans to maintain and hopefully increase the abundance and distribution of these species.

The project is focusing on Southern pygmy perch, Flat-headed galaxias and Macquarie perch, within the mid and upper Murray catchment.

Surveys, habitat mapping and research into the last known remaining Macquarie

Above *Southern pygmy perch*

perch population in the Murray catchment, Mannus Creek are being undertaken. There has been grave fears for this population due to massive floods that occurred during 2010 causing the failure of a large dam on the system. This failure combined with greater than 1:100 year flood event caused catastrophic damage to the system, including many fish standings. Initial surveys have revealed very exciting results with the first records of Macquaire Perch in the system since 2009 including large numbers of juveniles, indicating successful spawning and recruitment in 2016.

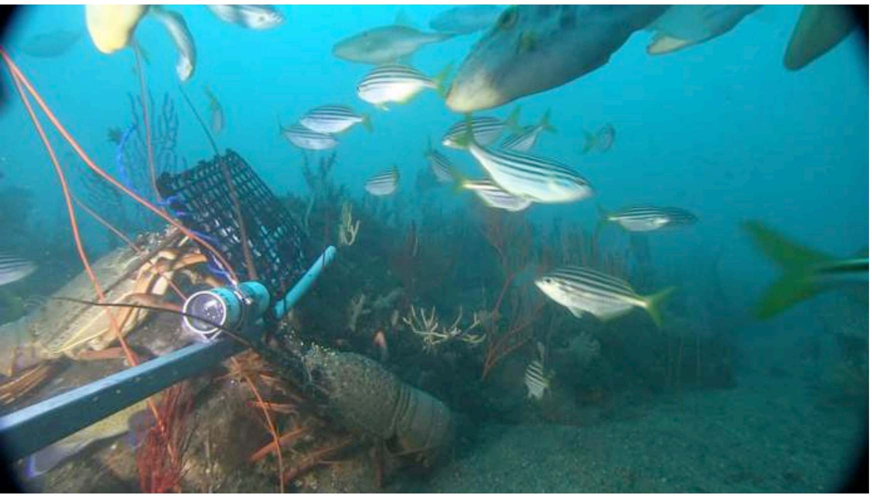
Flatheaded galaxias have not been recorded in NSW since 2010, this project will undertake targeted surveys in historical locations and other places where this species is likely to occur in an attempt to see if they still persist within NSW, the first step in better managing this species is to identify if and where they still occur.

Finally the project will also focus on Southern pygmy perch; again, targeted surveys for this species will occur in historical locations in an attempt to determine if it still persists in these locations, along with surveys in locations where potential reintroduction may occur in the future. In addition to this, detailed habitat mapping and population surveys will be undertaken on the Coppabella Creek population to provide input into the development of a targeted management plan for that system.

Taking a deeper look: quantifying the differences in fish assemblages between shallow and mesophotic temperate rocky reefs

By Joel Williams, Alan Jordan and David Harasti (NSW DPI), Tim Ingleton and Peter Davies (NSW OEH), Neville Barrett (University of Tasmania)

In 2016, with the support of the National Environmental Science Programme, Marine Biodiversity Hub, we established a project investigating rocky reef habitat in the Hunter Commonwealth Marine Park. To date, much of the focus of ecological fish research has been based on reefs in less than 40 m. Therefore, it is important that we attempt to understand the ecological role of mesophotic reefs. In this study we deployed baited remote underwater stereo video systems (stereo-BRUVS) on temperate reefs in two depth categories: shallow (20-40m) and mesophotic (80-120m). Shallow reef sites were located within the Port



Left and Above *Stills from BRUVs footage at mesophotic reef habitats in NSW*

Stephens-Great Lakes Marine Park while the mesophotic reefs sites were located within the Hunter Commonwealth Marine Park.

Sites were selected using data collected by multi-beam echo sounder (MBES) to ensure stereo-BRUVS were deployed on reef. MBES also provided rugosity, slope and relief data for each stereo-BRUVS deployment. The aims of this study were to 1) quantify the similarities/dissimilarities in the fish assemblages between shallow and mesophotic reefs, 2) model the effects of environmental conditions and habitat structure on the spatial distribution of fishery targeted species, and 3) provide baseline data for the Hunter Commonwealth Marine Park.

Multivariate analysis indicated that there are significant differences in the fish assemblages between shallow and mesophotic reefs, primary driven by *Ophthalmolepis lineolatus* and *Notolabrus gymnogenis* only occurring on shallow reefs and schooling species of fish that were unique to each depth category; *Atypichthys strigatus* on shallow reefs and *Centroberyx affinis* on mesophotic reefs. While shallow reefs had a greater species richness and abundance of fish when compared to mesophotic reefs, mesophotic reefs hosted the same species richness of fishery targeted species. *Chrysophrys auratus* and *Nemodactylus douglassii* are two highly targeted species in this region. While *C. auratus* was numerically more abundant on shallow reefs, mesophotic reefs provided habitat for larger fish. In comparison, *N. douglassii* were evenly distributed across all sites sampled. Generalized linear models revealed that depth and habitat type provided the most parsimonious model for predicting the distribution of *C. auratus*, while habitat type alone best predicted the distribution of *N. douglassii*. These results demonstrate the importance of mesophotic reefs to fishery targeted species and therefore have implications for informing the management of these fishery resources on shelf rocky reefs.

The next stage of this study is to incorporate a temporal component by sampling in both autumn and spring over a two year period. We also intend to expand the sampling programme by using MBES to extend the area of mapped rocky reef and enable greater spatial coverage of BRUV deployments in the Hunter Commonwealth Marine Park. In 2018, we will also be testing the use of ROV and AUV to passively sample the fish assemblages and to quantify and map the habitat of these mesophotic reefs. The images obtained from the BRUVs so far have revealed spectacular areas of extensive octocorals and sponge habitats on these mesophotic reefs. Stay tuned! For more information please contact Joel at joel.williams@dpi.nsw.gov.au or follow him on twitter at @joelfishecology.

Knot tying behaviour in Moral Eels

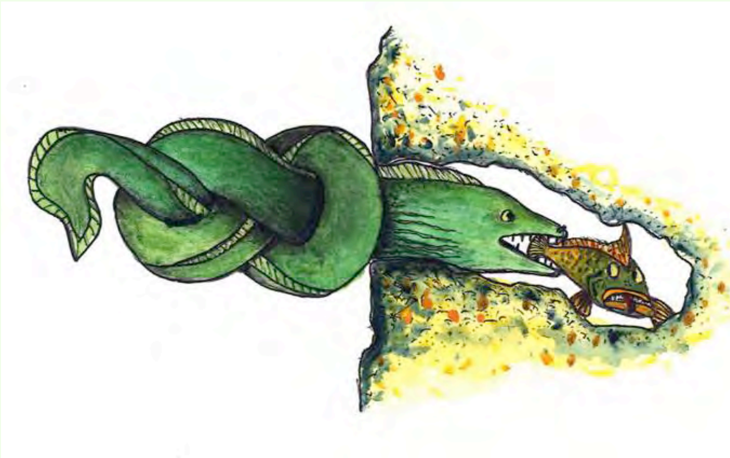
By Hamish Malcolm

People are not the only tyers and users of knots. A variety of elongated cylindrical-shaped animals with backbones also tie knots. In particular, moray eels are knot tyers. At least 11 types of moray eels are known to tie knots including overhand knots, double overhand knots and figure-of-eight knots. The working end is their tail, which ties the knot, with the standing end being their head. Moray eels are successful predators and scavengers in narrow spaces in reef such as cracks and holes. This success can be attributed to the combination of a long narrow body, slimy skin, a raptorial second jaw, ability to rotate, and knot tying.

Green morays (*Gymnothorax prasinus*), the ultimate contortionists, have now been observed tying at least five types of stopper knot. This includes two new recently described knots, which are variations on the figure-of-eight and banana knots. These are now called the 'moray knot' and the 'moray banana knot'. These two knots have only been observed a few times in green morays so they are not commonly used, unlike overhand knots. Green morays use overhand knots the most and some moray species only tie this knot. When needing a more robust knot with greater leverage, green morays tie figure-of-eight knots more commonly than double overhand knots. This is probably because this knot is wider, yet with fewer crossings making it easier for the eel to move the knot up its' body, while generating greater leverage. People are definitely the masters of knots, but we are by no means the only knot tyers.

Nature still has many secrets to share and there may be other knots used by animals and plants.

For further information refer to the published study: Malcolm, H. (2016) A moray's many knots: knot tying behaviour around bait in two species of *Gymnothorax* moray eel. Environmental Biology of Fishes: 99: 939–947.



"Oh No, it's a figure-of-8 knot not an overhand knot…". Illustration Hamish Malcolm"

State Reports

New Zealand- NZ

Compiled by Matt Jarvis

University of Otago

Gerry Closs' lab at Otago is working on a diverse range of topics within fish ecology, from salmonid migration and larval galaxiid ecology to estuarine and wetland fish assemblages. While in Tahiti at the 10th Indo Pacific Fish Conference in October, Gerry presented a (successful) bid for the next Indo-Pacific Fish Conference, which will be held in Auckland in 2021. The conference will be joint with the Australian Society for Fish Biology, so mark your calendars. As for the ASFB members within the Otago research group, PhD student Pavel Mikheev is partway through his PhD examining the causes and consequences of migration in Brown Trout in New Zealand streams. Fasil Wolebu is also partway through his PhD, which concerns the seasonal and spatial dynamics of estuarine fish assemblages in both permanently open and intermittently closed estuaries. Matt Jarvis has continued to work as an assistant research fellow in the group, working mostly on projects relating to the early life-history of diadromous fishes.

Above *Alpine galaxias and upland bully at NZ inland fieldsites*
Right *Galaxias 'whitebait'*

Northern Territory-NT

Compiled by Alison King and Grant Johnson

It's exciting times for Charles Darwin University and NT Government fisho's with lots of great projects and collaborations underway. Here are some recent highlights:

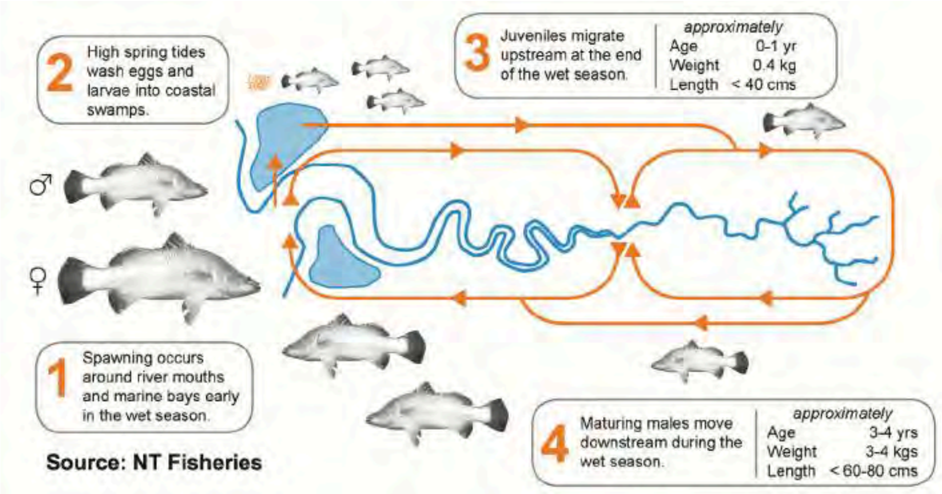
(1) A large team of CDU and NT Fisheries freshwater researchers (Alison King, Dion Wedd, Osmar Luiz, David Crook (CDU) and Thor Saunders, Quentin Allsop (NT Fisheries)) have been extremely busy collecting fish from across the Top End, as part of an ARC Linkage project assessing the resilience of freshwater fishes to potential environmental change. Sampling has included four 1-month long campaigns collecting adult fish from 15 different rivers. Now with all the fish in the freezer, many months of dissections and trait analysis begins! This project is a collaboration between researchers at CDU, NT Fisheries,

Griffith University (Mark Kennard), University of Western Australia (Michael Douglas) and University of Washington (Julian Olden).

(2) Krystle Keller and Brendan Adair (CDU) spent a 10-day stretch in October radio-tracking the fine scale movements and habitat use of sooty grunter *Hephaestus fuliginosus* in the Katherine River. It was over 40 degrees every day and very humid, so they came back pretty exhausted. With data now in hand, work will start on analysing and writing up this work. The research was conducted in collaboration with staff from the Department of Environment and Natural Resources (DENR) under the NESP Northern Australia Environmental Resources Hub project "Environmental water needs for the Daly River". For further information: http://www.nespnorthern.edu.au/projects/nesp/environmental-water-needs-daly-river/

(3) Dave Crook, Brendan Adair (CDU), Peter Dostine, James Wyatt (DENR) and Chris Errity (NT Fisheries) recently travelled to the Roper River to collect and tag barramundi as part of a long-term study of their movements in relation to river hydrology. So far, the team has tagged more than 150 barramundi across a range of size classes with acoustic transmitters. The results so far have been very interesting, with lots of individual variation in behaviour. There is still much to learn about this iconic species. The project is jointly supported via contributions from CDU, DENR, NT Fisheries and the Yugul Mangi Indigenous ranger group.

For more information: https://denr.nt.gov.au/__data/assets/pdf_file/0006/382434/Tracking-barramundi-in-the-Roper-River.pdf



Top *Diagram showing migration patterns of Barramundi in the Roper River*
Bottom *Sampling with Yugul Mangi rangers*

(4) On the CDU post-graduate student front, Sharon Every (shark trophic ecology) recently received examiners reports for her PhD thesis and is working up her final corrections. Kate Buckley (sawfish conservation) is working on her write-up and has recently had the first paper from her PhD research accepted (https://link.springer.com/article/10.1007/s11160-017-9501-2). Kyle Tyler (riverine fish reproduction and recruitment), Brien Baker (underwater video fish survey methods) and Brien Roberts (barramundi otolith chemistry and bio-chronology) have all recently completed their confirmation seminars and are busily working on data collection and analysis.

(5) NT Fisheries continues to be involved in a number of monitoring projects, and is into its second year of monitoring Golden Snapper and Black Jewfish in the Reef Fish Protection Areas (RFPA) using baited remote underwater videos (BRUV). Working in waters with poor visibility and large tidal movement isn't without its challenges when using BRUV techniques, but these are being overcome by project leader, Shane Penny. The forthcoming years will bring the introduction of split-beam acoustic surveys to compliment the BRUV work.

(6) Working with indigenous communities to develop viable aquaculture projects is one of the core activities of the Darwin Aquaculture centre. Research scientist and PhD candidate Samantha Nowland (University of Sunshine Coast) has been working with the communities on South Goulburn and Melville Islands to establish small scale aquaculture of tropical rock oysters. Samantha recently won an FRDC sponsored award for best student oral presentation which outlined an Indigenous economic development project in the Northern Territory focusing on the native Black-lip Oyster, at the recent Australian Marine Sciences Association (AMSA) Darwin conference. Additionally Samantha has recently published the paper "Elucidation of fine-scale genetic structure of Sandfish (*Holothuria scabra*) populations in Papua New Guinea and Northern Australia." A full-text link can be found at: http://www.publish.csiro.au/MF/MF16223

(7) Also recently published by CDU and Darwin Aquaculture Centre researchers was the paper "Cadmium uptake and zinc-cadmium antagonism in Australian tropical rock oysters: Potential solutions for oyster aquaculture enterprises", led by Niels C. Munskgaard. A full-text link can be found at: http://www.sciencedirect.com/science/article/pii/S0025326X17307671

State Reports

Queensland-QLD

Compiled by Geoffrey Collins and Leanne Currey

James Cook University

How tolerant are barra of hypoxia?

By Geoffrey Collins

I recently completed my PhD at James Cook University, which was a joint collaboration between JCU and the Australian Institute of Marine Science (AIMS), and focussed specifically on physiological (metabolic and haematological) responses of barramundi to environmental challenges, namely hypoxia and increased temperature. The main findings of my thesis were:

- Barramundi retain a high capacity to regulate metabolism in hypoxic environments at high temperatures
- Barramundi demonstrate improvement in hypoxia tolerance following prior exposure
- Intra-specific variability in hypoxia tolerance within populations is substantial

I am currently employed as a post-doctoral research fellow with MBD Energy based in Ayr, North Queensland. Through this position I spend a large amount of time in the lower Burdekin, which is one of the largest flood-irrigated regions in tropical Australia and contains extensive freshwater fish habitat.

Juvenile barramundi

ASFB member and PhD Candidate Quyen Banh has been investigating the mechanisms underlying sex differentiation in juvenile barramundi.

Quyen recently published a paper in the journal Aquaculture, which focusses on morphological variations during juvenile development and changes to gene expression.

The full text for this paper can be found here.

Above *Geoffrey Collins holds a barramundi he caught in a river just south of Innisfail, Qld*

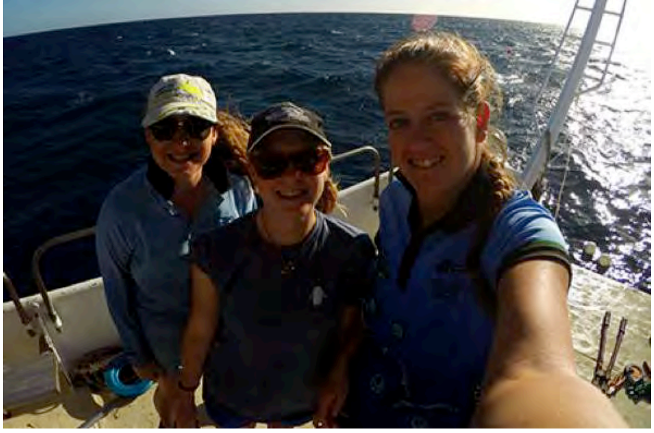
Reef shark movement patterns

The pursuit of understanding reef shark movement and site-specific behaviour is ongoing for Stacy Bierwagen's PhD at JCU (AIMS@JCU Scholarship). As a student under the Global FinPrint Project (funded by the Paul G Allen Foundation), Stacy has had an opportunity to use a combination of methodologies to better understand space use of these animals. From 2015-2017, six sampling trips were conducted at mid-shelf and offshore Townsville Reef sites. Using a combination of Baited Remote Underwater Video Systems (BRUVS), Underwater Visual Census (UVC), Diver Operated Stereo Video System (s-DOV), and acoustic telemetry, Stacy is working to characterize benthic and fish assemblages at sites within the home range of highly resident grey reef sharks.

By comparing movements with other reef predators, classifying abundance of potential prey groups, and incorporating environmental factors (such as currents),

drivers of movement and inter/intra-specific relationships can be determined. Traditional angling methods were also employed to research recapture rates and to collect blood and tissue samples of reef predators to compare diet profiles. All field components for data collection are now complete.
Stacy received a GBRMPA Science for Management award in 2017 and is heading to Hobart at the end of October to work with Heidi Pethybridge at CSIRO to receive training and perform fatty acid analysis of her samples to infer predator-prey interactions at the reef scale.

She plans to present her main thesis findings at ASFB and Sharks International in 2018. Stacy has finished her tenure as a student executive, but still sits on the Education Committee for ASFB and is committed to developing opportunities for students to communicate their science such as the SCiSC competition. For more information about her project feel free to visit https://globalfinprint.org/about/team/dr-michelle-heupel/stacy-bierwagen/, or email at stacy.bierwagen@my.jcu.edu.au



Top *Brooke D'Alberto, Michaela Farnham, and Stacy Bierwagen in the field*
Centre *Counting fish and collecting DOV footage*
Bottom *Collecting a blood sample from a grey reef shark*

Australian Institute of Marine Science

By Leanne Currey

AIMS has continued its research exploring fish communities and biodiversity patterns of teleosts and sharks using Baited Remote Underwater Video Systems (BRUVS). Research has focused on iconic reefs in WA, monitoring shoal communities for oil and gas industry projects, and reef sharks in the Pacific. BRUVS sampling forms part of many projects based in WA to monitor fish communities through time.

We are developing a greater understanding of species comprising coral reef, oceanic shoals, and coastal islands in the North West of Australia. The AIMS Townsville and Perth crews work together to collect fish data from BRUVS, benthic data from tow video and generate maps of unchartered locations using multi beam sonar. This information assists Industry partners in understanding baseline and post-work effects on fish and benthic communities. With many more projects and collaboration in an Australian BRUVS Synthesis on the horizon, stay tuned for more research from this team in 2018!

Above *Stereo BRUVS and tow-video ready for use on the AIMS vessel, RV Solander*

Global FinPrint Project

As part of the Global Fin Project (www.globalfinprint.org), AIMS Townsville has collected BRUVS footage from a number of exotic locations. To date, over 1800 lightweight BRUVS have been deployed to gain valuable data on shark and ray species richness and relative abundance.

This year we have ventured to the remote Kiritimati Island in the republic of Kiribati, which is located close to the equator and date line, and is the first island to celebrate the New Year each year. Together with a volunteer I worked with the Fisheries Division to identify the shark and ray species that occur in their waters, since no shark specific research has focused there in the past. Initial sampling of remote sites indicated greater numbers of large piscivorous teleosts and sharks compared to sites nearby the most populated villages.

On a trip to Samoa with colleague Audrey Schlaff, we provided training and worked with collaborators from the Secretariat of Pacific Regional Environmental Programme (SPREP), Ministry of Natural Resources and Environment and Fisheries. The aim was not only to collect data for the FinPrint Project, but to provide training in BRUVS procedures, baseline information, and to assist in monitoring areas over time to determine the efficacy of protected areas. Data will contribute directly to the SPREP Regional Shark Action Plan and management of elasmobranchs in the country, with the ability to continue BRUVS sampling into the future.

Top *Species diversity at Kiritimati Island, whitetip reef shark and grey reef shark*
Bottom *Leanne Currey providing training in BRUVS for SPREP, MNRE and Samoan Fisheries*

Above *Glenore Weir Cone Fishway (high flow) located in the Southern Gulf of Carpentaria*

Audrey has continued FinPrint sampling in the North West Hawaiian Islands on a NOAA ship, and data from this trip combined with the footage from other locations, are being analysed by a dedicated team of volunteers based at James Cook University.

The JCU and AIMS FinPrint Teams work together to provide the species identification and count data to the Global FinPrint database, which will be used to compare shark and ray richness and abundance among reefs worldwide, to provide information that contributes to management.

Australasian Fish Passage Services

Another Cone Fishway Success in North Queensland

By Tim Marsden

The Glenore Weir cone fishway located on the Norman River in the Gulf of Carpentaria Queensland, Australia, has passed its first flows during the 2016/17 wet season. The fishway is passing thousands of fish upstream and opening up the freshwater reaches of the Norman River to a wide variety of fish species for the first time.

The fishway was completed as part of the raising of the existing Glenore Weir, which did not have any fish passage facilities and blocked the migration of fish. Designed to pass tropical species of all sizes from juvenile perchlets (10 mm) to sub-adult sawfish (2.0 m), the fishway operates over a wide range of flows. From the first flow in the river, which is guided down the fishway, up until down out of the weir, the fishway maintains ideal migration conditions.

Top to Bottom *Traps set at the top of the fishway during low flows; Juvenile and small fish recorded using the fishway; Barramundi captured moving upstream; Adult and juveniles of an undescribed catfish species ascending the fishway; Freshwater Whip Ray ascending the fishway*

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During February to April 2017 AFPS staff have been monitoring the fishway to determine its success at passing fish upstream. The team has been trapping the fishway and sampling fish communities immediately below the weir to determine if the fishway was achieving its design goals.
The fishway has passed with flying colours, with records of a wide range of fish species using the fishway, including fishes as small as 10 mm, iconic recreational fishing targets such as barramundi, and other non-commercial species such as giant perchlet, bony bream, fork-tailed catfish and long tom.

The fishway has also revealed some interesting finds, with an undescribed species of eel-tail catfish recorded migrating through the fishway. This is only the second sighting of this species in Australia and adds vital information about the species' biology, as both adults and juveniles were recorded migrating. Other unusual fish species were also recorded, with freshwater whip-ray's seen moving through a fishway for the first time. Other aquatic animals including crocodile, file snakes and cherabin were also recorded using the fishway. Unfortunately, no sawfish, for which the fishway was specifically designed, were recorded during sampling. However, local fishermen have seen the species downstream of the weir so we hope there are future records of this species using the fishway.

The team is very proud that the fishway we designed is enhancing access to upstream habitats in the Norman River. It is a fantastic addition to the many other fishways we have designed and installed in the gulf region to date.

We thank the Carpentaria Shire Council for their ongoing commitment to maintaining free access for fish and look forward to working with them on some of the other barriers in the region in the future. For contact information please refer to: https://www.linkedin.com/pulse/glenore-weir-fishway-assessed-tim-marsden

Griffith University

Australian Rivers Institute

Mischa Turschwell has completed and been awarded his PhD with the Australian Rivers Institute at Griffith University (Supervisors Harry Balcombe, Erin Peterson and Fran Sheldon). His research had a strong quantitative focus and investigated the thermal and habitat characteristics of the northern river blackfish *Gadopsis marmoratus* in the Condamine River, QLD.

Above *Mischa collecting a temperature logger from one of his degraded sites in the Condamine*

He has since started a post-doc with Ben Stewart-Koster, and is exploring fish flow-ecology relationships in several locations across Northern Australia. Harry Balcombe (and Kate Hodges, Qld Gov) have been dragging nets around the lower Balonne River (hoping to find some elusive larvae), which has not been helped by a serious drought. This work seeks to understand temporal trends in spawning and recruitment of

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key fish species in relation to potential prey diversity and abundance. This study is part of the Environmental Water Knowledge and Research (EWKR) Project funded by the Australian Government.

Right *Mariel shows off her shark teeth* **Centre** *Johan explains all things shark* **Bottom right** *Mariel and Johan with Dr. Karl*

Sharks, at Splendour in the Grass

By Johan Gustafson, PhD candidate

2017 was the year sharks made their first appearance at the Splendour in the Grass music festival in Byron Bay! Thanks to Inspiring Australia and Future Crunch, who set up and organised this opportunity for around 40 leading Australian research scientists and science communicators to share their knowledge and passion for science with the Splendour crowds.

Presenters gave inspirational talks about science and their research, from viruses, frogs, eating bugs, solar energy to (the best talk) sharks! Johan Gustafson and Mariel Familiar Lopez, from Griffith University on the Gold Coast, hosted a presentation aimed at providing the public with basic knowledge on shark biology from sensory system to how research is undertaken. They were also able to present Johan's research on hammerhead sharks in southeast Queensland.

The presentation was dynamic, making use of multiple display specimens that the crowd could interact with, including shark jaws, shark eggs, fins and even shark skin.

It was surprising to see how little the public knows about sharks in general, and the use of props was an excellent tool in explaining shark teeth and the function of the skin denticles. The presentation was well received by Splendour assistants whose curiosity about sharks was denoted by the quality and quantity of questions.

The Science tent at Splendour gave the opportunity for people to connect with science in new ways through fun, dynamic presentations, musical performances and interactive experiences. Special guests included Dr Karl and the leader of the federal Australian Greens Party, Richard Di Natale.

South Australia – SA

Compiled by Gretchen Grammer

New research out this year by SA ASFB members

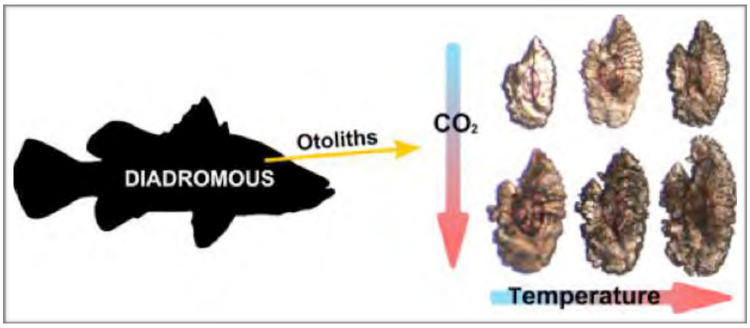
Elevated carbon dioxide and temperature affects otolith development, but not chemistry, in a diadromous fish
Elevated carbon dioxide (CO_2) threatens marine ecosystems and organisms. There are recorded disruptions of calcification processes, internal acid-base balance, behaviour and sensory systems. Our study investigated the effects of predicted CO_2 levels, alongside increasing temperatures, on fish ear bone (otoliths) development in a diadromous fish. We examined otolith size, shape and chemistry, with the latter aimed at developing a chemical tracer of environmental pCO_2. At elevated pCO_2 levels we found significant effects to otolith perimeter and contour, with otolith becoming more irregular and jagged. There was no affect to chemistry, suggesting elements tested are unsuitable tracers of pCO_2.
Otoliths are an important sensory organ and developmental disruptions may have long-term impacts to fish functionality and survivability. This study highlights the need to investigate species-specific effects of elevated CO_2 combined with relevant stressors, such as temperature, to understand full ecological implications.

Jasmin Martino, Zoë A. Doubleday, Skye H. Woodcock, Bronwyn M. Gillanders. 2017. Elevated carbon dioxide and temperature affects otolith development, but not chemistry, in a diadromous fish. Journal of Experimental Marine Biology and Ecology 495: 57-64. DOI: 10.1016/j.jembe.2017.06.003.

Full text available at: http://www.sciencedirect.com/science/article/pii/S0022098117303337

The other side of scientific writing: increasing reader engagement and readership

Publications are the universal currency for communication among scientists. But they are generally composed of dense, uninspiring language that can be laborious to wade through and difficult to understand.



Above *Diagram from Martino et al. showing the effects of CO_2 and temperature on otoliths*

While objectivity and scholarship are cornerstones of scientific writing, there is another ingredient that is rarely emphasised or taught: the accessibility of the prose, the X-factor that captures the reader's imagination with clear and engaging messages.

ASFB member Zoe Doubleday wrote about this in her latest paper in Trends in Ecology and Evolution, Full text is available at: http://www.cell.com/trends/ecology-evolution/fulltext/S0169-5347(17)30159-3, with her story summed up in The Conversation https://theconversation.com/bored-reading-science-lets-change-how-scientists-write-81688

Eight habitats, 38 threats and 55 experts: Assessing ecological risk in a multi-use marine region
Assessing ecological risk when you have lots of threats, lots of things to be threatened and little quantitative data…

Zoe A. Doubleday, Alice R. Jones, Marty R. Deveney, Tim M. Ward, Bronwyn M. Gillanders. 2017. Eight habitats, 38 threats and 55 experts: Assessing ecological risk in a multi-use marine region. PLoS One 12(5): e0177393. DOI: 10.1371/journal.pone.0177393.

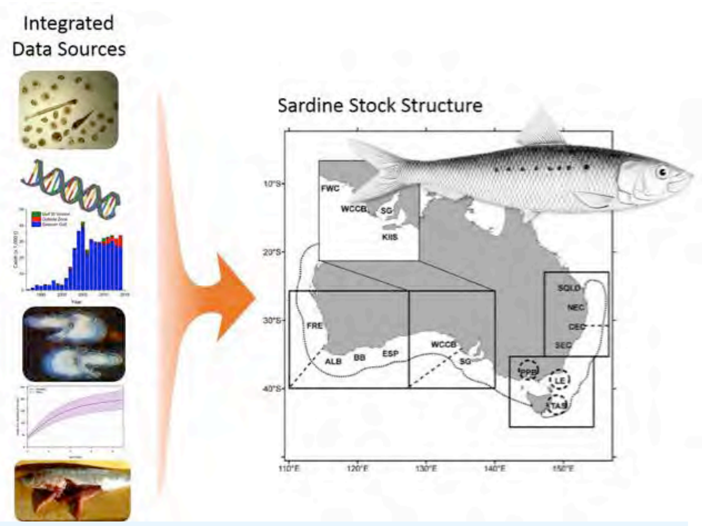
Integrated approach to determining stock structure: implications for fisheries management of sardine, *Sardinops sagax*, in Australian waters
The stock structure of small pelagic fishes is difficult to determine due to their patchy distribution and complex movement patterns. We integrate genetic, morphological, otolith, growth, reproductive and fishery data collected over 60 years using a Stock Differentiation Index (SDI).
The absence of strong separation of most adjacent sub-groups supports the hypothesis that sardine (*Sardinops sagax*) in Australian waters is a meta-population, but with effective isolation of at least four stocks. There is also evidence for sub-division within stocks.

We examine age-related and inter-annual patterns of stock structure off South Australia and the east coast through integrated analysis of otolith chemistry and shape data. Integrating historical data using a SDI is suitable for identifying fishery management units.

Integrated analysis of otoliths from archival collections is useful for examining temporal variability in stock structure, which is also important for fisheries management.

Our findings are relevant to fisheries where sustainability risks are increased by management arrangements based on assumptions that stock structure is absent or stable.

Christopher Izzo, Tim M. Ward, Alex R. Ivey, Iain M. Suthers, John Stewart, Stuart C. Sexton, Bronwyn M. Gillanders. 2017. Integrated approach to determining stock structure: implications for fisheries management of sardine, *Sardinops sagax*, in Australian waters. Reviews in Fish Biology and Fisheries 27: 267–284.



Above *Example of an integrated approach to determining stock structure*

Inferring absolute recruitment and legal size population numbers of southern rock lobster (*Jasus edwardsii*) in South Australia's Southern Zone fishery using extended forms of depletion modelling

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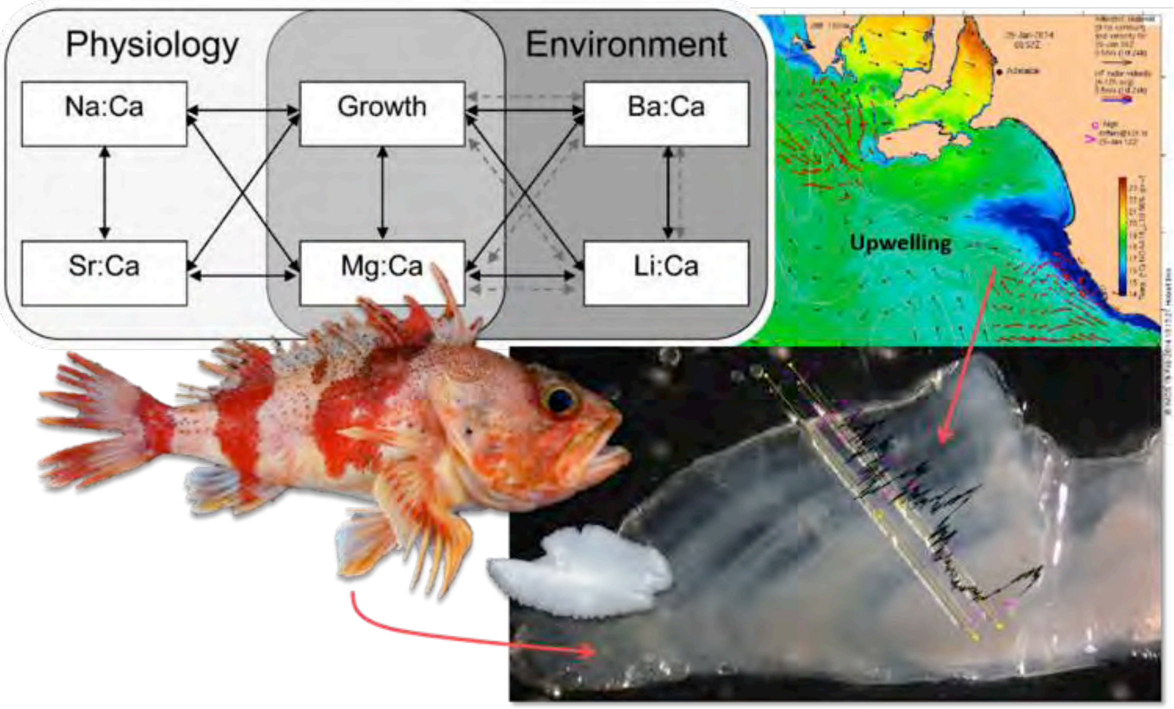


Above *Diagram showing how otoliths in ocean perch were used to extract growth and chemical chronologies, and track ocean changes through time.*

We present a couple of new extensions of the Leslie-DeLury depletion model that allows estimation of yearly total recruitment numbers as well as exploitable population, with results shown from applying this to the South Australian southern rock lobster fishery. It requires total fishery catch over a fishing season, a catch rate index for only part of the season during which no recruitment and constant catchability is assumed, and it hence does not need data on total fishing effort nor assumptions on catchability for the whole fishing season.

John Feenstra, André E. Punt, and Richard McGarvey. 2017. Inferring absolute recruitment and legal size population numbers of southern rock lobster (*Jasus edwardsii*) in South Australia's Southern Zone fishery using extended forms of depletion modelling. Fisheries Research 191: 164-178.

Tracking ocean change with fish ear bones: do's and don'ts

Changes in the environment are imprinted on the hard parts (e.g. ear bones (otoliths), teeth, feathers, toenails) of many animals. To use an animal's hard part as an environmental recorder, we work out the amount of control the animal's body (physiology) has on what it takes up from the environment, and if this changes as the animal ages (yes, it usually does). In our study, we used the ear bones of ocean perch, a deep-water fish from southern Australia, to learn more about how chemical elements are taken up from the environment and how we can best use the ear bones as environmental recorders.

The ocean perch live in a dynamic ocean region called an upwelling area, where deep water comes to the ocean's surface in the summer. This causes a change in the water's chemistry that can also be seen in the fishes' ear bones.
We blasted the ear bones with a laser (from centre to the edge) attached to a mass spectrometer to measure the different elements in the growth rings (think tree rings on a cross-section of a log).

We then used advanced statistical modeling to tie together measurements of the fishes' growth and the chemical elements, tease apart the influence of physiology, and extract our growth and chemical chronologies (17 years worth!). Some chemical elements were highly influenced by physiology (sodium and strontium) and some barely at all (barium and lithium). We could see the summer upwelling signal in the ocean perches' ear bones and fluctuations over the last 17 years. If you are someone interested in creating your own biochronologies from the hard parts of animals, especially fish ear bones, we provide detailed instructions on how to do it in our paper.

Gretchen L. Grammer, John R. Morrongiello, Christopher Izzo, Peter J. Hawthorne, John F. Middleton, and Bronwyn M. Gillanders. 2017. Coupling biogeochemical tracers with fish growth reveals physiological and environmental controls on otolith chemistry. Ecological Monographs 87(3): 487–507.

Awards and Recognitions

** **Bronwyn Gillanders** (University of Adelaide) was a finalist for the South Australian Scientist of the Year Award

** **Zoe Doubleday** (University of Adelaide) was a recipient of a 2017 South Australia Tall Poppy Award

** **Gretchen Grammer** (SARDI Aquatic Sciences), **Crystal Beckman** (SARDI Aquatic Sciences), **Emma Westlake** (SARDI Aquatic Sciences), and **Bronwyn Gillanders** (University of Adelaide) were featured by the Women's Industry Network Seafood Community (WINSC) during their International Women's Day 2017 initiative: http://winsc.org.au/international-womens-day/

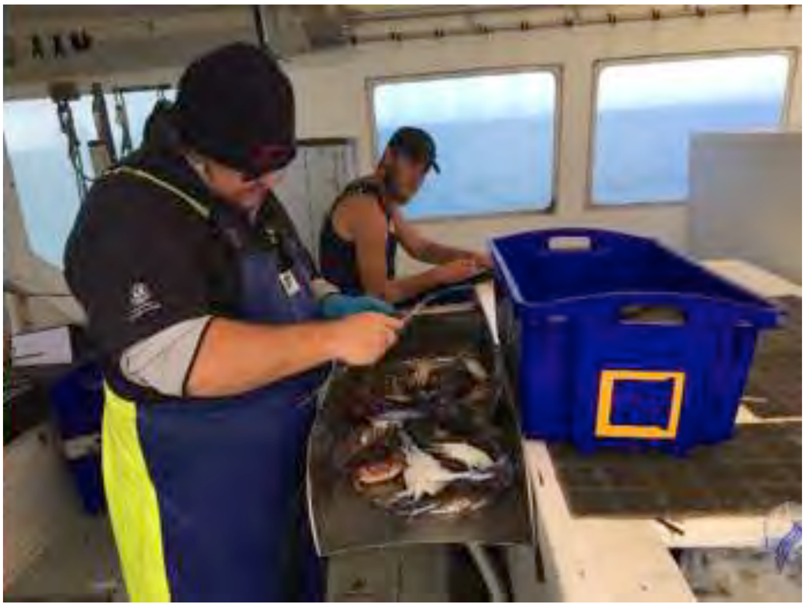
** **Adrian Linnane** (SARDI Aquatic Sciences), **Annabel Jones** (PIRSA Fisheries & Aquaculture), **Lachlan McLeay**, **Richard McGarvey** (SARDI Aquatic Sciences), **Kyriakos Toumazos** and **Trent Gregory** (NZRLF Assoc.) received the Research and Development Award at the 2017 Seafood Industry Awards for their research 'Expanding market opportunities for Rock Lobster' by investigating the impact that winter fishing in the South Australian Northern Zone Rock Lobster fishery would have on population sustainability and economic yield.

SA Fish & Fishery General News Items

Annual fishery independent surveys of the Blue Crab Fishery in Spencer Gulf and Gulf St Vincent

SARDI recently completed the annual fishery independent surveys of the Blue Crab Fishery in Spencer Gulf and Gulf St Vincent, South Australia led by ASFB member Dr Crystal Beckman, who is the principal investigator for the Blue Crab research program.

Since 2002, these surveys have been undertaken on-board industry vessels using standardised small-mesh research pots to measure the relative abundance of legal-size and pre-recruit crabs. SARDI observers, Graham Hooper and Matthew Heard, have been kept busy measuring every crab caught. In



Above *SARDI observers, Graham Hooper and Matthew Heard*

Left *Small-mesh research pots to survey* recent years, record high catch rates of blue crabs were reported in the South Australian gulfs.

Ugly, but fascinating: pouched lamprey (*Geotria australis*) in the Murray-Darling Basin

Chris Bice and Brenton Zampatti from the *South Australian Research and Development Institute (SARDI) – Aquatic Sciences Division* discuss research they have been conducting on primitive jawless fishes.

Pouched lamprey (*Geotria australis*) and short-headed lamprey (*Mordacia mordax*) are the only anadromous fish species native to the Murray-Darling Basin (MDB). Their life-histories include a parasitic marine adult life-stage, followed by large-scale upstream spawning migrations into freshwater habitats in winter–spring. Juveniles (ammocoetes) are filter feeders, living in mud or silt substrates in riverine habitats prior to metamorphosis and downstream migration to marine habitats. Adult migration appears to be guided by olfactory cues including pheromones from juveniles, and thus, the source of water encountered by upstream migrants is important in determining the direction of migration. As such, the life history strategy of lamprey is fundamentally dependent upon connectivity between marine and freshwater environments, and influenced by the provision and source of freshwater flow. Lamprey are now rarely encountered in the MDB, likely due to obstruction of migratory pathways by flow regulating structures (e.g. barrages and weirs) and diminished freshwater flows to the estuary of the River Murray (the Coorong). Many aspects of their biology and ecology remain poorly understood.

In 2015, we PIT (passive integrated transponder) tagged 56 pouched lamprey migrating upstream at the Murray Barrages, which separate the lower River Murray and Coorong estuary. Data from PIT tag readers on the lock and weir fishways along the River Murray indicated migrations extend at least as far upstream as Mildura (878 km upstream of the Murray Mouth), but the overall extent of migrations remains unknown, as does the location of freshwater spawning and nursery habitats.

Above *Pouched lamprey captured from the Mundoo Barrage fishway in August 2017 prior to tagging*

Over 2017–19, under a project funded by the Murray-Darling Basin Authority, we are using a combination of PIT and acoustic tags to investigate the movement and potentially spawning locations of pouched lamprey in the southern MDB. Together with colleagues from the Arthur Rylah Institute (Victoria) and NSW Fisheries, we have established a large-scale acoustic receiver array along ~2000 km of the River Murray from the sea to Yarrawonga, including major tributaries. This winter we trapped fishways on the Murray Barrages and tagged and released >40 pouched lamprey.

Initial data suggests four individuals have already reached Lock 1 (274 km upstream of the Murray Mouth), whilst several others appear to have migrated up a local tributary (the Finniss River).

Upstream migration will continue to monitored over the next 12 months. It is hoped this project will provide detailed information on the movement of pouched lamprey in the southern MDB and indicate locations that may support spawning. Ultimately, this information will inform management of river flows, including environmental water, that stimulate and support migrations of pouched lamprey.

Flinders University

Parasitic loading of *Octolasmis spp.* on blue swimmer crabs in South Australia
Tayla Dunn, Honours student

Through collaboration between Flinders University, SARDI, and the South Australian Blue Crab Fishery, I investigated the spatiotemporal variation in gooseneck barnacles (*Octolasmis* species) infestation in the blue swimmer crab (*Portunus armatus*) in South Australia.

Specifically, we assessed monthly and annual variation in *Octolasmis* infestation in both South Australian gulfs using crabs obtained from the commercial fishery and SARDI surveys. The study will improve our current knowledge on the spatial and temporal distribution of *Octolasmis* spp. in the temperate waters of the South Australian Gulfs.

Relative pot efficiency of the South Australian Blue Crab Fishery
Jess Priess, Honours student

This Honours project, in collaboration with SARDI and the Blue Crab Fishery, investigates differences in catch composition (e.g. size, sex, species) between crab pots of different sizes. These pots have been used during fisheries-independent surveys between 2002–2017 and vary in diameter and mesh size.

Understanding the differences in catches between the various commercial pots and research pot will allows for more accurate estimates of blue swimmer crab abundance, contributing towards setting total allowable commercial catch quotas for the fishery and ensuring its long-term sustainability.

Assessing the effects of cage-diving on marine ecosystems using biochemical tracers
Lauren Meyer, PhD student

Wildlife tourism is the fastest growing sector of the tourism industry, with white shark cage-diving at the Neptune islands in South Australia growing in popularity. The industry uses tuna bait and minced fish (chum/burley) to attract white sharks to within view of the diving cages.

However, the effects of various marine species interacting with the cage-diving industry remain unexplored. Using fatty acids and stable isotopes, we are able to assess the dietary effects of bait and burley input on both the target white sharks, and the myriad of non-target species which inhabit the Neptune Islands Group Marine Park. The results of this work provide critical information for effective management regimes that aim to minimise anthropogenic changes from wildlife tourism.

Top *Jess Priess shows off her catch*
Bottom *Great white shark, the focus of Lauren's study, © Andrew Fox*

Tasmania - TAS

Compiled by Sean Tracey

Inland Fisheries Service: Carp Management Program

By Jonah Yick

The outlook of the Carp Management Program (CMP) is positive moving into the 2017/18 season, and it is predicted that less than 200 carp remain in Lake Sorell. This follows a successful 2016/17 season in which a large proportion of the population was removed, and monthly juvenile surveys revealed no signs of spawning or recruitment. The remaining carp in Lake Sorell appear to be struggling in both size and maturity.

With high lake levels coming into spring, it is expected that there will be a strong drive from the carp population to push inshore as temperatures rise. As was the case last year, the priority again in the first half of the season will be spawning prevention and intensive inshore netting. This strategy will be used in combination with jelly gonad condition (JGC) radio transmitter carp to fish down the remaining population. Research conducted by IMAS PhD student Raihan Mahmud has shown that carp with advanced stages of JGC have little viable gonad tissue present, and are completely sterile.

However, despite being reproductively disadvantaged they have still been observed to respond to environmental cues.

In early September, six jelly gonad condition (JGC) carp were implanted with radio transmitters. Seven gram transmitters were used to suit the small average size of fish (750gm) being caught in the lake currently. The six transmitter carp were released back into Lake Sorell in preparation for the start of the carp spawning season. These fish will allow us to gain a better understanding of the movements of the carp population, indicate when the carp begin to move close to shore to look for spawning habitat, and hopefully result in more opportunities to target shallow water aggregations.

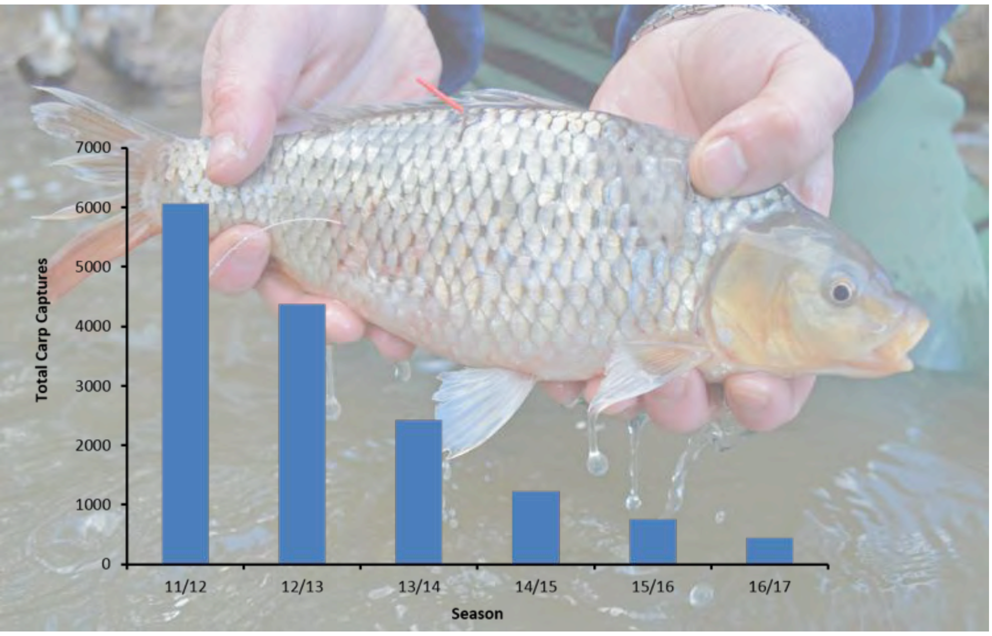
In early spring, large fyke nets were stitched into barrier nets and gill nets were set within the marshes behind the barrier nets. These were placed in strategic locations in response to current lake levels in order to capture mature carp seeking spawning habitat, and to ensure any carp that breach the barrier net can be captured.

Some carp have already shown signs of moving into the shallow areas of the lake. Depending on the changing environmental conditions encountered, the fishing/targeting strategy will be altered accordingly throughout the season.

University of Tasmania

By Jeremy Lyle

IMAS has begun a new project to assess the impact of degraded environmental conditions in Macquarie Harbour (western Tasmania) on the endangered Maugean Skate. The project aims to provide an understanding of how recent changes in the harbour environment



Carp have been dramatically reduced as a result of the Carp Management Program in Lake Sorell, Tasmania have affected the skate population, and to inform efforts to manage risks and improve conservation outcomes. The study will focus on the development and survival of the skate's eggs and the behavioural and physiological responses of adults to the changing harbour environment and in particular dissolved oxygen levels. The research will use a combination of laboratory and field sampling methods, including new generation sensors which will be attached to the skate to monitor the actual conditions that they experience in the wild, including dissolved oxygen, temperature and depth.

The project is funded by the FRDC, Tasmanian Government, aquaculture companies and WWF.

Victoria - VIC

Compiled by John Morrongiello

Quantitative Aquatic Ecology and Evolution ,The Morrongiello Research Laboratory, University of Melbourne

The Morrongiello Lab has some exciting research coming up this year with five master's students, three local PhD students, and one visiting PhD student. Students are working across a diversity of projects, including fish dispersal behavior, physiology, fisheries selectivity, climate change impacts and habitat restoration.

Masters Students

Thomas Schmitt (2nd year):
My research has focused on quantifying the individual growth rates, metabolic rates and behaviours of brown trout fry, *Salmo trutta*. These traits, often studied individually, have been shown to play an important role in driving the "pace of life", of an individual. The pace of life syndrome postulates that boldness (i.e. exploration and risk taking) should be positively correlated with greater metabolic capacity and, in turn, faster growth rates. After developing an understanding of how these traits relate at an individual level, I began to explore whether fishing could act selectively on one or more of these pathways. The selective removal of related traits may have the capacity to greatly affect fisheries-induced evolution and could have profound implications for the management strategies surrounding harvested populations.

Bill Coates (2nd year):
My research focuses on investigating the presence of personality traits and variable dispersal tendency in a native freshwater fish, the western carp gudgeon (*Hypseleotris klunzingeri*). I have found consistent differences in both boldness and sociability among individuals. I have also found that dispersal behaviour is highly repeatable within individuals and varies among the population. I am now looking to see whether dispersal behaviour can be predicted by an individual's boldness.

Gabriel Lyle (2nd year):
Gabriel is interested in how little fish in small streams use habitat, and why they are where they are. His masters is focusing on placing small wood in a degraded stream to see if the fishes respond in any way.

Sinead O'Dwyer (1st year):
My research is focused on the impact of climate change on estuarine fish. I will look at the commercial and recreationally fished species black bream to determine the influence of water temperature and feeding regime on growth rate.
I will test how temperature directly impacts growth rate, and assess how varying the timing and quantity of

feeding impacts the growth rate of black bream, as previous studies have indicated that the main food source of black bream is predicted to decline in future warming scenarios.
Along with looking at future conditions I will also look to the past through utilizing otoliths to create growth biochronologies allowing me to assess how black bream growth rate has varied over time in changing environmental conditions.

Julia Brueggeman (1st year):
I am going to be assessing the direct and indirect impacts of climate change on the bridled goby (*Arenigobius bifrantus*). This species is found abundantly in estuaries of Port Phillip Bay, which are particularly susceptible to climate change.
I am specifically going to be focusing on how changes in temperature and oxygen availability impact reproductive behaviours and egg development, as well as how the bridled goby is able to compete with an invasive species. I hope to gain insight on how this species will be influenced by climate change in order to draw conclusions for how other estuarine species will be impacted as well.

<u>PhD Students</u>
Henry Wootton (2nd year):
I'm interested in the effects of harvests on fish populations. Specifically, I'm investigating evolution in key life-history traits such as size- and age-at-maturity, growth rate, and reproductive investment in harvested populations. I aim to uncover the drivers of evolution if present, and develop tools for long term monitoring of these traits for use by managers. I am currently employing a suite of statistical and experimental techniques to ask questions within this space.

Josh Barrow (1st year):
Freshwater fish in the Murray-Darling Basin have been profoundly impacted by both natural and human induced change to flow regimes, temperature, and connectivity. I am interested in how these changes have influenced the productivity of native fish populations. My PhD project focusses on identifying the drivers of growth variation of Murray cod and golden perch at population and individual levels, using otoliths (ear stones) collected from throughout the Murray-Darling Basin. I also aim to determine whether small and large scale movements play a role in driving the growth of these important species.


Thomas Schmitt


Gabriel Lyle

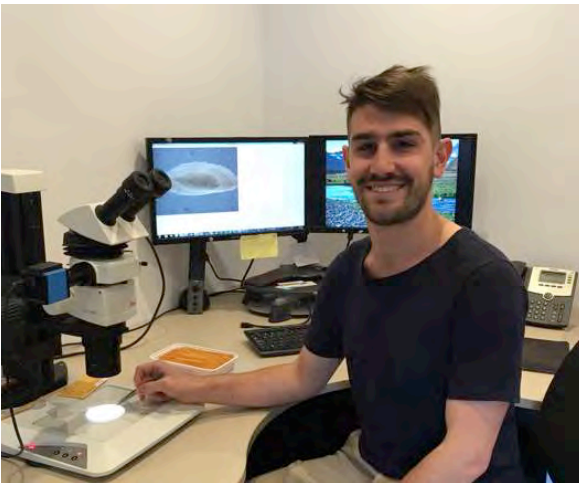
Jed Macdonald (3rd Year):
I've recently returned to Oz after spending a few years in more northern climes, pursuing a PhD at the University of Iceland. The PhD has focused broadly on understanding if/how collective decision making in fish schools can influence migratory traditions, using Atlantic herring (*Clupea harengus*), a long-lived, dense schooling species of high commercial importance, for illustration. By developing a space-time model for herring wintering dynamics, and combining outputs with particle tracking simulations and otolith chemistry tracking simulations and otolith chemistry analyses,


Sinead O'Dwyer


Julia Brueggeman


Henry Wootton

we were able to tease apart the intrinsic (i.e. social cues, collective learning) and extrinsic (i.e. environment, prey availability, fishing pressure) controls on dispersal, connections among juvenile and adult populations and tradition-formation in the species. The outcomes to date highlight the value of uniting demographic time series with non-stationary models in exploring evidence for collective learning in group-living animals, and in guiding spatial management decisions.


Josh Barrow


Jed Macdonald

Population models to assist the management of native freshwater fishes in the Murray-Darling basin
By Charles Todd

In the December 2015 newsletter, we informed the membership of a project funded by the Murray-Darling Basin Authority (MDBA) to develop a suite of population models for 8 native fishes of the Murray-Darling Basin (MDB). As many would be aware native fish have experienced significant declines since European settlement, so that the rehabilitation of native fish populations is an important natural resource management objective. Environmental water allocations are a key rehabilitation action under the Murray-Darling Basin Plan, and are provided for a range of biota including fish.

There is a need to demonstrate the potential benefits of water management actions, and the use of population models provides a method by which this can be undertaken. Modelling a range of flows allows for a comparison of a series of management options to be made so that the benefits to fish populations can be maximised.

The models developed collate the latest ecological and biological information and understanding on each of the species including how flow influences and impacts each stage of the species' life history.

For example, southern pygmy perch have largely receded from the larger rivers and wetlands in the southern basin, to mainly smaller upland streams and wetlands and may be subjected to catastrophic flow events (flash flooding).

However, general flow patterns are not the issue impacting southern pygmy perch, it is more about habitat alteration and loss, associated with swamp reclamation and river regulation, and impacts by invasive species. The model developed for southern pygmy perch accounts for this information as well as providing options for re-introductions, recruitment failure and catastrophic flow events to assess strategies for future management of the species.

Golden perch are another example; a MDB wide generalist flow dependent species, golden perch require variable flow for movement cues and spawning (also temperature). The model developed for golden perch required a meta-population structure (6 connected populations around the basin, and a sub-population for Menindee Lakes). Rules were developed for movement between each population based on flow and for each stage (eggs and larval drift, juvenile and adult movement). The early results from golden perch modelling is that golden perch require basin wide management for both flows and fishing, and that Menindee Lakes are important for both the northern and southern basin populations.

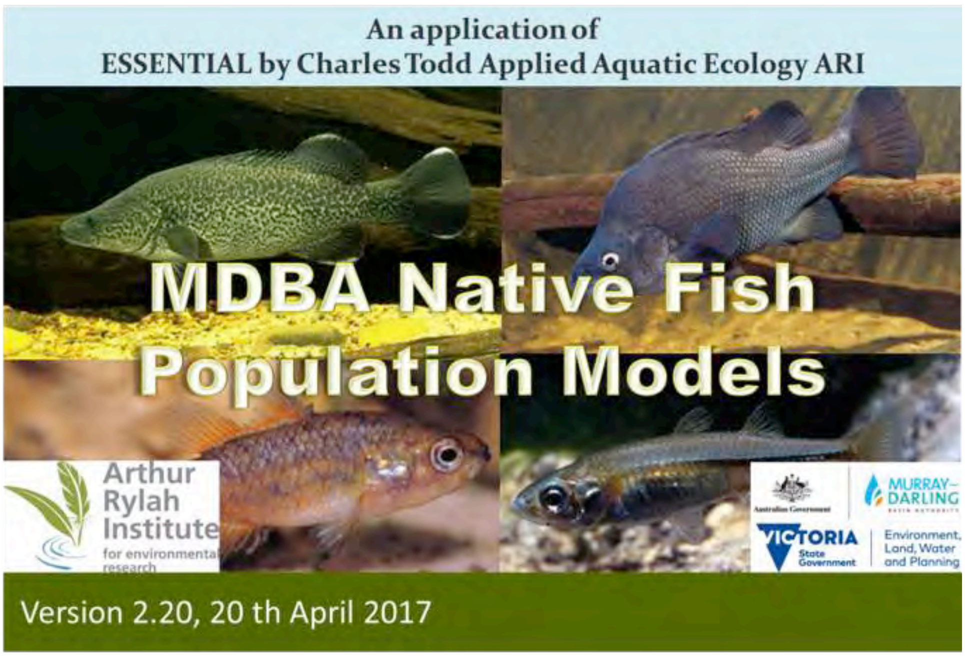
The models are currently being tested with some case studies to develop guidelines for their future use as well as ground truth the models.

Population models have been developed for 8 different MDB native fish species
These species have been selected to represent a range of habitats and flow requirements, (e.g. in-channel, wetland specialists; flow cued spawners) sizes and different management needs (e.g. threatened species, angling species):

- Golden perch
- Silver perch
- Murray cod
- Trout cod
- Macquarie perch
- Southern pygmy perch
- Olive perchlet
- Murray hardyhead

Some of the questions addressed by this project are:

- What are the likely responses of populations under differing flow and watering scenarios?
- What is the likely quantity of any population responses?



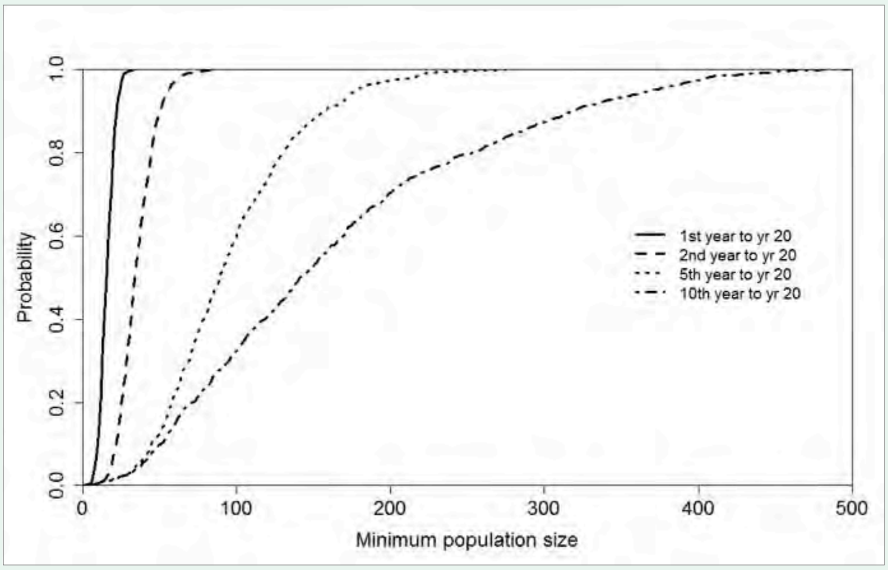
Left *Software developed for MDBA*

These models will provide important tools to assist native fish management at multiple scales: for both annual and longer-term planning into the future at both individual sites and across Murray-Darling Basin. The models will help demonstrate the potential benefits of environmental water management to populations of these fish species to agencies and the wider public.

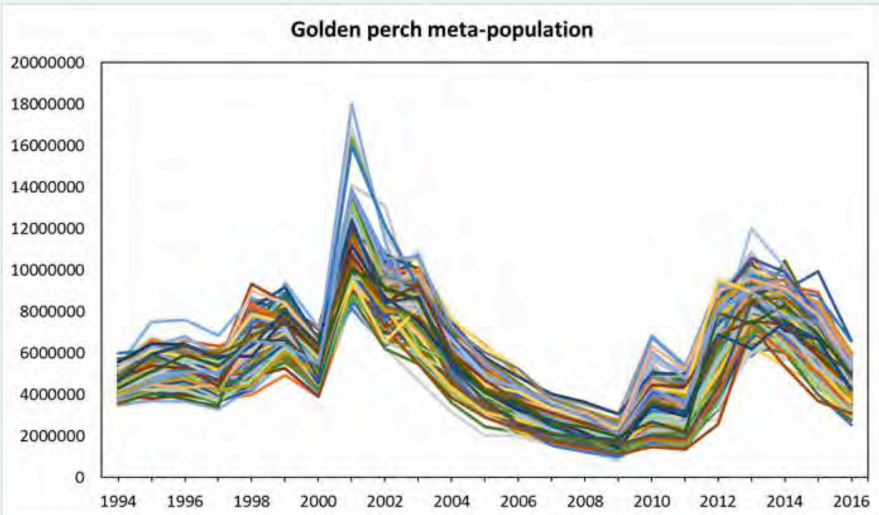
Project partners
This project is funded by the Murray-Darling Basin Authority and undertaken by the Arthur Rylah Institute for Environmental Research (DELWP, Victoria) in partnership with a wide range of experts from: South Australian Research and Development Institute, NSW fisheries, Kingfisher Research, Murray Local Land Services, Griffith University, University of Canberra, La Trobe University/ Murray-Darling Freshwater Research Centre, University of Melbourne, Fisheries Victoria, University of Canberra Charles Sturt University and several Consultants.

For further information contact *john.koehn@delwp.vic.gov.au*

EXAMPLES OF MODEL OUTPUTS FROM THE MDBA PROJECT



Risk curves for the probability of small population size of southern pygmy perch following a reintroduction or translocation in to habitat with an expected density of 500 female adults. A total 250 female adults were released over 5 years. By the 10th year, the likelihood that the population is small has decreased substantially.



Thousands of iterations for the Golden perch meta-population model response to flow and temperature.

State Reports

Western Australia - WA

Compiled by Emily Fischer and Chris Hallett

Department of Biodiversity, Conservation and Attractions

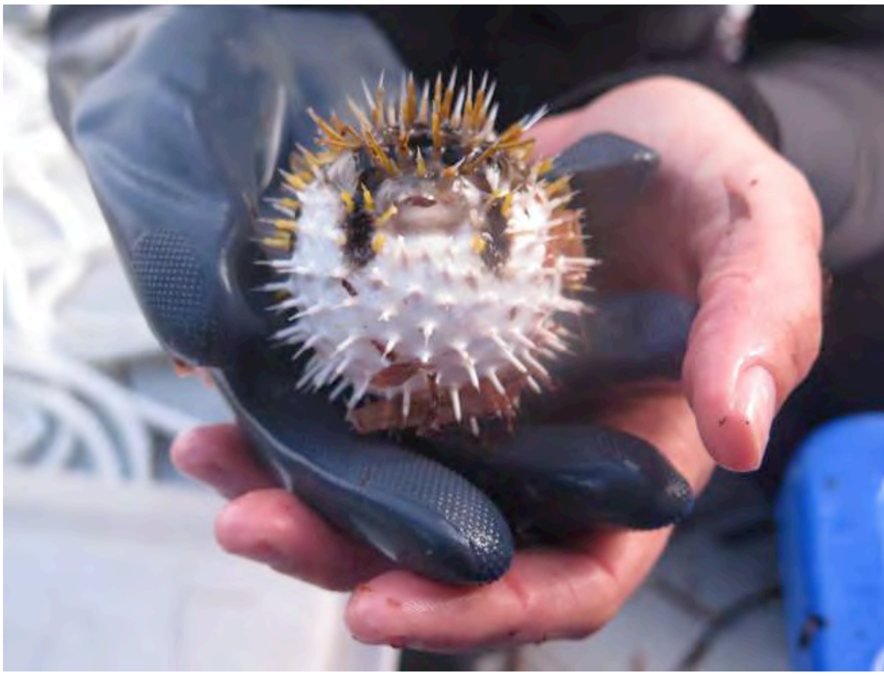
Compiled by Shaun Wilson

Over the past 12 months the Department of Biodiversity, Conservation and Attractions (DBCA; formerly Parks and Wildlife) have continued to monitor the condition of fish assemblages in WA's network of marine parks and reserves. With the help of regional staff and colleagues from the Universities of Tasmania and Western Australia we have completed surveys of fish in the Montebello and Barrow Islands, Jurien Bay, Ngari Capes, Shoalwater Islands and Marmion marine parks over the past twelve months. Surveys at the Rowley Shoals and Ningaloo marine parks are also to be completed by the end of the calendar year. The findings from these and other surveys are currently being combined with information on other ecological assets to produce publicly available reports for a selection of these parks. Each year a report will be published on three different marine parks covering the condition of key assets relative to natural and human pressures. This year the monitoring team has been focusing on reports for the Ningaloo, Jurien Bay and Shark Bay marine parks.

To improve our ability to monitor fish across different habitats we have also been carrying out research to determine which methods are most suitable for recording fish in seagrass meadows. DBCA Research Scientists Ben French, Mike Rule and Nicole Ryan have collected information on seagrass fish assemblages from Geographe Bay, Shoalwater Islands and Shark Bay using a combination of remotely operated video, diver and trawl methods.

The information from this study will also provide baseline information for fish surveys in seagrass habitats at these locations, complimenting existing monitoring data from reef habitats.

Our annual surveys of juvenile fish at Ningaloo were again carried out in February 2017, with the support of regional DBCA staff and colleagues from the Australian National University and Australian Institute of Marine Science. These surveys span ~150km of the Ningaloo coast and have been conducted each summer, in lagoon and backreef habitats, since 1999. This time frame includes some of the strongest La Niña and El Niño events on record, which has allowed us to investigate the effects of climate driven oceanic currents on recruit supply at Ningaloo.
Initially we focused on the relationship between juvenile lethrinids and the Southern Oscillation Index (SOI), finding higher juvenile densities during La Niña than El Niño years (Wilson et al. 2017).



Above *Slender-spined Porcupine or Globefish, Diodon nicthemerus, collected from a seagrass meadow trawl sample (Photo: Ben French)*

State Reports

Left *Pomacentrus milleri on an offshore reef near Onslow (Photo: Richard Evans)*

Subsequent investigations have found similar patterns among other fish families and coral spat, although the strength of the relationship varies among taxa and locations. Relationships are strongest among fish that are closely associated with coral or macroalgae as juveniles, though decline in coral habitats seems to have weakened these relationships at some locations. Interestingly, changes to both coral assemblages and macroalgal fields can also be linked to fluctuations in the SOI, emphasizing the importance of large scale climate effects on habitat forming biota, and the influence of habitat quality on local juvenile fish abundances.

Research on connectivity of fish, funded by the Wheatstone gas development offset in collaboration with WA Marine Science Institution partners, has identified barriers and restrictions to gene flow along the WA coast. Based on the genetics of the demersal spawning damselfish, *Pomacentrus milleri* and broadcast spawning snapper, *Lutjanus carponatatus*, DBCA Senior Research Scientist Dr Richard Evans and colleagues have identified a barrier to gene flow between Ningaloo and Shark Bay. There is also some restriction to gene flow from the Kimberley to the Canning and Pilbara regions. These patterns are more apparent among damselfish than lutjanids, implying stronger connectivity among sites for the broadcast spawning species.

Fish Section, WA Museum

Compiled by Glenn Moore & Mark Allen

This year has largely been a year of consolidation, completing identifications and working through outstanding projects. However, we started the year off with a trip to the Dampier Archipelago, collecting voucher material for ongoing genetic investigations into the taxonomy and systematics of Western Australia's fishes. This was followed by a trip to the Bradshaw Military Field Training Area in the NT to sample freshwater fishes. Outcomes from these projects are developing. Data analysis has finally got underway to make sense of six years of Kimberley surveys through our Marine Life of the Kimberley/Woodside Collection project. When complete, these data will make a substantial contribution to our ecological understanding of the Kimberley. The whole Aquatic Zoology team and other collaborators are involved, so we will eventually have a multi-taxon and environmental dataset along the Kimberley region. Preliminary findings of this project were presented at the Indo-Pacific Fish Conference in Tahiti.

Glenn has been involved in two collaborative WAMSI projects that have been completed this year: 1.1.3 Ecological Connectivity and 1.1.2 Recruitment. We have also completed hundreds of identifications for trawl material collected as part of WAMSI 1.1.1 Benthic Biodiversity.

Along with many collaborators, Glenn and Mark are co-authors on a soon-to-be published field guide to the freshwater fishes of the Kimberley. This book covers all known species, including many recently described. It includes tools for identification and details of habitat, distribution and biology. Biogeography features strongly and Aboriginal language names are provided throughout. We expect this will be an invaluable resource for a wide range of audiences.

Of course, the unique work of a Museum continues. We are always involved in public programs, including identifications, presentations, media and exhibitions. We are in a unique position of being part of the exciting New Museum project, due to open in 2020, and we are constantly providing scientific input and objects into the content of the exhibitions. The often overlooked part of working in a museum - caring for the State's collections - is never-ending and specimen accessioning, collection maintenance and databasing is balanced with a stream of visiting researchers and loans. This year saw our large specimens (too big for jars or even drums) transferred into bespoke compliant vats. Several new species descriptions have been published or are well advanced and a range of other taxonomic/systematics related research projects will be completed over the next 12 months.

Murdoch University
Centre for Fish & Fisheries Research

centreforfishfisheriesresearch.wordpress.com

Compiled by Chris Hallett

2017 has again been an exciting and productive year for members of the Centre for Fish & Fisheries Research. We have welcomed many new post-graduate students who are embarking on some extremely important research projects in many aspects of aquatic research. If you would like to enquire about pursuing postgraduate research with us, please email fish@murdoch.edu.au.

Estuarine Ecology

estuarine-ecosystems.webs.com

Chris Hallett is continuing his work on an ARC Linkage project with Fiona Valesini, entitled 'Balancing estuarine and societal health in a changing environment'. This multidisciplinary project, involving researchers from Murdoch University, Southern Cross University, UWA and the University of Hull (UK), and using the Peel-Harvey Estuary as a case study, seeks to identify those land-planning strategies that are most likely to achieve balance and better sustain our estuaries, and the industries, lifestyles and ecology they support, into the future. Along with assessing the condition of estuarine sediments and invertebrate communities in this system, Chris is now close to completing a two-year study of the fish fauna, from which a fish-based ecological indicator of estuarine condition will be developed.

Chris also continues to apply the Fish Community Index, which he developed during his PhD, to monitor and report the ecological condition of the Swan Canning Estuary, Perth, in conjunction with the WA Department of Biodiversity, Conservation and Attractions. Fiona, Chris and Alan Cottingham recently published a paper documenting the changes that have occurred in the ichthyofauna of this system in recent decades (doi:10.1111/jfb.13263), highlighting evidence of the marinisation of the estuary in response to declining flows.

The Estuarine Research Unit at Murdoch, in collaboration with Fisheries WA, have been undertaking extensive fish ecology research in the Walpole and Nornalup Inlets Marine Park, a permanently-open estuarine system on the south coast of WA with high social significance and importance as a recreational fishing destination. PhD student Dan Yeoh, who is supervised by Fiona Valesini and Chris Hallett, has been gathering detailed data on the fish composition of the system since 2014, to (a) examine any changes since they were last studied in the early 1990s and (b) create a reliable benchmark for its appropriate management and comparability with other estuaries into the future. In addition, the movements of several key fishery species were tracked using passive acoustic telemetry to gain further knowledge of how they use the system and respond to environmental change. Findings from this PhD project, including recently published work on diel shifts in the structure and function of nearshore estuarine fish communities (doi:10.1111/jfb.13222), have been used to devise a refined and cost-effective monitoring plan for the system into the future.

PhD student Sian Glazier is constructing a quantitative and predictive 'food web' for the Vasse-Wonnerup Wetland in Busselton, south-western WA, as part of a unique study to help scientists, environmental managers and locals better understand the water bird community in that Ramsar-listed wetland.

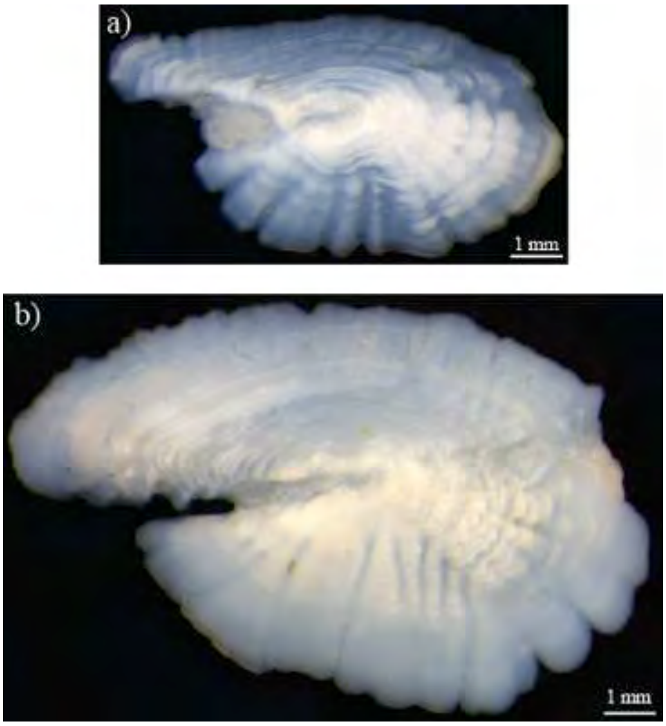
The project examines dietary linkages from the zooplankton to apex predators including key fish (e.g. black bream, sea mullet) and bird species (e.g. black swans, stilts, avocets), and interlinks with a concurrent project being undertaken by PhD student Rosh McCallum at Edith Cowan University, which in part examines the detrital and plant-based components of the food web. As well as producing a comprehensive food web for the estuary, Sian's project is also focussed on identifying those components at lower trophic levels, which are likely to provide good indicators ('early warning signals') of ecosystem health at higher trophic levels. She is using three complementary methods to discern dietary composition, including traditional gut analyses (fish), stable isotopes (all faunal groups) and e-DNA analyses (fish guts and bird faeces).

Right *Sampling fish fauna of the Walpole-Nornalup Estuary using a seine net.*

Sian has completed 2 of 4 field surveys to date (in both wet and dry conditions in 2016/17), and is currently undertaking her third sampling season.

Black bream biology and ecology
During the past year, Alan Cottingham, Norm Hall and Ian Potter have continued analysing data on the black bream in a range of different estuaries in southwestern Australia and particularly of the Swan River Estuary. Their recent studies have emphasized that the biological characteristics of the black bream have changed in response to the increase in hypoxia that has occurred in these systems over the last 25 years. This detrimental change in environmental conditions is attributed to marked reductions in freshwater discharge and thus flushing of the estuary, consequently leading to greater accumulations of organic material and nutrients in deeper waters and increased microbial activity.
The results demonstrate that increases in hypoxia are accompanied by reductions in growth and body condition and an increase in the age at maturity and the age at which individuals reach the minimum legal length. The remarkably plastic biological characteristics of the black bream make this sparid an ideal 'model' for detecting changes in the environment of estuaries.

Age validation of Southern armorhead
Peter Coulson, in collaboration with Simon Robertson (Fish Ageing Services) and Ross Shotton (Southern Indian Ocean Deepsea Fishers Association), is undertaking a project to validate and confirm ages for the Southern armorhead (*Pentaceros richardsoni*). Previous work, using whole otoliths, found that this species attains a maximum age of only 14 years and studies of its congener, *P. wheeleri*, in waters of the northwest Pacific suggested that this species has a very short life cycle of up to 8 years.



Above *The whole sagittal otoliths of Southern armorhead measuring a) 390 and b) 660 mm fork length*

In contrast, studies of three coastal species on boarfish off southern Western Australia found that, using transverse sections of sagittal otoliths, species in this family attain ages up to 55 years. Using samples collected predominantly from the southern Indian Ocean by AFMA observers and commercial fishing crews, appropriate methodologies for ageing this deep-water species will be developed. The whole otoliths of samples have been imaged, with the next step being to investigate the appropriate thickness for sectioning the otoliths of this species in order to clearly reveal all growth zones.

Elasmobranch energetics – Lemon shark home range scaling project
Generally, larger animals have larger home ranges, which encompass enough resources to meet their higher energetic demands. While this theory has largely stood the test of time, it has been based on data from terrestrial birds and mammals, and it is unknown whether the same mechanisms apply to aquatic organisms, such as fishes.
Therefore, we have started a new project that is examining how energetic demands govern the home range size

and habitat requirements of lemon sharks and how these change over ontogeny. Using respirometry, combined with field observations of sharks' movements and diet, and data on energy availability within the habitat, we aim to build energy integrative home range models for lemon sharks. These models will be used to make recommendations to improve marine protected area design to better accommodate elasmobranch habitat requirements. This project is led by new PhD student Evan Byrnes (supervised by Dr. Adrian Gleiss, Dr. Stephen Beatty, and Dr. Ryan Daly), as part of a new collaboration with Save Our Seas D'Arros Research Centre. The first acoustic accelerometers were deployed in August, and we are excited to see our first preliminary data. Stay tuned for exciting results!

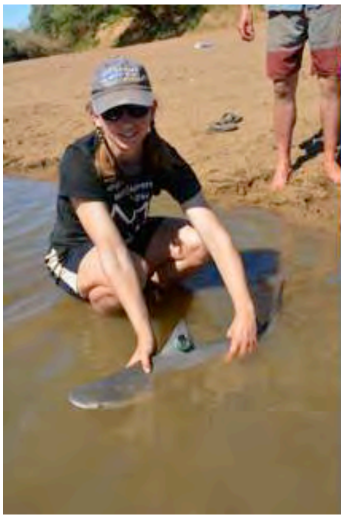
Above *Ryan Daly and Evan Byrnes transporting field gear across the flats of St. Joseph atoll, Seychelles during low tide*
Centre Right *Evan Byrnes implanting an acoustic accelerometer tag*
Bottom Right *Sicklefin lemon shark carrying a CATS diary tag*

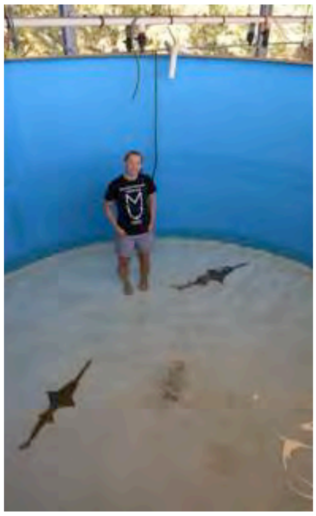
Elasmobranch energetics – sawfish
By Karissa Lear
With the big wet season in the Kimberley this year, we have had a spectacularly productive year, already tagging close to 100 young of the year sawfish in the Fitzroy, including deploying several accelerometers on wild sawfish and bull sharks to study their movements and behavioural patterns. In addition to the fieldwork, Adrian Gleiss and I collected five juvenile sawfish and transported them to the North Regional TAFE in Broome, where we are holding them for three months to do some captive behaviour and physiology research before releasing them back into the Fitzroy.

The research I'm conducting at the TAFE is similar to calibrating a FitBit for sawfish, through using accelerometers to study sawfish behaviour. Accelerometers measure fine-scale movements, and when they are attached to a sawfish, they can pick up every tail beat the fish makes and each change in pitch or posture. I am running behavioural studies to determine what this movement data looks like for specific behaviours, including feeding. I am also measuring the metabolic rate of sawfish while they are wearing their accelerometers, which tells me how much energy each specific behaviour costs.

These studies will allow us to put accelerometers on wild sawfish in the Fitzroy, look at what they are doing in their natural environment, estimate how much energy they are using based on their behaviour, and importantly, see how their behavioural patterns, feeding effort, and energy use change throughout the dry season as temperatures increase. This will give us an idea of how these animals may respond to the increased temperature regimes associated with climate change.

Elasmobranch energetics – White sharks
Oliver Jewell has recently joined the Centre for Fish and Fisheries Research, Murdoch University, to begin his PhD. He has a background in spatial ecology and oceanography and a keen interest in sharks. His PhD will focus on the movements and habitat use of white sharks, and he has already collected data from South Africa and is heading to California for fieldwork shortly. Oliver is supervised by Dr Adrian Gleiss and collaborators from Monterey Bay Aquarium and Stanford University, and together they are deploying high-resolution accelerometer and camera tags to large predatory sharks at multiple sites across the globe.





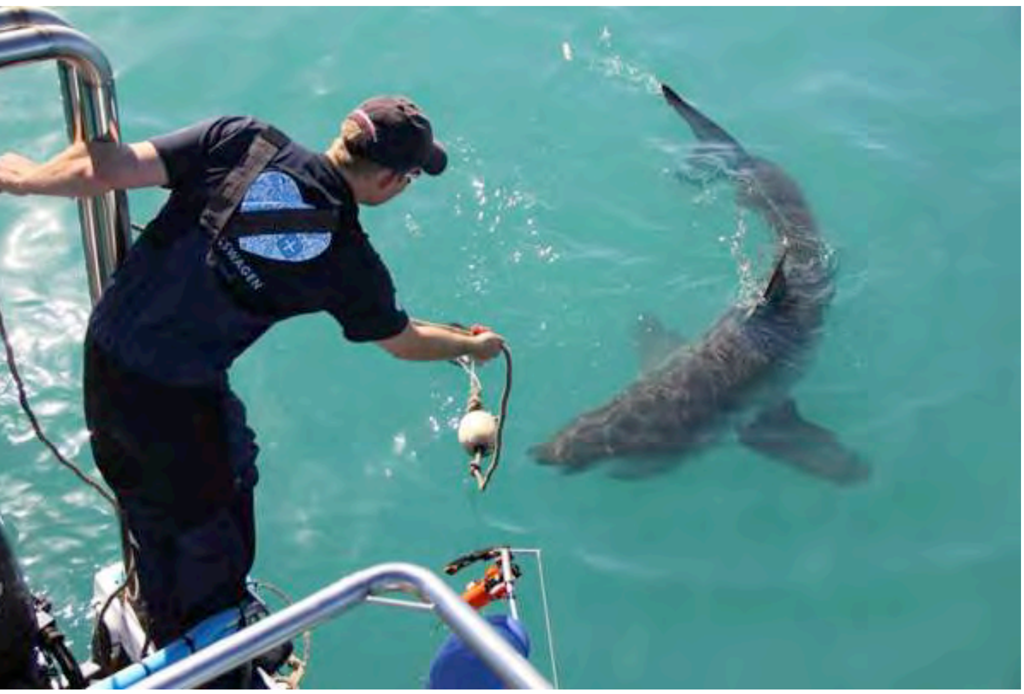
Action shots of Karissa Lear investigating the behavior of bull sharks and sawfish using accelerometry

Freshwater Fish Group & Fish Health Unit

freshwaterfishgroup.com

Marron habitat study
A habitat modelling study has commenced in Harvey Dam that will determine the movement and habitat use of marron in relation to a range of environmental variables, which will be a first for the species. Harvey Dam is a valuable reservoir in southwestern Australia for the iconic marron fishery.

The study is being led by Stephen Beatty and is part of a broader FRDC project led by EcoTone consulting. As part of the habitat modelling component, a multiple mark-recapture study has been completed with preliminary results showing that the species has high site fidelity, favours locations with complex woody debris, and has lower densities in areas that are



Left *PhD student Oliver Jewell getting up close and personal with his study subject*

Left *A good sized marron being marked and released* **Bottom** *Harvey Dam (Photos: Stephen Beatty)*

more readily accessed by recreational fishers.

The study will provide a robust baseline of abundances and distribution in relation to its environment that will directly complement the planned provision of artificial habitat and re-stocking of captively bred animals, which aims to boost the long-term viability and recreational catch rates of the species in the reservoir.

Team Sawfish

The wet season of 2016/2017 was a ripper, with sawfish pups entering the Fitzroy River nursery in massive numbers. After several lean years where the wet seasons were poor, this is a welcome sight. Some recent publications from the team include:

Morgan, D.L., Somaweera, R., Gleiss, A.C., Beatty, S.J. & Whitty, J.M. (2017). An upstream migration fought with danger: freshwater sawfish fending off sharks and crocodiles. *Ecology* 98: 1465-1467. doi: 10.1002/ecy.1737

Phillips, N.M., Fearing, A. & Morgan, D.L. (2017). Genetic bottlenecks in *Pristis* sawfishes in northern Australian waters. *Endangered Species Research* 32: 363-372. doi.org/10.3354/esr00815

Whitty, J.M., Keleher, J., Ebner, B.C., Gleiss, A.C., Simpfendorfer, C.A. & Morgan, D.L. (2017). Habitat use of a Critically Endangered elasmobranch, the largetooth sawfish *Pristis pristis*, in an intermittently flowing riverine nursery. *Endangered Species Research* 34: 211-227. doi.org/10.3354/esr00837

Fish Health Unit

Hosna Gholipour Kanani, from the University of Gonbad-Kavous in Iran, has just completed a nine-month sabbatical at Murdoch University. Hosna is a fish immunologist with a particular interest in the innate immune response as the first line of defence against infectious disease. While in Australia, she has been testing the bactericidal properties of a number of plant essential oils, as well as helping with an FRDC project on the immune response of cultured yellowtail kingfish to bacterial infection.

Susan Gibson-Kueh has also left us recently, although she hasn't moved too far.

Susan has taken up a position as a Fish Pathologist at the Department of Fisheries in Perth, but will continue to be involved in teaching the principles of fish health to veterinary students and in a number of collaborative research projects on fish diseases.

Above *Nyikina-Mangala Ranger Nathan Green with a new recruit to Team Sawfish (Photo: David Morgan)*

Erin Kelly, undertaking a PhD project on catfish health, has recently led a study with collaborators comprising ASFB members and others from around Australia describing the first recorded records of *Edwardsiella ictaluri* in wild fish in Australia (doi: 10.1111/jfd.12696). This bacterium, responsible for enteric septicaemia in cultured catfish, was found in *Tandanus tropicanus* in the Tully River catchment in Queensland. The study was a true collaborative effort, involving 14 people from seven different institutions across Australia.

Swan-Canning Acoustic Array

The installation of acoustic receivers in the Swan-Canning Estuary and the tagging of black bream is the first acoustic tracking study of fishes in the system and utilised the Swan-Canning acoustic array (SCAA) that is managed by the Department of Biodiversity, Conservation and Attractions. Jake Watsham and Nathan Beerkens completed their Honours (supervised by Stephen Beatty, Adrian Gleiss (MU), Tim Clarke (UTas), Paul Close (UWA)) that aimed to determine how black bream respond (in terms of residency, depth, and activity) to different environmental conditions, particularly the operation of two oxygenation plants in the system.

Vasse-Wonnerup PIT tagging project

Fish kill events have regularly occurred in the Ramsar listed Vasse-Wonnerup Estuary, south of Perth. The system is regulated by the operation of two sets of surge protection barriers. The key species most affected by the recent kill have been black bream and mullets (sea and yellow-eye). Very little was known of the movement patterns of these species in the Vasse-Wonnerup system

Above *Erin Kelly and Susan Gibson-Kueh processing catfish tissue samples in the field (Photo: Brendan Ebner)*

Top *Nathan Beerkens releases an acoustically tagged Black Bream for the Swan Fish Track project*
Centre *Busselton Senior High School students at a fish tagging day.*
Right *Tom Ryan installing the PIT antenna on the upstream side of the Vasse Surge Barrier (N.B. the major fish kill zone and note the cyanobacteria at his feet). Photos: (top and centre) Stephen Beatty, (bottom) James Tweedley*

or how their populations may recover following these fish deaths. A recent collaborative project between Department of Water, GeoCatch and Murdoch University determined the movement patterns and spatial and temporal distribution of the Black Bream within the Vasse Wonnerup system using acoustic tags that were internally implanted in 41 black bream. This revealed that the barrier acted as an ecological trap for bream, trapping a proportion of the population in the fish kill zone during the time when they usually occur.

The new PIT tag study, funded by the Department of Water (undertaken by Stephen Beatty, Tom Ryan and James Tweedley), has been instigated to specifically determine the conditions under which the movement through the fish pen-stock on the Vasse Surge Barrier occurs. In autumn 2017, a PIT tag antenna system was installed on the fish pen-stock to determine bi-directional movement through the gates (thanks to Karltek). With the help of community volunteers, 134 black bream and sea mullet were tagged and preliminary data has detected one-way passage only through the fish gate, supporting the acoustic study's findings.

The data will be used to model the conditions under which fish are passaging through the gate and help to refine its design and management to ensure fish can avoid periods of poor water quality that occur upstream.

Marine Management Research Group

By Prof. Lynnath Beckley

During 2016/17, the Murdoch Marine Management Research Group continued working on several projects in the southeast Indian Ocean. Alicia Sutton published four papers from her PhD thesis, which investigated the zoogeography and ecology of krill in the SE Indian Ocean. These included the first investigation of krill diversity and abundance throughout the Leeuwin Current system, a comparison of the krill in the northwest bioregion (Ningaloo and the Kimberley) and the influence of a large front created by a meander in the Leeuwin Current on vertical distribution of krill. These results were used to fill gaps in her GIS collation of all published distribution records of krill in the Indian Ocean, which she used to link zoogeography with oceanography across the basin. Collectively, these data revealed how the oxygen minimum zones in the north Indian Ocean reduce the diversity of krill (doi:10.3390/d9020023).

Erin McCosker completed her MSc study comparing the zooplankton at the three WA IMOS reference stations at Ningaloo, Rottnest Island and Esperance. Clear distinctions in assemblages were observed, becoming weaker in winter probably because of enhanced connectivity driven by alongshore and cross-shelf transport of species in the Leeuwin Current. Both physical and biogeochemical factors were revealed to be significant in shaping copepod assemblage structures, with seawater density exerting the greatest influence. The results suggest that both broad scale latitudinal gradients and mesoscale events contribute to variation in zooplankton assemblages off WA.

In January 2017, several research group members were fortunate enough to undertake a voyage with the RV *Whale Song* to investigate aspects of the pelagic ecology of the Bremer Canyon on the south coast of WA. A large aggregation of killer whales occurs there and the area is included in one of the new Commonwealth marine parks in the southwest bioregion. We completed many CTD profiles and collected plankton samples for food web analysis. Honours student, Nicholas Mondello, is using the CTD data to complement his oceanographic modelling study, which is revealing interesting results with respect to the influence of the Leeuwin and Flinders Currents. We also deployed an ARGO profiling float for CSIRO and are now following its path with much interest.

Above *RV Whale song in the Kimberley region of Western Australia*

Dani Hodgkinson is completing an Honours project on the age and growth of the small-tooth flounder (*Pseudorhombus jenynsii*) from estuaries and coastal waters in southwestern Australia. This project relies on archived otoliths collected by Dr Peter Coulson, many as by-catch to the inshore commercial prawn and scallop trawling fisheries.

As a by-product to the high resolution mapping of benthic habitats in the Ningaloo Marine Park using hyperspectral imagery led by Halina Kobryn, a paper has been published on an assessment of coastal land cover and off-road vehicle tracks adjacent to the park in northwestern Australia. Many of these tracks are created by four-wheel drive vehicles accessing coastal fishing and camping spots. The high resolution habitat mapping has also been used by Honours student Harriet Davies to publish a paper on integrating climate change resilience features into an incremental refinement of the zoning in the Ningaloo Marine Park (doi.org/10.1371/journal.pone.0161094).

MSc student Chris Nutt, in collaboration with the Yawuru rangers and the WA Department of Biodiversity, Conservation and Attractions has recently started an investigation into the environmental factors influencing distribution and abundance of *Lyngbya majuscula blooms* in Roebuck Bay Marine Park near Broome.

Following on from the detailed investigation of human use of the Kimberley coast, Lynnath Beckley presented several papers at international conferences highlighting the importance of understanding this in relation to zoning of Marine Parks as well as development of coastal infrastructure. Results from Eighty Mile Beach have highlighted the very high incidence of shore-based fishing and four-wheel driving in this remote part of NW Australia. Data from the surveys of the Dampier Peninsula have revealed the popularity of boat-based recreational fishing out of Broome. Upgrading of the road north to Cape Leveque will provide unprecedented access to fishing grounds in the Buccaneer Archipelago, previously difficult to access.

Lynnath Beckley continued her role as Australian representative on the International Scientific Committee of the SIBER programme, which focuses on sustained biogeochemistry and ecosystem research in the Indian Ocean. Together with American collaborators, Prof Raleigh Hood and Dr Jerry Wiggert, a major review of the biogeochemical and ecological impacts of boundary currents in the Indian Ocean was recently published (doi.org/10.1016/j.pocean.2017.04.011). Lynnath was also fortunate enough to spend three weeks at Scripps Institute of Oceanography working with Prof Mike Landry in their quest to understand how larvae of Southern Bluefin Tuna survive in the oligotrophic waters of their only known spawning ground between NW Australia and Indonesia.

As Chair of the Australian National Committee for the second International Indian Ocean Expedition (IIOE) Lynnath has been encouraging participation in this major oceanographic study. After several applications to the MNF, she was finally rewarded with a rare month of ship's time on the RV *Investigator* to re-examine the 110°E transect from 10°-40° S in May 2019. This transect was surveyed every six weeks during the early 1960s by the Australian navy vessels HMS *Gascoyne* and HMS *Diamantina*.

In addition to repeating the measurements made along this long transect during the 1960s to examine change in oceanic conditions, this voyage will focus on processes such as nitrogen fixation, primary production and trophodynamics of mesopelagic fishes particularly myctophids (lantern fishes). The voyage will also provide an opportunity to work on optics, ocean colour and ground truthing for the Copernicus satellite of the European Space Agency.

The 110°E transect intersects the western extent of several of the newly established Commonwealth Marine Parks in the southwest and northwest bioregions and will provide much needed ecosystem information on the oceanic regions of the Australian EEZ. **PhD opportunities exist for students wishing to conduct research on pelagic ecology and oceanic processes during this voyage – contact L.Beckley@murdoch.edu.au**

Edith Cowan University

Ecology of hybridisation in angelfishes at Christmas Island

By Federico Vitelli

Hybridisation has traditionally been considered rare in coral reef fish. However, recent studies have revealed that hybridisation is common in this group, and highlighted the importance of understanding the causes of this process. Since the majority of fish hybrids in the marine environment have been reported from coral reef ecosystems, this is particularly an issue in conservation programs for these systems. Determining the factors that facilitate hybridization provides an understanding of how marine fishes overcome the barriers of assortative mating, as well as predicting how hybrids will cope with changing environmental conditions, as is being seen in coral reef systems with climate change.

Top *Mixed species harem: two individuals of Centropyge flavissima (bottom left) swimming with a C. eibli (top right). The formation of mixed harems can facilitate hybridisation by increasing the chances of encounters between individuals of different species*
Bottom *A beautiful exemplar of hybrid between Centropyge flavissima and C. eibli at Christmas Island*

The angelfishes (family Pomacanthidae) have the greatest proportion (~30%) of hybridising species with 26 species reported to hybridise. This study aimed to examine a range of ecological factors that are considered to promote hybridization in terrestrial environments, and test these factors in the marine environment by studying hybridising angelfishes at Christmas Island (Indian Ocean).

In collaboration with the Department of Fisheries of WA, Parks Australia and Curtin University, we studied temporal and spatial patterns in abundance of the three parent species from the genus Centropyge (*C. flavissima*, *C. eibli* and *C. vrolikii*) and their hybrids, which have been reported from Christmas Island. We tested for overlapping patterns in habitat use and diet. Based on 14 years of surveys (2002-2015), *C. flavissima* was abundant, whereas *C. eibli*, *C. vrolikii* and all hybrid combinations were consistently rare. Parent species and their hybrids were more abundant at depths of 20 m compared to 5 m. All species and their hybrids had similar patterns of abundance around Christmas Island with significantly highest abundance recorded at the most sheltered sites. In addition, all parent species were recorded in similar microhabitats characterised by massive corals, encrusting and turf algae (see figures below). Spatial and taxonomic patterns in abundance were consistent across surveyed years. Parent species and their hybrids also had similar diets that were comprised of a mix of green, red and brown algae. Thus, rarity of parent species and niche overlap help promote hybridisation in angelfishes at Christmas Island.

This study provides empirical support that hybridisation in reef fishes conforms to terrestrial-based theories, and thus advances our understanding of this concept in coral reef systems. This research is ongoing, with the next aim to determine differences in the fitness of the three parent species and hybrids in terms of growth rates and histology, with final results expected in 2017.

Harvest rates for recreationally important finfish species

In July Alissa Tate completed her MSc study in collaboration with the Fisheries division at the Department of Primary Industries and Regional Development. The focus of this study was to assess generalised linear models (GLM) that can improve the harvest rates from shore-based recreational fishing in the Perth metropolitan region by standardising harvest rates according to influential factors. This study applied GLMs to analyse catch and effort data from a roving creel survey of shore-based recreational fishers in the Perth metropolitan area to determine the impact of factors (survey year and month, targeting, fishing platform, fishers' avidity, time of day and day type) on estimates of harvest rates for key nearshore species.

Due to the numbers harvested, and the high frequency of fishers targeting them, the species of interest were Australian herring (*Arripis georgianus*), School whiting *Sillago* spp, Garfish (Hemiramphidae family), Western Australian salmon (*Arripis truttaceus*) and Silver trevally (*Pseudocaranx georgianus*). Results showed that the significant variables and performance of models varied among each species. This variation in significant variables across species led to the conclusion that a blanket approach to choosing a model is not appropriate, and that the model choice, as well as explanatory variables, are species dependant.

Overall this study demonstrated the importance of standardising harvest rates for key nearshore species in the Perth metropolitan shore-based recreational fishery. The development of preferred models for each species, with specific distribution and explanatory variables, provide an approach that can be used to develop cost-effective survey designs, improve estimates of harvest rates, and inform future stock assessments and management of these valuable nearshore fisheries.

Curtin University
Centre for Marine Science and Technology

Compiled by Miles Parsons

Active acoustics

Before leaving CMST for the University of Tasmania, Sven Gastauer continued his work investigating the Northern Demersal Scalefish Fishery from an acoustic perspective, focussed on both the fish and their preferred seafloor (acoustic) habitat. Sven's PhD used acoustic and optical recording of catch data collected aboard a commercial fishing vessel to segregate acoustic backscatter in the water column into different groups. Through geostatistical modelling he has been establishing the likely distribution of these species groups across regions of the fishery that have been sampled using fisheries acoustics techniques (doi: 10.1007/s40857-017-0100-0, doi: 10.1016/j.fishres.2017.07.008). To help quantify this, Sven has also been developing techniques to relate the length dependent relationship between species and their acoustic reflectivity (doi: 10.1016/j.fishres.2017.05.001).

Fisheries acoustics continues to develop new technologies, with the use of broadband acoustics becoming more common. During her PhD, Arti Verma has been investigating the information that can be gleaned from having a swathe of frequencies, rather than a select group of narrow frequency bands, as a means to better discriminate between species using their overall frequency-dependent scattering characteristics (doi:10.1007/s40857-017-0105-8).

Top *Susan Martin interviews a shore-based recreational fisher on the rock wall at Ocean Reef*
Centre right *Daniel Yeoh counting fishers' at dusk along Fremantle North Mole*
Bottom right *North Mole. Shannon Mcnamara measuring a fishers' herring catch at Hillarys north wall (Photos: Alissa Tate)*

In conjunction with the Department of Biodiversity Conservation and Attractions services, Iain Parnum has been mapping parts of the Swan Estuary with sidescan sonar. From the Wyndam Bridge near Perth to the Reid Highway Bridge in the Swan Valley, Dr. Parnum has been identifying areas of the riverbed with differing topographic complexity.

Within selected areas, the CMST team has been deploying imaging sonar systems to investigate its use to observe habitat use by different size classes of fish. Where possible, these data will be matched with direct sampling collected by Chris Hallett and others at Murdoch University, during their biological sampling in the Swan–Canning River Park.

On a broader scale, Monserrat Landero has been comparing historical data from previous single-beam and multibeam mapping of the Ningaloo Reef. Using acoustic seafloor backscatter, together with the more commonly used bathymetric derivatives, Monse has been building towards investigating the benefits of including backscatter information in predictive modelling of species distribution. Closer to home, researchers Chandra Salgado Kent and Sarah Marley (together with Iain and Monse) have been keeping an eye and an ear on the dolphins in Fremantle Port using visual census from the nearby 'Hill' to locate feeding dolphins, and short-term echosounder surveys to get an idea of where fish are in the same area.

Miles Parsons has finalised his work on detecting sharks in shallow water (<20 m depth) using sonar, recommending specifications for a potential system that could maximise horizontal range and performance for detecting different sized megafauna.
Though not without limitations, Dr. Parsons noted length- and orientation-dependent returns, along with position in the water column and the ability to discern head and tail, even in an endfire position (up to ≈100 m range). He also observed behavioural characteristics (e.g. approach direction and speed) with some sharks changing position in the water column.

Underwater sound and fish
Associate Professor Rob McCauley continues to investigate the impacts of sound on marine fauna. Most recently through his Fisheries research and Development Corporation funded project studying responses of scallops and lobster to seismic air-gun surveys, Rob has also looked at how such surveys might impact plankton using a combination of single-beam echosounders, direct sampling and passive acoustic monitoring of sound exposure levels (doi: 10.1038/s41559-017-0195).

Miles Parsons and Rob McCauley, together with Jamie McWilliam, Christine Erbe, Chandra Salgado Kent and Sarah Marley have been characterising more fish calls around Australia (e.g. doi:10.3389/fmars.2017.00197, doi: 10.1007/s40857-017-0112-9). From the spatial distribution of mulloway (*Argyrosomus japonicus*) calls in the Swan River, Western Australia, to describing new fish sounds in coastal and coral reef waters of the northwest shelf and the Great Barrier Reef the team has looked at diel, lunar and seasonal patterns in these choruses.

Jamie McWilliam's PhD looking into the soundscapes of waters around Lizard Island on the GBR is also shedding a different perspective on how the fish choruses and overall soundscape have changed after environmental events, such as coral bleach and passing cyclones (doi: 10.1080/09524622.2017.1344930).

Researcher Klaus Lucke has been expanding his work on audiological tests on marine mammals to include several species of fish. With initial work showing promise, particularly given the complications of acoustic propagation within confined spaces that are often ignored in this research (https://www.youtube.com/watch?v=aQx3QWbf5aI&feature=youtu.be)

Finally, linking the active and passive acoustic study of fish, Miles Parsons and Iain Parnum, together with Surrich Surveying have been combining their CMST underwater sound recorders, with an MS1000 sidescan survey to investigate fine-scale tracking of individual mulloway within an evening chorus (doi:10.1007/s40857-016-0076-1).

Above *PhD student Camilla Piggott preparing RUV systems for deployment in the Kimberley*

University of Western Australia

Fieldwork like nowhere else: turning the tide on our understanding of fish recruitment in the Kimberley

By Camilla Piggott and Katherine Cure
University of Western Australia and Australian Institute of Marine Science

The Kimberley region of north Western Australia provides some unique challenges to marine scientists, such as 12 metre tides, high turbidity, 10+ knot water current and saltwater crocodiles to name but a few.
Coupled with its remoteness these challenges mean that, like most ecological processes, fish recruitment in the Kimberley is poorly described or understood.

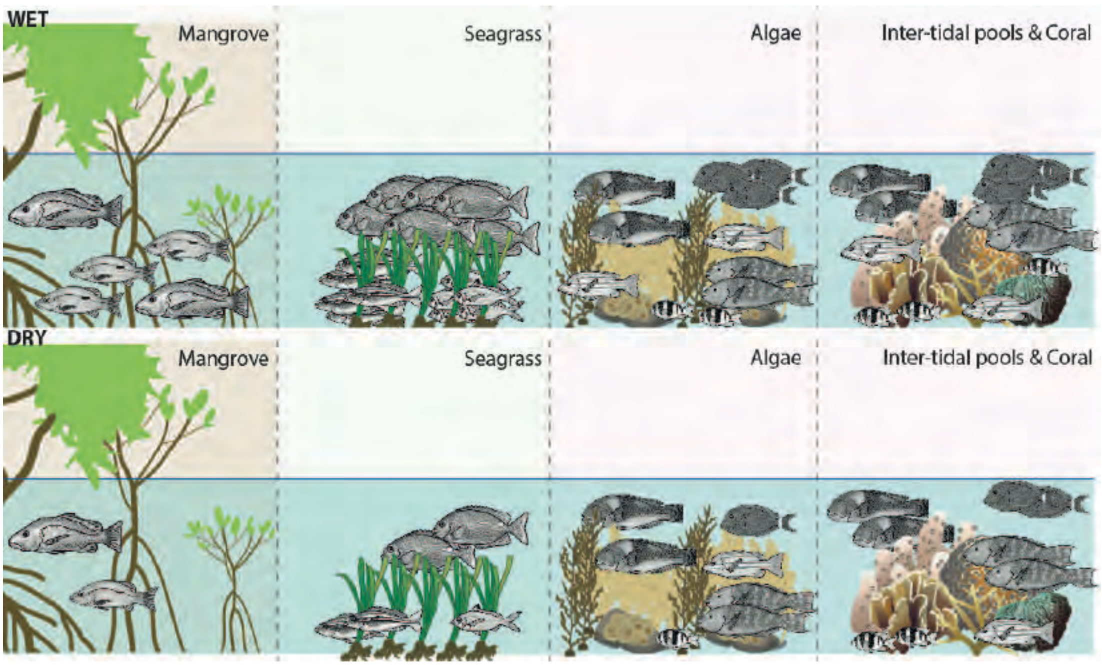


Figure 1. Summary of findings from juvenile RUV surveys during wet and dry seasons across five habitat types in the Kimberley region

In 2015 researchers from UWA, AIMS, DBCA, WAM and DoF trialed nine different methods to see which was most effective at quantifying recruitment in five different habitats; mangrove, seagrass meadows, macro algal beds and coral reef). We found that unbaited stereo remote underwater video (RUV) was unique in its ability to be deployed in all five habitats effectively, recorded a greater species richness and abundance of juvenile fish than its baited counterpart, and provided an accurate way to classify individual juvenile fish into recruitment cohorts, while keeping all researchers safely aboard the vessel.

Following on from our trials we deployed RUVs in the same five different habitats every eight weeks for one year to investigate seasonal variation in recruitment and how habitat type affects these juvenile fish communities. Our results show that juvenile fish assemblage differed between the habitats, with the snappers *Lutjanus argentimaculatus* and *L. russellii* associated strongly with mangrove habitats, *Gerres oyena*, *Siganus lineatus* and *Scaevius milii* with seagrass, and *Pomacanthus sexstriatus, Acanthurus grammoptilus*, *Choerodon schoenleinii*, *C. cyanodus*, *Dischistodus darwiniensis*, *Lutjanus carponotatus* and *Lethrinus laticaudis* with coral, algae and inter-tidal pools (Figure 1). Season strongly influenced patterns in fish recruitment strength with most recruitment occurring during the wet season. However, some species only recruited during the wet season whereas others showed some level of recruitment all year around (Figure 1).

While the use of RUVs didn't capture the diversity of recruitment occurring in this region of the Kimberley, it did provide quantitative information on recruitment in five different shallow water habitats and new baseline information on target fish species and those important to the local indigenous Bardi-Jawi community. Keep an eye out for publications relating to this research coming out in the next year.

Fish populations adapted to different temperatures connected during a marine heatwave

By Katherine Cure

In collaboration with scientists from UWA, Curtin University, and the WA Department of Primary Industries and Regional Development, we used genomic data to reveal genetic connectivity between populations of baldchin groper (*Choerodon rubescens*) along a temperature and habitat gradient in Western Australia.

The study showed that populations of this fisheries target species are adapted to different temperature profiles along the WA coast, but can be connected during extreme weather events such as marine heatwaves. In this example, baldchin groper larvae produced at the Abrolhos Islands, settled and survived to juvenile stages along the southwest coast of WA (400 km to the south and 3°C cooler), following a marine heatwave in 2011.

These findings reveal that extreme weather events may promote mixing of populations adapted to warmer *vs.* cooler oceans, impacting the way fish species respond to warming oceans, and possibly affecting the fisheries that depend on them. The study shows the power of genomic tools for better understanding how fish populations can adapt to local temperature profiles and connect with each other, potentially 'rescuing' species during times of environmental change via genetic exchange.

State Reports

Full text of the article can be found at: http://rdcu.be/u32Y.

Department of Primary Industries and Regional Development Fisheries Division

Compiled by Emily Fisher

Above *Baldchin groper Choerodon rubescens*
Right *Katherine Cure and Gary Kendrick collecting fish samples in the Abrolhos*

The past year has seen some structural changes to the Department, the most significant being the merging on 1 July 2017 with the Departments of Agriculture & Food and Regional Development to form a new Department of Primary Industries and Regional Development (DPIRD). Despite the name change, it has so far been business as usual for the Fisheries Division. In addition to the ongoing monitoring and assessment work, many staff attended this year's ASFB conference in Albany to present their research. Thanks to all those who have taken time out of their busy schedules and contributed material for this newsletter.

Ecosystem-Based Fisheries Management

Building on the back of the Department's third-party certification initiative and Marine Stewardship Council (MSC) certification of several WA fisheries over the past few years, the Ecosystem-Based Fisheries Management branch was formed in 2016. The focus of this group, which is headed up by past ASFB president Dan Gaughan and includes current members Alastair Harry, Emily Fisher and Fiona Webster, is to provide a more systematic approach to the monitoring and assessment of fishery impacts on non-target species, including bycatch, threatened species and habitats. Current projects include bycatch observation in the MSC-certified Peel-Harvey Estuary fishery in Mandurah, and sea snake and habitat monitoring in Shark Bay and Exmouth Gulf. Two recent observation trips have also been undertaken on board a commercial fishing vessel in the Kimberley barramundi fishery, collecting data on discarded bycatch and protected species.

Invertebrate Fisheries

Under the supervision of Nick Caputi, the Fisheries' Invertebrate Team has had another busy and rewarding year. For the molluscs team, including scientists Anthony Hart and Lachlan Strain, the key focus has been the "Principal One" assessments of four fisheries for MSC certification. Two fisheries have successfully attained MSC certification in 2017; the silver-lipped pearl oyster (*Pinctada maxima*) and the abalone fisheries (*Haliotis laevigata*, *H. conicopora*, *H. roei*). The other two fisheries under our purview applying for MSC certification are the Western Australian Sea cucumber fishery, which targets *Actinopyga echinites* (Redfish) and *Holothuria scabra* (Sandfish), and the Octopus Interim Managed Fishery, which targets the gloomy octopus (*Octopus tetricus*).

A survey of Sandfish stocks in the Dampier Archipelago was completed in early September 2017 to supplement the data and assessment evidence being provided to the MSC certification scheme. Additionally, in collaboration with the FRDC and Curtin University, we have been developing hatchery culture, grow-out, and restocking techniques for *Haliotis roei*, whose populations in the Kalbarri region experienced a catastrophic mortality in the marine heatwave event of 2010/2011.

Other work include the provision of research advice on how to improve fisher safety in the Perth recreational abalone fishery, which has experienced a number of fatalities over the past few years, testing of baited octopus traps to improve economic efficiency of fishing in octopus fisheries, and development of a RAM (Rapid Appraisal Methodology) to provide an opportunity for aquatic resource managers to innovate in areas of seafood production.

FRDC funded projects recently completed and due for submission in 2017 are: Seafood CRC Project No. 2011/762 – Recovering a collapsed abalone stock through translocation; FRDC Project No. 2012/016 – Demographic performance of Brownlip abalone: exploration of wild and cultured harvest potential; FRDC Project No 2012/237 – Decision tree and rapid appraisal methodology for new fisheries.

The trawl section, including scientists Mervi Kangas, Arani Chandrapavan and Inigo Koefoed report good news on the scallop front since a severe decline in abundance following the marine heatwave in 2010/11 prompted the closure of two key scallop fisheries in Shark Bay and Abrolhos Islands.

Emily and Alastair collecting bycatch information and biological data for barramundi during a recent fieldtrip to the Kimberley.

These industry-supported closures ensured that any remaining scallops were fully protected and allowed research to better understand why the stocks were so badly impacted. Following an improvement in the environmental conditions (cooler temperatures and El Niño conditions) after 2013, ongoing scallops surveys in November and February have showed a gradual increase in scallop abundance. This has allowed commercial fishing to re-commence in Shark Bay in 2015 and finally also in the Abrolhos in 2017, five years after the fishery closed. There has also been a major change in the management of scallops in Shark Bay, with a trial catch quota system operating in the last two years. The team is now working closely with industry to optimise the harvest of the available scallops and continue to improve our understanding of what makes these highly variable fisheries 'tick'.

Inigo Koefoed has continued work on his part-time PhD project, investigating the biology and environmental influences on penaeid prawn fisheries of Exmouth Gulf and Shark Bay. At the recent ASFB conference in Albany, he presented preliminary results from a global meta-analysis that described the relationship between latitude and growth for penaeid prawns. Since then, he has been busy collecting catch and reproductive data on the Endeavour prawns (*Metapenaeus endeavouri*) of northern WA, while also continuing to develop a harvest strategy for this species in the Exmouth Gulf fishery. Future work will attempt to incorporate this new information for Endeavour prawns into bioeconomic stock assessment models for the Exmouth Gulf and Shark Bay prawn fisheries.

The Invertebrate Team are also excited to announce that the 12th International Conference and Workshop on Lobster Biology (ICWL) has been awarded to a joint bid between DPIRD Fisheries Division and the Western Rock Lobster Council to be held in Perth in late 2020 or early 2021. The ICWL began in 1977 when a group of 37 lobster biologists from six countries met in Perth to discuss and compare their work on lobster ecology, physiology, and early stock management protocols, and to find common themes amongst the different species that were commercially fished. These conferences are held every 3 to 5 years and try to alternate from the northern to southern hemispheres. Participation has risen and held at approximately 200 people from 20 countries in recent events.

Tagging scallops in Abrolhos Islands on the RV Naturaliste in March 2017.

Subsequent ICWLs have been held in Saint Andrews, Canada (1985); La Habana, Cuba (1990); Sanriku, Japan (1993); Queenstown, New Zealand (1997); Key West, Florida USA (2000); Hobart, Australia (2004); Charlottetown, PEI, Canada (2007); Bergen, Norway (2011); and Cancun, Mexico (2014). This year it was held in Portland, Maine USA (4-9 June 2017). The tangible impact of these conferences is in the network of international collaborations they spawn and the resulting peer-reviewed publications in the conference proceedings and book chapters. There is synergy in the exchange of ideas and knowledge amongst biologists, managers, fishermen, and dealers from different parts of the world as we face the challenges of a changing environment and a global economy.

Top *Attendees of the inaugural Conference and Workshop on Lobster Biology in Perth WA in 1977*
Bottom *WA representatives at the 11th International Lobster Workshop receive a plaque from the hosts of the Maine lobster workshop*

Finfish

Over the past 12 months, the Finfish team under Brett Molony has continued to monitor and assess the state's finfish resources with major stock assessment completed in all four bioregions. Our new act, *Aquatic Resources Management Act 2016* (ARMA, replaces the *Fisheries Management Act 1994*), which becomes effective in January 2019, reflects an important shift in the Department's empowering legislation from a more conventional 'fisheries only' focus to a more holistic 'ecosystem-based' one. ARMA requires scientists and policy staff to think in terms of sustainable management at the 'resource' level, and critical discussions around how best to define the state's finfish 'resources' continue. Linked to this is the indicator species approach, a novel risk-based method to identify highest risk species groups that the Finfish group were involved in developing more than a decade ago. Steve Newman, Josh Brown and many others have co-authored an important paper on this approach recently accepted in *Marine Policy*. Finfish have also continued to work to apply the risk-based weight of evidence approach and better standardize the reporting of our assessment advice using this not-easy-at-first-reading format.

State Reports

Dave Fairclough has spent much of the year finalizing his West Coast Demersal Scalefish Resource assessment with details of snapper and West Australian dhufish to be made public very soon. Brett Crisafulli and Dave recently submitted a paper on acoustic tagging study of snapper in Cockburn Sound to the OTN special issue. Belated congratulations to Elaine Lek and partner on the arrival of daughter Maisie back in May.

Kim Smith and other Finfish/SADA staff recently participated in a week-long workshop on Australian Herring/ West Australian salmon at the Hillary's labs that also involved Mike Steer (SARDI) and Jon McPhail (PIRSA) from South Australia and Malcolm Haddon (CSIRO) and Jeremy Prince (Murdoch University). Local commercial (herring) fisherman, WAFIC and Recfishwest also participated in the workshop with a range of objectives that included reviewing the available biological and fishery data for herring and undertaking a weight of evidence stock assessment. Earlier in the year Kim was busy preparing for the first MSC annual audit for the Peel Harvey Net Fishery for which Chris Dowling is working on a sea mullet assessment. Rodney Duffy who came across to Finfish in July last year has now taken on more responsibility for South Coast estuarine research in particular with Cobbler in Wilson Inlet.

Interactions between the commercial sardine purse-seine fishery and flesh-footed shearwaters in the waters of King George Sound off Albany has been generating much interest and heated debate for many years with strong opinions on both sides. To better understand the actual level of interactions, Jeff Norriss and team (Emily Fisher, Tim Leary, Nick Jarvis and Neil Rutherford) were busy in March at sea observing fishing operations where they racked up more than 75 trips and observed more than 60 net shots. Results of this study will presented to industry at the Annual Management Meeting in Albany next week.

Herring are an important species in WA to both commercial and recreational sectors

Paul Lewis, with help from Brett Crisafulli and others in Finfish, completed the final survey in February this year of the 5-year project monitoring the southwest artificial reefs. He presented some of the results at the ASFB Albany conference. Paul has recently taken over the monitoring and assessment of the Large Pelagic Resource, including the WA Spanish Mackerel fishery.

In addition to coordinating planning for the Albany Conference, Gary Jackson spent much of the first 6-months of this year working with Ainslie Denham & Alex Hesp (SADA) and Emily Fisher on a Gascoyne Demersal Scalefish Resource assessment (snapper and goldband snapper), the results of which will also be publically available before end of the year. Gary and Nick Jarvis continue to work on shark depredation with the focus now on recruiting skippers/ operators to collect swabs following depredation events with charter vessels operating in the West Coast, Gascoyne and Pilbara. Gary is also working with Steve Taylor (SADA) writing up results of recreational boat ramp survey in Shark Bay in 2016/17, looking at the effects of changes in management of snapper in 2016 when the slot limit and harvest tag system (in Freycinet Estuary) were removed.

Over the past 30-40 years, post-graduate students and research staff at Murdoch University have been instrumental in determining the biology of many commercially and recreationally important fish and invertebrate species in southwestern Australia. Funding obtained by Prof. Ian Potter, largely from FRDC, enabled much of this research to be undertaken, with the data becoming invaluable in respect to providing historical information on the biological characteristics, such as length and age compositions and mortality rates. Following negotiations between Department and Murdoch, Peter Coulson has been working with us in Finfish and has collated data for 59 fish and invertebrate species to create a biological database that will ensure this irreplaceable resource is not lost and can be made available to other researchers. The willingness of the many past students and staff, who have kindly contributed data is greatly appreciated.

Fabian Trinnie, previously with the SADA group, has also recently shifted across to join Finfish where he now working in Steve Newman's Northern group. Currently he is analyzing data on Goldband snapper from fisheries independent surveys in the Kimberley as part of the stock assessment of the Northern Demersal Scalefish Resource. He is also looking at Lake Argyle Silver Cobbler fishery and the Kimberley gillnet and Barramundi fishery to determine whether CPUE can be standardised.

Following on from his work on the effects of the 2010/11 marine heatwave on fish species off the west coast of Australia that were published in *Regional Studies in Marine Science* in May 2017 (https://doi.org/10.1016/j.rsma.2017.03.005) Rod Lenanton, amongst other interesting projects, has been working with Belinda Cannell (Oceans Institute, UWA) on the dynamics of pilchards/scalies/anchovy populations in the lower Swan River/Cockburn Sound/Fremantle region and consequences for penguin breeding colonies on Garden and Penguin Islands.

Above *Brailing sardines aboard off Albany (Photo Jeff Norriss)*

Ex-Finfish scientist and ASFB Past President, Dan Gaughan, has been doing a difficult job in the seat vacated by previous Exec Director Research, Rick Fletcher, steering the Hillarys 'ship' post amalgamation of Fisheries, Primary Industry (Agriculture) and Regional Development, back in July. While this is a path well-trodden by many ASFB members in other state's over the last 15-20 years, it is very new territory for us here in the west.

Finally, sadly, in December 2016, the Finfish team lost an ex-colleague, and to some of us mentor and friend, with the untimely death of Mike Moran. Mike joined WA Fisheries in 1981, initially to work on the Shark Bay Snapper fishery before going on to other scalefish research in the Pilbara and Kimberley and on sharks. The research he undertook in waters of the State's northwest over more than 20 years formed the basis for development and sustainable management of important commercial and recreational fisheries.

Mike was a strong supporter of ASFB and regularly attended annual conferences. Vale Mike.

Above *Bunbury Reef showing benthic colonisation after 4 years in the water (Photo Paul Lewis)*

Student Spotlights

Anna Cresswell – PhD Candidate
University of Western Australia and CSIRO

'The role of coral morphology in structuring fish assemblages at Ningaloo Reef'

Supervisors: Timothy Langlois (UWA), Michael Renton (UWA), Gary Kendrick (UWA), Damian Thomson (CSIRO), Mick Haywood (CSIRO)

Anna after a day out surveying on Ningaloo Reef; Photo: Mat Vanderklift

In biological systems, structural complexity is recognised as an important driver of coexistence and species diversity. This is particularly true for coral reefs, where some of the most biodiverse life on Earth coexists. A key contributor to reef structural complexity is the varied morphologies into which reef corals can grow. My PhD research as part of the Ningaloo Outlook project (a partnership between BHP and CSIRO) investigates the diverse structural assemblages of coral on coral reefs and how this influences reef fish communities.

I am particularly interested in how acute and chronic disturbances impact coral and fish assemblages. One of my chapters develops a three-dimensional simulation model of coral growth through time, looking at how corals respond to their local light and hydrodynamic environment. This model will help us to understand how changes in acute disturbances regimes (e.g. cyclones) may change future morphological assemblages on coral reefs. To give the coral growth model relevance to the broader coral reef ecosystem I have conducted statistical analyses of changes in the cover of different coral morphologies, e.g. branching, massive, encrusting and tabular, over the last decade at Ningaloo Reef, WA and linked these changes to the fish assemblage. I presented the preliminary results of this at the ASFB conference in Albany, finding that declines, particularly in tabular corals, are linked to declines in the corallivores (the fish that are obligatory coral eaters). I am continuing and expanding this work through continued development of the 3D coral growth model and further analysis of temporal fish and coral data collected at Ningaloo Reef where chronic (e.g. fishing), and acute disturbances (e.g. cyclones, heat waves) are likely to have influenced both the fish and coral communities. The outcomes of this research will have applications in management of the marine park and fisheries both at Ningaloo and other coral reefs.

Left *Anna preparing for a transect survey; Photo: Damian Thomson*
Right *Fusilier on the reef slope, Ningaloo Reef; Photo: Anna Cresswell*

Lauren Peel– PhD Candidate

University of Western Australia

'Population dynamics, movement patterns and trophic ecology of the reef manta ray (Manta alfredi) at D'Arros Island, Seychelles'

Supervisors: Prof. Shaun Collin (UWA), Dr Mark Meekan (AIMS), Dr Guy Stevens (The Manta Trust), Dr Ryan Daly (Save Our Seas Foundation)

Above *Lauren at her field site*
Right *Manta in the Seychelles*

Manta ray populations have suffered drastic declines over the past 75 years as a result of targeted fishing practises which aim to supply manta gill plates to the traditional Chinese medicine market. As manta rays exhibit extremely slow life history characteristics, the impacts of these unsustainable pressures on manta ray population sizes are further intensified; placing these species (*Manta alfredi* and *M. birostris*) at an even greater risk of extinction. To determine the scale at which management strategies such as Marine Protected Areas (MPAs) need to be applied in order to benefit current and future conservation efforts to protect manta ray populations, it is important to first determine when, how, and why these animals are moving through their environment.

The overarching aim of my PhD is to assess the population dynamics, movement patterns, and trophic role of the reef manta ray (*M. alfredi*) at D'Arros Island, Seychelles, in order to better understand the conservation needs of this species at this location in the Western Indian Ocean. Population size will be modelled using data collected through photo-identification techniques, as individual manta rays can be identified from the unique pattern of spots that they possess on their ventral surface. Acoustic and satellite telemetry will then be used to track the local and broad scale movements of reef manta rays throughout the Amirante Island Group and wider Seychelles, and contribute important knowledge to our current understanding of the home range size of these animals. Lastly, stable isotope and fatty acid analyses will be used to investigate the trophic role and feeding ecology of reef manta rays at D'Arros Island. Ultimately, the results of this study will provide critical insights into the conservation needs of reef manta rays in Seychelles and will be used to promote the development of scientifically-informed management strategies aimed at protecting these animals in key areas throughout the country.

You can learn more at https://saveourseas.com/project-leader/lauren-peel/ and follow the Seychelles Manta Ray Project at: https://www.facebook.com/SeychellesMantaRayProject/

Evan Byrnes– PhD Candidate

Murdoch University

'Home range scaling in sicklefin lemon sharks (Negaprion acutidens): tests of bioenergetics mechanisms'

Supervisors: Dr. Adrian Gleiss (Murdoch), Dr. Stephen Beatty (Murdoch), Dr. Ryan Daly (SOSF-DRC)

Above *Evan Byrnes and Jenna Hounslow about to release a sicklefin lemon shark tagged with a CATS diary tag*

While we have a good understanding of the determinants of home range size of birds and mammals, we have a poor understanding of the mechanisms that govern home range size of marine organisms, such as elasmobranchs. Given the threatened and declining state of many shark populations around the world, as well as the integral role that knowledge of species' home ranges plays in conservation planning, it is important to understand the factors that govern shark home ranges. Body size is considered the primary determinant of the home range size, such that larger animals have larger home ranges that encompass enough resources to meet their energetic demands. My PhD thesis aims to understand how energetic mechanisms govern changes in home range size of sicklefin lemon sharks over ontogeny. Specifically, combining laboratory experiments with field observations of shark movements and behaviours, I aim to understand how metabolic rate of sharks' change over ontogeny and how these size specific energy requirements interact with environmental factors to determine individual shark home range requirements.

First, I aim to use respirometry and acceleration data loggers (ADLs) to determine the thermal and body size dependence of energetic expenditure in sharks, and to establish a predictive equation that can be used to calculate field metabolic rates. Then, this information will be combined with data on free-ranging sharks' movements and behaviours tracked using acoustic telemetry and ADLs, to decipher where and how sharks expend energy throughout their home range. In addition, I aim to examine how energetic constraints, such as resource density and competitor overlap influence home range size. Prey and competitor densities will be assessed using seine net and fishing surveys, respectively. Finally, data from these three aims will be used to incorporate size integrative home range models to determine the scaling relationship between body size and home range in lemon sharks.

Shazana Sharir – PhD Candidate

National University Malaysia, Bangi

"The Movement Ecology of Tor tambroides in Tiang River Royal Belum State Park, Malaysia"

Supervisors : Shukor Md Nor (National University Malaysia, Bangi), Amir Sah Ruddin (Universiti Sains Malaysia, Penang) and Paul Close (University of Western Australia, Albany)

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Above *Shazana in the jungle*

My PhD project is looking at the movement of a locally endangered species; *Tor tambroides* in Tiang River, Royal Belum Rainforest Malaysia. Being vulnerable to anthropogenic activity such as logging and over harvesting, I am interested to identify to what extent this species moves using acoustic telemetry. This project will help understand the movement behavior of this fish species and provide a base for its conservation management. Acoustic transmitters will be implanted on 30 fish and movements will be detected by six pairs of passive receivers and an active receiver. Through this passive and active technique, I will try to answer my main thesis objective, which is to investigate the movement and home range size of *T .tambroides*. I will also be taking water quality parameters, water flow, water level and rainfall data throughout the year to gain understanding relating to the environmental conditions along the areas of movement of this species. Another objective is to determine the daytime habitat preference of *T. tambroides* using active techniques. In this objective, physical factors such as canopy cover, overhanging vegetations, submerged logs, boulders and other possible available refuge, will be assessed.

I am still in the early phase of data collection for ichtyofaunal diversity in the Tiang river and have found 34 species of fish. These include alien species, as well as locally common and endangered species. To get myself ready for the telemetry part of my study, we conducted a three-week radio telemetry pilot study on a similar species. This has put me in a better position to start telemetry work on *T. tambroides* in December 2017. I'm privileged to have the Royal Belum Rainforest as my office; it is a pristine tropical environment, rich in biodiversity, and offers many opportunities for research.

Top Left *Tor tambroides or Kelah*
Top Right *Trying out telemetry at Tembat river, Terengganu*
Right *Major role players in my study; state park ranger, TNB research technician and the indigenous people of Royal Belum*

Publications from this study are underway and will be shared through my Research Gate site https://www.researchgate.net/profile/Shazana_Sharir2. You can also see updates on the journey and adventures of my PhD life via Instagram instagram.com/shazanasharir

Jarrad Baker– PhD Candidate

Curtin University

'Validation and development of biochemical markers of exposure to Australian light crude oils in fish'

Supervisors – Monique Gagnon & Christopher Rawson, Curtin University

Above *Jarrad's best fish face*

During my honours year, I conducted a field health assessment of sand flathead inhabiting Port Phillip Bay in Victoria. This health assessment included a range of measurements from the molecular level (such as DNA damage) through to organism level (physiological indices). This research has since been published in PLoS ONE (https://doi.org/10.1371/journal.pone.0164257).

This research positioned me well for acceptance into a PhD program researching biochemical markers (biomarkers) in fish exposed to crude oils. In Western Australia there is substantial crude oil exploration and production, and whilst rare, oil spills from these activities are an ever-present risk. My PhD research is looking at the tools used following oil spills to monitor the exposure and effects on fish. The composition and type of oil found in WA waters is vastly different from many oils found around the world. It is very light in colour and consistency and lacks many of the large (and more toxic) hydrocarbons associated with heavier oils. Questions are being asked about the usefulness of current biomarkers with this kind of oil, as many biomarkers rely on activation by the larger toxic components which are often not present in WA oil.

The first part of my research involves a controlled lab exposure experiment to validate responses in fish exposed to environmentally relevant concentrations of crude oil. This experiment will take a little over 2 months and is expected to begin very shortly. From there, I plan to investigate the use of 'novel' biomarkers for WA oils, with a focus on ones that can be undertaken rapidly, in the field in an oil spill scenario with only basic lab equipment. Finally, I plan to use a proteomic approach to investigate the up/down regulation of proteins in fish exposed to WA crude oil in an attempt to identify new biomarkers that may be suitable for development.

2017 Conference, Research and Travel Awards

Student International Travel Scholarship

Jordan Matley (PhD)

Postdoctoral Research Associate
Center for Marine and Environmental Studies
University of the Virgin Islands

This past October, I was fortunate to attend the Indo-Pacific Fish Conference in French Polynesia, in large part because of ASFB. My award for 'best paper' at the Hobart symposium in 2016 really opened the door to present research associated with my PhD. It was perfect timing as well because I was able to present new ecological perspectives using the experimental data affiliated with my award. The conference included ~500 scientists from Japan to New Zealand. Overwhelmingly it was the Australian contigent that led the charge, and must have contributed to at least half the numbers. There was never a dull moment during the sessions, as well-known ecologist and fisheries scientists were equally spread across the five rooms and five days. Whether it was shark ecotourism, parrotfish feeding modes, overfishing on small islands, or genetic diversity of mobile species, there was something new and interesting to be learned. Presenting in a room with chickens squawking in the background was something of a new adventure for me, one that only increased the appeal of Polynesian culture. No matter where you went, the French and the Polynesian people were eager to help, and excited to converse (even if your french is tedious!). And the diving and snorkeling outside the conference was immaculate! I have recently taken up a postdoc in the Caribbean, and the opportunity to return to the Indo-Pacific for the IPFC was rewarding, and not just because it allowed me to engage with past and ongoing collaborators. It was an undeniably emotional time for me as well. Being able to reconnect with so many people that made my time in Australia a wonderful experience was special, and at the base of many of those experiences is the ASFB, which I will always truly appreciate.

Above *Jordan at IPFC 2017*

Paloma Matis (PhD)

University of Technology Sydney, NSW

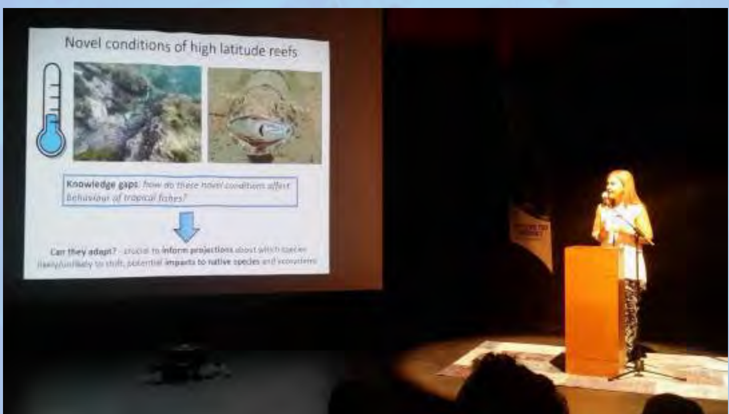
The rise in environmental temperature presents various challenges that threaten the survival of coral reef fishes as they are tropical ectotherms that have evolved in relatively stable thermal conditions and already live close to their upper thermal limits. However, the longer-term ability of species to respond to future warming is not well understood. But it's likely this response will be linked to species persistence at existing locations as well as shifts in their geographic distributions.

My PhD thesis aimed to assess how habitat associations of tropical fishes may vary with both latitude and temperature, in light of dynamic climate change impacts, including ocean warming and the poleward range expansion in species distributions. To address this I designed my research questions from two perspectives. Firstly, I explored habitat associations and behaviour of range expanding tropical reef fishes across a latitudinal gradient. Then, I looked at the effects of warming on habitat preferences of fishes in their natal tropical reefs.

The paper accompanying my ASFB Student International Travel Scholarship was 'Latitudinal variation in behavioural patterns and social group structure of range expanding coral reef fishes'. In this study I explored the behavioural time budgets, feeding patterns, social interactions and movement of three common tropical fishes (*Chaetodon auriga, Abudefduf sexfasciatus* and *Pomacentrus coelestis*) across a latitudinal gradient on the east coast of Australia, spanning from the Great Barrier Reef (23˚30'30"S) to Sydney (33˚48′06″S). Results showed significant differences in the behavioural patterns and social group structure of tropical fishes among latitudinal locations and among species. Differences in behaviour further highlights the constraints associated with high latitude reef environments (e.g. temperature, resource availability, predation and competition) and give us greater insight into how species may cope or adapt through modifications in their behaviour.

From winning this award I was lucky enough to be able to present my research at the recent Indo-Pacific Fish Conference, 2017 in Tahiti. I sincerely thank the ASFB for their support. Having just recently submitted my PhD thesis, participating at the conference was a fantastic experience and a great opportunity to contribute to and be amongst experts in various fields of fish biology.

For the latest updates on my research you can follow me on Twitter @paloma_matis



Above *Paloma takes the podium at IPFC 2017*

Victorian Marine Science Consortium Award

Mark Chambers

PhD Student, University of New South Wales

Supervisors: Dr Leesa Sidhu & Dr Ben O'Neill (UNSW), Dr Nokuthaba Sibanda (Victoria University, NZ)

My research has focused on statistical analyses of historical data arising from studies of southern bluefin tuna (SBT; *Thunnus maccoyii*), with an emphasis on Bayesian methods. Data arise from tagging studies run since 1959, together with spatially disaggregated catch, effort and length frequency data. I have published a couple of papers modelling tag shedding rates in SBT and one modelling growth.

My most significant work to date has been a synthesis of data informing the spatial structure of juvenile southern bluefin, up to the age of about five years. Juvenile SBT are widely distributed in the temperate marine waters of the southern hemisphere and there has been debate about the extent of mixing among juveniles found south of Africa and those observed off the southern and south-eastern coasts of Australia.

In a paper to appear in *Ecology and Evolution* (Chambers et al., Evidence of separate subgroups of juvenile southern bluefin tuna), we present multiple lines of evidence to contend previous speculation that the juveniles off South Africa remain mostly separate from those observed off southern Australia with limited intermingling. Qualitative summaries of tags released in oceanic waters, provide the first evidence that juveniles summering in the Great Australian Bight (GAB) exhibit fidelity to winter feeding grounds in the south east Indian Ocean and the Tasman Sea.

I argue that the apparent migratory behaviour is best explained by the so called "adopted migrant" hypothesis. One- and two-year-old SBT, spawned in the tropical east Indian Ocean, appear in the GAB in summer. These naïve juveniles learn established migration routes by following more experienced juveniles that winter in the south east Indian Ocean, or alternatively in the Tasman Sea. The first-time migrants repeat their adopted migration routes in subsequent years, and thereby pass on their knowledge to younger cohort

The adoption of migratory contingents via social interaction between naïve juveniles and slightly older congeners in the GAB explains the 1980s collapse of the pole and line/purse seine fishery for SBT off NSW, which has been previously difficult to understand. I claim high fishing mortality off NSW, led to disruption of the juvenile migratory structure. More precisely, the contingent of juveniles that migrated seasonally between NSW and SA was critically depleted such that naïve juveniles in the GAB lacked the guidance of more experienced congeners to direct them to wintering grounds off southern NSW. With the supply of the two-year-olds that previously sustained the fishery cut off, a highly capitalised fleet assisted by spotter planes quickly depleted any juveniles remaining in the Tasman Sea contingent.

Thank you to the Victorian Marine Science Consortium for their generous sponsorship of the award.

Above *1 yr old tuna tagged off Albany and providing data for Mark's project; photo:Alistair Hobday*

Gilbert P. Whitley Memorial Awards

Marianne Nyegaard- SENIOR AWARD

PhD Student, Murdoch University

As part of my PhD, I set out to do population genetics on the Short Ocean Sunfish (*Mola ramsayi*) in the Indo-Pacific, but instead inadvertently opened Pandora's Box of taxonomic sunfish confusion. Post-1950s, four species were recognised in the family Molidae, but this pleasingly simple taxonomy turned out to be more like a pretty lid hiding several hundred years of enthusiasm amongst early naturalists in describing new sunfish species – tallying over 50 at the end of the 1800s.

When I analysed sunfish tissue samples from the longline by-catch in New Zealand, it became apparent that we had chanced upon a mysterious genetic clade in the *Mola* genus, known only from three tissue samples in a decade old study. While it seemed the perfect opportunity to find out what species this was, it wasn't immediately apparent how one goes about finding an elusive fish with unknown morphology. The following three years was much like an unpredictable, complicated treasure hunt across New Zealand, relying on social media and local natural history museums to alert me to sunfish strandings, as well as sample and preserve key sunfish body parts for me. Meanwhile, I attended strandings myself when I could, and trawled through museum collections in Australia and New Zealand. In an iterative process of morphological and genetic analysis we managed to describe the unknown sunfish from 27 specimens across a size spectrum of 50-242 cm total length.

Above *Marianne and which Mola?*

Ironically, finding and describing the fish was easy compared with establishing if it had been described before. Sorting through the old species literature in a plethora of languages, some with sunfish depicted alongside mermen and other fantastical sea monsters, was a daunting and extremely time-consuming task. Together with researchers in Japan and New Zealand, we painstakingly pieced together the puzzle, and were surprised to find our fish had not been described previously. Most of the nominal sunfish species had been described from the Mediterranean and European seas during the 1700 and 1800s, however towards the late 1800s suspicion started to arise that all those different species were probably all one and the same. So just as ichthyology arrived in Australia and New Zealand, the lid on Pandora's sunfish box slammed shut, and the local sunfish swam forth incognito as *Mola mola*. It was a monuments day when I met with colleagues from Japan and New Zealand to prepare the holotype of *Mola tecta*, the Hoodwinker Ocean Sunfish, at the Museum of New Zealand Te Papa Tongarewa. And with Pandora's Box of Giants now wide open, who knows what we will find.

Cameron Desfosses- JUNIOR AWARD

Research Scientist
WA Department of Primary Industries and Regional Development

Macroalgae are increasingly being recognised as important nursery habitat in tropical ecosystems, yet little is known about their contribution to juvenile fish diets. My research examines the significance of macroalgae and associated infauna, to the diets of juvenile fish in the Ningaloo lagoon, focussing on its contribution to the diets and whether this varies seasonally.

For the first component of this project, juvenile fish were collected from macroalgal beds in the Ningaloo lagoon during February and July, 2015. Stomach contents from 164 fish, representing 11 species, were identified to 37 taxa in 14 broad categories, and the percent volume of items was recorded. Multivariate analyses quantified similarities in the stomach contents to define 3 trophic groups (herbivore, zoobenthivore and carnivore). The variation in specialisation or generalisation of prey items was also assessed between species and seasons.

Macroalgae represented 34.2% of *Naso fageni* and 41.1% of *Siganus fuscescens* stomach contents in February, which increased in July as fish became larger (37.7% and 58.2% respectively). Specifically, *Sargassum* spp. content increased by 10-fold in *Siganus* guts collected during winter, even though *Sargassum* biomass typically declines at this time. Infauna groups associated with macroalgal beds were the dominant components in the guts of juvenile Lethrinidae (*Lethrinus atkinsoni, Lethrinus nebulosus*), Lutjanidae (*Lutjanus kasmira, Lutjanus quinquelineatus*), and Mullidae (*Parupeneus barberinoides, Parupeneus spilurus, Upeneus* sp.). Intra-specific variation analyses found that smaller fish caught in February had a narrower trophic width and a more specialised feeding strategy than larger-bodied individuals of the same species in July.

These results highlight the importance of macroalgal beds to diets of the selected juvenile fish species and their contribution to trophic flows in the Ningaloo lagoon. These findings enhance our understanding of variation in diet with ontogeny, improve our understanding of fish diets and provide fundamental information for the second component of the project: to build an Ecopath with Ecosim food-web model to explore the dynamics of species interactions in the Ningaloo ecosystem.

The 2017 Australian Society of Fish Biology Conference, held in Albany, was my first opportunity to present my work. It was a real pleasure to present this project and meet other scientists from Australia and around the world at the networking events. While prior commitments meant I was unable to stay for the end of conference dinner and collect the award personally, I would like to express my sincere thanks to the ASFB Committee for selecting me for this award.

Above *Cameron collecting samples in Sargassum fields*

Barry Jonassen Award

Maud Kent- Winner

PhD Student, University of Sydney
Supervisor: Ashley Ward

I am interested in investigating the evolutionary history of sociality and collective behaviour. The aim of my PhD is to address this gap in our understanding by quantifying collective behaviour across species, lineages and over multiple generations using fish as a model organism.

Above *Maud Kent*

For my current project funded by ASFB, I plan to use Eastern mosquitofish, *Gambusia holbrooki,* as my study species. Alongside cane toads, mosquitofish are one of the most damaging invasive vertebrate species in Australia. Within NSW, mosquitofish have spread throughout many environments from coastal lagoons to mountain streams and pose a threat to endemic species and local biodiversity. Building on previous research outlining the phylogenetic distances and invasion history of five NSW populations, this study will attempt to identify which aspects of their behaviour have been conserved and which aspects have been lost as they radiated throughout NSW. Ultimately, this will lend valuable insight into which characteristics of their social behaviour form the foundation of their success as an invasive species.

Gabriel Cornell- Runner Up

MSc Student, University of Melbourne
Supervisors: Barbara Downes, Rob Hale and John Morrongiello

Many rivers across Victoria are degraded, with large stretches of many streams now buried under sand slugs, especially in part of the upper Goulburn catchment. This has led to a loss of many scales of complex habitat; pools are filled in and large wood is buried and washed out. Detritus is also lost from the degraded reaches as there are few retentive structures in these sandy bottomed streams. This can have notable impacts on the stream biota.

My Masters research follows on from a previous experiment that showed placing pairs of wooden garden stakes in a sand-inundated stream increased detrital loads by 1000% and invertebrate abundance and richness by up to 200%. I want to know if fishes show any response to this simple intervention.

This award will help me conduct a year-long field experiment, asking whether increasing food availability and small scale habitat complexity can impact on fish population demography and community structure. I hope this work will help uncover the relative importance of in-stream physical features (e.g. pools, large wood) and other resources (i.e. detritus and associated food) in structuring fish communities. Electrofishing surveys targeting juvenile and adult fishes are already underway, and larval sampling is likely to ramp up this summer. We have caught a fair few river blackfish and pygmy perch and, excitingly, some adult Macquarie perch.

Above *Gabriel's catch*

Michael Hall Award for Innovation

Katie Sambrook – Winner

PhD Student, ARC Centre of Excellence for Coral Reef Studies, James Cook University

Beyond the reef: the influence of seascape structure on coral reef fish communities, and their use of mangroves, seagrass and macroalgal beds

Coastal marine habitats, such as coral reefs, mangroves, seagrass and macroalgal beds, are extremely productive environments and support a range of commercially and ecologically important species. Although often viewed in isolation, these habitats are frequently linked via fish movements. For instance, several species of reef fishes use mangrove, macroalgae or seagrass habitats as juveniles, some make tidal or diel movements between habitats to feed and others migrate large distances across the seascape to access spawning grounds.

Although we know that many reef fishes use a range of habitats, we know very little about how the spatial arrangement of habitats surrounding coral reefs can influence fish communities on the reef, or the use of these non-reef habitats. So why might this be important to understand? Globally, we're witnessing the ongoing widespread loss, degradation and fragmentation of many shallow-water coastal habitats including coral reefs, mangroves and seagrass beds. This can alter the spatial arrangement and composition of habitat patches, which may in turn, affect how reef fishes use the wider seascape, as well as altering population dynamics and the structure of fish communities on reefs.

My PhD examines how the surrounding seascape can influence fish communities on reefs, as well as their use of non-reef habitats. As part of my PhD, I will be comparing fish communities on coral reefs that are at different distances from mangroves, seagrass meadows and macroalgal beds, as well as surveying reef fishes in these non-reef habitats. I'm conducting my research in Kavieng, New Ireland Province, Papua New Guinea at the National Fisheries Authority Nago Island Mariculture & Research Facility. I've chosen to carry out my research in this region because coastal communities there are heavily reliant on marine resources as a source of protein and/or income generation. As a result, the development of appropriate spatial management strategies is critical for long-term food security, as well as contributing towards economic stability.

I'm very honoured and grateful to receive the ASFB Michael Hall Student Innovation Award, and look forward to sharing my results in the future.

Above *Katie Sambrook, Michael Hall Award winner*

Leteisha Prescott- Runner Up

Master's Candidate, ARC Centre of Excellence for Coral Reef Studies and the College of Science & Engineering, James Cook University
Supervisors: Dr. Jodie Rummer & Dr. Naomi Gardiner

"What happens when fish settle onto a degraded coral reef? Impacts to the 'health' of the gill microbiome with implications toward overall performance."

Coral reef fishes rely on corals for food, shelter from predators, and structure for foraging and reproduction, but coral abundance is severely decreasing due to increases in anthropogenic activities. While the changes in coral cover and abundance has been explicitly documented, understanding the impact of loss of habitat on the associating fishes is rather scarce. Studies are starting to show, however, that there can be significant negative effects on fishes. Indeed, exposure to degraded habitat is altering the ability of the fishes to undertake several daily activities, including behaviors associated with assessing risk and overall survival. However, it is unclear as to which underlying physiological mechanisms are being altered.

My research focuses on trying to tease apart the underlying processes that may be impaired when coral reef fishes are exposed to degraded habitat, and in particular, during the critical early life stages when fishes are settling onto the reefs. Most coral reef fishes endure a pelagic larval period, where they spend weeks to months in the pelagic environment before finding a reef on which to settle. In the face of increasing anthropogenic activities and reduced habitat availability, the likelihood of a young fish settling onto a degraded habitat compared to a live, healthy habitat is becoming more common. My project is designed to determine how young fish settling onto a degraded habitat compare to those settling onto a live, healthy habitat. Specifically, I am investigating how the gill microbial communities – the first line of defense for the organism – change under different conditions. By understanding how the microbiome changes, we can determine whether the gills may be vulnerable to entry, growth, and investment of pathogens and diseases that are known to be associated with dead corals. Furthermore, linking habitat degradation with the types and levels of pathogens found on the gills of several species of coral reef fishes will help to define threshold levels and characteristics of gill pathogens that can

Above *Leteisha Prescott, Michael Hall Award runner up*

serve as indicators as fish and ecosystem health. Ultimately, this information can lead to a better mechanistic understanding of how coral reef fish populations are affected by degraded habitats. Additionally, because I am also investigating commercially and economically important species (e.g., coral trout), these findings will be important in linking habitat protection to effective fisheries management and conservation of coral reef fishes.

Student Communication in Science Competition

Salman Khan – Senior winner

PhD Student, Aligarh Muslim University, India

Salman Khan as won this year's SCiSC Video competition Award in senior category. Researchers from across the globe participated in the competition by submitting a "3-minute video of their research work". A total of seven videos were selected for the final phase that was based on public response to view, download, vote and comment. Salman's video got the highest number of views and appreciation. He received $1,000, a citation and most importantly, a chance to interact with internationally acclaimed top researchers and legendary scientists of his research specialty. Salman is a dynamic researcher with a good number of national and international publications, and also participations in Conferences/Symposia/Workshops. His research focuses on developing the precise and scientifically sound protocols for age and growth estimation, and stock delineation in commercially important freshwater fishes in India.

Joni Pini-Fitzsimmons – Members choice

Masters Candidate, Macquarie University

http://stingraydiaries.weebly.com/ | *http://thefishlab.com/*

Food provisioning in stingrays

It is common practice for recreational anglers to discard fish waste back into waterways, yet the effects of this incidental provisioning have not yet been

Above *Salman receives award from Harry, our new president*

assessed, and are not currently considered in the management of recreational fishing along Australia's coastline. At Jervis Bay, local anglers have been incidentally provisioning short-tail stingrays through fish cleaning activities for over 30 years, providing an opportunity to investigate the influence of provisioning from recreational fish cleaning on the behaviour and movement patterns of resident marine wildlife.

Fifteen female short-tail stingrays were found to use the Woollamia boat ramp at Jervis Bay, including at least 5 gravid individuals. Their presence was significantly correlated to the intensity of provisioning events, and their visitation increased in the afternoon when fish cleaning was more common. These data indicate a strong influence of provisioning on stingrays movements and site use. We suggest that stingrays may be at risk of experiencing negative impacts from continued provisioning in the absence of management, such as dependency, resulting in reduced fitness. On a positive note, stingray provisioning has enhanced human animal interactions and instilled a sense of custodianship in the local community.

This study highlights that management of recreational fisheries, with respect to appropriately handling waste and its potential impacts on wildlife, needs revision. Our data provide a baseline of effects on which monitoring and management programs can be built.

Moving forward, we are developing an extensive acoustic tracking project where the fine and broad scale movements of short-tail stingrays from within Jervis Bay, and elsewhere, will be assessed. This will help us to better understand their use of fish cleaning facilities whilst also addressing a number of knowledge gaps surrounding their basic biology and ecology.

I am very grateful to the John Glover Travel award for supporting my travel to the ASFB2017 conference, as well as to the members of ASFB for interest and their votes in the SCiSC competition. I would also like to thank Macquarie University and NSW DPI Fisheries for their financial support of this research.

Above *Joni and big momma*

Early Career International Travel Scholarship

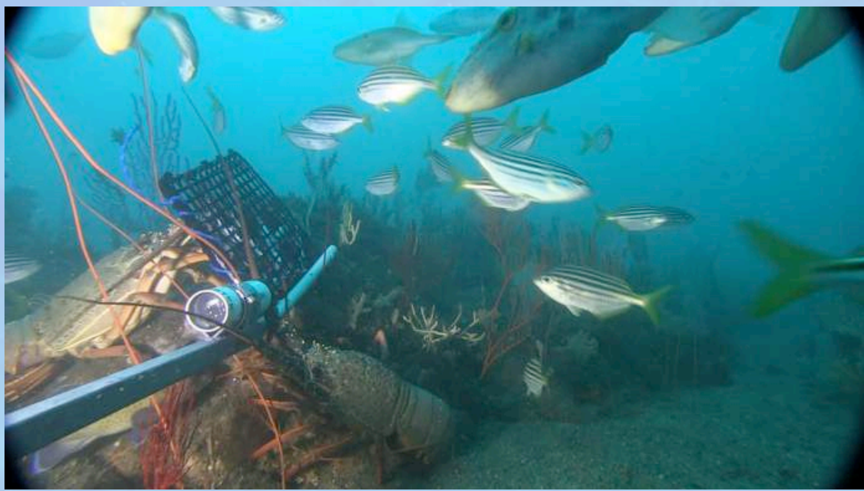
Dr Joel Williams
NSW Department of Fisheries

I was very fortunate to be able to attend the *10th Indo Pacific Fish Conference (IPFC)* in Tahiti. The IPFC is held every four years and provides an opportunity for fish scientists from around the world to gather and share their research. This year IPFC hosted over 550 delegates, representing 33 countries. This made for a very interesting and diverse programme. The programme was jam packed with four concurrent sessions running from 8am to 5pm for five days. There were a lot of talks on gobies and parrotfish! Interestingly, parrotfish was a popular choice at the conference dinner; subliminal marketing for fish scientist at work.

The highlights for me (apart from going to Tahiti) were the quality and diversity of presentations with a special mention of the plenary given by Daniel Pauly. His presentation titled 'Major Trends in Fisheries: where they lead to and how we turn them around' was at times scary and depressing but also highly motivating and highlighting the need that we as a scientific community really need to work better at communicating with managers, politicians and the corporate world. The excursion to Moorea Island was also very insightful as we toured the island visiting the research facilities of CRIOBE and snorkelling with sharks. I highly recommend that fish researchers attend the 11th IPFC in Auckland in 2021 as this has to be one of the most useful and interesting conferences.

At IPFC I presented my current research titled *"Taking a deeper look: Quantifying the differences in fish assemblages between shallow and mesophotic temperate rocky reefs"* in a mesophotic reefs session hosted by Luiz Rocha. In this study we used baited remote underwater stereo-video (BRUVs) to sample the fish assemblages on shallow rocky reef (20-40m) and on mesophotic reef (80-110m). All sampling took place in the Port Stephens-Great Lakes Marine Park (NSW state jurisdiction) and in the newly established Hunter Commonwealth Marine Park (federal jurisdiction). The aim of the study was to quantify the differences in the fish assemblages on shallow and mesophotic reefs, as well as provide baseline data for the Hunter Commonwealth Marine Park. In summary, the mesophotic reefs had lower species richness and overall fish abundance. However, when comparing recreational and commercial fishery targeted species there were similar abundances at both depth categories. This was primarily driven by blue morwong *Nemadactylus douglassii* and silver trevally *Pseudocaranx georgianus*. Interestingly, abundances of the most targeted species pink snapper *Chrysophrys auratus* were on average four times higher on shallow reef when compared to mesophotic. However, on average mesophotic reefs were hosting larger fish that were above the minimum legal length for retention. For more information please see the NSW state report or contact myself at joel.williams@dpi.nsw.gov.au or follow this project on twitter @joelfishecology.

Right *Joel BRUVing away*
Below *Images from one of the project's drops*



Dr Krystle Keller

Research Fellow, Charles Darwin University

As a recipient of the 2017 ASFB ECR International travel award, Krystle Keller attended the *10th Indo-Pacific Fish Conference (IPFC)* in Tahiti in October 2017.

Over 300 international delegates attended this conference from a broad range of backgrounds, including fish biologists, ecologists and taxonomists.
Krystle presented an oral paper titled *"Multispecies presence and connectivity around a designed artificial reef"* from her PhD research, based on the use of an artificial reef by fish and sharks and rays. The findings from this study indicate that artificial reefs may increase the connectivity between adjacent habitats and can aid in the dispersion of a range of benthic species. The presentation was given in the biotelemetry session, which promoted discussion with other delegates interested in acoustic telemetry.

Krystle also attended a special session at the conference which focused on highlighting *"Women in Marine Sciences in the Indo-Pacific"*. This session featured a series of women speakers providing a career overview of their research, experiences, insights and challenges in the profession. Attendants were left feeling inspired and the session continued into the evening with a networking event at the Pearl museum, with many people discussing their own experiences.

It was a great and enjoyable experience. Many thanks to ASFB for the support and opportunity to attend the IPFC!

Above *Krystle receives her award from previous ASFB president Chris Fulton*

Student Opportunities

ASFB Student Awards

The **Barry Jonassen Award** was established in 1999 and
is named in memory of Barry Jonassen, a keen freshwater angler and biologist, and passionate supporter of ASFB. The award is to assist with the research costs incurred by an honours or postgraduate
student in the field of freshwater fish biology or freshwater fisheries ("fish" includes commercially important invertebrates). The value of the award will be at the discretion of the Society President and Education Committee, up to a total of $2,000. For more info here.

The **Michael Hall Award for Innovation** was established in 2005 by Mr
David Hall in memory of his father Michael Hall to
assist innovative research in marine fish biology. The award is to assist with the research costs incurred by an honours or post-graduate student in the field of marine fish biology or fisheries ("fish" includes commercially important invertebrates). The application should show a significant contribution to science in general; a high degree of originality in choosing the research topic and methodology; the potential for significant benefits to the management of fisheries and aquaculture resources; and collaboration with other researchers. The value of the award will be at the discretion of the Society President and Education Committee, up
to a total of $2,000. For more info go here.

Both awards are restricted to full time
honours or post-graduate students in the first or second year or their degree. This award is open to any student member of ASFB who is currently enrolled at an Australian or New Zealand university. Applications consist of a 2 page research proposal on the proposed or underway research. The Society reserves the right not to make an award in any year. Closing date: 30th April.

The **Student Communication in Science Competition (SCiSC)** awards are aimed at creating an opportunity for early-career students to develop and demonstrate their multimedia and oral communication skills. To apply, eligible students should create & upload a video about their research, of up to 3-minutes in length to the competition page https://www.thinkable.org/competitions. A junior (Honours level) and a senior (Masters/PhD level) winner will be chosen via public online voting. One additional "Member's Choice" winner will also be chosen. Entries close April 30th 2017. For more info go here.

Applications/inquiries for these awards should be e-mailed to:
Dr. Stephen Beatty
Tel: 08 9360 2813
E-mail: S.Beatty@murdoch.edu.au

Student International Travel Scholarship

This scholarship has been made available to support a student to a present an oral paper at an international conference that is relevant to the activities of the Society, in the financial year of the award.

The scholarship comprises a return airfare, registration fees plus a living allowance up to a total value of $3,000. The scholarship may be divided by the judges if more than one paper is scored equally. Additionally the winner will be invited to present their research at the ASFB annual conference and receive free registration.

The award is open to students who are current financial members of ASFB at the time of award presentation and have been ASFB members for at least 12 months before applying. Applicants must be either currently enrolled as a post-graduate student at an Australian or New Zealand University or have graduated within the last 12 months.

Applications are in the form of a
research paper written on any aspect of fish biology or fisheries (fish includes commercially important molluscs and crustaceans). As part of the application, candidates should nominate in writing

what conference they wish to attend and its relevance to the aims and activities of the Society. The Society reserves the right not to make an award in any year if the quality of the applications does not meet the required standard. Papers should follow the general format required by Marine and Freshwater Research (or equivalent). Closing date for applications: 31st May.
More information and award conditions can be found here

Applications/inquiries should be e-mailed to:
Dr Michael Hammer
Tel: 08 8999 8253
E-mail: michael.hammer@nt.gov.au

PHD CANDIDATE WANTED to examine the global importance of benthic-pelagic coupling for the ecosystem function of coastal reefs.

Supervision team: Dr Rick Stuart-Smith, Assoc. Prof Julia Blanchard, Dr Asta Audzijonyte
Contact: *+61 3 6226 8214; rick.stuartsmith@utas.edu.au*

Project description: In order to improve management of reef resources and predict impacts of habitat loss (corals in the tropics and kelp in the temperate zone) on ecosystem dynamics it is essential to understand the importance of alternative primary production pathways supporting coastal reef systems. This project will focus on investigating the relative importance of pelagic versus different types of benthic primary production (coral, macroalgal, microphytobenthos) on shallow reefs. It will use a combination of chemical tissue analyses from reef organisms, field data on biomass partitioning across trophic groups and benthic cover estimates from the Reef Life Survey global database. The project will include field work from Tasmania up to the tropics to collect samples and record local habitat characteristics, laboratory work for stable isotope analyses and statistical analyses to interpret results and extrapolate the findings across other reefs in the global Reef Life Survey database.

Curtin University

PhD Scholarship in Ecotoxicology

We are seeking a highly motivated PhD candidate to undertake research in aquatic ecotoxicology, as part of a research team focused on assessing the impacts of oil and gas activities on the marine environment.
The position is based at Curtin University, Perth, Australia.

Overview: This is an exciting opportunity to join a small team of researchers to develop an ecotoxicological toolbox adapted to the oil and gas industry. The project involves the development and application of a variety of biochemical and molecular tools responsive to exposure to petroleum hydrocarbons in marine fish. The specific topic of the project is flexible and can be based on the skills of the candidate. The candidate will be expected to work as part of a team and to present to national and international conferences.

Project Supervisor: Assoc. Prof. Marthe Monique Gagnon

Project Outline: Australian light crude oils have a chemical composition significantly different from other crude oils around the world and hence, biota exposed to these via regular discharges of produced formation waters or via accidental oil spills will respond differently, from a physiological point of view. In this project, a variety of biochemical and molecular markers in fish will be explored and evaluated for their sensitivity to detect exposure and/or effects following exposure to Australian light crude oils.

Research Environment: This research project will be based at the Curtin Aquatic Research Laboratories. This world-class facility is equipped to conduct ecotoxicological studies on freshwater, brackish and marine organisms. The Ecotoxicology laboratory is part of this facility, and has modern equipment including kinetic spectrophotometer, spectrofluorimeter, microplate readers, qPCR instruments, and a comprehensive array of fieldwork equipment. The student will interact with the oil and gas industry and have the opportunity to build a strong network of collaborators. Results arising from this project will be disseminated via conference presentations and peer-reviewed publications.

Applicant Requirements: The applicant must have completed an undergraduate degree in Biological or Molecular Sciences with a First Class Honours degree (or equivalent) in Marine Biology, Ecology or Molecular Science, and preferably has at least one research publication. The successful applicant must have molecular laboratory skills. Previous experience in ecotoxicology would be advantageous.
It is expected the applicant would be enrolled at Curtin University early 2018 to commence the project.

The applicant must have Australian citizenship. A 3-year stipend is available however the successful applicant will also be encouraged to apply for an RPT - https://scholarships.curtin.edu.au/scholarships/scholarship.cfm?id=3085.0

Applications: Please send your expression of interest and a CV to Assoc. Prof. Marthe Monique Gagnon (m.gagnon@curtin.edu.au).

Make tomorrow better. curtin.edu.au

Early Career Opportunities

ASFB Early Career Awards

The **Early Career International Travel Scholarship** has been made available by the Australian Society for Fish Biology (ASFB) to support an early career scientist to present an oral paper at an international conference that is relevant to the activities of the ASFB. Only one scholarship will be given each year, and only if a candidate of acceptable quality applies. The scholarship will provide a return airfare, conference registration and accommodation up to a total value of $3,000, plus a full registration for the Scholar to attend the next ASFB annual conference where they will present the work as a plenary talk.

Conditions
• The award is open to early career scientists who are current financial members of ASFB at the time of the award presentation at the annual conference and who have been financial members of ASFB for at least 12 months prior to applying for the award;
• The early career applicant must apply within 5 years of the conferral of their last postgraduate degree (either a Masters or PhD) by an Australian or New Zealand University. Extensions to this eligibility timeframe due to career breaks will be considered upon application to the Committee;
• An award will be made based on the application process outlined below.
• Judging for the award will be made by an anonymous Committee consisting of three ASFB members, and the decision of the Committee is final; and
• The ASFB Early Career International Scholar must provide a written report of their experience for publication in the ASFB Newsletter.
Applications close 31st of May.
For more information and how to apply please go here.

The **Early Career Excellence Award** is given to an early career scientist who has made an exceptional advance in the study of fish biology and/or fisheries that has fundamentally changed our understanding and/or management of fishes (fish includes commercially important molluscs and crustaceans). Only one award will be made in a given year, and only if a candidate of exceptional quality is nominated.

Nominations
Nominations for the award are made by the full Executive Committee during May each year, and the winning candidate selected by a selection committee comprising a diversity of ASFB members (across age groups, gender & disciplines). For more information, or to suggest a nominee, please contact your State/Territory/NZ Representative on the ASFB Executive Council or the ASFB President. *Nominees must be ASFB financial members at the time of nomination.
For more information please go here.

Applications/inquiries should be e-mailed to:
Dr. Harry Balcombe
Tel: 07 37357308
E-mail: s.balcombe@griffith.edu.au

Upcoming Events

11–16 February, 2018
Ocean Sciences Meeting
Portland, OR, USA

7-9 March, 2018
Fifth World Ocean Summit
Riviera Maya, Mexico

19-20 March, 2018
World Conference on Ecology
Theme: Raising awareness to Conserve Natural resources and Ecology
Berlin, Germany

24-26 April, 2018
Asia Pacific Aquaculture 2018
Taipei-Taiwan
https://www.was.org/meetings/default.aspx?code=APA2018

13-16 May, 2018
4th World Conference on Marine Biodiversity
Montreal, Quebec
www.wcmb2018.or

28-29 May, 2018
10th Euro-Global Summit on Aquaculture & Fisheries
London, UK
https://aquaculture-fisheries.conferenceseries.com/europe/

3-8 June, 2018
Sharks International Conference
João Pessoa, Brazil

1-5 July, 2018
Australia Marine Sciences Association
"Canyons to coast"
Adelaide, Australia

3-5 July, 2018
Society for Conservation Biology 5th Oceania Congress
Wellington, New Zealand

15 - 20 July, 2018
International Symposium of Genetics in Aquaculture
Cairns, Australia

23-27 July, 2018
ECMTB 2018
11th European Conference on Mathematical and Theoretical Biology
Lisbon, Portugal
http://www.ecmtb2018.org

7-18 October, 2018
ASFB Conference
Melbourne, Australia
http://asfb2018.org.au

10-14 December, 2018
Fish Passage 2018
Charles Sturt University in Albury, New South Wales, Australia

Executive Council Meetings

Minutes ASFB Executive Council Meeting
Monday 14th of November 2016, 1100-1300 AEDST
Teleconference

Executive Council members: Chris Fulton, Harry Balcombe, Heather Patterson, Charles Todd, Gary Jackson, Brendan Ebner, Michelle Treloar, Andrew Katsis, Ben Broadhurst, Sally Hatton, Lee Baumgartner, David Harasti, Mike Hammer, Grant Johnson, Nick Ling, Brendan Hicks, Leanne Currey, Geoffrey Collins, Gretchen Grammer, Mike Steer, Stacy Bierwagen, Lachlan Fetterplace, Sean Tracey, Heidi Pethybridge, Scott Raymond, John Morrongiello, Peter Coulson, Emily Fisher

Apologies:
Brendan Ebner, Sally Hatton, Lee Baumgartner, Mike Hammer, Nick Ling, Leanne Currey, Geoffrey Collins, Gretchen Grammer, Stacy Bierwagen, Lachlan Fetterplace, Heidi Pethybridge, Scott Raymond, Peter Coulson.

Agenda

1. Welcome / apologies
2. Minutes from previous meeting
3. Actions from previous meeting
4. New members
5. Treasury report
6. December 2016 Newsletter
7. Student & State Representative reports
8. Hobart 2016 report
9. Albany 2017 update
10. Melbourne 2018 update
11. World Fisheries Congress 2020 update
12. ASFB financial review
13. Update on proposed "fisheries managers" society
14. Other business
15. Next meeting

Minutes complied by Charles Todd

1. ***Welcome / apologies***

   Chris welcomed everyone to the meeting, especially the new members of the Executive. Chris asked us to spare a thought for our NZ members who experienced the recent earthquake.

2. ***Minutes from previous meeting***

   Mike Steer proposed to accept the minutes from the previous meeting and Sean seconded the motion, the motion was carried.

3. ***Actions from previous meeting***

   Action: Chris, Brendan to continue discussions in trying to work towards a mega-conference in 2018 or 2019.
   Ongoing

Action: Chris to report the outcome from the meeting with the investigators to the next Executive meeting.
Done - see below

Action: Sean to send Chris details on the Paul Hardy-Smith: fish vet.
Done

Action: Chris to discuss with ASFB members who are AEC reps, and then prepare a submission from ASFB to the proposed changes, which is to be e-mailed out to members for comment prior to submission to the NHMRC.
Done

Action: Chris to raise the issue at the AGM, if time allows. Not achieved, but email sent out to all members, which received many positive response, so letter was sent to NHMRC on the deadline.

Action: Special day/ workshop on animal ethics at a conference as soon as possible.
Ongoing

4. ***New members***

Heather provided a list of new members that had joined ASFB over the period of 9th of August to 25th of October 2016.

Harry proposed to accept the new members, John seconded motion carried, the motion was carried.

5. ***Treasury report***

Heather reported that there has been relatively little activity (outside of ASFB-OCS conference, which is managed on separate budget) since July. Since July, we have received a $7,200 in sponsorship, including a milestone payment of $6,000 from FRDC and $1,200 from VMSC. We also received a $13,176 disbursement from the acquittal of the Hobart conference, $2,749 in interest from the main term deposit and $4,718 from memberships. The $7,190 venue deposit for the Hobart conference was also returned. Expenses so far this financial year have mainly consisted of payment to ASN for their 2015–16 services ($7,540; note this includes a dual services discount of $2,399 as they also ran the conference) and payment of awards associated with the ASFB conference ($17,026). There have also been the standard expenses of the Communications Manager ($1,500) and the newsletter editor ($1,255).

6. ***December 2016 Newsletter***

Michelle reported that she put out a call for content in September. Deadline for submissions is 25 November. If you wish to contact members in your area, please send content of your email call to Bree Knights (bk@asnevents.net.au), who will send it out on your behalf (we are no longer sharing members e-mails with our reps, due to privacy concerns). A general call needs to be made on ASFB Social Media in mid-Nov.

Michelle asked for the award winners as she didn't have a list. Michelle also asked for a feature article as she hadn't received on yet. David asked Michelle if she wanted stories as dribs and drabs or put it all in one document. Michelle preferred one document.

Andrew pointed out that the award winners are listed on the blog post.

Gary congratulated Andrew on his latest social media summary sent around to the exec before the meeting. Chris concurred with Gary and highlighted the excellent communication via social media that Andrew curated and developed at the Hobart conference.

John asked what was actually required for a feature article. Michelle gave an overview and suggested looking at past newsletters. Andrew said he had a feature article that he could supply if interested.

Action: Andrew make a call for content for the newsletter highlighting a feature article

7. ***Student & State Representative reports***

NSW – Dave just waiting on feedback for the newsletter
SA – Mike is trying to persuade members to supply content for the newsletter
Vic – just getting content for the newsletter sorted out
NZ – Brendan mentioned a discussion with Pamela Mace the NZers need to get more organised and hasn't had the chance to contact all members to get input. Chris mentioned a teleconference with NZ members earlier in the year that Brendan wasn't able to attend. Chris developed some notes from that and will send to Brendan to refresh memories on what was decided.

8. ***Hobart 2016 report***

Sean provided the following summary of the Hobart conference.

The 2016 ASFB conference was held as a joint event with the Oceania Chondrichthyan Society at the Wrest Point convention center in Hobart from 4-7 September 2016. The conference theme was 'Intersections in Ichthyology'. The program included a pre-conference meeting of the ASFB Threatened species committee, and a post-conference workshop hosted by ARGOS-CLS on satellite tracking of animals on the 8th of September.

A highlight of the 2016 conference was the successful execution of two exciting new initiatives. The first was a celebration of the contributions of women to fish and fisheries research in Australasia led by the presidents and some committee members from both societies. This initiative included a poster display in the main foyer area showcasing the career achievements of some of the many women who have been recognised by the society for their contribution to our field, six keynote addresses directly after the opening of the conference by established and early-career women in fish and fisheries research from both societies, and a panel discussion that explored gender equity in fish and fisheries research.

The second initiative was based around a communication theme for students. For the duration of the conference short videos, previously uploaded on the Thinkable competition platform and voted on by the public, were run in the foyer of the conference venue. The videos showcasing the research and creativity of 15 students. Many of the video participants then deliver a 3 minutes 'unplugged' presentation of their work without visual aids. This series of talks was allocated its own time slot with many conference delegates in attendance.

• 268 delegates (including 72 students) attended the conference, including 22 international delegates from 7 countries in Asia-Pacific, Europe and the Americas (including 12 from NZ).
• 200 oral presentations (including 10 keynotes) and 22 posters.
• 8 keynote conference presentations: Prof Bronwyn Gillanders (University of Adelaide); Dr Kara Yopak (University of Western Australia); A/Prof Gretta Pecl (Utas - IMAS); Dr Jodie Rummer (JCU); Dr Michelle Heupel (JCU); Dr Gretchen Grammer (University of Adelaide); Dr Patrick Lehodey (Collecte Localisation Satellites (CLS), Paris); Dr William White (CSIRO).
• 2 ASFB keynote presentations: 2015 KRA winner: Prof David Bellwood (JCU); 2015 ECR Travel Award recipient: Dr Heidi Pethybridge (CSIRO).
• The conference income was $210,240.00 and the expenditure was $191,546.80 equating in a profit of: $16,921.78. The profit was distributed between both societies based on a pre-signed MOU. The MOU stated that profits would be distributed commensurate with the proportion of society member registrations at the conference. ASFB members accounted for 78% of society member delegates, accordingly, a profit of $13,263 was distributed to ASFB and the remainder to OCS.
• The direct costs associated with ASN as conference organisers equated to $47,485.
• 5 sponsors, 7 trade booths, and miscellaneous advertising revenue contributed $66,990 to the conference income. Gold sponsors included FRDC, IMAS and CSIRO. Sponsorship enabled the organising committee to subsidise the cost of the conference, in particular student registrations. The FRDC sponsorship underpinned several student awards.

• The ARGOS post-conference workshop was attended by 37 people. 13 presentations were delivered on the satellite systems that underpin tracking of animals using satellite telemetry and applied presentations on the tracking of a range of marine and terrestrial biota. The workshop was hosted by CLS-ARGOS (free registration) and held at IMAS-Salamanca,
• The Government House reception was attended by 120 delegates.
• The student-mentor mixer was attended by 179 delegates.
• The conference dinner at MONA was attended by 210 people, and included the announcement of several awards from both societies, including the announcement of the 2016 KRA Award recipient, Professor Bronwyn Gillanders.

John asked how the profits were split between OSC and ASFB. Sean replied that if joint members they didn't contribute to the proportion for the split of profits, otherwise profits were split along membership numbers attending.

Sean mentioned that all the photos are available on a secure website and asked if the photos should be made available to the delegates. It was agreed that it was ok for delegates to get access to the photos provided they could ask for any to be removed if they so desired.

Action: Sean to get ASN to send an email on how delegates can get access to conference photos and to ask that if anyone wants a photo removed to contact Sean.

Sean asked if anyone wanted to see the feedback from the conference. Gary and John said the feedback would be useful for their respective planning of future conferences. Sean gave an overview of the feedback, what worked and what didn't.

Action: Sean send the conference feedback to the Executive

9. Albany 2017 update

Gary and Emily provided the following summary of preparations for the 2017 Albany conference. Emily is hoping to get the website up and running before end of year.

Planning for the 2017 ASFB conference in Albany WA (21-24 July) has continued to progress through fortnightly meetings with the local organising committee, which now includes representatives from a range of State Government departments, WA universities and research institutes, as well as local and ASFB student representatives and ASN staff. The conference aims to continue the strong focus of the Hobart conference on student members, with most of the first morning of the conference set aside for the education committee and student reps to run the popular

Rapid Talks and any other group/panel sessions that they wish to lead (ahead of the student mixer social event to be held later that night). The committee is also determined to incorporate the cost for last night's conference 'party' (promised to provide great food, local beer and wine and live music without the white tablecloths and need to master fine dining etiquette!) in the registration to maximise the number of students that can attend this event.

With a proposed overarching theme of 'Turning points in fish and fisheries science', key sessions of the conference will likely include migration, range shifts and environmental stress on fish, threatened species (freshwater focus), changes to habitats (marine focus), fisheries management and certification, as well as more general sessions to incorporate the many other interesting topics discussed during planning meetings. Although the setup of the conference venue for concurrent sessions (two large rooms at the Albany Entertainment Centre and additional 'workshop rooms' at the UWA campus a 5-minute walk away) will limit the number of oral talks that can be accepted (~120 15-minute talks), the conference promises to provide sessions that will attract a broad range of disciplines and interests.

The conference also hopes to run a public lecture on one evening of the conference, which will open up the doors of the Albany Entertainment Centre to the Albany community and provide them with an opportunity to learn more about the current research on fish and fisheries, both locally and in a broader sense.

More information will be available on conference website, which will be active by the end of the year.

Chris asked if the main conference theme was now settled. The overall theme will be 'Turning Points in Fish & Fisheries'

Chris asked about planning for getting people from Perth to Albany with modest cost. Gary said they will have options up on the website in December, which will include low-cost minibus/coach alternatives.

10. Melbourne 2018 update

John provided the following summary of the preparations for the 2018 Melbourne conference

The 2018 ASFB conference will be held in Melbourne during the week of 24th Sept or 1st Oct. These dates will be confirmed once John has an indication from University as to when the mid-semester non-teaching period will be. John has put out a call for those interested to become members of the organising committee. To date the response has been a little underwhelming, especially from members based at Government agencies (e.g. Fisheries Victoria and ARI). Hopefully this will be addressed in the next few weeks. Currently, John has commitments from Museum Victoria staff, two consultants and University of Melbourne students, and he thinks involvement of ARI or Fisheries personnel will help in negotiating sponsorship from Government.

John is in discussions with University of Melbourne about hosting the conference on campus, but has yet to hear anything concrete from them in terms of costs and available facilities. There are a plenty of accommodation and dining options near the campus and closer to the city (5 min tram ride). Once the organising committee is sorted we'll workshop a theme. At the moment we've informally discussed the idea of 'sustainable resource use' (maybe get someone like Daniel Pauly or Boris Worm to be keynote talking about global fisheries and aquaculture), 'Scale in biology and management' (maybe someone like Beth Fulton or Anna Kuparinen/ Geoff Hutchings to talk about integrated resource and catchment management or importance of biocomplexity in managing fisheries), or 'climate change' (revisit the theme of last Melbourne conference and see where we've come in terms of detection, attribution and adaptation).

Chris asked if John has contacted John Koehn at ARI. John responded pointing out that he is liaising with Jarod Lyon (Applied Aquatic Ecology leader at ARI) to get involvement from staff at ARI, and Charles noted that they discussed this at a staff meeting and volunteers should be forthcoming.

Chris suggested contacting the Vic Marine Science Consortium (funds one of the student conference awards) to see how they want to be involved.

11. World Fisheries Congress 2020 update

The tender process for the PCO (i.e. Conference Secretariat) is almost complete. A total of five companies applied. The process is largely being driven by the SA Government policies and procedures. Once the PCO is appointed, the Chair of the Organising Committee (Gavin Begg) would like to hold a "planning day" to decide on major items such as the conference theme, keynotes and principal scientific sessions. Likely that this will not happen until early-2017.

Action: Ongoing agenda item

Chris asked the Executive to start thinking about how they wish to be involved, collectively and individually. This includes things like running special sessions, as well as suggestions for keynote speakers, themes, etc. Please forward this to Chris so that we have it ready for the planning day.

12. ASFB financial review

Questions have been raised about how we should use the ~$300k in ASFB member's funds, which appear to have been a relatively stable balance in our annual account summaries (see attached). However, the ASFB has entered into several new financial agreements over the past few years, and estimates suggest there is an imbalance between regular earnings (~$24k from annual membership & bank interest on ~$255k in term deposits) and our regular expenditure (~$34k pa for ASN, Editor, Communications Manager, student research & student/ECR international travel awards).

One-off conference profits (ranging from $6k to $27k over past 5 years) have helped us maintain a healthy surplus, but in an unpredictable and relatively ad hoc way. In relation to this, it is important to note that the FRDC currently supports $20k of conference expenses (including all the student conference awards, bar the VMSC), and there is always a risk they may not renew our 3-year contract (current one expires 2018). We have to be able to justify why people should join/renew their memberships via the services we provide. This means culling services to cut costs is not a preferred option. Many members argue that we need to identify how we should be investing more funds into existing and/or new ASFB initiatives. Preliminary discussions with ASFB Committee Chairs (Education, Threatened Fishes, Alien Fishes) confirms this, with suggestions of increased support for existing activities (e.g., increase student research awards), the creation of new grants/awards, and setting up new initiatives (e.g., casual position to collate and archive datasets held by ASFB Retiree members).

Given the ASFB appears to have no financial plan, there are two key questions we need to address: (1) What is a minimum surplus that the ASFB should hold to protect our core services to members over the long term (i.e., 2026 onwards)? (2) How should we invest any surplus above this minimum to support ASFB activities and initiatives for our members?

Gary saw that the issues fall in to 2 parts: 1) routine service that we provide our members; and 2) the big one off things that the Executive might like to do, which requires some process for deciding how we spend the money on ASFB activities. Gary highlighted our low membership fees that have not increased in a long time, and whether we should consider an increase. Harry agreed with Gary on his suggestions, but pointed out that we need to be careful about raising membership fees. Chris agreed, and said that we would need to provide a clear financial plan, both for how $300k will be invested/kept, and if needed, and why any increase in membership fees is necessary.

John asked if decreasing funds in those term deposit accounts that earn interest would significantly impact our bottom line. Chris said that interest rates are very low at the moment, so the return generated on our deposits isn't much, but in total they are a significant amount of our regular income.
Chris pointed out that we have a responsibility to future Executives to ensure they have the capacity to fund any large changes/ideas they might see as important for the ASFB, as well as insuring against any risks (e.g. loss of FRDC contract, several years of losses on conferences, etc).

Chris suggested we reinstate the Future of the Society (FoS) committee to deal with these issues. Perhaps include a financial advisor in the discussions. Sean suggested talking to ASN for their advice. Chris agreed Gary asked about timing, and Chris said he would like to have something ready to present to the 2017 AGM and devote time to discuss the suggestions with the members. Gary suggested that conferences should be required to make a profit where at the moment it is only required to break even, Chris pointed out that if we lost the FRDC funding then the conference would have to pick up the loss to cover all the awards.

Gary suggested a small group who was interested in looking at options might be the best way to progress this issue, and the group should probably include someone with a financial background or experience. Heather agreed that having a professional financial person involved was important, as did John.

Chris gave a history of the FoS and that there might be a cost in reinstating this type of mechanism, principally for airfares for ~10 people to meet in a capital city airport.

Chris put forward the motion to establish a sub-committee to develop a financial plan for the ASFB.

Harry proposed to accept the motion, Charles seconded the motion, the motion was carried.

Action: Chris to work with Harry to form a sub-committee to put something together for the next Executive meeting

Action: Ongoing agenda item

13. Update on proposed "fisheries managers" society

Chris met with the lead investigator Tim Emery in Hobart on 8 Sept. Evident that the project team has very little experience with running a Society, which has led to some poor assumptions and misunderstandings of how things might work for a new fisheries managers society. Chris provided an overview of the ASFB's position (as discussed at September Executive meeting), and that we would like to find ways to better engage with fisheries managers. Tim agreed to have two ASFB questions (see below) added to a survey of fisheries managers via the Australian Fisheries Management Forum (which we believe was sent out in October). We hope to have the data from that survey by the end of the year.

Are you currently a member of the ASFB? If not, why?

Would you renew or become a member of ASFB if there was a dedicated "fisheries management and policy" Committee within the ASFB, which would provide dedicated coverage of these issues in workshops, symposia, the newsletter and website?

Mike mentioned that we need to speak with middle managers, try to engage with them to get them to join up as members of ASFB. He has also spoken with Sean Sloan (Director of Fisheries, SA) to clear up any misunderstanding or perceptions of ASFB's overall objective and capability in accommodating Fisheries Managers as contributing members. There has been a broad scale discussion on managers objectives and ASFB.

John asked if the Society has any information that can be sent to managers. Chris said that managers have restricted budgets and often very few people from a given organisation can attend each conference. Heather pointed out that she was the only person who put her hand up as an employee of AFMA to attend the Canberra conference. More discussion on managers role in ASFB. Gary pointed out in the past that managers used to attend ASFB conferences and have been engaged at ASFB but now policy people do not have the background that connect with fisheries science. Mike also raised that when WFC comes around many managers will want to be involved.

Chris highlighted that being involved in the WFC2020 means action right now, and repeated the call that this should be done via formation of a Committee within the ASFB, through which they can have instant access to our resources and start communicating with the management community, and have a direct line of communication with the WFC2020 planning team. Chris hopes to have responses from the survey before the next meeting.

14. Other business

Andrew said that a member had contacted him wanting to know the dates of the next conference. Gary said we can probably get something out on Facebook/Twitter pretty quickly, and the ASFB website thereafter.

Action: Gary to liaise with Andrew to get this information out.

15. Next meeting

Week beginning 20th of March 2017

Action: Charles to undertake a doodle poll in early January for best day.

Minutes ASFB Executive Council Meeting Wednesday 15th March 2017, 1100-1300 AEDST Teleconference

Executive Council members: Chris Fulton, Harry Balcombe, Heather Patterson, Charles Todd, Gary Jackson, Brendan Ebner, Michelle Treloar, Andrew Katsis, Ben Broadhurst, Sally Hatton, Lee Baumgartner, David Harasti, Mike Hammer, Grant Johnson, Nick Ling, Brendan Hicks, Leanne Currey, Geoffrey Collins, Gretchen Grammer, Mike Steer, Stacy Bierwagen, Lachlan Fetterplace, Sean Tracey, Heidi Pethybridge, Scott Raymond, John Morrongiello, Peter Coulson, Emily Fisher

Apologies:
Ben Broadhurst, David Harasti, Geoffrey Collins, Lachlan Fetterplace, Heidi Pethybridge, Scott Raymond, Peter Coulson, Grant Johnson.

Agenda
1. Welcome / apologies
2. Minutes from previous meeting
3. Actions from previous meeting
4. New members
5. Treasury report
6. Student & State Representative reports
7. Mid-year newsletter & retiring Editor
8. Communications
9. Albany 2017 update
10. Melbourne 2018 update
11. World Fisheries Congress 2020 update
12. ASFB financial plan committee
13. Update on proposed "fisheries managers" society
14. Proposal for VP and President candidate election statements
15. Nominations for 2017 Early Career Excellence award
16. Other business:
17. Next meeting

Minutes complied by Charles Todd

1. ***Welcome / apologies***

Chris welcomed everyone to the meeting.

2. ***Minutes from previous meeting***

Harry proposed to accept the minutes from the previous meeting and Mike Steer seconded the motion, the motion was carried.

3. ***Actions from previous meeting***

Action: Chris, Brendan Ebner to continue discussions in trying to work towards a mega-conference in 2018 or 2019. Ongoing

Action: Special day/ workshop on animal ethics at a conference as soon as possible.
Ongoing

Action: Andrew make a call for content for the newsletter highlighting a feature article
Done

Action: Sean to get ASN to send an email on how delegates can get access to conference photos and to ask that if anyone wants a photo removed to contact Sean.
Done

Action: Sean send the conference feedback to the Executive
Done

Action: Chris to work with Harry to form a sub-committee to put something together for the next Executive meeting
Done

Action: Gary to liaise with Andrew to get this information out. Andrew said that a member had contacted him wanting to know the dates of the next conference
Done

Action: Charles to undertake a doodle poll in early January for best day.
Done

4. ***New members***

Heather provided a list of new members that had joined ASFB over the period of 26th of October 2016 to 3rd of March 2017.

Chris proposed to accept the new members, John seconded motion carried, the motion was carried.

5. ***Treasury report***

Heather provided a summary of our accounts, noting that since the last Executive meeting there have been relatively few transactions. For income, we received two milestone payments from FRDC (totaling $18,000), $955 from membership fees and $102 in interest. We have also received $2,000 in trade income for the 2017 conference (note that this will be transferred to a separate conference budget when it is created). Main expenses during this period have included the standard payments for our Communications Manager ($1,500) and Newsletter Editor ($1,250), as well as expenses for the Science Meets Parliament event ($1,971). Travel to attend the Finance Planning Committee meeting in May has just started to be booked (total so far is $855).

6. ***Student & State Representative reports***

Student Representative: Stacy said things are coming along well. Both student reps have been participating in

planning meetings for the 2017 Albany conference and are awaiting a better estimate of the number of delegates before deciding what to organize for the student mixer on the first night of the conference.
New Zealand: Brendan Hicks pointed out that there is a conference in November 2017, 2017 5th Biennial Symposium of the International Society for River Science (ISRS), IPENZ/Water NZ Rivers Group (NZRG) and the New Zealand Freshwater Sciences Society (NZFSS), we invite you to attend the Conference which is being hosted by the University of Waikato in Hamilton, New Zealand over 19-24 November 2017, in partnership with the Waikato River Authority (WRA). Brendan Hicks asked if a link could be put on the ASFB website and Chris said best to contact Andrew so that the information can go out on twitter and facebook.

Nick and Gerry Closs hope to complete an IUCN assessment of all freshwater species in Australia. Mike Hammer informed the Executive that the Threatened Species sub-Committee had been reviewing freshwater groups and suggested that Nick contact Mark Lintermans to discuss work already undertaken.
ACT: Sally said that she and Ben were planning a pub night in May
NSW: Lee received two items from NSW members, one question about the release of the carp virus and whether ASFB should put out a position paper, and the other on how to ethically euthanase crustaceans and how ASFB can play an educational role here. Noting ongoing action item above, Brendan Ebner suggested taking this to the Melbourne 2018 conference as a special session/key session or workshop, Chris suggested adding in a broader debate about the issues around animal wildlife research and medically-oriented national guidelines - John agreed to look at including it in the programme.
SA: Mike Steer and Gretchen are on the hunt for early career excellence nominees (due by 30 April).
WA: Emily informed the Executive about lawn bowls evening promoting the conference and organisation.
NT: Mike Hammer informed the Executive about a farewell for Rex Williams who had passed away recently
Qld: Leanne has had contact about getting notifications out to members, and that there is an International Conference on Telemetry in June that will be promoted on facebook and twitter

7. ***Mid-year newsletter & retiring Editor***

After many outstanding years of guiding and editing our newsletter, Michelle has decided to step down after completion of the 2017 mid-year newsletter in June. Michelle is keen to hear about items the Executive would like to see in the mid-year newsletter, and discuss how we find a replacement newsletter editor to take on the role in July, to allow time for a handover before preparation of the December 2017 issue. Also need to discuss rising cost of printed copies of our newsletter (current quote is ~$30 per copy!), and whether we should discontinue this practice.

Chris thanked Michelle for all her hard work and her key role in making our newsletters such a great success.

Michelle pointed out getting some more in depth information for the mid-year newsletter, including promotion of the upcoming ASFB Albany 2017 conference and other fish-related conferences that members may be interested in attending.

Action: Michelle & Andrew - call for content and contact Andrew to get this call out on twitter and facebook

Gary thanked Michelle for her hard work as well. Chris pointed out that the newsletter plays a very important role in both a communication strategy, as well as fulfilling our obligations under our constitution and for Consumer Affairs Victoria.

Discussed rising cost of printing hard copies of our December newsletter (now ~$30 each for six of our 300+ members). It was discussed whether to cease printed copies altogether. Brendan Ebner questioned whether we need to ask members at the AGM for their views, Chris said the Executive has the authority to make a decision on this. Gary proposed ceasing printed copies of the newsletter immediately, Gretchen seconded the motion, the motion was carried.

Chris asked about how the Executive would like to find a replacement Newsletter Editor, with a desire to put someone in place before the Albany conference to allow time for handover and lead-up to Dec 2017 issue. Chris, Gary and Gretchen all mentioned people who may be quite able to undertake the role, and asked whether we should approach them. Chris said the process should be an open one but people are welcome to point potential applicants to the position. Chris also suggested that someone with at least a strong interest in fish and fisheries would be preferable, given the decisions the editor needs to make about content, cover story, etc. Leanne suggested sending to only the ASFB members first, and the Executive agreed.

Action: Harry and Michelle to begin the process of finding Michelle's replacement initially from within the membership before Albany 2017 AGM.

8. Communications

Andrew presented a summary of ASFB media communications that he has undertaken. Andrew would also like to discuss the recruitment of volunteer communication assistants who will learn some new skills from Andrew while helping to diversity how we communicate our work with the wider community. Andrew thought that this would suit an early career member.

Gary pointed out the Wikipedia page Andrew had created. We need to make sure the info is accurate. Andrew informed the Executive that only third party sources could be used for citing content. Thanks Andrew for bringing ASFB into the new age.

Action: Gary to work with Kevin Rowling and Andrew to flesh out the history of the ASFB on our Wikipedia page

Action: Andrew to put out a call to members to volunteer with assisting him on ASFB communications

9. Albany 2017 update

Gary and Emily provided the following summary of preparations for the 2017 Albany conference. Emily is hoping to get the website up and running before end of year.

Planning for the 2017 ASFB conference in Albany WA is progressing well, with early bird registrations and abstract submissions opening on March 7. The local organising committee has been busy putting together a draft program with many interesting special sessions, whilst also undertaking a site visit to the Albany Entertainment Centre, securing venues for the conference social functions and organising merchandise etc. Although we had previously considered running one of the concurrent sessions at the neighbouring University of Western Australia campus across the road, we are now aiming to have all session housed within the Entertainment Centre.

After the success of the "Women in Ichthyology' forum on the first day of the 2016 Hobart conference, we will be kicking off the Albany conference by turning our focus to the many student members of ASFB. The "Nurturing Fish Scientists' session will take us all on a journey from the post-graduate (larval) phase to fully-recruited fish scientists, discussing the experiences and skills that may help you successfully land a job in this competitive field. The first day of the conference will also include the popular Rapid Talks, which gives students an opportunity to take to the stage for three minutes to spruik their research to the whole audience.

In 2017 we are also experimenting with a few new things in the conference program. After a few years of working hard to get both marine and freshwater contributions in as many sessions as possible, we are going to mix it up, or rather un-mix it for a day. On one of the days of the Albany conference we are going to have two concurrent sessions, with one being specifically for marine habitat based topics and the other for freshwater related issues.

There will also still be a number of other special sessions during the conference that champion the mixing of freshwater and marine themes, have a look at the conference website for more details and to register (www.asfbconference.org).

Moving on to the social functions, will be offering (all free as part of a full 3 day registration!):
- a Friday welcome sundowner at the waterfront Due South bar and restaurant,
- a Saturday night student mixer at the White Star Hotel,
- a Sunday evening public lecture, and
- a Monday end-of-conference 'bash' that promises delegates a fun evening of live music, good food and local wine & beer in the rustic Albany boatshed, which is situated right on the waterfront and only a short walk from the town centre.

Sponsorship invitations will be emailed to prospective financial supporters over the next few weeks.

10. Melbourne 2018 update

John provided the following summary of the preparations for the 2018 Melbourne conference.

We have assembled a committee of 10-12 members and will have our first meeting by the end of March. John Morrongiello and Steve Swearer have been developing ideas on the theme, venue and structure, but we are very keen to make this an inclusive event so will seek input from the committee before decisions are made. Brendan Ebner is providing excellent support.

Want to continue on the great work from Hobart. One aim is to have less concurrent sessions, as well as focusing on student members.

Chris asked about the Executive about their perspective on having relatively few concurrent sessions, John isn't sure what that will look like yet but wants to explore how this might be done. Sean thought about it as well for Hobart but found the only way this would work would be to have an extra day. Leanne commented that she enjoyed the opportunity to hear more talks without have to rush between sessions. John agreed, but acknowledged the need to foster opportunities for delegates to present and provide an open forum for.

11. World Fisheries Congress 2020 update

As the current ASFB contact with the WFC2020 organising committee, Chris has repeatedly contacted Gavin Begg to formalise our MoU to ensure important ASFB activities and principles are included in the WFC2020. Offered several times to travel to Adelaide to expedite. Likewise for WFC2020 planning day, but no progress on either of these issues to date.

Mike Steer commented that the government process is frustrating but a contract has been negotiated and is currently with Crown awaiting signoff, which is standard Government procedure. Once this is done it is anticipated that a critical workshop will be arranged as the first order of business and will include appropriate ASFB representation. Mike Steer did say that Gavin is happy to brief the Executive to keep the organisation appraised of developments. Chris responded that this is the role of the ASFB Executive members (Chris & Harry) who are on the WFC2020 organising committee. Lee noticed that they are doing Presidential elections in AFS and they are looking to promote WFC2020. Chris commented that Bronwyn will also play a key role here as President of the WCFS. Mike Steer pointed out that there is a World Recreational Fishing Conference wanting to hold their event in Australia in 2020: it has been suggested to them that they might amalgamate with WFC2020. Gary provided some additional background. Similarly, it has been suggested that 'Seafood Directions' consider aligning their conference with WFC2020.

Action: Ongoing agenda item

12. ASFB financial plan committee

Chris reported that the ASFB Financial Planning Committee is now formed (Chris F, Heather P, Harry B, Alison K, Gary J, Bronwyn G, Charles T, Gretchen G, Chris I, Zoe D), and we have scheduled a date to meet at Adelaide airport (10 May). The ASN accountant and Heather are preparing background details on finances over past 2 years, and some modelling of different funding scenarios (e.g., with and without conference surpluses and FRDC grant for the committee to consider. Chris hopes to undertake a range of complex modelling and testing of different scenarios. We will provide a committee report at the next Executive meeting in July.

Action: Ongoing agenda item

13. Update on proposed "fisheries managers" society

Chris provided the results from the survey of fisheries managers (connected to the AFMF) to the Executive and pointed out that the results were interesting in that it highlighted a lack of visibility of the ASFB to fisheries managers. The survey itself has likely helped to address this issue, as further discussions between Chris and the team have led to the outcome that the proponents will join the ASFB and form an ASFB Fisheries Management Committee. Project team is attempting to do this in time for 2017 AGM, but time is tight due to move of the lead investigator to new job in Canberra. Chris will continue discussions with the group, who will now put the proposed goals, convener and members of the new committee to the AFMF group for discussion.

Lee asked to consider equal numbers between freshwater and marine backgrounds. Chris agreed and it may depend on their terms of reference as well people who put their hand up. Brendan Ebner suggested getting a couple of people from AFMF on the conference organising committee in Melbourne. John agreed it was a good idea.

Action: Chris and John to ensure fisheries management committee members (when formed) are involved in the Melbourne 2018 conference organising committee

14. Proposal for VP and President candidate election statements

Several members have asked about more information on how we select our future leaders on the Executive, and after some thought and discussion with several of the Executive, including many of the past and potential future Presidents, Chris suggested we ask the candidates to prepare a short statement on their background, key interests, and what they'd like to achieve for members of the ASFB. Chris also suggested we do this in time for the upcoming elections of nominees at the 2017 AGM in Albany.

Harry thought it was a good idea, and was happy to provide such a statement at the upcoming AGM. Brendan Ebner pointed out that as we get larger and more professional that this is necessary, perhaps even having multiple Vice Presidents to assist with the workload and to allow the individuals to experience more of what is required before potentially being nominated for or considering taking on the workload of the presidency. Gary also said that most people have no idea about the large workload that the President is required to undertake in their two years in the role. John suggested that this creates a pathway for more involvement in running the organisation, especially for State Representatives. Gary reiterated that there is a big step up required from State Representative responsibilities to the Vice President role and ultimately the President. Lee asked about Chris' experience and Chris pointed out you need to have organisational support to be able to undertake the role, and accept some need to work many extra hours around key periods like the conference, AGM and Executive meetings. Gary then suggested that one thing we could do is to have a larger number of State Representatives and appoint one State Representative to manage the State group (similar to AFS structure), thereby providing experience opportunity to equip members for higher office.

Action: Include this as an agenda item for 2017 AGM; Chris, Harry, Gary and Charles to develop a range of proposals on governance to discuss at the next Executive meeting and then present at 2017 AGM.

Gary noted that we had been thinking about how we could more effectively use the Dead Presidents and other long-standing senior members since Darwin conference. Maybe we should canvas this group on how to better prepare younger members for higher office in the modern era of less-secure employment and the such.

Leanne suggested that past Presidents could give a summary of their experiences as ASFB Presidents, perhaps a casual story that can be included in the newsletter (and social media) – this would be to introduce themselves to new members, highlight their achievements as president, what they may have wanted to do if able to go again, which will help the members understand what our ASFB presidents do in the role.

Action: Chris to ask the 'Dead Presidents' about organisational structure, and a summary/story of the learnings from their time as President.

Action: Chris to consult past presidents on structure of candidate statement, and then send to Charles so he can convey this request to 2017 nominees to the positions of VP and President.

15. ***Nominations for 2017 Early Career Excellence award***

ASFB reps – please suggest at least one candidate you'd like to be considered for this award. E-mail suggestions to Chris by April 30.

Lee asked if all nominees could receive a letter stating they were nominated. Chris responded the timing can be tricky for this, with decisions on the award being made just 2-3 weeks before conference.

16. ***Other business:***

ASFB statement on National Carp Control Plan. ASFB member Keller Kopf (CSU, Albury) and Lee Baumgartner have requested that we consider an ASFB position statement on the proposed release of the cyprinid herpes virus to control European carp in the Murray-Darling Basin. Chris would like it noted that ASFB member Matt Barwick is the Coordinator of the National Carp Control Plan, and he should be consulted by the ASFB Alien Fishes Committee.

Action: Lee & Keller to work with Matt Barwick and Alien Fishes Committee to develop a draft position statement, if deemed a good idea by this group. Executive to consider this statement for ASFB to communicate to public and/or key stakeholders.

Chris informed the Executive about a proposal to support IPFC women in marine science travel bursaries. Jodie Rummer has requested support from the ASFB for women from across Australasia to travel to the 10th Indo-Pacific Fish Conference in Tahiti (October 2017) to present in the "Women in Marine Science" special session. They have received 5,000 euro already, but need ~15,000 euro in total. Please see attached letter for details of the session and request. Chris asked would the Executive support this request. Leanne liked the idea that people are coming from small developing Indo-Pacific countries. There was general support from the Executive for the proposal, especially for supporting early career women from developing nations. John suggested that we should also support an ASFB member from Australia/NZ to attend, and Chris responded that this is possible by offering a second EC travel award in 2017 specifically to attend the IPFC.

Sean asked about whether supporting this request is setting a precedent. Chris said that this type of one-off request for funds from members is something that the Executive is supposed to consider (and has happened before), and in this case, the request relates to an issue that affects a large number of our members (gender equity), and which the ASFB recently discussed (at 2016 Hobart conference) as needing action.

Gary pointed out that Bronwyn Gillanders had established the aspiration that when a conference made a profit that some of that money be used to provide additional support/awards for members, and that the 2016 Hobart conference had made a profit.

Chris proposed that ASFB provides $5000 to assist an Indo-Pacific woman from a developing Indo-Pacific nation to present at the 2017 Indo-Pacific Fish Conference, Mike Steer seconded the motion, the motion was carried unanimously.

Chris proposed that ASFB provides $3000 to assist a female ASFB member to attend the 2017 Indo-Pacific Fish Conference, Brendan Ebner seconded the motion, the motion was carried unanimously.

Action: Chris to contact Jodie Rummer about the Executive agreeing to provide $5000 to support travel of a woman from a developing Indo-Pacific nation to 2017 IPFC, and discussing the criteria that the ASFB requests in making these funds available.

Action: Chris to work with ASN to develop the criteria for a female ASFB member to apply for the $3000 to attend the 2017 Indo-Pacific Fish Conference and advertising.

Chris asked the Executive to note recent efforts by the STA to highlight our organisation (http://scienceandtechnologyaustralia.org.au/member/australian-society-for-fish-biology/) and conference events (http://scienceandtechnologyaustralia.org.au/event/australian-society-for-fish-biology-conference-2017/) on the STA website, and via their social media accounts.

17. Next meeting

Action: Gary and Emily to organise the venue and time for the Executive meeting that will take place on July 21, the Friday prior to the Albany Conference.

Minutes ASFB Executive Council Meeting
Friday 21st July 2017, 1500-1700 WST
Function Room (Ground level), UWA Science Building, 35 Stirling Terrace, Albany, WA & Teleconference

Executive Council members: Chris Fulton, Harry Balcombe, Heather Patterson, Charles Todd, Gary Jackson, Brendan Ebner, Katherine Cure, Andrew Katsis, Ben Broadhurst, Sally Hatton, Lee Baumgartner, David Harasti, Mike Hammer, Grant Johnson, Nick Ling, Brendan Hicks, Leanne Currey, Geoffrey Collins, Gretchen Grammer, Mike Steer, Stacy Bierwagen, Lachlan Fetterplace, Sean Tracey, Heidi Pethybridge, Scott Raymond, John Morrongiello, Peter Coulson, Emily Fisher

Apologies:
Leanne Currey, Sean Tracey, Nick Ling, Brendan Hicks, Heather Patterson, John Morrongiello, Heidi Pethyridge, Geoffrey Collins, Lee Baumgartner, David Harasti, Peter Coulson, Mike Steer, Andrew Katsis, Ben Broadhurst, Sally Hatton, Grant Johnson, Stacy Bierwagen, Lachlan Fetterplace.

Agenda

1. Welcome / apologies
2. Minutes from previous meeting
3. Actions from previous meeting (Chris)
4. New members (Heather)
5. Treasury report (Heather)
6. Student & State Representative reports (All)
7. Newsletter (Kathy)
8. Communications (Andrew)
9. Albany 2017 update (Emily/Gary)
10. Melbourne 2018 update (John/Brendan)
11. World Fisheries Congress 2020 update (Chris)
12. ASFB financial plan (Chris)
13. Other business:
    a. Financial support for Fish Passage 2018 (Lee)
    b. Bid for IPFC11 in Auckland, NZ 2021 (Chris)
    c. Nomination of new Life Members (Chris)
14. Next meeting

Minutes complied by Charles Todd

1. ***Welcome / apologies***

   Chris welcomed everyone to the meeting.

2. ***Minutes from previous meeting***

   Harry proposed to accept the minutes from the previous meeting and Emily seconded the motion, the motion was carried.

3. ***Actions from previous meeting (Chris)***

Action: Michelle & Andrew - call for content and contact Andrew to get this call out on twitter and facebook.
Done
Action: Harry and Michelle to begin the process of finding Michelle's replacement initially from within the membership before Albany 2017 AGM.
Done
Action: Gary to work with Kevin Rowling and Andrew to flesh out the history of the ASFB on our Wikipedia page.
Done
Action: Andrew to put out a call to members to volunteer with assisting him on ASFB communications.
Done
Action: Chris and John to ensure fisheries management committee members (when formed) are involved in the Melbourne 2018 conference organising committee.
Done
Action: Include this as an agenda item for 2017 AGM; Chris, Harry, Gary and Charles to develop a range of proposals on governance to discuss at the next Executive meeting and then present at 2017 AGM.
Done
Action: Chris to ask the 'Dead Presidents' about organisational structure, and a summary/story of the learnings from their time as President.
Not done
Action: Chris to consult past presidents on structure of candidate statement, and then send to Charles so he can convey this request to 2017 nominees to the positions of VP and President.
Done
Action: Lee & Keller to work with Matt Barwick and Alien Fishes Committee to develop a draft position statement, if deemed a good idea by this group. Executive to consider this statement for ASFB to communicate to public and/or key stakeholders.
Not done
Action: Chris to contact Jodie Rummer about the Executive agreeing to provide $5000 to support travel of a woman from a developing Indo-Pacific nation to 2017 IPFC, and discussing the criteria that the ASFB requests in making these funds available.
Done
Action: Chris to work with ASN to develop the criteria for a female ASFB member to apply for the $3000 to attend the 2017 Indo-Pacific Fish Conference and advertising.
Action: Gary and Emily to organise the venue and time for the Executive meeting that will take place on July 21, the Friday prior to the Albany Conference.
Done

4. ***New members (Heather)***

Heather provided a list of 84 new members that had joined ASFB over the period of 3rd of March to 30th of June. Chris pointed that as usual some are familiar names that have previously allowed their financial status to lapse, but have now joined up again. Note that most are from the home state of the 2017 conference (WA), similar to the Tasmanian trend last year. The ASFB currently has 412 financial members (incl. 135 students)

Harry proposed to accept the new members, Gretchen seconded motion carried, the motion was carried.

5. Treasury report (Heather)

Chris presented the Treasurer's report on Heather's behalf.

At the end of the 2016-17 financial year the Society is in a good financial position with $449,416 in the bank:
- ASN account = $136,479
- General account = $5,482
- Business online saver = $52,808
- Term deposit – main = $233,293
- Term deposit – KRA Bequest = $21,355

[Note: The ASN account contains Albany 2017 event accruals in the amount of $91,545]

The majority of this money (~$255K) is invested in Term Deposit accounts that accrue interest that can be used by the Society. The Term Deposit accounts are setup in a way to provide both emergency funds if the Society was to be financial difficulty and to provide seeding funds to bid and host future joint international conferences. The majority of income for this financial year was derived from grants, mainly FRDC ($37,800), profit from the Hobart conference ($13,176) and membership fees ($17,564). Over the financial year, the Society raised $6,713 in bank interest.

The largest outgoings were awards and prizes ($26,708). Other major expenditures included the Newsletter editor ($5,004) and Communications officer ($6,000). ASFB also provided sponsorship for one-off events ($9,843), like for the IPFC Women in Science Travel Bursary, as well as delegates to attend Science Meets Parliament and the World Fisheries Conference planning day ($12,107).

ASN handle the day to day expenses of the society and membership management. ASN also organised the independent audit for 2015-16 and have done so for 2016-17. The audit will be completed by mid-August. Services from ASN for 2015-16 were $8,211. Overall, the Society has managed to maintain a very stable budget over the past 5 years and having ASN handle the membership and financial aspects has been a good investment and has streamlined operations.

6. Student & State Representative reports (All)

No reports

Mike gave a brief update on the Threatened Species sub-committee, and thanks Murdoch University

7. Newsletter (Kathy)

Katherine Cure is the ASFB's new newsletter editor. Chris pointed out to Katherine that it is not her role to chase State Reports for the newsletter, it is the responsibility of the State Representatives. Katherine asked if the newsletter can be named. Gary suggested a competition to name the newsletter.

8. Communications (Andrew)

Chris presented Andrew's report. Andrew has developed an ASFB Wikipedia page. Facebook has 4,367 likes which apparently is a very good statistic.

9. Albany 2017 update (Emily/Gary)

As of 14 July we have 169 registrations, including 46 students, for the 2017 ASFB conference in Albany. This includes 14 day registrations, which mainly comprise Albany locals and Albany High School students and teachers. The three-day conference program includes 137 oral presentations and five plenaries, as well as a number of other talks in the *Nurturing Fish Scientists and Student Rapid* talk sessions on the first day of the conference. We also have 10 posters that will be the focus of the Sunday lunch break poster session. We have secured around $21 K in sponsorship to date.

Chris thanked the people involved in organising the Albany conference. Brendan reiterated Chris' thanks.

10. Melbourne 2018 update (John/Brendan)

Brendan presented the update in John's absence. Science into Practice, Practice into Science, 7-11th October 2018, Rydges on Swanston, Carlton. The conference organising committee has agreed upon a conference theme (Science into Practice, Practice into Science) which will explore the nexus of research and resource management/ policy development. We are very keen to showcase a series of positive case studies through plenaries and special sessions to ensure that the overall conference feel is one of us collectively masking progress. We discussed that whilst this might seem somewhat contrived, we decided that collectively we often get caught up in the negatives of science-implementation with the sometimes differing priorities. It is easy to talk about what didn't work when we should really be focussing on what has worked, what we can learn from this, and how we can continue to improve our practice into the future. We are planning a public lecture on one evening to revisit the climate change symposium from the 2010 conference. This event will involve a series of readily accessible presentations followed by a panel discussion. It will be hosted at the Museum.

We have booked a conference venue (Rydges on Swanston). This was chosen due to its location and cost. This venue includes a plenary hall that can be broken into four separate rooms for concurrent sessions. The hotel has offered us an attractive package. Whilst we have some reservations about the plenary space (it is a flat room as opposed to an auditorium), we were unable to find another venue for an appropriate cost and in such a convenient location. We are currently investigating venues for the conference dinner. We will host a welcome mixer on the Sunday evening (7th) and close the conference with the dinner (11th).

Scott asked if there was going to be animal ethics session. Brendan advised that Callum was championing this.

Gary noted that he had been asked by Chris Fulton to develop a document clarifying the roles of the ASFB Conference Coordinator, Local Conference Chair and ASN for future reference.

Action: Gary to develop a conference coordinators guidance document .

11. World Fisheries Congress 2020 update (Chris)

The first WFC2020 planning day was held on 29 May 2017. Gary Jackson and Harry Balcombe represented the ASFB (among 16 delegates in total). Immediately prior, Chris, Gary, Harry and Bronwyn Gillanders (WCFS President) discussed obligations of the WFC2020 to the host society (ASFB) and World Council of Fisheries Societies (WCFS). We have agreed on most of the terms in an MoU to protect the needs of the ASFB (i.e. usual core functions we need to complete in our annual conference), which will be finalised by end of this year. The planning day discussed a broad range of issues, but essentially just decided on conference sub-committee structure (ASFB will have representation on the Local Organising, Program, Comms, Education, and International Steering Sub-committees), and a broad timeline for future work. Themes, speakers and sponsorship prospectus will be developed in future meetings. Both ASFB and WCFS delegates noted a lack of gender and career diversity within current group of people involved in conference planning, which was highlighted with WFC Chair Gavin Begg – we hope this will be addressed via more inclusive recruitment to the various Committees.

Action: Fixed agenda item

Gretchen asked about logo's and in particular ASFB logo whether it should be included. Gary thought that both SA Government and ASFB logo's should be included.

12. ASFB financial plan (Chris)

The ASFB Financial Planning Committee met at Adelaide airport on 10 May and considered suggestions made by many of the Exec, as well as the financial summary provided by our accountant at ASN. Our report is attached below. We would like the Executive to consider our key suggestions for investing member's funds back into the ASFB (highlighted in yellow in report), so that we can discuss which ones we put forward to members at the 2017

AGM. Note that some suggestions are recurrent (i.e. will incur increased expenditure each year), while others are one-off investments.

There was general discussion about continuing to develop a financial plan, a 5-year plan was suggested.

Chris proposed the motion to accept the Financial Working Group financial plan to be presented to the AGM, Brendan seconded the motion, the motion was carried.

13. Other business:

a. Financial support for Fish Passage 2018 (Lee)
b. Bid for IPFC11 in Auckland, NZ 2021 (Chris)
c. Nomination of new Life Members (Chris)

a) As it is not possible to co-host the Fish Passage conference due to constitutional conflicts, we have been asked to sponsor the conference. Chris suggested that we sponsor the conference for $5000, where $2500 is for general sponsorship and $2500 as a travel bursary.

Gretchen proposed the motion to accept Chris' suggestion, Scott seconded the motion, the motion was carried.

b) Submitting bid next month, possibly October.

c) Chris wants to nominate 2 Life Members. Executive agreed.

Gary enquired about how discussions with the Australian Fisheries Management Forum and a possible ASFB Fishery Management sub-committee were progressing. Gary is not sure that anyone from the AFMF group is going to present to the 2017 ASFB AGM.

14. Next meeting

Sometime in mid-October

Annual General Meeting

Auditorium, Albany Entertainment Centre, 2 Toll Place, Albany, Western Australia
2.00-3.30pm, Monday 24th of July, 2017

Draft Minutes complied by Charles Todd

1. Welcome and apologies

Welcome

Chris Fulton (ASFB President) welcomed everyone to the meeting. A quorum was achieved with 71 members present.

Apologies

Leanne Currey, Sean Tracey, Nick Ling, Brendan Hicks, Heather Patterson, John Morrongiello, Heidi Pethybridge, Lachlan Fetterplace, Geoffrey Collins, Lee Baumgartner, David Harasti, Peter Coulson, Katherine Cure, Lynnath Beckley, Chris Bice, John Pogonosti.

2. 2016 AGM Minutes

Chris declared the minutes of the 2016 AGM (as published in the December 2016 ASFB Newsletter) as being a fair representation of the 2016 Annual General Meeting. Mark Lintermans motioned to accept the 2016 AGM minutes and Di Bray seconded the motion, the motion was carried.

3. Executive Council's Report

Chris stated that the ASFB Executive have met three times since the last AGM, and that the minutes of all these meetings will be available in the December 2017 newsletter. Some key activities that have occupied the Executive have been:

Newsletter Editor: After many outstanding years of guiding and editing our newsletter, Michelle decided to step down after completion of the 2017 mid-year newsletter in June. Chris thanked Michelle for her many years of service to the ASFB, and welcomed Kathy Cure as our incoming Newsletter Editor.

Communications: We lost a huge chunk of our online historical archives in the move from TRI to ASN that links back to our website. We are now working to re-build that legacy. Thanks to our Communications Manager Andrew Katsis and member Kev Rowling, some of this information has been captured on our new ASFB Wikipedia page. Kev Rowling has also started scanning the first paper-based ASFB newsletters, and they have been uploaded to our website. Chris will be scanning the rest to bring together a full electronic database up to the present day. We believe this is important to complete in time for the ASFB to celebrate our 50th Anniversary in 2021.

World Fisheries Congress 2020: The first planning day for WFC2020 was held in May, with Harry Balcombe and Gary Jackson in attendance to represent the ASFB. Decisions were made on the committee structure and general timeline for planning the event. We also made progress in developing an MoU with the SA Government to ensure our core ASFB business will be happen as part of the meeting, since this will be our conference event for 2020.

Officer Election Statements: members would have seen the e-mail sent out this week about this, which arose from the Executive deciding to ask all nominees to the positions of Vice-President and President to provide candidate statements in the lead-up to the AGM. This is to provide members with the background and intentions of each candidate. The Executive is also planning a revision of the process for VP nominations, the transition to President, development of a Nomination Committee and the criteria they might use to develop a shortlist of candidates for election, as well as potential move to online voting (i.e., anonymous, open to all members regardless of making to the AGM) ahead of the relevant AGM (every two years).

4. ASFB Financial Plan (2017-2021)

In the first half of this year the Executive decided to formulate a financial plan to guide how the ASFB structures our savings and investment in ASFB activities. After examining historical trends in our finances, a group of ASFB members (spanning early career, Committee Chairs, past Presidents and some of the current Executive to be known as the ASFB Financial Plan Committee) met in Adelaide for a one-day workshop to consider ASFB savings targets, and where we think we could invest some of our savings into new initiatives. Chris presented the core findings and key recommendations form this process.

ASFB historical bank balances over the past ten years indicated an average of $307k in savings, while the balance between income and expenses suggests an average operating surplus of $15.4k each year. However, over the past three financial years the average cash balance has been $348k, with an operating deficit of -$5.4k per annum. Some other important things to note are that: the ASFB has no current financial plan to manage & invest member's equity; we currently receive ~$6k pa in bank interest (off ~$250k in term deposits) and ~$16k pa in membership fees; the ASFB has some of the lowest membership fees ($60 pa for ordinary member) in our region (cf. ASL = $75, AMSA = $86, ESA = $99); we have rising costs to maintain high quality services to members (secretariat, conferences & workshops, communications); additional annual income could come from an increase in members (e.g. 10% = $1,842 pa) and/or annual fees (e.g. 10% = $1,539 pa); FRDC sponsorship ($22k pa) is a major component of conference support which is not certain to continue (currently on 3-year contract); and if we do have surplus savings, then investing these wisely could provide new opportunities to attract & support our diverse membership, including our international relevance and connections across the Asia-Pacific region.

Based on these considerations, our key findings and recommendations were that the ASFB should over the next two Presidential terms (i.e. four years):

1. Maintain minimum cash balances of:
    a. $100k "emergency" fund (invest for 3-5 years); and
    b. $100k "strategic" savings (large conferences/workshops);
2. Invest current surplus savings of ~$150k over next four years (two Pres terms), then revisit operating surplus/deficit (e.g. membership fees) in 2021.
3. Make new recurrent expenditure (+$74k over 4 years) for increased student grant support (+$3.5k pa), an ASFB-wide competitive grant (annual theme; +$5k pa), an ASFB-wide competitive grant (threatened species; +$5k pa), increased support for ASFB Communications (+$2.5k pa), and digitisation and archiving of retiring member datasets (+$2.5k pa).
4. Consider investing the remaining surplus (~$76K) into one-off strategic investments over 2017-2021, which could include the World Fisheries Congress 2020, the Indo-Pacific Fish Conference 2021, and increased support for ichthyologists from across Asia-Pacific to attend ASFB and other fish & fisheries events in our region.

Dave Morgan asked about the difference between the "strategic funds" and the one-off investment suggestions. Chris responded that they are essentially the same thing, with the exception that for this first financial plan, we have a large operating surplus which could be used first (to be conservative), and then see how we go from there. Chris emphasised that this is really the first draft of the financial plan for consideration, and if the ASFB accepts this, then the Executive can use this as a base for making future decisions, and adjust as necessary.

Ben Broadhurst asked about the "emergency" funding and what might be considered a likely loss form a bad conference? Chris responded that the Society has fortunately not had a deficit conference in recent years, but that $80-100K could be expected for a typicaly ASFB conference if a major catastrophe occurred (e.g. airline failure).

Culum Brown asked if shopping around different banks could possibly get us a better interest rate? Chris agreed that this could be possible, but noted that moving banks isn't a simple process for all of our accounts (e.g. written notice of 30days). Chris mentioned that the larger argument may need to be around what type of investment does the ASFB feel comfortable to make, considering that an investment horizon of 3+ years might provide scope for something other than a term deposit.

John Koehn asked about an update on previous discussions about ASFB involvement with indigenous researchers and organisations. Chris reaffirmed that this was a priority for the ASFB, and that although early progress had been made in developing an Indigenous Liaison Committee with representatives from across Australia and New Zealand, we were yet to formalise any expenditure to support this committee.

Chris Hallett suggested the available funds could be used to support childcare at future conferences. Chris agreed and supported the idea, the plan has flexibility and this may be something that future Executives may support depending on the circumstances.

Sara Hearne asked about whether the ASFB would consider making ethical investments. Chris responded that this should be considered carefully by the Executive, but that investment in ethical ventures with a long-term future would likely be the best approach for the ASFB.

Mark Lintermans asked about the current FRDC sponsorship contract. Chris responded that the current FRDC agreement expires in June 2018, and that the level is at the lower end of what is required to really invest in the full range of networking opportunities that the ASFB provides. Chris reinforced that the ASFB is very grateful for FRDC support, which at Albany, included the nurturing scientists' session, the student travel and presentation awards, and the harvest strategy special session.

Chris proposed a motion to accept the four-year ASFB Financial Plan as presented. Gary Jackson motioned to accept the financial plan and Nick Ling seconded the motion, the motion was carried unanimously.

5. World Council of Fisheries Societies Report

The WCFS has worked to separate its accounts from AFS – this has required the society to be registered as a non-profit society (in the State of Maryland, USA), obtain an employee identification number and apply for tax exempt status. Moving forward this enables improved tracking of budget and finances. Societies are now paying back dues, including the ASFB. Small executive group comprising immediate past President, President, Executive Director AFS and two Vice Presidents have held several Skype calls since Busan meeting in May 2016. There is a Skype meeting scheduled for early August and an informal meeting will be held at the AFS Tampa meeting. WCFS has drafted an MOU with the ASFB and SA Government for WFC2020.

6. Treasury Report

Chris presented the Treasurer's report to the AGM in Heather Patterson's absence. Chris said that if there are questions he is unable to answer, he will take them on notice and provide a detailed reply via post-AGM amendments to the minutes.

At the end of the 2016-17 financial year the Society was in a good financial position with $449,417 in the bank. Amounts in each account on the presentation:

- ASN transaction account = $136,479*
- General transaction account = $5,482
- Business online saver = $52,808
- Term deposit – Main = $233,293
- Term deposit – K Radway Allen Bequest = $21,355

Note that these totals include a $91K accrual for the Albany 2017 event, all of which will be paid to our suppliers, venues, etc in this new financial year. Effectively, this means we have $353,237 in cash assets, which is slightly up on last year.

The majority of income for last financial year was derived from our partnership with FRDC to support conferences, workshops and student awards, the ASFB's share of the 2016 Hobart conference profits, and membership fees. Over the financial year, the Society raised $6,713 in bank interest, primarily on our two term deposits. The greatest expenditure items were awards and prizes, newsletter editorial, communications management, and attendance of ASFB representatives at events such as the AFS meeting, the WFC planning day, and the Financial Planning Committee meeting.

We have increased our membership to 438 financial members (up from 377 last year). ASN handle the day to day expenses of the society and our membership database, with expenditure approved by two signatures (President/Vice-President & Treasurer). The current cost of these services is $10,000 per calendar year.

Important to note, as we did last year, that without unusual income sources (e.g. conference surplus), our revenue stream does not cover our annual expenses at present, with a $4k deficit. Given our large cash reserve at present, this is not a major concern, but as discussed for the financial plan, we suggest revisiting any imbalance in regular income and expenditure once we start to spend down our savings.

We believe this is a true record of ASFB income and expenses for the 2016-17 financial year, and an independent audit of our accounts will be provided in the December 2017 newsletter.

Ben Broadhurst asked about the miscellaneous $55 item. Chris said he will have to check.

Mark Lintermans asked about the single institutional member. Chris was not sure, but thought it was a library associated with a state government department.

John Koehn motioned to accept the treasurer's report and Bronwyn Gillanders seconded the motion, the motion was carried unanimously.

Finance Report

Australian Society for Fish Biology Cash Flow Statement: from 1 July 2016 to 30 June 2017		
	2017	**2016**
Income		
Conference Distribution	$13,176	$26919.99
Interest Received	$6,713	$9,271
Membership Fees	$17,564	$15,082
Miscellaneous	$55	
Sponsorship	$37,800	$22,000
Total Income	**$75,308**	**$73,273**
Expenses		
Accounting Fees	$582	$145
Administration Costs	$7,540	$2,135
Auditors Remuneration	$770	$900
Bank Charges	$393	$350
ConferencesCommittee	$12,107	$2,473
Filing Fees	$56	$224
Consultants	$6,000	$6,500
Functions	$788	$0
Meeting Costs Committee	$2,152	$1,221
Miscellaneous Expenses	$0	$30
Postage	$0	$395
Prizes and Awards	$26,708	$20,139
Printing and Publications	$6,435	$6,539
Speaker Costs	$0	$8,014
Sponsorship	$9,843	$382
Subscriptions	$2,622	$2,576
Travel and Accommodation	$3,363	$453
Website	$90	$1,121
Total Expenses	**$79,448**	**$53,599**
Net Surplus/(deficit) from operating activities	($4,140)	$19,674
Total changes in equity of the Association	**$4,140**	**$19,674**
Opening retained profits	$357,377	$337,703
Net surplus/(deficit) attributable to the Association	($4,140)	$19,674
Closing retained profits	**$353,237**	**$357,377**

7. *Committee Reports*

a **Education Committee Report**

Steve Beatty reported on the Education Committee.

The Education Committee held its annual meeting on Sunday 23rd July 2017 during the Albany Conference. Thanks to the other members of the Committee including Chris Hallett, Stacy Bierwagen, Lachlan Fetterplace, Katie Ryan and John Morrongiello.

Awards

Thanks again go to the FRDC for funding the awards and supporting the future of fisheries research in Australia. Application for student research awards in 2017 almost doubled the number 2016 entrants with 22 applications for the Michael Hall and Barry Jonassen awards. The quality of the research projects and applications were exceptionally high and the judging was again tight. The Executive approved the introduction for a $1000 runner-up category for both awards. We thank the ASFB Executive for approving this initiative. I look forward to announcing the winners and runner-ups for the awards at the Conference Bash tomorrow night. This year, the John Glover Travel Bursaries supported 15 students to attend the Albany conference. Thanks to all students who have attended Albany, it is a long journey for many of you but I am sure you have found it very worthwhile. We had 15 students enter the Gilbert Whitley Oral Presentation (several eligible for the Victorian Marine Science Consortium Award). Winners of the conference awards Conference Bash and thanks to the following judges: Katie Ryan, Ben Broadhurst, Alastair Harry, Shaun Wilson, Chris Hallett.

Second New Student Competition in Science Communication Award (SCiSC)

The Education Committee doubled the prize pool to $4000 in 2017 with re-structuring also seeing all entrants sharing in the prize money. We also introduced the "Members Choice" award that has been voted on during the conference. We also decoupled the video and rapid oral presentations and introduced 'hidden' online voting for the video awards.

The video round of the SCiSC competition had 7 entrants and were very well produced and attracted 27,000 views (same as 2016) and 1722 votes (up from 1,251 votes last yaer) (https://asfb-student-competition-in-science-communication-awards.thinkable.org/). It was terrific to have two international entrants giving exposure to the ASFB in India and Malaysia.

There were 8 students who presented their Rapid Fire talks on Saturday afternoon and showcased some exceptional research. The winners will have their conference registration refunded by ASFB and thanks to the delegates who turned out to support the students.

Changes to Awards

The award forms (Hall and Jonassen) and criteria have been changed to a 1000 word limit (was 2 pages) and specify that references and budgetary table should be included but are not counted in the total. This will create a fairer application process.

ASFB Facebook, Twitter, Newsletter

ASFB Facebook and Twitter was used very well this year and likely boosted the application for student awards, thanks again to Communications Manager Andrew Katsis.

Please continue to promote your activities and news through the ASFB newsletter via your State Representatives.

Melbourne Conference
All suggestions are welcome for initiatives for the Melbourne Conference, please chat to the Education Committee members and Brendan Ebner. We are particularly keen to hear about poster sessions and multi-media suggestions.

b Alien Fishes Committee Report
Ben Broadhurst reported that the Alien Fishes Committee was largely inactive in the past 12 months with little input from most current members. To reinvigorate the committee, we have decided that a membership spill is the best course of action so we are looking for interested parties from each state to join. We are hunting for new members and I've already had some willing participants but the membership's open so please see myself or Dave Morgan if you're interested or want more information.

Di Bray asked about increasing female membership of the committee. Ben responded that anyone is welcome to join, and he encourages more female members to get involved.

Morgan Pratchett asked whether vagrants/translocated species are included. Ben responded he thought it would be ok. Mark Lintermans saw no problem with the idea, it had not been considered previously as no one had previously suggested it.

c Threatened Species Committee Report
Mike Hammer presented the report from the Threatened Fishes Committee (TFC).

1. Updates to Committee
(a) Michael Hammer has taken up the positon of Co-convenor assisting Mark Lintermans with a view for a transition to handover. Mark has been Convenor for almost 8 years and we thank him for his significant contribution. The Committee will seek a Vice to the convenor for future succession.
(b) The Committee has a solid core group of contributors spread across the Country, however we are always looking for fresh ideas, information and people to share applied experience as part of a network of expertise. Each state and territory can have both a freshwater and marine representative, noting that many species and workers span both environments. Other interested members are welcome and encouraged to participate. Four new members have joined the TFC during the Albany conference, and we look forward to their involvement:
Western Australia – Claire Greenwell (Murdoch University)
New Zealand – Nick Ling (Waikato University)
Northern Territory – Krystle Keller (Charles Darwin University)
ACT – Karl Moy (University of Canberra)

2. 2017 workshop

The Threatened Species Committee met immediately before this year's annual ASFB conference in Perth at the Senate Suite at Murdoch University with the major focus of the meeting being a full day workshop to review the conservation status of species in the several families/groups including smelts, eels, carp gudeons and cave fishes (including presentations by Peter Unmack, University of Canberra and Bill Humphries, ex-WA Museum). Several species were flagged as candidates for which detailed nominations should be prepared. This was the fourth workshop in a series that will proactively review the entire Australian freshwater fish fauna over a series of workshops over the coming years, with the fifth and final planned coinciding with next year's conference in Melbourne.

3. Nominations

Two nominations to the ASFB Threatened Fish List were received and assessed at the workshop. These covered Galaxiella species from south eastern Australia subject to recent taxonomic revision. The committee noted these species had multiple national and state conservation listings and warranted assessment, however additional information would be required to consider the nominations. Feedback and support will be provided to encourage resubmission.

The committee welcomes new nominations or proposals for re-categorisation. Could anyone working on species that they consider threatened but which are not currently on the ASFB Threatened Fish list, please contact their State/Territory rep or the Co-Convenors. Nominations must be received at least one month before the annual conference date to allow distribution to and consideration by committee members, and can be considered out of session.

4. 2017 annual meeting

We had 12 committee and guests attend the face to face meeting at Albany. Meeting time and venue to be included specifically in the 2018 conference delegate booklet. Key discussion points included:

(a) Reinvigorating/growing state representation.

(b) A dedicated effort to provide social media contributions to help promote ASFB, the committee and threatened species: things like faces, places and critters images; short videos; threatened species profiles/blogs.

(c) A threatened fishes award through the society to support conservation and research especially for species that fall through the cracks of not being on legislated lists difficult to fund otherwise (e.g. recently described species).

(d) Digitising TFC historic records.

(e) National Action Plans: examples from other vertebrate groups are available, with potential for fishes.

(f) Developing a threatened species Special Session at next year's Conference to showcase threatened species research in Australia and New Zealand, updates on recovery efforts, and sharing IUCN red list experience to support a national review of freshwater fishes in Australia.

8. 2016 Annual Conference Report – Hobart wrap up

Brendan Ebner presented the final wrap up from the 2016 Hobart Conference on behalf of in the absence of Heidi Pethybridge and Sean Tracey.

Last year's conference was held at Wrest Point Conference Centre in Hobart, Tasmania from 4-7th September and going by the feedback of the ASN poll, it was a great success. Major highlights included the roll out of two new initiatives that celebrated women and students in ichthyology, respectively. The incredible women in ichthyology event kicked off the conference with 6 women keynotes followed by an informative panel discussion. In addition to this there was an ongoing poster exposition that included several high-achieving women inducted on the ASFB Hall of Fame. This allowed for the contributions of women in the society from all career stages to be celebrated and presented a clear message that ASFB promote gender equality. There was also a focus on student communication with short videos of all entries submitted into a Thinkable competition run earlier in the year presented in the foyer. Many of the video participant's then delivered a 3 minute presentation of their work without visual aids in the Plenary Hall. There were 4 additional keynotes including the ASFB K.Radway Allen Award recipient, David Bellwood, and French ecosystem modeller Patrick Lehodey. Social events included canapes at Government House, a student mentor mixer and an enjoyable dinner at Hobart's infamous MONA.

¥ Total number of registrants: 268 with delegates from more than 8 countries

¥ Society members: 134 from ASFB, 29 from OCS and 22 from both societies

¥ Number of abstracts presented: 190 oral presentations and 22 posters

¥ Total profit: $16,922 (78% going to ASFB - $13,263)

9. 2018 Annual Conference, Melbourne Vic

Henry 'Rex' Wootton and Josh Barrow presented the following key points for the Melbourne 2018 ASFB Conference and AGM.

The conference will run over four days, 8th – 11th of October, and will focus on exploring the relationships between scientific research, natural resource management and policy formulation. The 2018 conference will celebrate our successes at the science-practice nexus. We want to challenge delegates to share their experiences, priorities and new ideas about how science can better inform management, and how management can better focus research activities. We are planning a public forum to revisit the 2010 Melbourne conference's climate change symposium. Speakers will discuss marine and freshwater developments in this field, including challenges met, and challenges outstanding. We will then have a panel discussion with questions from the floor. A call for special sessions will be made later this year. The welcome mixer will be held on the evening of Sunday 7th October, followed by four days of presentations. We will close the conference with a gala dinner on Thursday 11th October showcasing a unique Melbourne experience.

10. Elections

Chris explained to the members that every year ASFB changes over half the State and Student Representatives. Chris noted that retiring members of the Executive could re-nominate for another term, however, he also urged members to participate in the running of the society and that being involved in the Executive is the best way to influence the management and direction of the society. Chris warmly thanked those retiring members for their contribution to the Executive Committee and the Society as a whole.

State Representatives and Student Representative who retired from the Executive were: Ben Broadhurst, Lee Baumgartner, Mike Hammer, Nick Ling, Leanne Currey, Gretchen Grammer, Stacy Bierwagen, Sean Tracey, Scott Raymond, Peter Coulson.

The following nominations were received for the available Officer, State and Student Representative positions. All nominees were elected unopposed.

President
Stephen (Harry) Balcombe — Motion unanimously carried

Vice President
Alison King — Motion unanimously carried

Treasurer
Lenore Litherland — Motion unanimously carried

Secretary
Charles Todd — Motion unanimously carried

State	Nominee	Proposer	Seconder
ACT	Matt Bietzel	Ben Broadhurst	Katie Ryan
NSW	Keller Kopf	Charles Todd	John Koehn
NT	Mike Hammer	Charles Todd	Alison King
NZ	Gerry Closs	Nick Ling	Chris Fulton
QLD	Leanne Currey	Harry Balcombe	Karl Moy
SA	Gretchen Grammar	Bronwyn Gillanders	Harry Balcombe
Student	Sherrie Chambers	Jonie Pini-Fitzsimmons	Culum Brown
TAS	Sean Tracey	Charles Todd	Krystle Keller
VIC	Scott Raymond	Charles Todd	Mark Lintermans
WA	Chris Hallett	Emily Fisher	David Morgan

11. Other Business

Life Members: Chris had the great pleasure to announce that as retiring President he is allowed to confer life membership to a member of the society. After discovering that a few past Presidents have skipped their option to do so, and on the blessing of the current Executive, Chris was able to offer two life memberships this year. The first was to someone who has been on the ASFB Executive Committee continuously for the past 13 years, starting with when he was tapped on the shoulder in 2004 to run our workshop and conference programs so that they were inclusive of all our members and activities. Since then, at many an Exec meeting we would often hear the phrase "Can I just say something?", which was usually a comment strongly advocating for the ASFB and its members. He is a stalwart of the ASFB, and will continue to be so, which is why Chris was very happy to offer Gary Jackson Life Membership of the ASFB. The second Life membership was to someone who has also contributed well over a decade to the ASFB, serving on the Education and Executive committees, as well as the various award selection committees, and even after leaving leadership roles in the ASFB, has now gone on to lead the World Council of Fisheries Societies. As Steve Beatty said the other day, she has become an invaluable person to the ASFB, who is often called on, and most importantly accepts, many roles within our Society. This is why Chris was very happy to offer Bronwyn Gillanders Life Membership of the ASFB.

Chris proposed we transfer the signatures associated with the Australian Society of Fish Biology's bank accounts at the Commonwealth Bank to the new President Stephen (Harry) Balcombe and Treasurer Lenore Litherland. The motion was proposed by Gretchen Grammer, and seconded by Culum Brown, and the motion was carried unanimously.

Gary Jackson suggested making the award of the ASFB K Radway Allen award for established researchers an open nominated process. At present, the ASFB President is required to put together a selection committee to nominate and judge the winner from what is often a long list of outstanding people. Gary noted the work that Chris has already done towards formalising this nomination and selection process, and asked what the next steps should be? Chris elaborated on what Gary had mentioned, in that: the current statement for the ward is very broad (significant contribution to fish and fisheries in our region, with brief outline of nomination and selection process. Chris spoke about some of the key changes to the nomination process he has implemented in recent years, which included: formalising a 50-50 shortlisting (50% of people on shortlist from each gender), encouraging a spectrum of people on the selection panel (including gender equity and diverse career representation), judging contributions made outside of just publications (e.g. teaching, mentoring, policy changes, leadership), making allowances for merit relative to opportunity (which includes time spent on things other than research/management, parental leave, etc). Chris agreed that Executive should consider changes to nomination process to allow for open nominations from ASFB membership.

Brendan Ebner highlighted the opportunity for conference special sessions to be suggested by members, ideally by a mix of early and late career members, for the next conference in Melbourne. Brendan then reminded the AGM about the conference debate to be held right after the AGM.

12. Next AGM and close
Next AGM will be held in Melbourne Victoria during 7^{th} – 11^{th} of October 2018.

Chris thanked everyone for their attendance and closed the meeting.

Attachment to the minutes required by Associations Incorporation Reform Act 2012
No. 20 of 2012 in accordance with Part 7 of the Act s.94(4)

ASFB Committee Reports

Alien Fishes Committee

Compiled by Ben Broadhurst
Convenor, ASFB Alien Fishes Committee

Committee disbanded and revamped!
In an attempt to revamp the lagging but important alien fishes committee, a decision was made at the 2017 AGM by the active members of the committee to disband and reform with a revitalised membership. The new membership is currently comprised of those below, though notably we still have some vacancies. If you have an interest in alien fishes ad reside or conduct research in one of the vacant slots below and think you might like to be a member or contribute to the committee, please get in touch ben.broadhurst@canberra.edu.au

2017 Alien fishes committee
Ben Broadhurst (ACT, Convenor)
David Morgan (WA, Deputy convenor)
Mark Lintermans (ACT)
Karl Moy (ACT)
Daniel Smith (QLD)
Mischa Turshwell (QLD)
Stephen Beatty (WA)
Cindy Palermo (WA)
Brendan Hicks (NZ)
Nicholas Ling (NZ)
Martin Asmus (NSW)
(NSW)
Michael Hammer (NT)
(VIC)
(VIC)
Rob Freeman (TAS)
Jonah Yick (TAS)
Nick Whiterod (SA)
(SA)

Please read on for the exciting and important research and management actions being undertaken in each jurisdiction!

Australian Capital Territory

Carp out – Matt Beitzel
ACT Aquatic ecologists removed 5 tonnes of carp from two urban ponds in April 2017. The ponds were to be drained for construction of a larger weir and wetland construction as part of the ACT Healthy Waterways Program. Volunteers from the Southern ACT Catchment Groups indigenous Green Army team and Waterwatch processed carp. 1510 carp were removed from the 4.4 ha pond and 765 from the 6.8 ha pond. The removal project aimed at correlating standard electrofishing with total carp abundance and density once the ponds had been drained.

Trout tagged
To examine the drivers behind their movements in an upland reservoir, Dan Owin (as part of his masters by research degree) has acoustically tagged 20 adult rainbow trout. Dan will be monitoring their movements over the next few years trying to disentangle their movement patterns in light

Above *Carp scooping; photo Jeremy*

Above *Some of the carp removed; photo Mark Jekabsons*

of resource use and competition with Macquarie perch.

Above *Cotter Reservoir rainbow trout with incision where acoustic transmitter was inserted; photo D. Orwin*

Rheyda Hinlo is in the final stages of her PhD looking at eDNA detection capacity for alien fish in flowing systems. Her major results were:

Above *In situ pumping of river water to examine for the presence of alien fish eDNA*

- First, we improved the understanding on how laboratory and field methods affect eDNA recovery, and provided practical guidelines that increase the cost efficiency of the eDNA method;

- Secondly, we provided evidence of improved detection of low-density species using the eDNA method and answered some basic questions related to seasonal detection and spatial distribution of eDNA in natural systems;

- Thirdly, we contributed to the understanding of eDNA dynamics in flowing water - specifically on production, persistence and detection in relation to distance from source;

- Fourth, we demonstrated the positive performance of the eDNA method across a gradient of species density, even for a highly secretive fish species;

- The results of this study are highly useful in the development of a robust detection framework for monitoring species using eDNA;

Native fish forum
The 2017 Native Fish forum held in Canberra in August had a couple of great presentations relevant to alien fish species in the Murray-Darling Basin;

- The National Carp Plan – Matt Barwick
- What do Carp do during a flood in Gunbower Forest - Jason Lieschke
- A Retreat for Maccas – cooperatively working with recreational fishers to bring Macquarie Perch back – Luke Pearce

New South Wales

Compiled by Martin Asmus, NSW DPI Fisheries

NSW Biosecurity Act 2015
On 1 July 2017 the NSW Government implemented the new *Biosecurity Act 2015* (the Act), and all aquatic pest and disease issues previously managed under the *Fisheries Management Act 1994* are now managed under this new Act. All former noxious fish listings have been revoked and aquatic pest listings are included as either Prohibited matter (Schedule 2 of the Act) and aquatic pest species found in the Biosecurity Regulation 2017 (Part 2 Schedule 1). Prohibited Matter includes those species that are not currently found in NSW and are considered a major threat to native fauna and environment. It is illegal to possess, buy, sell or move any of the aquatic pest fish species listed in NSW and heavy penalties can apply.

Under the new Biosecurity legislation people are expected to have a basic level of knowledge about the biosecurity risks they might encounter in their normal work and recreational activities. All community members have a general biosecurity duty to consider how actions, or in some cases lack of action could have a negative impact on another person, business enterprise, animal or the environment. We must then take all reasonable and practical measures to prevent or minimise the potential impact.

Redfin Perch flyer
Following commencement of the *Biosecurity Act 2015* NSW DPI has updated the Redfin Perch flyer called 'Keep native fish in play hold redfin at bay', which describes some of the new rules and how they apply to Redfin Perch. Copies can be requested from aquatic.pests@dpi.nsw.gov.au

Changes to management of ornamental fish
Since 2006, NSW DPI has been implementing a national strategy for management of ornamental fish, which includes a National Noxious Fish List. On 16 December 2016, the fourth addition to the National Noxious Fish List was included in NSW legislation which means a further 65 species have been added to the Prohibited Matter list (previously NSW Noxious Fish List). NSW DPI provided industry stakeholders and hobbyists with a six-month advisory period (1 March 2017 until 31 August 2017), and compliance with these new listings is now mandatory.

Tasmania

Redfin Perch Eradication – North West Tasmania
By Rob Freeman – Inland Fisheries Service

The Mersey River in Tasmania's northwest is one of the state's most valued and well-used waterways. The river supports a major fishery based on the introduced species brown and rainbow trout. More importantly however, the river provides important habitat for numerous native fish species and the giant freshwater crayfish, *Astacopsis gouldi.* Over several years there have been a few irregular reports of the introduced fish redfin perch *(Perca fluviatilis)* captured from the Mersey River following flood events. Despite surveys of the river, its tributaries and numerous farm dams, the source population could not be found. However, in the summer of 2015 a commercial eel fisher captured several redfin perch from a large farm dam that feeds Parramatta Creek, which flows into the Mersey River. A survey conducted by the Inland Fisheries Service confirmed this population as the source of the incursion. It seems like this population was dispersing downstream during flood events and resulting in episodic captures by anglers.

Following assessment of the dam and the downstream distribution of redfin perch, a decision was made to attempt an eradication of redfin perch by treatment with rotenone. In late April 2017, following assessment and approval, the dam outflow was screened to 3 mm and pumped down to low levels. An appropriate concentration of rotenone was applied by mixing product and dispersing it using 50 and 75 mm trash pumps. The treatment was immediately effective with numerous redfin perch quickly dying. The only by-catch noted was short finned eels. The dam level was left low until the treatment solution had broken down and was no longer active. Observations over several weeks suggest the treatment was successful, so the dam was allowed to refill. A follow up survey to confirm the result is planned for early 2018. An adjacent downstream dam that has also been invaded by redfin perch is scheduled for treatment in autumn 2018. If successful this should result in the complete eradication of the source population and hopefully remove the ongoing threat to the Mersey River. While some redfin perch may remain in the main stem of the river, the signs are that no significant or on-going recruitment has occurred. If this is the case, then the Mersey River could become free of redfin perch

Above *Some of the diverse range of freshwater species captured during surveys of the Mersey River, Tasmania*

Right *Redfin Perch*

Above *Application of the treatment solution to eradicate redfin perch* again.

Carp removal
By Chris Boon
The 2016/17 carp-targeting season required a dramatically different fishing strategy compared to that utilized in 2015/16. Lake Sorell filled rapidly after good winter rain, reaching full supply at the end of September 2016. The lake continued to rise into early October, peaking at 160mm above full supply level. This tested the levee banks and outflow screens containing carp to the lake. The high water levels also tested the barrier netting that is in place to prevent carp entering wetland spawning areas. These environmental conditions stimulated carp to move into inshore regions. For the first time in many seasons, fyke nets and gill nets set close to shore were the primary method of carp captures.

At a number of sites, carp breached the barrier netting. This became the priority and carp were targeted using gill nets and electrofishing gear in order to prevent spawning. This focus on inshore fishing effort is in contrast to the 2015/16 season in which the majority of carp were located in the deeper regions of the lake.

Above *The rocky backwater, which was the site of the first and only carp aggregation detected for the 2016/17 season. Entry points were blocked off, and trammel gill nets were zig zagged through the whole area in conjunction with backpack electrofishing*
Left *A large jelly gonad male carp caught in December in a trammel net over shallow, rocky substrate*

The targeting of radio-transmitter fish continued to be an effective technique, resulting the removal of several key carp individuals. One small 'feeding' aggregation of carp was also located, which occurred in mid-March after a period of warm settled weather. The main advantage of targeting aggregations as opposed to non-targeted gill netting effort is that the CPUE of aggregations are high, and large numbers of key fish can be removed quickly.

Monthly sampling for spawning started in November, culminating with a large survey in March which failed to detect any sign of recruitment. Downstream surveys in Lake Crescent and the Clyde River indicate that carp remain contained to Lake Sorell. The remaining carp in Lake Sorell appear to be struggling in both size and maturity. The observations of jelly gonad condition (JGC) carp have increased from 33% to now over 50% of the male population being adversely infected and infertile.

The State Government has continued its support for carp eradication with annual funding, while the Australian Government funding through Landcare Australia finished on 30 June 2017. Further negotiations are underway with the Australian Government for financial support to finish the project.

Queensland

By Mischa Turschwell - Australian Rivers Institute, Griffith University

Continuing research led by Dr Ryan Woods of DSITI has several European carp tagged in the lower Balonne River. Carp are one of several species tagged in an attempt to better understand and quantify fish movement patterns and responses to flows in the northern MDB. One of the primary aims of this research is to understand the flow requirements of carp to potentially develop flow management strategies to manage them.

A population of spotted tilapia have recently been found in the Mitchell River catchment in north Queensland. For more information on this and about this species, please visit: https://www.daf.qld.gov.au/about-us/news-and-updates/fisheries/news/tilapia-returns-to-mitchell-river-catchment

Western Australia

By David Morgan

Recent developments for alien fishes in Western Australia include the spread of the Molly in the Fortescue River which was delivered at 'The Good, The Bad, and The Ugly" session at the recent ASFB Conference in Albany by Dean Thorburn. The assisted spread of redclaw crayfish is occurring throughout the Pilbara. The Pilbara does not have any native crayfish, so these ecosystems are naïve to crayfish; their spread is likely to have devastating consequences for the Pilbara ecosystems. Cane Toads continue their spread throughout the Kimberley, and are also having huge impacts on native animals.

Sightings of redclaw and other invasive species should be reported to FishWatch WA on 1800 815 507 (download the App). http://www.fish.wa.gov.au/About-Us/Contact-Us/Pages/Fish-watch.aspx

Murdoch University researchers teamed up with others across the nation to discover the first evidence of *Edwardsiella ictaluri* in wild Australian fish, which can have drastic consequences (see Kelly et al. 2017 (below)).

On a positive note, the removal of redfin from a reservoir led to an explosion of native fish and crayfish (see Beatty et al. 2017 in references at the end of this section).

Above *Redclaw crayfish; photo S. Beatty*

South Australia

By Nick Whiterod

The illegal trade of Mexican dwarf crayfish (*Cambarellus patzcuarensis)* was shut down (Rob McCormack, Australian Aquatic Biological battled for this to occur and finally got the result). The species is a known carrier of crayfish plague, which could have devastating consequences for native crayfish (including the more than 50 species of spiny crayfish). More details can be found here: http://www.psnews.com.au/aps/564/news/departments-claw-at-crayfish-trade.

Recent publications

Beatty, S.J., Allen, M.G., Whitty, J.M., Lymbery, A.J., Keleher, J.J., Tweedley, J.R., Ebner, B.C. and Morgan, D.L. (2017). First evidence of spawning migration by goldfish (*Carassius auratus*); implications for control of a globally invasive species. *Ecology of Freshwater Fish* 26:444-455. DOI: 10.1111/eff.12288

Beatty, S. J. & Morgan, D. L. (2017). Rapid proliferation of an endemic galaxiid following removal of an alien piscivore (*Perca fluviatilis*) from a reservoir. *Journal of Fish Biology* 90: 1090-1097. DOI: 10.1111/jfb.13214

Bylemans, J., E. M. Furlan, L. Pearce, T. Daly and D. M. Gleeson (2016). "Improving the containment of a freshwater invader using environmental DNA (eDNA) based monitoring." Biological Invasions 18(10): 3081-3089.

Hinlo, R., Gleeson, D., Lintermans, M. and Furlan, E., 2017. Methods to maximise recovery of environmental DNA from water samples. *PloS one*, *12*(6), p.e0179251.

Hinlo, R., Furlan, E., Suitor, L. and Gleeson, D., 2017. Environmental DNA monitoring and management of invasive fish: comparison of eDNA and fyke netting. Management, 8(1), pp.89-100.

Kelly, E., Gibson-Kueh, S., Morgan, D.L., Ebner, B. C., Donaldson, J., Buller, N., Crook, D., Brooks, S., Davis, A., Hair, S. & Lymbery, A.J. (2017). First detection of *Edwardsiella ictaluri* in wild Australian catfish. *Journal of Fish Diseases*. DOI: 10.1111/jfd.12696.

ASFB Threatened Fishes Committee Report – to September 2017

Compiled by Mark Lintermans and Michael Hammer (Co-Convenors)

Threatened Species Committee

State representatives for the committee are listed below. The committee tends to meet once a year during the Annual Conference of the society, and the meeting is open for all to attend. For further details, ideas, questions or suggestions, please contact your state representative or anyone listed below.

Following a recruitment drive at the last ASFB meeting in Albany, we welcome six new state reps!

Co-Convenors

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Australian Capital Territory

Mark Lintermans, see Co-convenor details

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New South Wales

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NEW – Claire Greenwell
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New Zealand

Bruno David
Freshwater Scientist Water, Air and Waste, Environment Waikato
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NEW – Nick Ling
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ASFB Threatened Fishes Committee Updates:

Threatened Fishes Workshop

The ASFB Threatened Species Committee met at Murdoch University on 20 July for a full day workshop to continue the review the conservation status of Australian freshwater fishes. This was the fourth workshop in a series that will proactively review the entire Australian freshwater fish fauna, with the final workshop to be held in 2018. The workshop focussed on a number of smaller fish groups, namely the Retropinnids (smelts and Grayling), Anguillids (eels), Muraenidae (Moray eels), Clupeidae (heerings), Toxotidae (archerfish), Synbranchidae (cave eels) plus the Eleotrid genera Hypseleotris and Milyeringa.

As in previous workshops, it was not intended that this workshop would prepare detailed nominations for individual species. The intention of the workshops is that over a number of years the entire Australian freshwater fish fauna will be proactively reviewed, rather than just reactively waiting for nominations of threatened taxa. The workshop was intended to canvas opinion, knowledge and the current status of species, and identify those that are priorities for further knowledge synthesis and/or development of individual nominations

Twelve people attended the workshop with a series of presentations given. Peter Unmack (Uni of Canberra) provided a background on the phylogeny and taxonomy of the Retropinnids and the Hypseleotrids and Brendan Ebner provided a review of the distribution, abundance and ecology of the eels and Morays of the wet tropics. Bill Humphreys talked on the cave fauna of the Exmouth region.

The workshop participants identified five taxa considered to warrant the preparation of full nominations or review of existing status. The species were:

Milyeringa justitia
Hypseleotris aurea
Hypseleotris sp. (Lake's (sexual population))
Kimberleyeleotris notata
Kimberleyeleotris hutchinsi

An additional five species were considered to warrant inclusion on a watch list as a result of their extremely restricted distribution. These are:

Hypseleotris aurea
Hypseleotris barrawayi
Hypseleotris ejuncida
Hypseleotris sp3 (Carson River)
Hypseleotris kimberleyensis

Preparation of nominations will continue over the next 1-2 years, and species will then be formally assessed. It is intended to conduct the final workshop in 2018 to consider the remaining 44 taxa. Thanks to the ASFB and Freshwater Fish Group and Fish Health Unit, Centre for Fish and Fisheries Research, Murdoch University who provided assistance in organising the workshop.

Annual TFC meeting

We had 12 committee and guests attend the face-to-face meeting at the Albany conference.

Key discussion points included:

(a) Reinvigorating/growing state representation.

(b) Meeting time and venue to be included specifically in the 2018 conference delegate booklet.

(c) A dedicated effort to provide social media contributions to help promote ASFB, the committee and threatened species: things like faces, places and critters images; short videos; threatened species profiles/ blogs.

(d) A threatened fishes award through the society to support conservation and research especially for species that fall through the cracks of not being on legislated lists difficult to fund otherwise (e.g. recently described species).

(e) Digitising TFC historic records.

(f) National Action Plans: examples from other vertebrate groups are available, with potential for fishes.

(g) Developing a threatened species Special Session at next year's Conference to showcase threatened species research in Australia and New Zealand, updates on recovery efforts, and sharing IUCN red list experience to support a national review of freshwater fishes in Australia.

Changes to ASFB Threatened Fish Listings in 2017

The TFC considered threatened species nominations for two *Galaxiella* species but is seeking further information from the proponents before assessment of these nominations can be finalised.

The complete 2017 ASFB Threatened Fish list is at the end of this report.

A new Convenor

After 8 years in the role as Convenor of the ASFB TFC, Linto has gratefully accepted the offer from Michael Hanmmer to be a Co-convenor in 2017 and 2018, with Linto to step down as Co-convenor (but remain on the committee) at the end of 2018. Thanks Michael!

New Nominations sought

The committee welcomes new nominations or proposals for recategorisation. Could anyone working on species that they consider threatened but which are not currently on the ASFB Threatened Fish list, please contact their State/Territory ASFB TFC rep, or contact the Convenor. Nominations must be received at least one month before the annual conference date to allow distribution to and consideration by committee members.

National

Compiled by Mark Lintermans

EPBC Act 1999

Common Assessment Methodology

As part of a process to harmonise national and state/territory threatened species lists, a Common Assessment Methodology (CAM) has been developed. IUCN criteria are being used, with the addition of a Conservation Dependant category for commercial species that are being managed under a fishery management plan (e.g. eastern gemfish, some sharks). Under the CAM, a species can only be listed once, with all new nominations to be assessed at national level first, and if they don't meet the criteria for national listing, then they can be listed as populations within a jurisdiction. Species already listed (legacy species) will need to have their national status agreed upon, or be reassessed, over the next 2 years.

New fish species listed
Although crayfish are outside the current scope of the TFC, The Fitzroy Falls Spiny Crayfish was listed as critically endangered in December 2016.

Recovery and threat abatement plans
As alluded to in the 2016 newsletter, the draft national recovery plan for Macquarie perch was released for public comment in mid-May 2017 with comments closing on 1 September. Macquarie perch was one of 3 freshwater fresh first listed as nationally endangered in 1980, so after a 37 year wait, there is finally at least a draft national recovery plan for the species.

Threatened Species Strategy and Action Plan
The Commonwealth Threatened Species Strategy and Action Plan has now identified 20 birds, 20 mammals and 30 plants as priority species, but still no fish. http://www.environment.gov.au/biodiversity/threatened/publications/strategy-home

After 3 years as the Threatened Species Commissioner, Gregory Andrews is moving to another position and so by the time this newsletter is published there will be a new person in that role.

IUCN Freshwater Fish Specialist Group
Anyone with an interest in freshwater fish conservation should have a look at the IUCN Freshwater Fish Specialist Group (FFSG) newsletters. Mark Lintermans has stepped down as the Regional Chair for Australia/New Zealand, and Gerry Closs and Nick Ling have taken on this role. Either Gerry or Nick can provide further information about the FFSG to interested people or go to the FFSG website at http://www.iucnffsg.org/

NESP Threatened Species Recovery Hub: Publication of threatened species monitoring in Australia
A book emanating from the September 2016 national workshop on threatened species monitoring is nearing publication. The book: *Monitoring Threatened Species and Ecological Communities.* (Eds: Sarah Legge, David Lindenmayer, Natasha Robinson, Ben Scheele, Darren Southwell, & Brendan Wintle) will be published by CSIRO Publishing in early 2018, and will include a chapter on the extent and adequacy of threatened freshwater fish monitoring; stay tuned.

Western Australia

Compiled by David Morgan, Murdoch University

There has been a great deal of research into threatened fish in Western Australia during 2017. These publications cover both marine and freshwater fishes from the Critically Endangered Spotted Galaxias to the Whale Shark. Western Australia also hosted the 2017 ASFB Conference in Albany, with threatened fish talks dominating the special session on "*The Good, the Bad, and the Ugly*".

A selection of these studies are outlined below. See also the State Report for Western Australia, where other examples are covered.

Morgan, D.L., Somaweera, R., Gleiss, A.C., Beatty, S.J. & Whitty, J.M. (2017). An upstream migration fought with danger: freshwater sawfish fending off sharks and crocodiles. *Ecology* 98: 1465-1467. doi: 10.1002/ecy.1737

Phillips, N.M., Chaplin, J.A., Peverell, S.C. & Morgan, D.L. (2017). Contrasting population structures of three Pristis sawfishes with different patterns of habitat use. *Marine and Freshwater Research* 68: 452-460. doi.org/10.1071/MF15427

Phillips, N.M., Fearing, A. & Morgan, D.L. (2017). Genetic bottlenecks in Pristis sawfishes in northern Australian waters. *Endangered Species Research* 32: 363-372. doi.org/10.3354/esr00815

Reynolds, S.D., Norman, B.M., Beger, M., Franklin, C.E. & Dwyer, R.G. (2017). Movement, distribution and marine reserve use by an endangered migratory giant. *Diversity and Distributions.*

Rowland, F., Close, P.G., Beatty, S.J., Allen, M.G., Gill, H.S., Berkelaar, J.S. & Morgan, D.L. (2017). Larval development and dietary ontogeny of a critically endangered galaxiid within a Mediterranean climatic zone of Australia. *FiSHMED Fishes in Mediterranean Environments* 2017.001: 1-14.

Whitty, J.M., Keleher, J., Ebner, B.C., Gleiss, A.C., Simpfendorfer, C.A. & Morgan, D.L. (2017). Habitat use of a Critically Endangered elasmobranch, the largetooth sawfish *Pristis pristis*, in an intermittently flowing riverine nursery. *Endangered Species Research* 34: 211-227. doi.org/10.3354/esr00837

Above *Endangered spotted Galaxia*

South Australia

Compiled by Chris Bice

Prepared by Chris Bice (SARDI), Nick Whiterod (Aquasave–NGT) and James Donaldson (DEWNR).

Riverland populations of Murray hardyhead disperse after 2016 flood

Following flooding in 2016, surveys at the two Riverland strongholds of the Endangered Murray hardyhead – Berri Evaporation Basin and Disher Creek – in late 2016 and early 2017 have shown decreases in abundance relative to recent years. This mirrors patterns observed in these populations after extensive flooding in 2011 and is likely the result of natural dispersal in response to high flows. We suspect decreased abundance is no cause for alarm, and anticipate these populations will recover in coming years as occurred post-2011. In recent years, both Disher Creek and the Berri Evaporation Basin have been the subject of engineering works and environmental water delivery to manage salinity and water levels, and favour Murray hardyhead. The Commonwealth Environmental Water Holder has continued to grant environmental water allocations for both sites, which will allow DEWNR to actively manage salinity and water depth throughout the year.

The loss of Yarra pygmy perch from the Murray-Darling Basin?

Yarra pygmy perch could become the first freshwater fish to become extinct from the Murray-Darling Basin. Its only Murray-Darling Basin population, around the Lower Lakes, was first believed to have been lost as its habitat dried during the millennium drought. Fortunately, fish were rescued prior to the drying of habitats (and used to set up surrogate refuges), which enabled the reintroduction of almost 7000 fish into former habitats; firstly, through Drought Action Plan and Critical Fish Habitat projects (collaboration between SARDI and Aquasave-NGT, funded by Australian and South Australian governments) and continued since 2014 by Aquasave-NGT (through funding by the South Australian MDB Natural Resources Management Board). Despite short-term persistence following reintroductions, the species again appears lost to the region (and Murray-Darling Basin) having not been detected since late 2015. Additionally, two surrogate refuges have collapsed. Concerted effort is now required to build surrogate populations to allow for future reintroductions of sufficient magnitude (e.g. 10s of thousands each year) to re-establish self-sustaining wild populations of the species. Without this effort, the first freshwater fish extinction from the Murray-Darling Basin will occur. The plight of the species is featured in an article in the latest edition (40) of the Australian River Restoration Centre's RipRap magazine.

Southern purple-spotted gudgeon conservation in the Lower Murray

Southern purple-spotted gudgeon is hanging on in the Lower Murray thanks to regular reintroductions by Aquasave-NGT (and funded by the SA MDB NRM Board). The species was rediscovered at a single wetland site in the Lower Murray in 2002, but this site dried completely at the height of the millennium drought. Since 2014, 750 individuals have been released from surrogate refuges into the former wetland, with evidence of the species persisting with recaptures detected over a two-year period. The path forward is simple (as it is with Yarra pygmy perch) with more fish needed to be released more often – let's hope we can work towards this!

Searching for Murray crayfish in the Lower Murray

After five years of searching by Aquasave-NGT, which included over 8500 net hours (number of nets per site times by the number of hours each net was set for - that's also 356 net days), at almost 30 sites we have failed to detect a single Murray crayfish in the South Australian section of the Murray River (e.g. the Lower Murray). We can't rule them being present somewhere, but obviously, any remnant population would be small. That said, we sampled likely sites – those with reasonable lotic habitat (which are rare in the weir pools of the SA River Murray), and from where anecdotal reports had come (thanks to the Field Naturalists of South Australia for funding sampling this year). Whilst we haven't tracked down the last official record, we believe that it will be from the late 1980s – that's a likely absence for thirty years. We are convinced that the species can persist in the Lower Murray, so our attention is turning to assessing the feasibility of re-establishing the species.

Australian Capital Territory

Compiled by Mark Lintermans, Canberra University

Murray-Darling Basin

The 2017 Murray–Darling Basin Native Fish Forum was held in Canberra on 23rd – 24th August. A range of talks covering a variety of species and issues were presented with approximately 200 people attending. There were several presentation on threatened fish ecology including talks on Silver perch movement in response to eflows; links between river flow and Silver perch population dynamics; changes in growth patterns of Murray cod over the last 30 years; Reintroduction of Macquarie perch into the Retreat River, NSW; and conservation of Murray hardyhead, Yarra pygmy perch, southern pygmy perch and Southern purple-spotted gudgeon in the lower Murray. A pf of the abstracts/ proceedings is available viedos of the epresentations are available on youtube https://www.youtube.com/playlist?list=PLG4856nlXnJ5IadZX3H6zmVYspawT7WlM

Above *Lower Murray River*

University of Canberra

Mark Lintermans has been beavering away trying to raise the profile of threatened freshwater fish in Australia. He has met with the Threatened Species Commissioner and is continuing to have input to the Threatened Species Recovery Hub (run out of the University of Queensland) to include freshwater fish in the Red Hot Red List project (identifying species with a high risk of extinction in the next 20 years unless management intervention occurs).

The University of Canberra in collaboration with ANU has completed the first 3 years of phase 2 (2013-2016) of the long-term monitoring program for the enlarged Cotter Reservoir, with the focus on Macquarie perch. For 3 years now there has been a lack of YOY in the reservoir, and this is considered the result of a series of impassable natural barriers during the Macquarie perch spawning season.

A Collaborative ARC Linkage project has kicked off, led by Monash University, looking at Genetic Rescue for various threatened species. Many threatened species suffer from low genetic diversity, which likely compromises a population's ability to deal with future threats such as climate change. In the ACT this involves Macquarie perch and so after many months of gaining approvals, in early May 2017 Mark Lintermans and Matt Beitzel collected 31 Maccas from Cataract Reservoir (originally introduced in the early 1900s from the Murrumbidgee), and transported them to Canberra where they were held in quarantine for 5 weeks and tested for EHN virus and assessed for general fish health. The fish were then released in into the Cotter River in mid June at 3 sites between Cotter and Bendora dams. It is proposed to repeat this translocation process in 2018, and to monitor to see if genetic diversity of the riverine Macca population responds.

In a project lead by Ben Broadhurst, adult Macquarie perch were acoustically tagged in the Cotter Reservoir to determine if natural instream barriers in the river upstream were preventing passage to spawning habitat (likely reason for failed recruitment since enlarged Cotter Reservoir started to till in 2013). If barriers were causing aggregations of Macquarie perch during the spawning season, environmental flows were to be released to facilitate passage. Fortunately (or unfortunately, depending on how you look at it), a wet winter and spring rendered the system largely unregulated (all dams upstream spilling) and flow were sufficient to drown out natural barriers (confirmed by acoustic loggers placed instream). Subsequent monitoring in Autumn 2017 detected the first successful recruitment event since 2013. The project will be again repeated for the 2017 spawning season.

Above *Juvenile Macquarie Perch; photo Ben Broadhurst*

Alan Couch, who is studying Murray cod recruitment at the Uni of Canberra has recently found genetic evidence suggesting that Murray cod in the upper Murrumbidgee River are pairing up with the previous partners for breeding. If this proves to be the case this finding of multi-year pair-bonding is particularly exciting, because for it will be the first time this breeding strategy has been recorded in freshwater fish in the wild. It is likely that multi-year pair-bonding exists alongside other breeding strategies such as polygyny and polygamy rather than being the only mating strategy in use.

Above *A photo of a pair of cod in Glen Lyon Dam. Both fish are >1 m and the female is in front (note the distended abdomen); photo Brian and Debbie Dare, Glen Lyon Tourist Park, Mingoola Qld*

Hugh Allan (Masters student) has been investigating the ecology of a newly-described species of upland galaxiid, the Stocky Galaxias *Galaxias tantangara*. The range of the species has been severely restricted by the introduction and spread of trout species in the Tantangara Ck catchment and today the species is limited to a single headwater stream only 3 km long, and is protected from alien trout by a natural waterfall barrier. Monthly trips are undertaken to the field site in Kosciuszko

National Park to sample the population and collect specimens for laboratory analysis. Specifically, changes in reproductive condition (GSI) over the course of the year have been investigated in preparation for spawning later this year. In the lab the suitability of PIT tags in a surrogate species (*Galaxias olidus*) have been successfully tested, and so PIT tagging *Galaxias tantangara* will commence next field season in a study of the movement, home range and habitat use of the species.

One of the last self-sustaining populations of the endangered Macquarie perch and an alien conspecific, Rainbow trout are being studied using acoustic telemetry in the enlarged cotter dam (ECD). Since the dam was increased from 4GL to 78GL in 2013, important habitat for Macquarie perch and its food sources has been lost. Dan Orwin is studying movements and diet on an all-of-dam scale to determine any preferences for recently inundated habitat, as well as interspecific competition for space and resources between the two species.

Karl Moy (Masters student) has been busy with conservation actions for Running River Rainbowfish. Stocking into Deception Creek which took place from November 2016 to January 2017 appear to have been successful with greater numbers of fish recorded during May 2017 surveys than recorded in the days following releases. The status of fish stocked into Puzzle Creek during May 2017 will be assessed during upcoming surveys set for mid-October.

ACT Government

A revised ACT Aquatic and Riparian Strategy has been drafted with action plans for four fish species (Trout cod, Macquarie perch, Silver perch and Two-spined blackfish) and Murray crayfish, and is expected to be out for public comment in late 2017.

The ACT government has released a draft conservation strategy for Murray Cod in mid 2017 and amended the Fisheries Act in late 2016 to totally protect two species of upland spiny crayfish *Euastacus reiki* and *Euastacus crassus*.

Recent publications

Unmack, P.J., Sandoval-Castillo, J., Hammer, M.P., Adams, M., Raadik, T.R. & Beheregaray, L.B. 2017. Genome-wide SNPs resolve a key conflict between sequence and allozyme data to confirm another threatened candidate species of river blackfishes (Teleostei: Percichthyidae: Gadopsis). Molecular Phylogenetics and Evolution, 109, 415–420.

Lean, J., Hammer, M.P., Unmack, P.J., Adams, M., & Beheregaray, L.B. 2017. Landscape genetics informs mesohabitat preference and conservation priorities for a surrogate indicator species in a highly fragmented river system. Heredity, 118, 374–384.

Couch A.J., Unmack P.J., Dyer F.J., Lintermans M. (2016) Who's your mama? Riverine hybridisation of threatened freshwater Trout Cod and Murray Cod. PeerJ 4:e2593https://doi.org/10.7717/peerj.2593

Bylemans, J., Furlan, E., Hardy, C., McGuffie, P., Lintermans, M. and Gleeson, D. (2017). An environmental DNA (eDNA) based method for monitoring spawning activity: a case study using the endangered Macquarie perch (*Macquaria australasica*). *Methods in Ecology and Evolution 8: 646–655*

Harrisson K.A., Amish S.J., Pavlova A., Narum S., Telonis-Scott M., Rourke M.L., Lyon J., Tonkin Z., Gilligan D., Ingram B.A., Lintermans M, Gan H.M., Austin C.M., Luikart G., Sunnucks P. (accepted). Signatures of polygenic adaptation associated with climate across the range of an Australian freshwater fish species. *Molecular Ecology*

Lintermans, M. (2016). Finding the needle in the haystack: comparing sampling methods for detecting an endangered freshwater fish. *Marine and Freshwater Research, 67*(11), 1740-1749. doi:http://dx.doi.org/10.1071/MF14346

Pavlova, A., Beheregaray, L. B., Coleman, R., Gilligan, D. M., Harrisson, K. A., Ingram, B. A., Kearns, J., Lamb, A. M., Lintermans, M., Lyon, J., Nguyen, T., Sasaki, M., Tonkin, Z., Yen, J. D. L. & Sunnucks, P. (2017). Severe consequences of habitat fragmentation on genetic diversity of an endangered Australian freshwater fish: a call for assisted gene flow. *Evolutionary Applications*, 10(6): 531-550.

Pavlova, A., Gan, H.M., Lee, Y.P., Austin, C.M., Gilligan, D., Lintermans, M. & Sunnucks, P. (2017). Purifying selection and drift shaped Pleistocene evolution of mitochondrial genome in an endangered Australian freshwater fish. *Heredity* 118, 466–476.

Queensland

Prepared by Steve Brooks and Ebb

The community hatchery in Cooroy has commenced its breeding season of Mary River cod and fingers are crossed for a good season.

The Running River rainbowfish work is progressing nicely as a function of Karl Moy's PhD work, and the initiative of the University of Canberra research team headed by Peter Unmack. The captive breeding of the Running River rainbows was conducted at the TropWATER aquarium Facility at James Cook University in Townsville. Special thanks to Jason Schaffer for giving Karl a hand.

In terms of cling gobies, there is a new paper out providing the first record of *Sicyopterus cynocephalus* in Australia. James Donaldson and Brendan Ebner came across this large bodied cling goby during snorkel surveys in a small coastal stream south of Cairns. The species is highly elusive and a bank of ten GoPro cameras was used to film the species which hides in crevices and comes out to graze on biofilms.

Barry Lyon and colleagues have just published a foundation paper outlining the habitat use of the Speartooth shark *Glyphis glyphis* in the Wenlock estuary. The paper outlines telemetry of 40 individuals over almost 2 years. Significantly the Wenlock has an important flow regime for this species.

Ebner, B. C., Donaldson, J. D., Allen, G., and Keith, P. (2017). Testing an underwater video network and first record of *Sicyopterus cynocephalus* in Australia. *Cybium* **41**, 117–125.

Lyon, Dwyer, Pillans, Campbell, Franklin. (2017). Distribution, seasonal movements and habitat utilisation of an endangered shark, *Glyphis glyphis*, from northern Australia. MARINE ECOLOGY PROGRESS SERIES, Vol. 573: 203–213.

Northern Territory

Compiled by Michael Hammer

Secretive fish discovered with the help of Defence

Katherine Times, 14 June 2017

Scientists have doubled the number of known global locations of a secretive fish after finding it in an area managed by the Department of Defence. The Angalarri grunter, a type of bream, was discovered at two new sites in the Bradshaw Military Field Training Area near Timber Creek in the Northern Territory. The training area is located about 180km south west of Katherine. Fish experts Dr Michael Hammer, from the Museum and Art Gallery of the Northern Territory, and Dr Glenn Moore, from the Western Australian Museum discovered the new habitat during a Bush Blitz in the western Top End recently.

Above *The stunning red form of the Malanda rainbowfish, an undescribed species which probably warrants national conservation listing under the EPBC Act. Cullum Brown championed the nomination of this species through the ASFB listing of threatened species (listed as Critically Endangered).*

Dr Hammer said they'd been looking for more records of the Angalarri grunter for some time. "This Bush Blitz gave us an amazing chance to sample the Angalarri River that flows through Bradshaw," he said. "The result was all we could have hoped for. We not only found new records of the fish, which tells us a lot about their habitat, but we found juveniles that have not been observed before." Dr Moore said the Bush Blitz survey continued to expand their understanding of Australia's unique fauna. "This is just one of many important discoveries made whenever a Bush Blitz survey is undertaken," he said.

The Angalarri grunter is a large fish with stunning markings and exceedingly rare. It is assessed as a vulnerable threatened species in the Northern Territory due to its highly localised distribution. One of the only other records of the existence of this fish comes from a previous Bush Blitz survey at Judbarra / Gregory National Park, about 50km south of Bradshaw, in 2015. Drs Hammer and Moore were part of a 16-strong team from museums, herbaria and universities taking part in this Bush Blitz survey. The team were joined by five science teachers through the Bush Blitz TeachLive project.

Two weeks were spent surveying the Defence property while other discoveries including new species of spiders along with potentially undescribed frog and reptile species and new records of plants, butterflies and dragonflies were found. These discoveries reveal the environmental values of the site and help conservation planning for species such as the Angalarri grunter. Bush Blitz manager Jo Harding said building a body of knowledge around new and threatened species was a central component of the Bush Blitz Program.

"This information is crucial for learning more about the species and the habitats required for their protection, and it wouldn't have been possible without Defence's help." Steve Grzeskowiak, Deputy Secretary of the Department of Defence Estate and Infrastructure Group, said they managed the largest Commonwealth land holding in Australia and took their environmental stewardship responsibilities seriously. "What a great outcome from this Bush Blitz to find such a rare species," Mr Grzeskowiak. "We often find that Defence training facilities are havens for wildlife due to the relative lack of human activity."

Above *The Angalarri grunter was discovered at two new sites in the Bradshaw Military Field Training Area near Timber Creek in the Northern Territory; photo M Hammer, MAGNT.*

The Bush Blitz program is a partnership between the Australian Government, BHP Billiton Sustainable Communities and Earthwatch Institute.

Tasmania

There have been several recent articles discussing the conservation of spotted handfish in the Derwent River, see: http://www.abc.net.au/news/2017-09-15/spotted-handfish-captive-breeding-program-csiro/8948636

Conservation Status of Australian Fishes – 2017
ASFB Threatened Fishes Committee
Mark Lintermans, Convenor
(Mark.Lintermans@canberra.edu.au)

IUCN conservation categories and criteria are used

* denotes taxa where formal taxonomic description has not been published but where listing is essential because of concern over their conservation status. Early formal publication will be encouraged to resolve their taxonomic status.

Category	Scientific Name	Common name
EXTINCT IN THE WILD	*Galaxias pedderensis*	Pedder galaxias
CRITICALLY ENDANGERED	*Brachionichthys hirsutus*	Spotted handfish
	Carcharias taurus (east coast population)	Grey nurse shark
	Chlamydogobius micropterus	Elizabeth Springs goby
	Chlamydogobius squamigenus	Edgbaston goby
	Craterocephalus fluviatilis	Murray hardyhead
	Galaxias fontanus	Swan galaxias
	Galaxias fuscus	Barred galaxias
	Galaxias truttaceus hesperius	Western trout minnow
	Galaxias longifundus	West Gippsland galaxias
	Galaxias lanceolatus	Tapered galaxias
	Galaxias mungadhan	Dargo galaxias
	Galaxias aequipinnis	East Gippsland galaxias
	Galaxias supremus	Kosciuszko galaxias
	Galaxias mcdowalli	McDowall's galaxias
	Galaxias gunaikurnai	Shaw galaxias
	Galaxias brevissimus	Short-tail galaxias
	Galaxias sp. Tantangara	Stocky galaxias
	Glyphis glyphis	Bizant River shark
	Maccullochella macquariensis	Trout cod
	Maccullochella mariensis	Mary River cod
	Melanotaenia sp.	Running River rainbowfish

	Melanotaenia sp.	Malanda rainbowfish
	Nannoperca pygmaea	Little pygmy perch
	Pristis pristis	Freshwater sawfish
	Scaturiginichthys vermeilipinnis	Redfinned blue-eye
	Stiphodon semoni	Opal cling goby
ENDANGERED		
	Centrophorus harrissoni	Harrisson's deepsea dogfish
	Galaxias auratus	Golden galaxias
	Galaxias johnstoni	Clarence galaxias
	Galaxias parvus	Swamp galaxias
	Galaxiella nigrostriata	Black-striped minnow
	Glyphis garricki	Northern river shark
	Lepidogalaxias salamandroides	Salamanderfish
	Maccullochella ikei	Eastern cod
	Macquaria australasica	Macquarie perch
	Melanotaenia eachamensis	Lake Eacham rainbowfish
	Nannoperca oxleyana	Oxleyan pygmy perch
	Paragalaxias dissimilis	Shannon paragalaxias
	Paragalaxias eleotroides	Great Lake paragalaxias
	Paragalaxias mesotes	Arthurs paragalaxias
	Pristis clavata	Dwarf sawfish
	Pristis zijsron	Green sawfish
	Pseudomugil mellis	Honey blue-eye
	Zearaja maugeana	Maugean skate
VULNERABLE	*Anoxypristis cuspidata*	Narrow sawfish
	Bidyanus bidyanus	Silver perch
	Brachaelurus colcloughi	Colclough's shark
	Brachionichthys politus	Red handfish
	Brachiopsilus ziebelli	Ziebell's handfish
	Cairnsichthys rhombosomoides	Cairns rainbowfish
	Carcharodon carcharias	Great white shark
	Carcharias taurus (west coast population)	Grey nurse shark
	Centrophorus zeehaani	Southern dogfish
	Chlamydogobius japalpa	Finke River goby

	Chlamydogobius gloveri	Dalhousie goby
	Craterocephalus amniculus	Darling River hardyhead
	Craterocephalus dalhousiensis	Dalhousie hardyhead
	Craterocephalus gloveri	Glover's hardyhead
	Epinephelus daemelii	Black rockcod
	Galaxias rostratus	Flat-headed galaxias
	Galaxias tanycephalus	Saddled galaxias
	Galaxiella pusilla	Dwarf galaxias
	Guyu wujalwujalensis	Bloomfield River cod
	Himantura dalyensis	Freshwater whipray
	Maccullochella peelii	Murray cod
	Melanotaenia utcheensis	Utchee rainbowfish
	Milyeringa veritas	Blind gudgeon
	Mogurnda clivicola	Flinders Ranges gudgeon
	Mordacia praecox	Non-parasitic lamprey
	Nannoperca obscura	Yarra pygmy perch
	Nannoperca variegata	Variegated pygmy perch
	Nannatherina balstoni	Balston’s pygmy perch
	Neoceratodus forsteri	Australian lungfish
	Neosilurus gloveri	Dalhousie catfish
	Ophisternon candidum	Blind cave eel
	Prototroctes maraena	Australian grayling
	Rexea solandri (eastern stock only)	Gemfish
	Rhincodon typus	Whale shark

ASFB Education Committee Report -December 2017

The Albany Conference demonstrated how a regional meeting can provide a slightly different, yet equally rewarding experience for delegates and exceeded the Organising Committee's expectations of attendances. I sincerely thank all the students who attended and 'took a punt' on using their precious conference funding to attend ASFB in what is (to many of you) a far-flung corner of the country. This year had a special focus on students; including a special session on Nurturing Fish Scientists that explored how we can help to increase the recruitment rates of fish and fisheries scientists and reduce career mortality. Feedback on the Albany conference has been highly positive and we eagerly look forward to Melbourne, I am certain will build further on the past few excellent meetings.

Thanks to a concerted effort by the Education Committee to boost the awareness and prize pool of the ASFB student research awards in 2017, there was a doubling of applications for the Michael Hall and Barry Jonassen awards from 2016. The quality of student member research applications was again outstanding and thanks to the judges who had the difficult task in ranking the applications. We also thank the Executive for approving the inclusion of runner-up prizes for both these awards. John Glover Travel Bursaries supported 15 students to attend the Albany conference. This award can make the difference in students being able to attend a conference and thanks again go to the FRDC for funding the ASFB student awards and supporting the future of fisheries research in Australia. There was also a big increase in the applications for the Student International Travel Award that the Education Committee has also increased in promotion during the year. Students are again encouraged to submit a manuscript (or paper) to be eligible for $3000 plus registration to the next years ASFB conference.

The student conference awards were again of extremely high quality and it was very difficult to select the winners from 15 entrants. Thanks to all the judges of these awards (Katie Ryan, Ben Broadhurst, Alastair Harry, Shaun Wilson, Chris Hallett). The second year of the Student Competition in Science Communication (SCiSC) awards saw the de-coupling of the online video awards from the Rapid Fire oral presentations and an increase in the prize pool to $4000; including all video applicants being eligible for monetary support to attend the Albany meeting. The online video competition had seven entries including overseas entries for the first time boosting the profile of ASFB into Asia. The videos attracted 27,000 views (the same as 2016) and 1722 votes (up from 1,251 votes last year) (https://asfb-student-competition-in-science-communication-awards.thinkable.org/). The addition of a 'Members Choice' award for the video entrants that was voted on at the Albany conference with the videos being played throughout the venue was very popular and provided additional exposure and networking opportunities to the students who attended Albany. There were eight students who presented their Rapid Fire talks on Saturday afternoon and showcased some exceptional research and engaging public speaking. The inclusion of presentations from budding young scientists from Albany SHS was a terrific initiative and the high quality of the research that was presented I think took many delegates by surprise.

On a personal note, I would like to Stacy Bierwagen, Lachlan Fetterplace, Katie Ryan, Chris Hallett and John Morrongiello for making the Education Committee such a positive influence on the ASFB. Thanks again to communications manager Andrew Katsis and the previous ASFB newsletter coordinator Michelle Treloar for their work on promoting the ASFB and the activities of the Committee. Finally, congratulations to outgoing President Chris Fulton on his outstanding term and being so open to trying new initiatives and I wish Harry Balcombe and Alison King all the best in their new roles.

Stephen Beatty - Chair

Above *Marianne Nyegaard receives the Gilbert P. Whitley Student Award from new ASFB President Stephen "Harry" Balcombe*

Treasurer's Report

At the end of the 2016-17 financial year the Society was in a good financial position with $449,417 in the bank. Amounts in each account were:

- ASN transaction account = $136,479*
- General transaction account = $5,482
- Business online saver = $52,808
- Term deposit – Main = $233,293
- Term deposit – K Radway Allen Bequest = $21,355

Note that these totals include a $91K accrual for the Albany 2017 event, all of which will be paid to our suppliers, venues in the 2017-2018 financial year. Effectively, this means we have $353,237 in cash assets, which is slightly up on last year.

The majority of income for 2016-2017 was derived from our partnership with FRDC to support conferences, workshops and student awards, the ASFB's share of the 2016 Hobart conference profits, and membership fees. Over the financial year, the Society raised $6,713 in bank interest, primarily on our two term deposits.

The greatest expenditure items were awards and prizes, newsletter editorial, communications management, and attendance of ASFB representatives at events such as the AFS meeting, the WFC planning day, and the Financial Planning Committee meeting. ASN handle the day to day expenses of the society and our membership database, with expenditure approved by two signatures (President/Vice-President & Treasurer). The current cost of these services is $10,000 per calendar year.

Important to note, as we did last year, that without unusual income sources (e.g. conference surplus), our revenue stream does not cover our annual expenses at present, with a $4k deficit. Given our large cash reserve at present, this is not a major concern, but as discussed for the financial plan, we suggest revisiting any imbalance in regular income and expenditure once we start to spend down our savings.

Finally, the audit of our 2016-17 financial year accounts indicated that they were a true and proper record (see below).

Financial report
See the financial report in the audit documents of the minutes of the AGM for the financial state of the society.

Membership
We have increased our membership to 438 financial members (up from 377 last year).

Schedule 1

Regulation 15

Form 1

Associations Incorporation Reform Act 2012

Sections 94 (2)(b), 97 (2)(b) and 100 (2)(b)

Annual statements give a true and fair view of financial performance and position of incorporated association

We Christopher Fulton and Charles Todd being members of the committee of the Australian Society for Fish Biology certify that –

"The statements attached to this certificate give a true and fair view of the financial performance and position of the above named association during and at the end of the financial year of the association ending 2017."

Signed: ____________________

Date: 24.07.2017

Signed: ____________________

Date: 24/7/17

WOOTTONS

CHARTERED ACCOUNTANTS
AUSTRALIA - NEW ZEALAND

Directors:
Alex MacLeod BEc FCA
Darren Forsyth BBus CA

Consultant:
Susan L Milton BEc FCA

REPORT OF INDEPENDENT AUDITOR

Scope

We have audited the financial statements comprising the Profit & Loss Statement and Balance Sheet of the Australian Society for Fish Biology and Oceania Chondrichthyan Society Conference 2016 (ASFB Joint Meeting) for the period ended 30th June, 2017. The Trustee is responsible for the preparation and presentation of the accounts and the information they contain. We have performed an audit of these accounts in order to express an opinion on them.

Our audit has been planned and performed in accordance with Australian Auditing Standards to provide a reasonable level of assurance as to whether the accounts are free of material misstatement.

Our procedures included examination, on a test basis, of evidence supporting the amounts and other disclosures in the accounts, and the evaluation of accounting policies and significant accounting estimates. These procedures have been undertaken to form an opinion whether, in all material respects, the accounts are fairly presented.

The audit opinion expressed in this report has been formed on the above basis.

Audit Opinion

In our opinion, the financial statements of the Australian Society for Fish Biology and Oceania Chondrichthyan Society Conference 2016 (ASFB Joint Meeting) are drawn up so as to present fairly:

(1) the financial position of the entity as at 30th June, 2017 and the performance of the entity for the period ended on that date.

(2) other matters required by law and in accordance with applicable accounting standards.

Dated at Mornington, 15 August 2017

Alex MacLeod
WOOTTONS

WOOTTONS BUSINESS SERVICES PTY LTD ACN 125 947 168
Mornington Office - 326 Main Street (PO Box 265) Mornington 3931 Tel: (03) 5975 3666 Fax: (03) 5975 9734
Balnarring Office - Office 20, Balnarring Village (PO Box 40) Balnarring 3926 Tel: (03) 5983 1504 Fax: (03) 5983 2310
Email: admin@woottons.com.au

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31/07/17
Cash Basis

ASFB JOINT MEETING
Profit & Loss
July 2016 through June 2017

				Jul 16 - Jun 17
Ordinary Income/Expense				
Income				
REVENUE				
ONLINE DELEGATE REGISTRATION				
4010 · Registration Fees			114,636.36	
4011 · Addons			19,090.91	
4015 · Accommodation Deposit Received			42,096.36	
ONLINE DELEGATE REGISTRATION - Other			0.02	
Total ONLINE DELEGATE REGISTRATION				175,823.65
4018 · Accommodation Deposit Paid				-42,096.36
REVENUE - Other				
4020 · Trade Income				
4021 · Sponsorship		44,000.00		
4023 · Exhibition		11,750.00		
4024 · Advertising		1,650.00		
4020 · Trade Income - Other		0.00		
Total 4020 · Trade Income			57,400.00	
Total REVENUE - Other				57,400.00
Total REVENUE				191,127.29
Total Income				191,127.29
Expense				
EXPENSES				
6100 · FIXED EXPENDITURE				
6120 · AUDIO VISUAL EQUIPMENT				
6121 · AV Equipment		7,031.82		
6122 · Technician		1,390.91		
Total 6120 · AUDIO VISUAL EQUIPMENT			8,422.73	
6200 · ADMINISTRATION				
6211 · Accountancy		581.82		
6212 · Bank Charges		24.00		
6213 · Creditcard Fees		874.58		
Total 6200 · ADMINISTRATION			1,480.40	
6250 · MANAGEMENT CONSULTANCY				
6251 · ASN Consultancy Fee		10,000.00		
6252 · ASN Sponsorship Commission		3,336.14		
6254 · ASN Delegate Fee		17,640.00		
6255 · ASN Abstract Fee		3,996.00		
6256 · ASN Travel		947.68		
6257 · ASN Accommodation		778.18		
6258 · ASN Onsite Staff		1,636.36		
Total 6250 · MANAGEMENT CONSULTANCY			38,334.36	
6280 · MARKETING & ADVERTISING				
6282 · Web		27.27		
Total 6280 · MARKETING & ADVERTISING			27.27	
6300 · MEETING EXPENSES FOR COMMITTEE				
6301 · Phone Meetings		245.81		
6302 · Committee Travel & Accomm		1,577.81		
6300 · MEETING EXPENSES FOR COMMITTEE - Other		323.20		
Total 6300 · MEETING EXPENSES FOR COMMITTEE			2,146.82	
6330 · PRINTING & PUBLICATIONS				
6334 · Program/Abstract Book		798.00		
6337 · Other Printing/Stationery		136.36		
Total 6330 · PRINTING & PUBLICATIONS			934.36	
6350 · REGISTRATION				
6351 · Computer Hire - Rego Desk		181.82		
6355 · Stationary On Site		213.05		
Total 6350 · REGISTRATION			394.87	
6370 · SPEAKERS				
6371 · Accommodation		3,549.86		
6374 · National Speaker Travel		2,568.04		
6377 · Speaker Gifts		646.33		

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ASFB JOINT MEETING
Profit & Loss
July 2016 through June 2017

	Jul 16 - Jun 17		
6370 · SPEAKERS - Other	0.00		
Total 6370 · SPEAKERS		6,764.23	
6390 · MISCELLANEOUS			
6391 · Freight & Courier	394.98		
Total 6390 · MISCELLANEOUS		394.98	
Total 6100 · FIXED EXPENDITURE			58,900.02
6400 · VARIABLE EXPENSES			
6420 · FOOD & BEVERAGES [IN SESSION]			
6423 · Lunch	49,036.35		
Total 6420 · FOOD & BEVERAGES [IN SESSION]		49,036.35	
6430 · OTHER FUNCTIONS			
6432 · Welcome Function	11,221.54		
6433 · Conference Dinner	33,386.37		
6434 · Student Function	4,458.91		
Total 6430 · OTHER FUNCTIONS		49,066.82	
6450 · DELEGATE EXPENSES			
6452 · Name Tags/Lanyards	1,227.27		
6457 · Satchels	2,195.00		
6458 · Bus Transfers	7,354.55		
Total 6450 · DELEGATE EXPENSES		10,776.82	
Total 6400 · VARIABLE EXPENSES			108,879.99
6490 · TRADE/EXHIBITION			
6491 · ASN Exhibitor Commission		2,863.64	
6492 · Equipment Hire/Power		318.18	
6493 · Shell Scheme		2,700.00	
6494 · Poster Boards/Furniture		654.55	
Total 6490 · TRADE/EXHIBITION			6,536.37
Total EXPENSES			174,316.38
Total Expense			174,316.38
Net Ordinary Income			16,810.91
Other Income/Expense			
Other Expense			
9030 · Distribution Paid			16,810.91
Total Other Expense			16,810.91
Net Other Income			-16,810.91
Net Income			0.00

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Cash Basis

ASFB JOINT MEETING
Balance Sheet
As of June 30, 2017

	Jun 30, 17
ASSETS	0.00
LIABILITIES	0.00
NET ASSETS	0.00
EQUITY	0.00

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WOOTTONS

CHARTERED ACCOUNTANTS
AUSTRALIA + NEW ZEALAND

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REPORT OF INDEPENDENT AUDITOR

Scope

We have audited the financial statements comprising the Profit & Loss Statement and Balance Sheet of the Australian Society for Fish Biology for the period ended 30th June, 2017. The Trustee is responsible for the preparation and presentation of the accounts and the information they contain. We have performed an audit of these accounts in order to express an opinion on them.

Our audit has been planned and performed in accordance with Australian Auditing Standards to provide a reasonable level of assurance as to whether the accounts are free of material misstatement.

Our procedures included examination, on a test basis, of evidence supporting the amounts and other disclosures in the accounts, and the evaluation of accounting policies and significant accounting estimates. These procedures have been undertaken to form an opinion whether, in all material respects, the accounts are fairly presented.

The audit opinion expressed in this report has been formed on the above basis.

Audit Opinion

In our opinion, the financial statements of the Australian Society for Fish Biology are drawn up so as to present fairly:

(1) the financial position of the entity as at 30th June, 2017 and the performance of the entity for the period ended on that date.

(2) other matters required by law and in accordance with applicable accounting standards.

Dated at Mornington, 22 August 2017

AMacleod

Alex MacLeod
WOOTTONS

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Mornington Office - 326 Main Street (PO Box 265) Mornington 3931 Tel: (03) 5975 3666 Fax: (03) 5975 9734
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Email: admin@woottons.com.au

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AUST SOCIETY FOR FISH BIOLOGY
Profit & Loss
July 2016 through June 2017

	Jul 16 - Jun 17
Ordinary Income/Expense	
Income	
REVENUE	
MEMBERSHIP	
4040 · Online Membership	17,563.60
Total MEMBERSHIP	17,563.60
REVENUE - Other	
4020 · Trade Income	
4021 · Sponsorship	37,800.00
Total 4020 · Trade Income	37,800.00
4030 · Miscellaneous Charges	54.55
Total REVENUE - Other	37,854.55
Total REVENUE	55,418.15
Total Income	55,418.15
Expense	
EXPENSES	
6100 · FIXED EXPENDITURE	
6200 · ADMINISTRATION	
6210 · Audit	770.00
6211 · Accountancy	581.82
6213 · Creditcard Fees	392.89
6215 · Communications Management	6,000.00
6216 · Filing Fees	55.80
Total 6200 · ADMINISTRATION	7,800.51
6250 · MANAGEMENT CONSULTANCY	
6259 · ASN Membership Management	7,540.00
Total 6250 · MANAGEMENT CONSULTANCY	7,540.00
6280 · MARKETING & ADVERTISING	
6282 · Web	90.00
6286 · Sponsorship	9,843.00
Total 6280 · MARKETING & ADVERTISING	9,933.00
6300 · MEETING EXPENSES FOR COMMITTEE	
6301 · Phone Meetings	381.86
6302 · Committee Travel & Accomm	3,362.81
6303 · Committee Catering / Venue Hire	1,770.00
6309 · Event Attendance	12,107.32
Total 6300 · MEETING EXPENSES FOR COMMITTEE	17,621.99
6330 · PRINTING & PUBLICATIONS	
6331 · 1st Notice/Flyers/Posters	1,430.20
6343 · Newsletter	5,004.72
Total 6330 · PRINTING & PUBLICATIONS	6,434.92
6370 · SPEAKERS	
6375 · Prizes & Awards	
6375a · Travel Award	12,642.00
6375d · Gilbert Whitley Award	1,960.00
6375e · VMSC Award	600.00
6375 · Prizes & Awards - Other	11,505.82
Total 6375 · Prizes & Awards	26,707.82
Total 6370 · SPEAKERS	26,707.82
6390 · MISCELLANEOUS	
6395 · Subscriptions / Memberships	2,621.86
Total 6390 · MISCELLANEOUS	2,621.86
Total 6100 · FIXED EXPENDITURE	78,660.10
6400 · VARIABLE EXPENSES	
6430 · OTHER FUNCTIONS	
6434 · Student Function	201.37
6430 · OTHER FUNCTIONS - Other	586.95
Total 6430 · OTHER FUNCTIONS	788.32

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Cash Basis

AUST SOCIETY FOR FISH BIOLOGY
Profit & Loss
July 2016 through June 2017

	Jul 16 - Jun 17
Total 6400 · VARIABLE EXPENSES	788.32
Total EXPENSES	79,448.42
Total Expense	79,448.42
Net Ordinary Income	-24,030.27
Other Income/Expense	
Other Income	
8030 · Conference Distribution	13,176.39
8050 · Interest Received	734.69
8060 · Interest Received -Term Deposit	5,978.70
Total Other Income	19,889.78
Net Other Income	19,889.78
Net Income	-4,140.49

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14/07/17
Cash Basis

AUST SOCIETY FOR FISH BIOLOGY
Balance Sheet
As of June 30, 2017

		Jun 30, 17
ASSETS		
Current Assets		
Chequing/Savings		
1150 · NAB Operating Account		136,478.61
1152 · CBA General Account		5,482.38
1153 · CBA Business Online Saver		52,807.78
1154 · CBA Term Deposit - Main 7/04/18		233,292.50
1156 · CBA Term Deposit - Holding A/c		21,354.76
Total Chequing/Savings		449,416.03
Other Current Assets		
1300 · Refundable Deposits		
1310 · Venue Deposit	5,000.00	
1330 · Dinner Deposit	770.00	
Total 1300 · Refundable Deposits		5,770.00
Total Other Current Assets		5,770.00
Total Current Assets		455,186.03
TOTAL ASSETS		**455,186.03**
LIABILITIES		
Current Liabilities		
Other Current Liabilities		
2150 · Accrual - Event		91,545.05
2200 · GST Payable		10,404.30
Total Other Current Liabilities		101,949.35
Total Current Liabilities		101,949.35
TOTAL LIABILITIES		**101,949.35**
NET ASSETS		**353,236.68**
EQUITY		
3900 · Retained Earnings		357,377.17
Net Income		-4,140.49
TOTAL EQUITY		**353,236.68**

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Society's Committees

Any member or non-member can contact the convenors of the various Committees with their concerns. Details about the function and membership of the Committees can be obtained from the convenors. Each Committee usually meets once a year during the Annual Conference.

Threatened Fishes Committee

Co-convenors:

Mark Lintermans

Institute for Applied Ecology, University of Canberra

Ph (02) 6201 2853, fax (02) 6201 5651, email: mark.lintermans@canberra.edu.au

Michael Hammer

Curator of Fishes, Museum & Art Gallery of the Northern Territory

PO Box 4646, Darwin, NT 0801

Ph (08) 8999 8253, fax (08) 89998289, email: michael.Hammer@nt.gov.au

Alien Fishes Committee

Convenor: Ben Broadhurst

Ben.Broadhurst@canberra.edu.au

Education Committee

Convenor: Dr Stephen Beatty

Murdoch University

S.Beatty@murdoch.edu.au

Appendix VIII. Artificial Reefs in Australia: A Guide to Aquatic Habitat Enhancement Structures

Artificial Reefs in Australia

A GUIDE TO DEVELOPING AQUATIC HABITAT ENHANCEMENT STRUCTURES

FRDC
FISHERIES RESEARCH & DEVELOPMENT CORPORATION

recfishwest
fish today for tomorrow

Recfishwest

Artificial Reefs in Australia: A Guide to Developing Aquatic Habitat Enhancement Structures

This project was undertaken with the support of partners including the Fisheries Research and Development Corporation, Western Australian Department of Fisheries, Murdoch University and Ecotone Consulting.

Guide prepared by James Florisson and Michael Tropiano

Disclaimer: The authors of this report advise that it is to be used as a basic guide in the initial stages of Habitat Enhancement Structure planning only. It's not guaranteed that information in the guide is free from errors and omissions. The nature of Habitat Enhancement Structure development elicits that policies, designs and techniques will change with time. Those acting upon information in this report do so entirely at their own risk and the authors accept no responsibility or liability from for any error, loss or other consequence which may arise from relying on any information in this publication.

Recfishwest. 2017. Artificial Reefs in Australia: A Guide to Developing Aquatic Habitat Enhancement Structures. Suite 3, 45 Northside Drive, Hillarys, Western Australia.

If you wish to find out more about the guide or HES process, please email
recfish@recfishwest.org.au

Introduction

Habitat Enhancement Structures (HES) are purpose built constructions placed in the aquatic environment (oceanic, estuarine, river or lake) for the purpose of creating, restoring or enhancing habitat for fish, fishing and recreational activities generally. HES involve the use of a range of objects and materials to create new habitat and provide ecological services in an aquatic environment. They include artificial reefs, Fish Aggregation Devices (FADs) and materials of opportunity.

HES have been created in at least 50 countries around the world for many varying purposes including snorkelling, SCUBA, surfing, energy production, eco-tourism, erosion mitigation, aquaculture, research, infrastructure and conservation. However, in the majority of cases HES are used for commercial, recreational and artisanal fisheries enhancement.

An artificial reef is any man-made or altered material placed into an aquatic environment to mimic certain characteristics of a natural reef. Artificial reefs are often used to create new fishing and diving opportunities, and to shift pressure from other popular locations. To date, at least 150 artificial reefs have been deployed in Australian waters and they are one of the most common types of aquatic infrastructure deployed for fisheries enhancement.

Figure 1: A previously bare surfaced concrete module from the South West Artificial Reef Trial in WA.

The purpose of this guide is to assist organisations to develop HES around Australia by detailing the major steps and considerations that are needed to deliver a purpose-built HES, particularly artificial reefs. The guide does this by containing a background and considerations for HES as well as describing the process from start to finish for HES development.

While HES also includes materials of opportunity, FADs, Large Woody Debris, restoration and translocation (of corals and seagrass), this document will mainly focus on purpose-built artificial reefs, as these are more commonly utilised around Australia, are environmentally friendly and have demonstrated clear ecological, social and economic benefits to communities world-wide through fisheries enhancement. The guide will also only consider HES deployed for the purpose of fisheries enhancement.

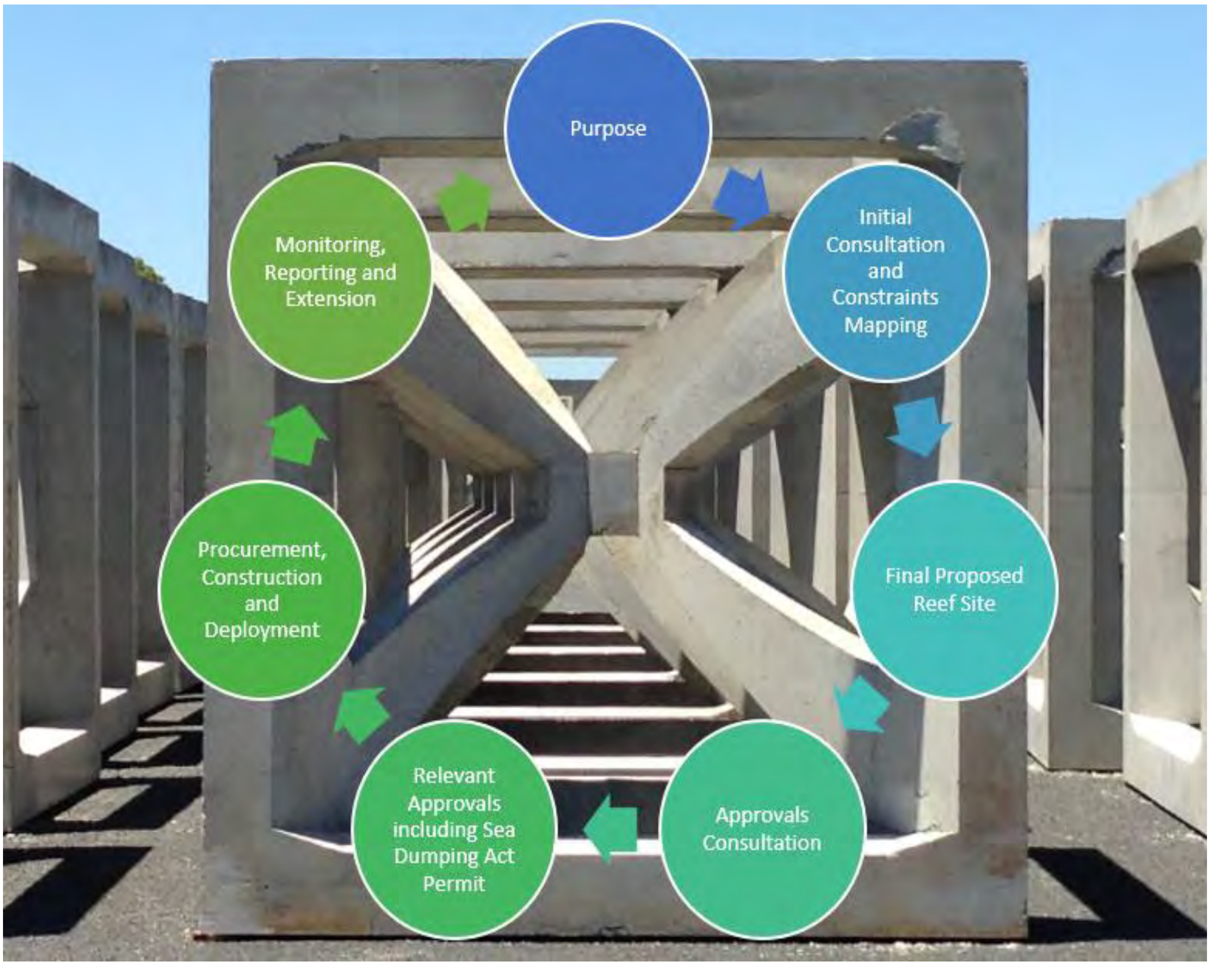
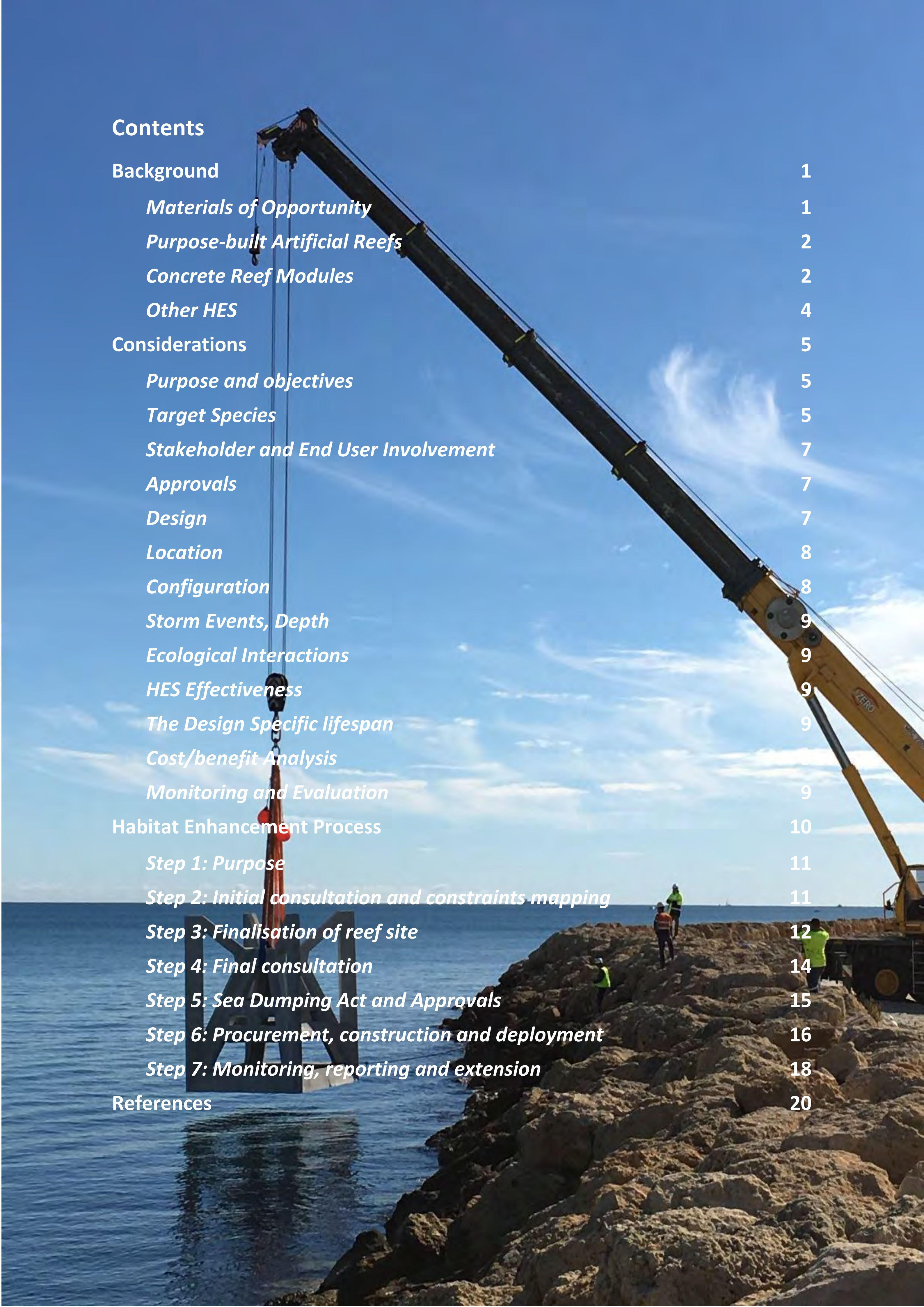


Figure 2: The broad-scale process for developing Habitat Enhancement Structures.



Contents

Background

Artificial reefs and other HES have an extensive history dating back thousands of years. In the Mediterranean, tuna fishers accumulated ballast stones to fish between tuna seasons in Sicily, and Greek temple stones were disposed during harbour construction creating reefs as early as 3,000 BC (Riggio 2000; Surman 2015). HES have been created all over the world, earlier HES's were mainly constructed of materials of opportunity such as woody debris, rocks and rubble and sunken vessels (from ancient fishing boats to modern warships).

In 1952, the Japanese Government began subsidising artificial reefs, triggering a phase of reef development. Japan now have over 130 diverse reef modules purposely designed to target an array of species such as oysters, octopus, squid, algae, abalone, sea urchins and demersal and pelagic fish (Thierry, 1988; Polovina and Sakai 1989; Barnabe and Barnabe-Quet, 2000; Surman 2015 Unpublished). Since then Southeast Asia has been at the forefront of HES development with China, Korea and Japan investing well over $3 billion since the 1970s.

Materials of Opportunity

Since 1979, the United States of America has developed a significant program that decommissions offshore oil rigs transforming them from functioning oil extraction plants to artificial reefs. The program is known as 'Rigs to Reefs (RTR) and the concept has been extended to several countries throughout Southeast Asia. With many offshore oil rigs around the world coming to the end of their productive lives, the RTR concept could be expanded globally in the near future. RTR is known as one of the more acceptable 'materials of opportunity' still in use and these oil rigs require serious environmental approvals before being converted into a reef.

Figure 3: Materials of opportunity, from left to right; the Tangalooma Wrecks (www.queensland.com), Tyre reef at Moreton Bay, Queensland (www.divingthegoldcoast.com) and disused oil rig (www.nytimes.com).

HES constructed from materials of opportunity include pre-existing materials and structures not constructed for the purpose of HES. These materials can include concrete blocks used for building, rubble, stones, polyvinyl pipe, tyres, derelict ships, car bodies, oil extraction equipment and disused armed forces equipment and vehicles. Most materials of opportunity have become unfavourable globally, due to adverse environmental effects and stability during severe weather events.

Some of the negative effects include pollution from heavy metal leaching, asbestos and a range of hydrocarbons as well as the destruction of natural habitat when structures that are not stable move on the ocean floor. Current Australian artificial reef policy has shifted to purpose-built HES due to environmental responsibilities, however adequately cleaned and modified (re-purposed) types of materials of opportunity including decommissioned oil and gas infrastructure may have its place in future developments with strict cleaning, alteration, management and monitoring of these structures. Due to general preferences in HES type, this guide will focus only on purpose-built HES.

Purpose-built Artificial Reefs

Purpose-built artificial reefs are specifically designed for target species, habitats, effects (such as upwelling) or purposes having specific shapes, voids, surfaces and profiles. A big benefit of purpose-built artificial reefs is that the shape, size and form can be altered to increase the abundance of certain species and to meet objectives. Modern purpose-built reefs can have substantial positive effects on surrounding aquatic ecosystems and can be built out of metal framework, steel, steel-reinforced concrete or concrete as well as recycled plastics, ceramics and fibreglass. Examples of these reefs include species specific reefs (such as abalone habitat reefs), larger Offshore Artificial Reefs (OAR), such as the Sydney OAR (a 12m tall metal structure aimed at facilitating the propagation of pelagic species) and concrete fish homes (such as Fish Boxes ™ and Reef Balls ™) designed to form habitats for a myriad of different species.

Figure 4: Purpose-built artificial reefs, from left to right; Abalone habitat reef, a Fish Box™ and the Sydney OAR (http://haejoo.com/).

Concrete Reef Modules

The most practicable and common artificial reef type in Australia is high strength marine-grade reinforced concrete reefs. An advantage of purpose-built concrete reefs is that moulds can be fabricated to create a range of different sizes, shapes, voids and structures. They are also pH balanced, non-toxic, built with universally available material and can provide more suitable surface textures for colonising organisms, such as corals.

Figure 5: Concrete reef modules awaiting deployment.

There are many different concrete module designs that are used all over the globe. Designs vary for different environments and water depths and are continually evolving (shape, size, and weight, internal and external surfaces) to better accommodate target species. In Japan and Korea, commercial fishers and aquaculturists harvest sea cucumbers, abalone, shellfish, squid, octopus, lobsters and finfish from purpose-built artificial reefs. Variation in module design allows reefs to mimic different natural reef profiles and varying habitat complexity. Knowing the target species and environmental conditions drives artificial reef design choice. For example, larger modules with larger openings and high vertical profile would better suit large cods and groupers as well as pelagic species as they can swim through the modules, while smaller modules with lots of habitat complexity may favour cryptic species and concentrate higher numbers of smaller fish. Many reefs mix differently shaped and sized modules to accommodate larger species abundance and diversity.

Steel Reef Modules

Along with concrete, welded steel is the preferred material for artificial reef construction (Diplock, 2010 and Surman, 2015). These reefs can be built to be considerably larger then concrete modules. The structures have a large amount of surface area and vertical profile with structures as tall as 35m in Japan.

The large vertical profile allows substantial amounts of habitat in different areas in the water column benefitting benthic or bottom dwelling species (such as flathead and flounder), epi-benthic species (those close to the bottom, such as snapper and emperor) and free ranging pelagic species (such as mackerel and kingfish).

Many steel reefs are specifically designed to congregate smaller baitfish. This is done by providing a large surface area in which colonising organisms such as macro algae are a source of food for smaller invertebrates which are then a food source for baitfish, and providing a protective area for baitfish to avoid larger predators.

Metal panels can also be incorporated into the design of steel reefs to take advantage of currents and tides to create upwelling that increases primary productivity (food sources for larval fish). Steel lattice like structure added to steel reefs can also provide shelter and safe areas for baitfish to congregate.


Figures 6-8 from Top: The Rottnest Fish Towers, The Queensland 'Fish Caves' (http://haejoo.com/) and a samson fish found on pelagic HES caught on jig.

A recent study on the Sydney Offshore Artificial Reef found that the reef provided enough habitat and refuge to safely support around 130kg of Mado (a small schooling species of fish found on coastal reefs) on the reef that fuels fish production by feeding on zooplankton supply (Champion et al, 2015).

Differing colonising communities will establish on Steel and concrete structures borers preferring concrete over steel until the steel has corroded, however other species, such as corals can prefer metal. For example, a study in Hawaii found that the highest coral recruitment occurred on metal rather than concrete reefs (Fitzhardinge, 1989).

Other HES

Other HES types aside from artificial reefs, include those that replicate or restore natural habitats including woody debris, shellfish reefs and translocation and restoration of corals and seagrasses. Wood is used for a variety of in-water restoration and enhancement activities including the creation of wood structures and resnagging. In freshwater and estuarine environments, woody debris is put into water bodies where they provide shelter and breeding locations, thermal variation, roosts for water birds and support the food web (Curtiss et al., 2006).

Figures 9 and 10: (left) Oyster Reef trial in Albany (image by Bryn Warnock) and (right) Wooden 'Fish Motels' (fishingworld.com).

Shellfish reefs are complex productive ecosystems that support a wide range of marine organisms. They provide shelter as well as direct and indirect food sources with research into oyster reef restoration in USA finding that restored reefs had 212% more biomass of fish and invertebrates than mud-bottom (Humphries and Peyre, 2015).

They also provide shoreline protection and can filter large amounts of water. Shellfish reefs can largely be captured under either Oyster Reef or Mussel Bed restoration. Finally the translocation or relocation of seagrass, corals and mangroves is a type of habitat enhancement that is important globally due to habitat loss and the ecosystem services these organisms provide, however these HES are not included in the scope of this guide. This is because the process of development of these HES greatly differ to artificial reefs and included HES types.

Considerations

This following section outlines the key considerations that need to be taken into account when developing a new HES. These factors include a range of social, legislative, ecological and economic aspects that need to be taken into consideration throughout the process and are all vital to the success of any HES developments.

Purpose and objectives

The starting point for any proposed HES is to define clearly, the purpose and objectives for the reef. The purpose needs to be based on why stakeholders, end users and managers are aiming to deploy a reef and the objectives need to steer the purpose. For example, a purpose may be to provide a safe fishing location for tourism, and objectives may revolve around safety, accessibility and enjoyment and could include being a safe distance from shore, near a populated coast, in an area protected from wind and large seas as well as creating a habitat that would favour target species in the area such as pink snapper or trevally.

Target Species

Target species are fish or other organisms that will most effectively increase end user satisfaction by being present on a HES. Assigning target species is an important factor in guiding purpose and objectives. The choice of species help guide what sort of HES design will be deployed, the proposed depth, habitat and location. Aspects that need to be considered include natural distribution and abundances of the target species in the area of the proposed reef location, seasonality, life history of target species and requirements and preferences of the species such as habitat (benthic/pelagic, temperature, visibility), shelter (refuges, surfaces, lighting) and food requirements (Surman, 2015).

Figure 11: Potential target species, samson fish (top left), baldchin groper (top right, other tuskfish species in states other than WA), mulloway (bottom left) and pink snapper (bottom right).

Materials

While materials vary for HES, the two main types include concrete and metal. The advantages and disadvantages of these materials can be seen in the table below (adapted from: London Convention and Protocol/UNEP, 2009; FRA-SEAFDEC, 2010 and FAO, 2015).

Table 1: Advantages and disadvantages of HES materials including concrete and metal.

Material	Advantages	Disadvantages
Concrete	• Compatible with the marine environment. • Durable, stable and readily available. • Readily formed into any shape for the deployment of prefabricated units. • Provides adequate surfaces and habitats for the settlement and growth of organisms, which in turn provide a substrate, food and places of refuge for other invertebrates and fish. • Universal and easily applied by community groups. • Concrete's weight makes modules stable and ensures module do not move during storm events.	• Concrete's weight, which necessitates the use of heavy equipment to manipulate it. This increases the land and marine transport costs. • The deployment of large concrete blocks or prefabricated units requires the use of heavy sea equipment, which is not only costly but also dangerous. • The weight on concrete increases the possibility of it sinking into the marine sediments. However constraints mapping should ensure that concrete modules are deployed on appropriate substrate to minimise this risk.
Metal	• Steel is easy to work, can be made in accordance to specific environments and species. • Steel is high strength, has a stable quality and is durable. • Possibility of developing large prefabricated units of very high relief and unmatched complexity. • Steel is free from harmful material and quickly colonised by organism and thus produces effects fast.	• Reduced design life in shallow or highly oxygenated water bodies (i.e. rough exposed coastlines). • High relief of large singular modules may cause stability issues requiring increased anchoring considerations of units resulting in increased reef costs. • Unit size may need specialised or large scale deployment equipment which will increase project costs.

Stakeholder and End User Involvement

Stakeholders and end users should have their needs and expectations met and feedback considered, throughout the project process particularly in early stages, when setting a purpose for the HES, as well as in the design, use, location and management of the HES. Formations of steering committees can assist in ensuring adequate representation of various individuals and groups involved.

Approvals

Installation of infrastructure such as HES (artificial reefs) requires environmental assessment and approval from relevant State and Commonwealth agencies and/or authorities. This can be seen in more detail on page 15.

Design

HES designs need to consider target species as well as other biological, ecological and physical aspects. In terms of biological and ecological factors, different HES designs may have a biological impact on their level of complexity. The creation of holes, crypts and refuges will allow for a large diversity and abundance of organisms to use the modules for shelter. Different organisms prefer different design features, for example, lobster and octopus prefer blind ended holes while other species such as smaller fish may prefer shaded open ended voids. A variation in size and a large amount of voids and refuges increases habitat complexity and thus increases the type and number of organisms that will use the modules, however cost should be considered.

Overall, the total surface area is much more important than the overall size in relation to productivity and reef biomass, so total surface area and internal surface area are also important when looking at different types of artificial reefs. 'The higher the surface area available for the settlement of algae and invertebrates, the greater source of food for other levels of the reef community and, therefore the greater productive capacity' (London Convention and Protocol/UNEP, 2009).

Figure 12: Different concrete artificial reef module designs for different purposes and species (http://www.subcon.com/).

Physical characteristics of reef module designs that need to be considered when planning a reef include:

- Surface texture
- Reef profile and orientation
- Shelter and shading
- Interstitial spaces
- Reef size, internal surface area
- Reef configuration
- Hydrological factors
- Social usage (e.g. space for fishers)

Location

The location of a HES needs to take into consideration ecological, environmental and social factors. While explained later in the HES process, the location needs to meet environmental standards while in an area accessible to end users that is within the distribution and requirements of target species.

Configuration

The configuration of HES varies with purpose, type, depth, current and tides. Artificial reef modules are usually installed parallel to the tide, perpendicular to prevailing currents and/or in clusters. Effective configuration can increase fisheries enhancement around the structures. Species preferences to different hydrological effects such as upwelling, eddies and slipstreams can enhance habitat, move nutrients and create feeding opportunities. Module configuration also creates interstitial spaces (corridors between modules) which in turn create new habitat. Specialised configuration can also enhance fishing opportunities by providing more space for fishers and by spreading fishing effort.

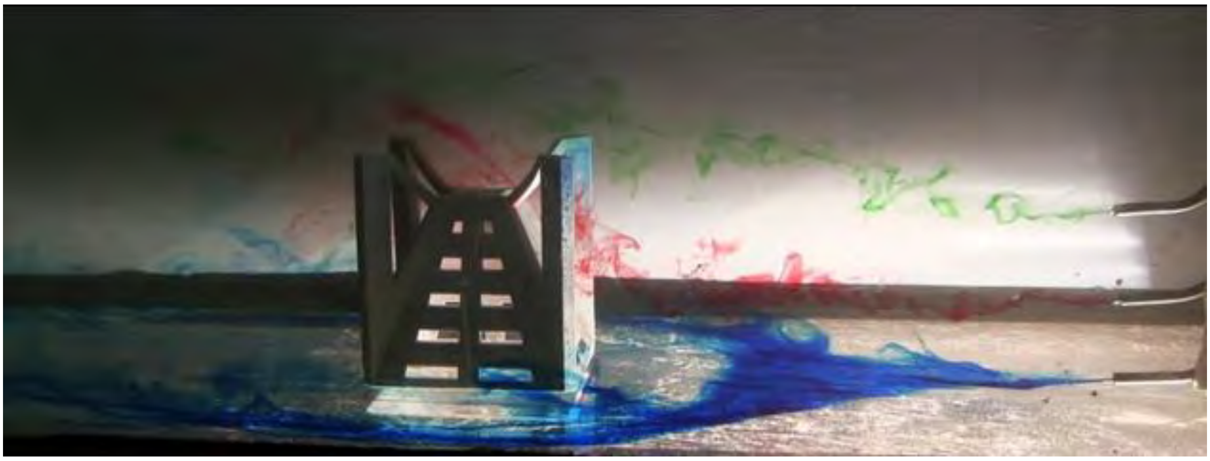


Figure 13: artificial reef module being tested in a university flume tank (Subcon Technologies Pty Ltd).

Artificial reefs consisting of small clusters of modules have been found to be successful, particularly in the artificial reefs in WA. This allows fish a high level of habitat complexity in an immediate area, a larger area of interstitial zones (between reefs) and it allows a larger numbers of fishers to use the reef simultaneously, increasing its societal useability. Interstitial zones are pathways for fish migration between modules and are areas of high diversity and abundance. These areas include a module's interior space as well as corridors between modules. These zones increase liveable habitat for species and decrease mortality rates as fish have 'safer' passages between shelters.

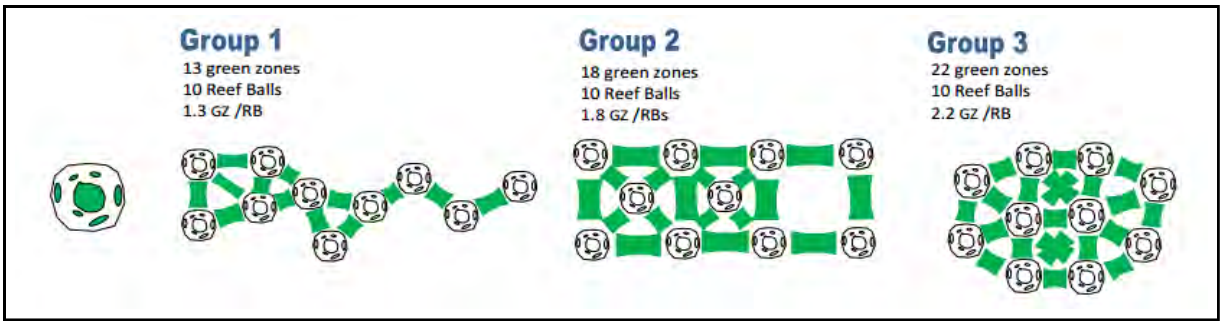


Figure 14: an example of interstitial spaces as 'Green zones' using ReefBallTM modules (Lennon, 2011).

Storm Events, Depth

HES designs need to be able to withstand a 1 in 100 year storm events and not become unstable, move position or collapse. They should have strong structural integrity and be deployed in appropriate water depths. Water depth should also be suited to HES design, purpose and target species.

Ecological Interactions

HES, if deployed for fisheries enhancement should be in areas with relatively low current fish diversity and abundance. Vulnerable and productive habitats and benthos (such as coral reefs) should be avoided. HES should not be deployed where they could significantly harm or damage any critically listed habitats or threatened species.

HES Effectiveness

It is extremely important that all aspects of the HES process and the environment are considered prior to deployment in order to maximise the effectiveness of HES. The HES type, design, configuration, materials, construction and deployment need to be considered in relation to hydrology (currents, tides), depth, light penetration as well as sediment dynamics, substrate characteristics and surrounding environments, objectives and target species.

The Design Specific lifespan

Design specific lifespans of HES need to be considered and evaluated against the investment going into the project and the benefits the HES will bring as well as the other considerations. Locations can also maximise or minimise life spans depending on hydrological and climatic events at the site. When applicable, HES with the longest lifespans (>30 years) should be utilised to allow for longer ecological development resulting in further economic and social benefits.

Cost/benefit Analysis

HES need to be carefully designed, approved and installed to ensure that the ecological, social and economic benefits of the HES outweigh the investment into the infrastructure. Innovative deployment methods and module design, local business contributions and community monitoring increase cost efficiency across the project. Relevant state fisheries regulators as well as state peak bodies should be contacted to provide indicative HES costs and project budgets.

Monitoring and Evaluation

HES need to be evaluated against the main purpose and objectives. They must also be monitored to meet legislative requirements. HES need ongoing structural monitoring, while ecological and social monitoring is extremely useful to measure the performance of HES.

Habitat Enhancement Process

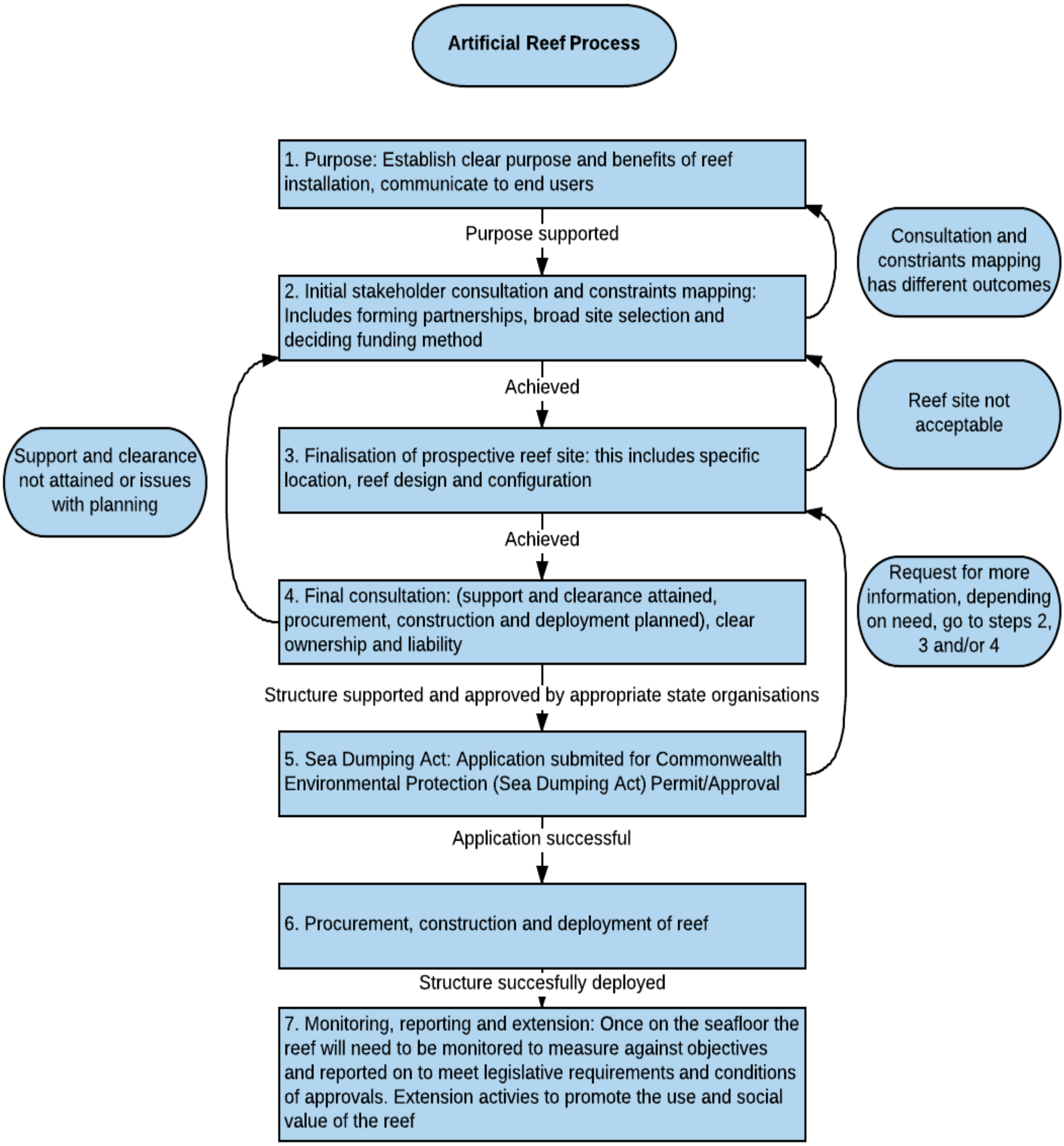


Figure 15: An in-depth flowchart of HES development process from establishing an initial purpose to extension activities in local communities following deployment.

Step 1: Purpose

Deciding the purpose of an artificial reef is the most important stage of the artificial reef process. It underpins the reef's success and dictates which path is taken for each of the steps outlined in this guide. Specific purposes will determine the broad location, specific site, type, target species, reef type and configuration. A clear purpose also drives the creation of objectives to assist in measuring the performance of a reef. For example, the purpose could be to enhance recreational fishing leading to objectives around access to target species and proximity to boat ramps.

To establish an effective artificial reef the need or desire for the reef must be clearly understood. The purpose of the reef should take into account the considerations explored in this guide, to assist in the further stages of development, such as site selection. For example, if the purpose is to provide increased target species in a safe fishing location, the reef should be in close proximity to shore, in a protected embayment and in a populated area. If the purpose of the reef is to concentrate pelagic sportfish for avid anglers, metal structures should be deployed further from shore at suitable depths and environments for pelagic species (such as in the paths of currents or migration routes).

Step 2: Initial consultation and constraints mapping

The initial consultation is done with other stakeholders (including government and non-government) and end users to establish the target species, reef type (design and configuration), location and other important factors. Individuals and organisations that need to be involved in this stage consultation include Local Government Authorities, end users, potential partners, end user peak bodies, clubs and associations and groups with demonstrated capacity and expertise in the area. The objective of this initial consultation is to determine whether the purpose of the reef (step 1) is reflective and the best outcome for the target end users, as well as:

- What is/are the target species(s) and why?
- What reef modules/design best suit the target species?
- Which location would best suit the end users and the target species?
- Are the modules and configuration suitable for the location?

Once these questions are answered and agreed upon between project managers, stakeholders and end users, constraints mapping and site selection can begin. Site selection is one of the most integral parts of the process in creating a HES. Like the construction of a park or sports stadium, an artificial reef site has to adhere to environmental requirements, be socially acceptable, be in a location accessible by the population and be in an area that fits its purpose and maximises its infrastructure. Constraints mapping assists in site selection by narrowing down a large area of potential reef locations to more specific and suitable area.

The most important considerations in constraints mapping include distance (from shore, boat ramps and population centres), shipping activity (lanes, anchorages and port authority zones), Depth, distribution of target species and military and mining activities. Mapping software such as ArcGIS can be used to reduce the size of an area by excluding areas that are not compatible with a reef installation such as ship anchorages and depths and is particularly beneficial if pre-existing benthic habitat maps are available to overlay on the map (note: may only be possible if data has already been collected in other studies).

Tables 2-4: the main components to site selection including biological/ecological, physio-chemical/environmental and social/anthropogenic factors. These will differ with your HES design and purpose.

Biological/ecological	Physio-chemical/environmental	Social/anthropogenic
• Existing fish communites • Protected and endangered species • Target species distribution • Competition for colonisation • Predation of target species • Larval availability • Sensitive habitats	• Sedimentation and turbidity • Light • Water temperature • Depth • Geomorphology • Water quality • Salinity • Wave exposure and energy	• Cultural or historic areas • Distance from shore • Marine Protected Areas • Military Areas • Mining and Shipping areas • Existing commercial fishing areas • Population size • Developement plans

Step 3: Finalisation of reef site

Once a broad site is selected, a more specific site can then be finalised. This is usually done by the creation of a steering committee composed of managers, stake holders and end users. Constraints mapping is then discussed and a final site selected, which is then tested. This step involves two stages. Stage one involves the biological and environmental analyses of the site and its characteristics to find an ideal deployment zone/reef site.

Firstly as part of a pre-assessment survey, a grid needs to overlaid on the final area chosen, its area varying, depending on the size of the reef to be deployed, for example a $2km^2$ grid when aiming to deploy a $200m^2$ artificial reef. At each grid intersection (in the previous example at every 500m), a depth reading needs to be taken and the habitat type evaluated. This can be done by towing a underwater camera along transect lines or dropping cameras at grid intervals to ascertain the habitat type (ie seagrass, low profile natural reef, sand, shale, coral etc) and is then best combined with GIS mapping technology (particularly LIDAR imagery). The most suitable area can then be side scanned to find the most ideal location for installation to ensure that the habitat is suitable (for example bare sand).

Once the habitat is identified as acceptable, side scan surveys and sediment probes can be used to look at sediment characteristics to ensure the type and depth of mobile surface sediments will suit the modules and ensure that they will be stable and not shift or sink once deployed. Stability analysis will also need to be undertaken looking at hydrological variables at the site such as wave and current conditions at the site as well as the influence of tides and extreme weather events such as cyclonic activity and 1 in 100 year storm events. This hydrological and climatic data then needs to be compared with reef module design and configuration and depth to ensure that the reef will survive its lifespan, be productive and meet its objectives and purpose.

Finally there should also be an ecological survey of faunal assemblages of the reef location and immediate area around the area. This is done to establish a baseline of the ecological community that currently exists in the area and to collect baseline data to compare with future monitoring results. The most suitable method for this would be the use of Baited Remote Underwater Video (BRUVs) which can collect footage of the habitat in the field of view as well as the abundance and diversity of other aquatic organisms at the site. Other methods of monitoring may also be used such as towed video, Diver Operated Video (DOVs) or acoustic methods in turbid water. Stage two involves seeking clearance for the site from factors that may preclude the identified site and the reef purpose and includes aspects such as submerged cables, mining leases, commercial fishing groups, Native Title claims and areas of heritage or cultural significance such as wrecks. Stage two is undertaken in the next step, in the final consultation with the organisations that manage these extra factors.

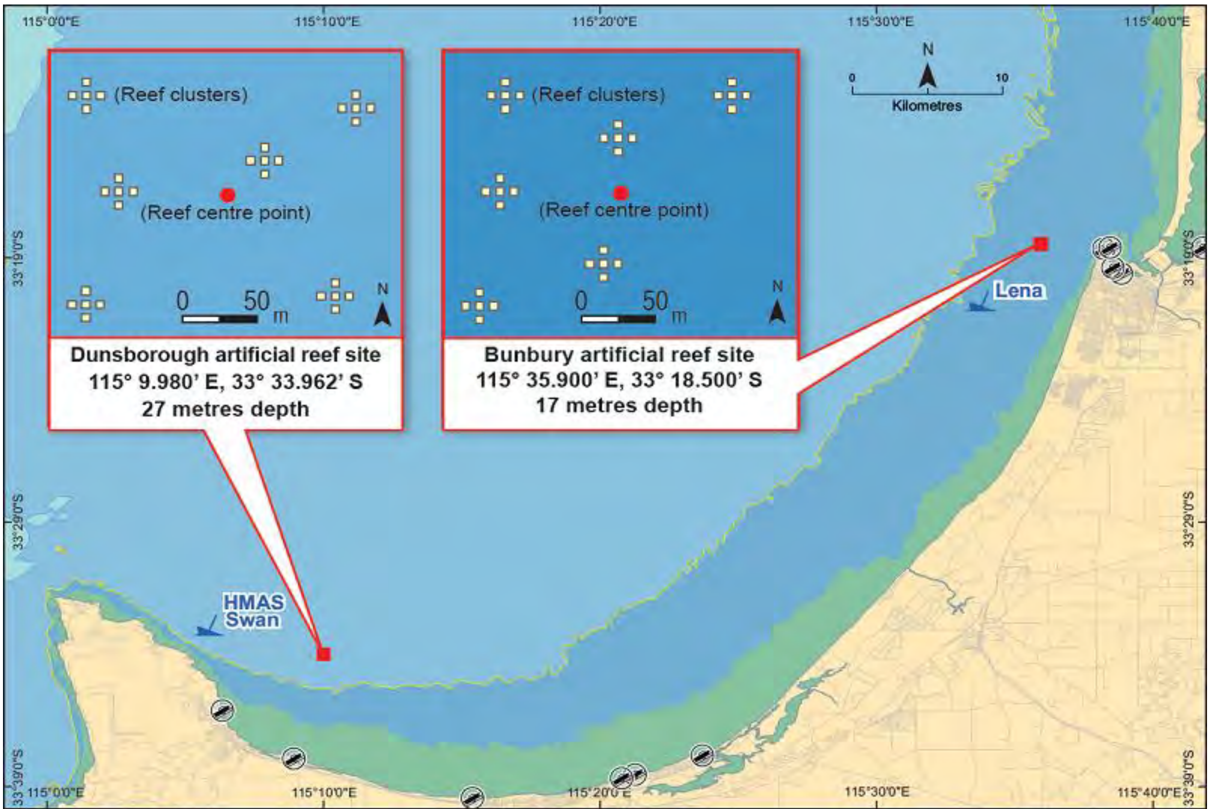


Figure 14 and 15: (top) the final reef sites that were chosen after a consultation period in Geographe Bay, Western Australia. The photo below shows the reef three years after deployment.

Step 4: Final consultation

The final consultation period involves establishing a framework to decide which stakeholders need to be consulted to what level and what outcome is required from that consultation. Local businesses, local interested groups, Local government authorities, government departments and the broader community need to be consulted with, however the level of consultation varies between jurisdictions. Communication tools on traditional and social media can be utilised to assist with engaging and informing relevant parties. Some of these tools include community meetings, updates, information pages on websites, advertisements, newspaper articles and establishing online groups and forums. Depending on the purpose of consultation and organisation, the results will vary between informing them, gathering support or attain clearance for the project. Letters of support and clearance from organisations such as the Royal Australian Navy and Australian Maritime Safety Authority are vital for attaining an exemption from the Dumping at Sea Act and preferable when seeking funding.

Tables 5 and 6: organisations that need to be informed and consulted with when developing HES projects (note that this list will vary between jurisdictions and while some of these groups it's a vital legal requirement to consult, others it is just beneficial to inform and gain support from).

Affected Stakeholders (Inform)	
Accommodation Providers	Fishing Stores
Any Mining, Oil or Gas Providers	Historical Societies
Aquaculture Council	Local Businesses
Boating Stores	Local Development Commissions
Chamber of Commerce and Industry	Local NRM and Conservation Groups
Commercial Marine Services	Local Recreational Fishing Councils
Community Groups	Local Shires and Councils
Diving Charters	Local Visitor Centres
Diving Clubs	Logistics Services
Diving Stores	Marine Rescue Services
Fish Stocking Organisations	Regional Development
Fishing Charters	Tourism
Fishing Clubs	Volunteer Sea Rescue Groups

Regulators/Clearance/Approvals (Consult)	
Australian Fisheries Management Authority	Relevant Natural Resource Management Organisations
Australian Hydrographic Office	Relevant Port Authorities
Australian Maritime Safety Authority	Relevant Recreational Fishing Peak Bodies
Maritime Archaeological Associations	Relevant State-based Fisheries Regulators
National Offshore Petroleum Safety and Environmental Management Authority	Relevant Environmental Regulators
Relevant Aboriginal Affairs Organisations	Relevant State-based Heritage Administrators
Relevant Commercial Fishing Peak Bodies	Relevant Transport and Infrastructure Regulators
Relevant Mines and Petroleum Administrators	Royal Australian Navy

Step 5: Sea Dumping Act and Approvals

To minimise any potential adverse environmental impacts of HES, and to optimise social, economic and ecological benefits, the HES process requires approval. Approvals vary with HES design, location, configuration, deployment and jurisdiction. HES in varying distance from shore are likely to require differing support and approval from Local, State and Commonwealth Governments as well as organisations that own or manage aquatic areas or resources (see step 4).

Approvals and permits are necessary to ensure that (DOEE, 2008):

- Appropriate HES sites are utilised
- Construction materials are suitable, environmentally friendly and prepared properly
- There are no significant negative impacts on the surrounding marine environment
- The HES pose no danger to navigation or end users
- That the HES is chartered on maritime maps
- The reef is aligned with state and commonwealth laws and policies

In Australia the majority of artificial reefs deployed for fishing enhancement (aside from some aquaculture purposes), require approval from the state government. There may be an exception in some states with freshwater systems, particularly on private land. Applications may also need to be aligned with state policies on Habitat Enhancement Structures. Any groups wanting to deploy HES need to contact fisheries regulatory bodies in their jurisdiction to find any relevant policy positions.

Artificial reefs deployed in Commonwealth waters must also obtain Commonwealth Government approval in the form of an exemption from the Environment Protection (Sea Dumping) Act 1981. The Sea Dumping Act fulfils Australia's international obligations under the London Protocol to prevent marine pollution by dumping of wastes and other matter. HES in state waters may also need an exemption depending on the HES type and relevant state policies.

The Sea Dumping Act also ensures appropriate site and material selection to minimise adverse impacts upon the environment and public and is a legislative requirement to HES developments. The only HES deployed in commonwealth waters that do not require an exemption from the Sea Dumping Act are FADs, however they still need approvals from related State Government Departments such as Transport. While the Environmental Protection (Sea Dumping) Act 1981 is the relevant legislation at the commonwealth level, applicable State legislation relevant will also need to be investigated. This may include marine tenure and tenements, marine transport and safety, aboriginal heritage and native title, other user groups including commercial and recreational fishing, aquaculture, local government, environmental protection and those listed in Table 6.

Other approvals may also need to be required depending on relevant location of the selected HES site. If the HES is to be deployed in a Marine Protected Area, related Departments should provide support. If it’s deployed within Port Authority or local shire boundaries, the relevant approvals must also be acquired (obtaining ‘some’ of these approval may negate the need to acquire an exemption from the Environmental Protection (Sea Dumping) Act).

Step 6: Procurement, construction and deployment

Once the relevant approvals are gained, procurement of the reef can begin. Reefs are usually installed by a company or organisation with artificial reef expertise that can design, construct and deploy modules however, in some cases community groups, commercial businesses and other organisations can also design, build and deploy their own reefs, however there is still a requirement to obtain engineering approval. Artificial reef Procurement is usually done at one of two stages:

- Step 2 or 3: Some organisations may desire to get an artificial reef expert at early stages to guide consultation and constraints mapping, potentially undertake approvals and to give input as to the suitability of the design for purpose and the site characteristics.
- Step 5: Some groups, particularly those with previous experience may wish to engage an expert or reef supplier at stage 5 to assist in acquiring the permit. While other groups may choose not to engage an external supplier and to build and deploy their own reefs.

Figure 16: Crane and barge deployment of concrete artificial reef modules in Western Australia.

Installation can be a costly stage of HES projects. Reef modules need to be cleaned, parts tested and an in-depth deployment procedure, including a risk assessment needs to be undertaken. Deployment for HES varies from simply pushing modules off a boat to large ships with cranes deploying 30m tall steel towers. Deployment is logistically challenging due to using large heavy materials and deployment tools in the marine environment. Therefore, deployment is best undertaken in the calmest conditions possible.

The majority of larger artificial reefs deployed are installed by using a crane and barge. Once modules are loaded onto the barge they are towed to the final reef site. Modules are then lifted by cranes and deployed to the sea floor and deposited using releasing mechanisms. Some crane hook attachments may be specialised to lift large singular modules or even multiple modules at once deploying in clusters. Some metal reefs are then anchored by chains being shackled to the module and mooring weights. For example, the Sydney Offshore Artificial Reef has 40 tonne moorings attached to each corner of the singular reef unit, while the Queensland 'Fish Caves' also have a similar anchoring system.

Some reefs have other innovative deployment methods such as the Perth Metropolitan Fish Towers. These two 70t four storey high modules were deployed in new a cost effective method that doesn't require ships, cranes or barges at the deployment site. Instead, the towers each have 4 buoyancy chambers which double as ballast tanks with valves that can be controlled by an umbilical cord that along with other ropes attach the unit to the vessel. A tug boat is used to tow the unit to the deployment site. The module is transported off the hardstand and lowered into the water via a ship lifter. It is then tethered to its vessel and towed to the site location. Once in the deployment zone, the valves in the ballast tanks are remotely opened and the module sinks to the seafloor. Once settled, the cables and ropes are released from the unit via a release mechanism and float to the surface with the assistance of a large float.

Figure 17: Tug boat towing a 'Fish Tower' module to its final deployment site.

Other types of HES have differing deployment methods. Timing of deployment is a crucial factor with Shellfish Reefs to ensure the best conditions for natural processes and to minimise mortality of living material. While any HES are being deployed, a notice to mariners needs to be put in place to reduce navigational hazards while working on the installations. An observer should also be in place to look out for interactions with sea life, particularly with endangered species. Once deployed, co-ordinates of modules will need to be recorded and given to the Australian Hydrographic Office to be put on navigation charts.

Figure 18: Large snag being installed on the Murray River (Source: Fish Habitat Network).

Step 7: Monitoring, reporting and extension

Monitoring is the process of gathering data and information over time to measure changes in an environment. There is a legislative need to monitor HES to ensure they have no adverse environmental impacts. HES should be socially, structurally and ecologically monitored to ensure they are performing at or above expectations and fulfilling approvals, objectives and purposes. Monitoring techniques are categorised into two areas, extractive and non-extractive methods. Extractive techniques are those that have an impact on biodiversity in that they extract, displace or disturb organisms, while non-extractive techniques involve observational analysis of species, that can occur at the HES site or off site (such as recording on slate or water proof paper, photography, videography and acoustic research). Non-extractive techniques are generally preferred as they have less of an impact on the marine environment.

Social monitoring is used to analyse the level of use of HES and how they have influenced or impacted the community. This is most commonly done by surveying end-users, stakeholders and beneficiaries regarding their direct and indirect interactions with the reefs. Structural monitoring involves analysing the structural integrity, stability, position and any changes to the surrounding environment that any HES installation may have caused. It can also study excessive scouring, corrosion, sedimentation or fouling by pollution.

Monitoring HES is best split into two different areas, specialist monitoring and community monitoring. Specialist monitoring involves monitoring to meet environmental approvals. Structural, social and some ecological monitoring of HES. If one or more HES are deployed in a state, a streamlined and standardised monitoring approach may decrease costs. The community can also assist with monitoring through data collection and analyses with what is known as citizen science, which is best used for ecological and social monitoring of HES. An example of citizen science is *Reef Vision*.

Figure 18: The *Reef Vision* Team for the South West Artificial Reef Trial in Western Australia.

Reef Vision monitors the Western Australia South West Artificial Reef Trial using local fishers and members of the community. Volunteers record boats on the reef and fish caught in logbooks, take part in surveys, record boat numbers using long range scopes and play an important role in BRUV monitoring. Local fishers use cheap, light and durable custom built BRUVs that utilise Go Pros and deploy them on the artificial reefs. In October, 2016, volunteers had collected over 160 videos on the reef lasting over 200 hours. Analysed footage to date has shown over 34,000 individual fish from 67 species and the program will expand to include other HES in WA. Using citizen science to monitor HES engages the community, provides large and cost effective data sets and creates stewardship and ownership over HES and aquatic environments.

Figure 19: A Dhufish, an iconic Western Australian species observed in volunteer footage on the artificial reefs.

Finally, it is strongly recommended that any HES developments produce a communications and extension plan to inform the community of deployment and how HES are performing against objectives. The plan should include scheduled discussions, notifications and events with the stakeholders, end users and community. Information on how to use the HES, code of conducts, site co-ordinates and monitoring results are all important to disseminate with the public. With HES objectives often including social utilisation and economic boosts, advertising the structure(s) and the opportunities related to the structure from recreating to commercially harvesting seafood is vital to the success of the HES. With the use of social and traditional media, local communities will often take ownership once the HES begins to develop and disseminate their own information which will in turn assist in support for future HES developments.

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Appendix IX: Habitat Enhancement Structure Extension and Adoption Timeline 2015-2017

Habitat Enhancement Structure Extension and Adoption Timeline 2015 - 2017

2015											
JAN	FEB	MAR	APR	MAY	JUNE	JUL	AUG	SEPT	OCT	NOV	DEC
						Facebook Weekly Image and Monthly Update	Facebook Weekly Image and Monthly Update	Recfishwest E-News	Mandurah Boat Show	Facebook Weekly Image and Monthly Update	Recfishwest E-News
							Youtube Video Update	Facebook Weekly Image and Monthly Update	Facebook Weekly Image and Monthly Update	Youtube Video Update	Facebook Weekly Image and Monthly Update
										Milestone 3 Due	

2016											
JAN	FEB	MAR	APR	MAY	JUNE	JUL	AUG	SEPT	OCT	NOV	DEC
Facebook Weekly Image and Monthly Update	Facebook Weekly Image and Monthly Update	Hillarys Boat Show	Press Release: Deployment Anniversary	Facebook Weekly Image and Monthly Update	Facebook Weekly Image and Monthly Update	Facebook Weekly Image and Monthly Update	FRDC FISH HES development in WA	Facebook Weekly Image and Monthly Update	Mandurah Boat Show	Facebook Weekly Image and Monthly Update	Recfishwest E-News
Youtube Video Update		Facebook Weekly Image and Monthly Update	Regional Papers		Milestone 4 Due	Youtube Video Update	Facebook Weekly Image and Monthly Update		Facebook Weekly Image and Monthly Update		Facebook Weekly Image and Monthly Update
			Recfishwest E-News						Recfishwest E-News		Milestone 5 Due
			Facebook Weekly Image and Monthly Update						Youtube Video Update		
			Youtube Video Update								

2017											
JAN	FEB	MAR	APR	MAY	JUNE	JUL	AUG	SEPT	OCT	NOV	DEC
Regional Papers	Recfishwest E-News	Hillarys Boat Show	Press Release: Deployment Anniversary	Facebook Weekly Image and Monthly Update	Facebook Weekly Image and Monthly Update						
Facebook Weekly Image and Monthly update	Facebook Weekly Image and Monthly Update	Facebook Weekly Image and Monthly Update	Recfishwest E-News	Youtube Video Update	End of Project						
Youtube Video Update		Milestone 6 Due: Promotion of the Guide	Facebook Weekly Image and Monthly Update								

Events	
Traditional Media	
Social Media	
Project Components	

Appendix X: HES Pamphlet

Artificial reefs are **purpose built structures** installed in aquatic environments (marine, estuarine, river or lake) for the purpose of **creating, restoring or enhancing** habitat for fish, fishing and other recreational activities. Artificial reefs mimic the characteristics of natural reefs by creating **new habitats and providing shelter,** feeding opportunities and varied changes to the water column.

Artificial Reefs in Australia

Changing Aquatic Landscapes of Australia's Coastal Communities

recfishwest

Recfishwest

Recfishwest is Western Australia's recreational fishing peak body representing the 750,000 members of the community who go fishing in WA each year. We are a not-for-profit organisation that works hard to ensure high-quality fishing experiences are maintained and enjoyed, as an integral part of the WA culture and lifestyle.

Artificial reefs are rapidly shaping Western Australia's seafloor, with Recfishwest leading the installation of over 1000 tonnes and 120,000 m2 of artificial reef habitat in local waters. Our artificial reef experts, along with our trusted partners, have built extensive artificial reef capabilities and knowledge to ensure artificial reefs have a consolidated place in WA's ongoing conservation of Western Australia's important aquatic habitats.

Recfishwest has a long, trusted working relationship with state and federal governments, world-leading engineers and sub-sea infrastructure experts and, most importantly, with the community. We pride ourselves on using best practice scientific methods and public engagement to ensure maximised environmental and community benefits from all of our reef investments.

Artificial Reefs

Artificial reefs are purpose-built structures installed in aquatic environments (marine, estuarine, river or lake) for the purpose of creating, restoring or enhancing habitat for fish, fishing and other recreational activities. Artificial reefs mimic the characteristics of natural reefs by creating new habitats and providing shelter, feeding opportunities and varied changes to the water column. This leads to a boost in productivity, abundance and diversity of aquatic life. Artificial reefs have been created in at least 50 countries around the world for many varying purposes, including snorkelling, SCUBA, surfing, energy production, eco-tourism, erosion mitigation, aquaculture, research, infrastructure and conservation, however, their most common use in Australia is to enhance recreational fishing opportunities.

Artificial reefs are one of the most popular types of aquatic infrastructure deployed for fisheries enhancement. Not only do artificial reefs provide an ecological benefit, they are also proven to provide positive social and economic gains for local communities. There are four main types of artificial reefs currently used in Australia: concrete, metal, integrated and other.

"Artificial reefs provide a complex habitat for a range of different species. Once algae, corals and invertebrates make themselves at home, they produce additional biomass in the food chain, creating a food source for fish and other species"

Recfishwest Research Officer James Florisson

Concrete artificial reefs

Durable, stable and can be moulded into many different shapes and sizes.

Metal artificial reefs

Pre-fabricated to build large units with unmatched complexity, steel reefs are particularly high strength, durable and easy to work with.

Integrated artificial reefs

Using several different materials, including concrete and steel, these reefs tend to produce the most diverse habitats.

Other artificial reefs

Include 3D printed plastic reefs, ceramic reefs and geotextile reefs. While some of these reefs have been used for decades, most of these structures are new and innovative concepts which are still being developed in Australia.

Considerations

Social, legislative, ecological and economic aspects need to be taken into consideration throughout an artificial reef development:

- Reef Purpose and Objectives
- Target Species
- Materials
- Stakeholder and End User Involvement
- Regulations and Approvals
- Reef Design (size, texture, profile and orientation)
- Location
- Module Configuration
- Storm Events
- Depth
- Ecological Interactions
- The Design Specific Lifespan
- Cost/Benefit Analysis
- Social Usage
- Monitoring and Evaluation

Getting Reefs in the Water

The processes of deploying an artificial reef involves many steps, from establishing a specific purpose for the reef all the way through to post-deployment monitoring.

Purpose → Initial Consultation and Constraints Mapping → Final Proposed Reef Site → Approvals Consultation → Procurement, Construction and Deployment → Monitoring, Reporting and Extension

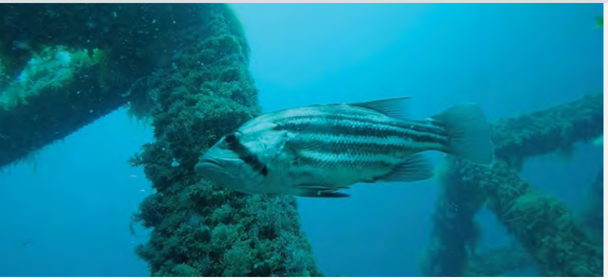
Monitoring

The performance of an artificial reef is measured by collecting data over time to track changes in the reef's environment. Monitoring artificial reefs allow us to understand:

- The reef's ecology (predominantly fish communities).
- Positive social and economic gains for local communities.

Traditional reef monitoring can be expensive so Recfishwest uses community-based 'citizen science' monitoring to collect large amounts of information at a reasonably small cost. It is a requirement to monitor artificial reefs in Australia to see how they change the surrounding environment. We successfully monitor artificial reefs in Western Australia through an engaging volunteer program called Reef Vision. Reef Vision uses fishers and divers to deploy specialised underwater camera equipment known as Baited Remote Underwater Video systems (BRUVs) off their personal boats to collect footage of marine life associated with the artificial reefs. These videos are then used by scientists to analyse the types of marine organisms on the reefs.

Reef Vision volunteers who have monitored two artificial reefs in the south west of WA captured footage of 83 different species. To read more about our monitoring check out **recfishwest.org.au/our-services/research/reef-vision-artificial-reef-monitoring/**.



REEF VISION

Future - The Artificial Reef Solution

Artificial reefs have been used all over the world for centuries, however their popularity as an area for recreational activities has only begun to accelerate in Australia during the last few decades. The research and development into reef materials, design, configuration and deployment is continuing to make structures more productive and cost-effective.

With the associated economic boost, social impacts and ecological production, artificial reefs will continue to increase around the Australian coast, providing accessible, safe and enjoyable fishing locations for all.

If you would like to see an artificial reef in your area or would like more information on artificial reefs, please see the contact details below.

This document provides a brief summary of the larger 'Guide to Artificial Reefs in Australia'. To get your copy, please email info@recfishwest.org.au

recfishwest

Call (08) 9246 3366 | **Email** info@recfishwest.org.au | **Web** recfishwest.org.au

Visit Suite 3, 45 Northside Drive, Hillarys WA 6025 | **Post** PO Box 34, North Beach WA 6920

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Appendix XI: Reef vision: A citizen science program for monitoring the fish faunas of artificial reefs

Reef vision: A citizen science program for monitoring the fish faunas of artificial reefs

Article *in* Fisheries Research · June 2018

DOI: 10.1016/j.fishres.2018.05.006

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Reef Vision: a citizen science program for monitoring the fish faunas of artificial reefs

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Abstract

There has been a marked increase in the number of artificial reefs being deployed around the world, many of which are designed to increase catches of recreationally-targeted fish species. As artificial reef deployments should be accompanied by clear and measurable goals and subsequent environmental impact monitoring and performance evaluation, there is a need to develop cost-effective monitoring programs. This study provides proof of concept for a citizen science approach to monitoring the fish faunas of artificial reefs (Reef Vision). Recreational fishers were recruited to collect video samples using baited remote underwater video systems and submit the resultant footage for analysis and interpretation by professional scientists. Reef Vision volunteers were able to collect enough data of sufficient quality to monitor the Bunbury and Dunsborough artificial reefs in Geographe Bay, south-western Australia. Data were extracted from the footage and used in robust univariate and multivariate analyses, which determined that a soak time of 45 minutes was sufficient to capture 95% of the number of species, abundance, diversity and community composition of the fish fauna. The potential for these data to detect differences in the characteristics of the fish fauna between reefs and seasons was also investigated and confirmed. With the continuing deployment of artificial reefs around the world, the use of similar cost-effective citizen science monitoring approaches can help determine the effectiveness these structures in achieving their aims and goals and provide valuable data for researchers, managers and decision makers. Projects such as Reef Vision can also benefit volunteers and communities by enhancing social values, creating ownership over research projects and fostering stewardship of aquatic resources.

Keywords: baited remote underwater video; community engagement; habitat enhancement; recreational fishing

Introduction

Artificial reefs are widely deployed around the world and are increasingly becoming a part of the seascape in coastal environments, including in Australia (Diplock, 2010; Fabi et al., 2015). The term 'artificial reef' is variously used (Seaman and Jensen, 2000), however, most usage falls within the broad definition of Sutton and Bushnell (2007), i.e. "one or more objects of natural or human origin deployed purposefully on the seafloor to influence physical, biological or socioeconomic processes related to living marine resources". One of the most common applications is as a tool in fisheries management to improve fishing (Seaman, 2007; Fabi et al., 2015; Becker et al., 2017) and, in regions such as Australia and the United States of America, particularly recreational fishing (Seaman and Jensen, 2000; Lowry et al., 2014). These installations are popular with recreational fishers as they can enhance fishing experiences and catch rates by providing access to target species and, in the longer term, stimulate *in situ* production, thereby increasing total fish stocks (Bohnsack, 1989; Brickhill et al., 2005; Cresson et al., 2014; Smith et al., 2016).

The artificial reefs used in fisheries enhancement in developed countries are now typically purpose-built, rather than constructed from materials-of-opportunity (Diplock, 2010; Lowry et al., 2014), ideally with considerable planning directed towards ensuring that the reef design, configuration and location is suited to its designated purpose (Diplock, 2010; Fabi et al., 2015). Post deployment of the structures, it is crucial to assess the extent to which a reef is achieving the intended purpose (Seaman and Jensen, 2000; dos Santos and Zalmon, 2015; Becker et al., 2017), and to determine the type and magnitude of any environmental impacts (Department of Fisheries, 2012; Department of the Environment, 2016; International Maritime Organization, 2016). Without such an assessment, there is a risk of repeatedly reusing suboptimal or even undesirable reef materials and designs, and incurring large costs in the process (Diplock, 2010). For example, the size, configuration and location of a reef is known to influence the density, biomass, and composition of the fish fauna and the long-term productivity of a reef, as well as fishing effort (Bohnsack et al., 1991; Jordan et al., 2005; Fabi et al., 2015). However, how these interactions manifest is still poorly understood (Diplock, 2010; Lowry et al., 2014). Information on the spatial and temporal variability of the fish fauna on an artificial reef can be used to put in place actions that maximise returns from the fish resources on the reef (dos Santos and Zalmon, 2015), to understand ecosystem-level responses of fishes to the reef (Scott et al., 2015) and to integrate the reef into a broader management framework (Lowry et al., 2014; Fabi et al., 2015). Thus, long-term monitoring of the fish assemblages associated with artificial reefs for fisheries enhancement is essential (dos Santos and Zalmon, 2015; Becker et al., 2017). This requirement can, however, add considerable costs to an artificial reef project (Fabi et al., 2015).

The financial costs of monitoring the fish faunas of an artificial reef could potentially be reduced by involving citizen scientists. Citizen science describes an approach where members of the public, usually non-experts or non-professionals, participate in scientific research or monitoring on a voluntary basis (Chase and Levine, 2016; McKinley et al., 2017). This approach has been applied in a variety of settings (Dickinson et al., 2012; Cigliano et al., 2015; Follett and Strezov, 2015; McKinley et al., 2017) and is being increasingly used in natural resource monitoring (Boakes et al., 2016; Chase and Levine, 2016). Although the use of citizen science in marine research and monitoring has recently started to gain traction (e.g. Fairclough et al., 2014; Thiel et al., 2014; Anderson et al., 2017), Cigliano et al. (2015) have pointed out that there is considerable potential to expand in this area. Citizen science monitoring can be a cost-effective method of data collection, whilst also increasing stakeholder engagement and buy-in (Dickinson et al., 2010; Fairclough et al., 2014; Aceves-Bueno et al., 2015; McKinley et al., 2017). However, if the program is poorly designed and managed, it can result in unsystematic data collection, leading to uncertainty about the efficacy of the data (Dickinson et al., 2010; Boakes et al., 2016). It is also important to consider the 'hidden costs' of administering citizen science programs, such as the recruiting, training and retaining volunteers (Thiel et al., 2014; McKinley et al., 2017). Ultimately, the costs and benefits of using citizen science in natural resource monitoring are context dependent (see Chase and Levine, 2016; McKinley et al., 2017). Success or failure will depend on the outcome of the interactions between a range of key variables, such as the type and goals of the monitoring, the tasks and levels of responsibility given to the member of the public and how the project is administered (Chase and Levine, 2016).

The overall objective of this study was to provide a proof of concept of a citizen scientist program (called Reef Vision), where recreational fishers used Baited Remote Underwater Video systems (BRUVs) to monitor the fish fauna of two artificial reefs. These purpose-built reefs were recently deployed in a marine embayment (Geographe Bay) on south-western coast of Australia, with the aim of enhancing recreational fishing opportunities and experiences. A BRUV monitoring method was chosen because it is cost-effective (Cappo et al., 2003); relatively robust to user skills and bias (Thompson and Mapstone, 1997); unaffected by depth and time limitations unlike, for example, diver surveys (Willis et al., 2000); actively attracts fish to the camera, thereby increasing the chances of observing more fish (Stobart et al., 2015); and has been successfully used by scientists to study the fish fauna of artificial reefs (e.g. Folpp et al., 2013; Scott et al., 2015; Becker et al., 2017). BRUVs also provide a permanent record of the data, which means that fish identifications and counts can be done later and checked for accuracy by qualified scientists, thus removing a potential source of error from the data set (Cappo et al., 2003; Whitmarsh et al., 2017). The specific aims of the study were to (i) elucidate whether sufficient quantities of video footage could be collected to constitute an effective monitoring regime; (ii) determine quantitatively the duration of a video that needs to be examined before there is no significant change in the characteristics of the fish fauna; and (iii) investigate whether data of sufficient quality can be extracted from the video footage to enable robust univariate and multivariate analysis of any spatial and/or temporal changes in fish faunal composition.

Materials and methods

Study site

The citizen scientists monitored two artificial reefs in Geographe Bay, a shallow, open embayment in south-western Australia (Fig. 1). This region experiences a Mediterranean climate, with hot dry summers and cool wet winters (Gentilli, 1971; Belda et al., 2014). Geographe Bay is well flushed with ocean water and the salinity is around full strength seawater throughout the year (Fahrner and Pattiaratchi, 1995). Water temperatures range from a minimum of ~13 °C in winter to maximum of ~26 °C in summer (Australian Institute of Marine Science, 2017). Tides are semi-diurnal with a low range (usually < 1 m, i.e. microtidal; Tweedley et al., 2016b) and water movement is predominantly wind-driven (Fahrner and Pattiaratchi, 1995; Dunn et al., 2014). The substrate consists of unconsolidated sediments over clay and limestone formations, which are exposed in some areas, and seagrass coverage (predominantly *Posidonia sinuosa*), is extensive throughout much of the bay (McMahon et al., 1997; Van Niel et al., 2009). Recreational fishing is a popular activity in Geographe Bay (Geographe Catchment Council, 2008).

Each of the two artificial reefs comprises 30 ‘Fish Box’ modules (Fig. 2b), placed in six clusters of five units, and deployed over a four-hectare area (Fig. 1). Each module, which measured 3 m^3 and weighed 10 tonnes, was constructed from steel-reinforced concrete with curved cross braces designed to promote upwelling. Both reefs were deployed in April 2013, creating the South West Artificial Reef Trial Project (Tweedley et al., 2016a). The reefs were placed in Geographe Bay in the vicinity of two urban centres, i.e. Bunbury and Dunsborough (Fig. 1), and within 5 km of boat ramps to allow for easy boat-based access by recreational fishers. The Bunbury reef lies at a depth of ~17 m, whereas the Dunsborough reef is at ~27 m (Fig. 1). These reefs were designed to increase the abundance of recreationally-important fish species, such as the sparid *Chrysophorus auratus*, and the carangids *Pseudocaranx* spp. and *Seriola hippos,* and thus improve recreational fishing opportunities.

Citizen science program

Citizen scientists were recruited and managed through a branded citizen science program called 'Reef Vision' (Recfishwest, 2017) operated by Recfishwest, the peak body representing recreational fishers in Western Australia. Recreational fishers who lived in close proximity to one of the reefs and fished regularly were recruited through a targeted print, radio and social media campaign. Applicants were interviewed to ensure their suitability for the project, i.e. they owned a suitable boat and safety equipment, held a valid skipper's licence and fished regularly; with the six most suitable participants recruited to monitor each reef (note this number was selected solely based on the cost of the equipment provided to each participant). Each participant attended a short (2 hour) training workshop held locally in October 2015, where the aims and importance of the research, as well as instructions on how to use the camera equipment, were presented. At the workshop, each volunteer was provided with a BRUV (Fig. 2a), waterproof log book, data storage devices, prepaid envelopes, bait vouchers, training manuals and the contact numbers of project staff able to help with any issues.

To facilitate retention, all participants were invited to join a closed Facebook page, which provided a platform for volunteers to interact with each other and project staff. The amount and timing of any monitoring done by a participant was at the discretion of the participant, although it was recommended that each person should monitor one of the artificial reefs for at least one 60 minute period each per month, if possible, over the course of a year (October 2015 to September 2016). While this flexibility had the potential to impact on the number of videos collected, it was preferred to a more regimented approach, which has been shown to result in low recruitment and retention rates in other citizen science projects (Dickinson et al., 2010).

The BRUVS (Fig. 2a) employed in Reef Vision were designed by Ecotone Consulting and constructed from readily available materials to increase cost effectiveness and ease of use by volunteers (Florisson, 2015; Tweedley et al., 2016a). Each BRUV frame was constructed from Polyvinyl Chloride (PVC) irrigation pipe (rated to 891 kPa) and PVC cement, and covers an area of ~580 mm x 450 mm (Fig. 2). The frame was connected to two stabilising skids, each filled with four 680 g lead weights to ensure the unit was negatively buoyant (5.5 kg total weight) and did not fall over upon landing on the substratum. A GoPro Hero 4 Silver Action Camera, which has an ultra-wide angle lens and the ability to record video footage with resolution of 1080 p at 60 frames per second, was mounted on the pipe using brackets. The camera was equipped with a waterproof housing rated to 40 m. A bait arm, with a length of 600 mm from the BRUV central point, and a plastic mesh bait bag (180 mm x 100 mm) placed 500 mm from the camera, was suspended 150 mm above the seafloor. These dimensions are consistent with those used in other BRUV studies (e.g. Ellis and DeMartini, 1995; Willis and Babcock, 2000; Heagney et al., 2007). To aid BRUV deployment and retrieval, a 35 m rope and float was attached to a tie point (stainless steel loop) in the central PVC cross brace. Each of the twelve BRUVs cost a total of AU$685 to produce. The largest individual cost was the labour required to construct the BRUV ($315), followed by the GoPro camera and SD card ($254), with the material needed to build the frame and attachments (ropes, floats, boom and bait bag) only costing $116 (17% of the total unit cost).

Sampling methodology

Following training, participants began to deploy BRUVs on the two artificial reefs in October 2015. On each sampling trip to their assigned reef (either Bunbury or Dunsborough), a volunteer was asked to deploy the BRUV on one of the five clusters (chosen randomly) for at least 60 minutes and fill out a log book. The book contained the date and time the BRUV was deployed and retrieved, the latitude and longitude of the deployment, cluster number and any other observations (e.g. how many people were fishing and what fish they caught). Prior to deployment, 500 g of Australian Sardine *Sardinops sagax* was placed in the bait bag of the BRUV, as the soft oily flesh of this species is known to attract fish. This fish is regarded as the most effective bait for BRUVs in Western Australia (Watson et al., 2010; Goetze et al., 2011; Dorman et al., 2012; Mallet and Pelletier, 2014). Once back onshore, participants downloaded the video footage on to a USB drive and posted it, together with the corresponding log-book sheet, to project staff at Murdoch University using the pre-paid envelope. Volunteers were encouraged to watch their videos and could share footage (Fig. 2b) on social media, particularly the closed project Facebook page.

Data extraction

Prior to analysis, each video was examined to determine the quality of the footage. Videos in which the camera faced into the sediment or towards the surface of the water were excluded, as were videos that did not capture the reef modules and those in which the water and/or light clarity precluded the accurate identification of fish. One video was selected, at random, from each reef, in each month between October 2015 and September 2016 for analysis (i.e. 12 videos per reef, total of 24). The MaxN, i.e. the maximum number of individuals of a particular species seen in any one video frame (Fig. 2b; Whitmarsh et al., 2017), was recorded for each five-minute interval of each video from the moment the BRUV touched the substrate until 60 minutes later. Taxa were identified to the lowest possible taxonomic level, typically species.

Statistical analysis

Soak time analyses

A suite of univariate and multivariate statistical analyses were employed to determine the length of video that needed to be observed before the characteristics of the fish fauna exhibited no significant change with increasing time. The MaxN of each species in each five-minute interval of each of the 12 videos collected from each of the two reefs were subjected to the DIVERSE routine in PRIMER v7 (Clarke and Gorley, 2015) to calculate the number of species, total MaxN (i.e. the sum of the MaxN values for individual species) and Simpson's Diversity Index. The resultant 288 values (i.e. 24 videos [12 per reef] x 12 five minute intervals) for each of the three univariate variables were then averaged to provide a single value for each variable in each five-minute interval at each reef and thus remove any potentially confounding influence of month. Increases in the mean for each of the three univariate variables with increasing five minute time intervals were plotted as rarefaction curves (Ugland et al., 2003).

Changes in species composition over time on each reef were also examined. In this case, the MaxN values of each species in each five-minute interval at each reef were firstly dispersion weighted, by dividing the counts for each species by their mean index of dispersion, i.e. the average of the variance to mean ratio in replicate videos (Clarke et al., 2006). This pre-treatment then ensures all species have equivalent variability by down-weighting the abundances of heavily-schooling species, such as the carangid *Trachurus novaezelandiae*, whose numbers are erratic over replicate videos relative to those species which return more consistent values, e.g. the aracanid *Anoplocapros amygdaloides* (Veale et al., 2014; Potter et al., 2016). These dispersion-weighted data were then square-root transformed to balance the contribution of relatively abundant species, compared to those with lower MaxN values (Clarke et al., 2014a). The transformed data for each five-minute interval were then averaged across the 12 replicates for each reef and used to construct a Bray-Curtis resemblance matrix. This matrix was subjected to hierarchical agglomerative clustering (CLUSTER; Clarke et al., 2014a) to determine the time intervals that were ≥95 % similar in terms of their species composition. The matrix was also used to construct a non-metric Multi-Dimensional Scaling (nMDS) ordination plot (Clarke, 1993), which provides a visual representation of the changes in fish faunal composition over time for both reefs.

The dispersion-weighted and square-root transformed MaxN data for each time interval on each reef were used to construct a shade-plot (Clarke et al., 2014b). The shade plot is a visualization of the averaged data matrix, where a white space for a species demonstrates that the fish was not recorded, while the depth and colour of shading, ranging from grey shades through the spectrum to black, represents increasing values for the abundance of that species in that time interval. The averaged samples (x axis of the plot) are ordered from lowest to highest time interval for each reef. Species (y axis of the plot) are ordered to optimise the seriation statistic ρ by non-parametrically correlating their resemblances to the distance structure of a linear sequence and constrained by a cluster dendrogram (Clarke et al., 2014a).

Differences in fish fauna between artificial reefs and seasons

On the basis of the above analysis, a video interval of 45 minutes was deemed appropriate to provide a robust determination of the fish fauna present on each of the artificial reefs (see Results). Thus, the MaxN of each species after 45 minutes from each reef in each of the 12 months were extracted from the above dispersion-weighted and square-root transformed data. These data were used by DIVERSE to calculate the number of species, total MaxN and Simpson's Diversity Index. Prior to subjecting the data for each variable to

Permutational Multivariate Analysis of Variance (PERMANOVA; Anderson et al., 2008) in Primer v7, each variable was tested to ascertain if a transformation was required to meet the test assumptions of homogeneity of variance and normality. This was achieved by plotting the $\log_e$ mean against the $\log_e$ standard deviation of every group of samples and determining the slope of the relationship, comparing it to the criteria in Clarke et al. (2014a). This analysis indicated that only total MaxN required transformation and was $\log_e(X+1)$ transformed. The data for each of the three dependent variables were used to construct a Euclidean distance matrix, which were, in turn, subjected to a two-way PERMANOVA to determine if the values for that variable differed significantly between Reef (2 levels; Bunbury and Dunsborough) and Season (2 levels; Summer [October-March] and Winter [April-September]). In these, and all subsequent tests, the null hypothesis of no significant difference among *a priori* groups was rejected if the significance level (P) was ≤ 0.05.

The dispersion-weighted and square-root transformed species composition data were used to construct a Bray-Curtis resemblance matrix, which was subjected to the same two-way PERMANOVA design used above. In this analysis PERMAOVA was primarily used to test for the presence of an interaction and a subsequent two-way Analysis of Similarities (ANOSIM; Clarke and Green, 1988) test used to determine the relative size of the overall Reef and Season effects on fish faunal composition using the universally scaled R statistic (Lek et al., 2011). An nMDS ordination plot was constructed form the above resemblance matrix to show the extent to which fish faunal composition differed between the reefs. To simplify and further illustrate the differences between Reef and Season, a centroid nMDS plot was produced using a distances among centroids matrix, which creates averages in the 'Bray-Curtis space' from the six replicate samples representing each season in each reef (Lek et al., 2011). A shade plot was constructed from the transformed and averaged data matrix to illustrate the trends exhibited by species with respect to Reef and Season. Note that as 44 species were recorded, many of which only occurred in a few samples, the shade plot was restricted to those 18 and 17 species that represented >2.5 % of the total fish abundance in a reef and season, respectively.

Results

Citizen science data collection

Twelve main volunteers were utilised in the project, with six monitoring each of the two artificial reefs, and a further 20 participants involved as crew members. Over the course of the year-long study (October 2015 to September 2016) there was an attrition rate of 16%, with two of the 12 volunteers leaving the project due to unrelated issues (i.e. receiving employment in other parts of Western Australia and ill health). These two volunteers were replaced with two new and trained personal to ensure the quality and quantity of footage collected was maintained.

Throughout the sampling period 59 and 52 individual videos were collected from the Bunbury and Dunsborough artificial reefs, respectively, totalling ~10,000 minutes of footage (Table 1). At least four videos were recorded from each reef in each month with the exception of June and August in Bunbury and June and September in Dunsborough. In no months were data not collected from each reef. Typically greater numbers of videos were collected in between November to March, i.e. around the austral summer, with fewer video collected in the austral winter (June and August; Table 1).

Fish faunal composition

A total of 44 species, representing 29 families were recorded from the 24 videos from the two artificial reefs (Table 2). Five species, each of which contributed ≥10% to the total MaxN, comprised the majority of the assemblage (77% of all individuals). These comprised the pempherid *Parapriacanthus elongatus*, which lives in close association to the reef modules, the epibenthic kyphosid *Neatypus obliquus* and labrid *Coris auricularis*, and the pelagic carangids *Trachurus novaezelandiae* and *Pseudocaranx* spp. (Table 2). This latter taxon, which was a target group for the reefs, ranked third in terms of MaxN and was recorded in 75% of all videos. Other recreationally-targeted species recorded included *Seriola hippos*, *Chrysophrys auratus* (both also target species) and *Glaucosoma hebraicum* and

Choerodon rubescens. In addition to *Pseudocaranx* spp., other species that were frequently recorded included *C. auricularis*, *S. hippos* and *A. amygdaloides* (Table 2).

Soak time analyses

Rarefaction curves for each of the mean number of species, total MaxN and Simpson's diversity index for both the Bunbury and Dunsborough reefs reached an asymptote prior to the 60 minute mark (Fig. 3). Approximately 95% of maximum values for each univariate variable recorded from the videos from each reef was achieved after ≤45 minutes, with the exception of total MaxN at Bunbury (92% and 95% at 45 and 50 minutes, respectively). Moreover, the timing at which the asymptote occurred was similar among the two reefs, despite the values for the number of species and total MaxN always being greater at Dunsborough, whereas the reverse was typically true for Simpson's diversity index (Fig. 3).

A clear pattern of increasing similarity in fish faunal composition among samples for each reef was detected as the duration of the video increased. Thus, for both reefs, samples at 5 and 10 minutes were the most distinct (~75% similarity), whereas those samples derived from video footage at between 40 and 60 minutes were all >95% similar (Fig. 4a). As with the univariate variables, similar trends among times were detected for both reefs, despite the fish fauna of the two reefs having a relatively low similarity (58%). In other words, larger differences in fish fauna composition were detected between reefs, than among time intervals within a reef, with the same temporal pattern occurring on both reefs. This is shown on the associated nMDS plot, where the samples representing the different time intervals are well separated for each reef, but show the same pattern of increasing proximity to one another with increasing time (Fig. 4b).

The shade plot illustrates that only the mullids *Upeneichthys vlamingii* (Bunbury) and *Parupeneus chrysopleuron* (Dunsborough) were recorded for this first time after 45 minutes, albeit their MaxN values were very low (Fig. 5). For most species, including abundant ones such as *C. auricularis, Pseudocaranx* spp. and *N. obliquus*, their MaxN values changed little with increasing time. Moreover, even for those species whose abundance on both reefs did change with increasing time, e.g. *A. amygdaloides* and the gerried *Parequula melbournensis*, these values changed little after 45 minutes (Fig. 5).

The above results suggest that 95% of the maximum values for the number of species, Simpson's diversity index, fish faunal composition and, to a lesser extent, total MaxN occur within 45 minutes of video footage. Thus, in the case of the Bunbury and Dunsborough artificial reefs, faunal data extracted from 45 minutes of BRUV footage is sufficient to determine accurately the univariate and multivariate characteristics of the fish fauna.

Differences in fish fauna between artificial reefs and seasons

Two-way PERMANOVA demonstrated that the number of species and total MaxN differed significantly between reefs and seasons, but not the Reef × Season interaction (Table 3a,b). The number of species was greater on the Dunsborough than Bunbury artificial reef and during summer rather than winter (both ~13 vs 9; Figure 6a,b). Total MaxN values were more than four times larger at Dunsborough (118) than Bunbury (26) and almost three times greater in samples collected in summer (104) as opposed to winter (40). A significant difference between the values for Simpson's diversity index was detected only between reefs (Table 3c), with values in winter being higher than those summer (0.80 and 0.65, respectively; Fig. 6e).

Fish faunal composition was shown by PERMANOVA to differ between reefs and seasons and that there was no interaction between these main effects (Table 3d). The $\bar{R}$ statistic value for Season (0.303) was larger than that for Reef (0.255), indicating that temporal rather than spatial effects were slightly more influential in structuring the fish assemblages of the artificial reefs. This is shown on the nMDS plots where the points representing summer and winter typically form more discrete groups than those for the two artificial reefs (Fig. 7). Species such as *C. auricularis*, *Pesudocaranax* spp., *C. rubescens* and *G. hebraicum* were more abundant in summer than winter, whereas the reserve was true for *A. amygdaloides*, *S. hippos* and the labrid *Austrolabrus maculatus* (Fig. 8a). Although both artificial reefs contained substantial numbers of *C. auricularis* and *A. amygdaloides*, fish such as *N. obliquus, Pseudocaranx* spp. and the pinguipedid *Parapercis haackei* were more abundant at Dunsborough. In contrast, only the relatively uncommon aracanid *Anoplocapros lenticularis* was comparatively more abundant on the Bunbury artificial reef (Fig. 8b).

Discussion

There has been a marked increase in the number of artificial reefs being deployed to increase catches of key recreationally-targeted fish species and thus also act as a tool for fisheries and broader ecosystem management (Baine, 2001; Seaman, 2007; Diplock, 2010). Any responsible artificial reef deployment should have clear and measurable performance goals, the successes of which are evaluated using a monitoring program (Becker et al., 2017). However, given the fact that longer term monitoring programs, i.e. those lasting several years, are required to gain a sound understanding of the influence of these artificial structures (e.g. Coll et al., 1998; Relini et al., 2002; dos Santos and Zalmon, 2015), there is a need to develop cost-effective monitoring regimes. This study determined that citizen scientists using BRUVs could collect sufficient quantities of adequate quality data to develop a robust monitoring program for two artificial reefs in a marine embayment in south-western Australia. It follows that this methodology could be used to help to monitor and determine the effectiveness of other artificial reefs in achieving their aims and goals.

Participant involvement

Each of the 12 main volunteers were asked to each collect a single video of at least 60 minutes duration from their respective reef in each month of the study using the supplied BRUV equipment. If completed successfully, this would provide six replicates from each reef in each month and thus allow for robust statistical examination of the resultant data. Throughout the sampling period, volunteers were able to effectively collect data from both artificial reefs, amassing a total of 111 videos (averaging 4.9 and 4.3 per month from the Bunbury and Dunsborough reefs, respectively). This success is consistent with other studies employing citizen science, which suggest that this method can result in the collection of large quantities of data over broad spatial and temporal scales, which could otherwise be cost prohibitive (Silvertown, 2009; Dickinson et al., 2010; Pecl et al., 2014). Moreover, despite, due to financial limitations, only having six volunteers per reef, at least four videos were collected from a reef in 19 of the 24 reef and month combinations. The months when less than the targeted number of samples were obtained occurred either at the start of the project, while participants were still being trained, or around the austral winter during prolonged periods of poor weather and sea-state. This shows that our participants were actively engaged in the project, but also the value in having as many volunteers as is practically and financially possible. Note however, unlike many citizen science projects, where participants use their own equipment (e.g. a smartphone) or are provided with online or printed material (Johnson and Johnston, 2013; Pecl et al., 2014; Jenkins et al., 2017; Tweedley et al., 2017), the current study had to supply volunteers with relatively expensive equipment, which limited participant numbers.

All volunteers recruited to Reef Vision were avid recreational fishers (20% were also SCUBA divers) who lived in the vicinity of the reefs. Participants with these interests were sought out for the project, due to them being frequent users of the artificial reefs and thus able to deploy the BRUVs regularly, but also having extensive knowledge of the local conditions and commonly encountered fish species. Recruiting these types of volunteers increased engagement, thus reducing attrition and helped ensure the provision of regular videos and that safety was not compromised.

Although there has often been stigma about quality of the data provided by citizen science, as it is not collected by experts (Conrad and Daoust, 2008; Dickinson et al., 2010), the use of video prevents this issue influencing the resultant data. Thus, unlike observation counts (e.g. underwater visual census) and similar *in situ* data collection methods, video footage is able to be permanently archived and analysed by experts (as in the case of the current study) and any footage can be replayed and reanalysed in the future (Willis et al., 2000; Tessier et al., 2005; Mallet and Pelletier, 2014).

Soak time analyses

For a faunal monitoring regime to be successful, it must provide accurate data on abundance of each species, whilst, at the same time, being relatively economical. Although many studies have cited the cost-effectiveness of BRUVs in comparison to visual surveys, mainly due to the reduction fieldwork time (e.g. Cappo et al., 2003; Watson et al., 2005; Langlois et al., 2010), the time required to extract the data from the video footage can be considerable (Francour et al., 1999; Stobart et al., 2007). An obvious way of reducing this cost is to decrease the soak time of the BRUV. However, Gladstone et al. (2012) showed that greater improvements in precision occurred from increasing soak time rather than replication. In the current study, a soak time of 45 minutes was found to provide a statistically robust estimation of the abundance, diversity and composition of the fish fauna of the artificial reefs in Geographe Bay.

Whitmarsh et al. (2017) in a meta-analysis of 161 BRUV studies found that cameras were deployed between 15 minutes and 120 minutes, with peaks in frequency of 30, 60 and 90 minutes. While the value of 45 minutes calculated in the current study was similar to that recorded for demersal species in Hawaiian coastal waters (Misa et al., 2016), it is substantially greater than that for natural and artificial reefs in estuarine and marine waters of New South Wales (Folpp et al., 2013; Harasti et al., 2015). Differences in the length of soak time required are likely due to the diversity of species present at a site, with longer soak times needed in more diverse areas (James Tweedley, Murdoch University unpublished data) or in areas with very low and/or highly variable abundance of fish. This is the case in pelagic environments, where 120 minutes of soak times is often used and, even then, can produce zero inflated data (Santana-Garcon et al., 2014). While, comparative studies on soak time are rare, Harasti et al. (2015), showed that on temperate reefs in New South Wales, the MaxN for many reef-associated species occurred within 12.5 minutes, with this value rising to 30–40 minutes on similar habitats in South Australia (Whitmarsh et al., 2017). This variability highlights the importance of determining for any monitoring regime, as in the current paper, the soak time required to generate statistically-robust data. Note that, in additional to elucidating how the number of species and total MaxN change over time (e.g. Stobart et al., 2007; Gladstone et al., 2012; Santana-Garcon et al., 2014; Harasti et al., 2015; Misa et al., 2016) there is also value in, as in the current study, assessing how the faunal composition changes over time. This because while many studies focus on community rather than species level changes in abundance (e.g. Wakefield et al., 2013; Lowry et al., 2014), few demonstrate the effect soak time has on faunal composition.

Differences in fish fauna among artificial reefs and seasons

The results of univariate and multivariate analysis showed that the number of species, total MaxN and fish faunal composition differed significantly with Reef and Season and that Simpson's diversity index changed between reefs. Although not the main focus of this proof of concept study, this demonstrates that the sampling methodology employed by the citizen scientists can generate data of sufficient quality for use in statistical analyses. This was not the case with preliminary trials using cameras that provided a live video stream to the surface, where the resolution and quality of that video was too poor to adequately identify and count fish (Florisson, 2015; Tweedley et al., 2016a).

Although based on a relatively small suite of data, the trends reported in the current study mirror those found elsewhere, thus providing reassurance that the data generated are sound. For example, both the number of species and total MaxN differed among seasons, being greater during summer and winter, resulting in a change in species composition. This is thought to reflect an increase in water temperature in Geographe Bay during summer (McMahon et al., 1997). Such increases in temperature have been shown to similarly influence the fish communities of several artificial reefs around the world (Bohnsack et al., 1994; Relini et al., 1994; Mills et al., 2017; Rosemond et al., 2018).

When comparing between the two reefs, the number of species, total MaxN and Simpson's diversity index were all greater on the Dunsborough than Bunbury artificial reef. While these data are preliminary, their trends do match those obtained by Tweedley et al. (2016a) and could be due to the locations of the two reefs within Geographe Bay. The south-west edge of this embayment has a high level of reef connectivity, due to the number of limestone and granite reefs occurring near Cape Naturaliste. These natural reefs have been shown to significantly influence nearby fish communities (Westera et al., 2007) and have likely facilitated utilisation and colonisation of the near-by Dunsborough artificial reef by fishes. It is also noteworthy that data collected independently on the Bunbury and Dunsborough artificial reefs using Diver Operated Video and BRUVs demonstrate that the fish faunas of these two reefs are different (Paul Lewis, Department of Primary Industries and Regional Development, unpublished data).

Effectiveness of the monitoring program and recommendations

The effectiveness of the citizen science monitoring of the artificial reefs in this study was facilitated by the BRUV design. The frame was lightweight, durable and built to similar specifications as BRUVs in other scientific studies (e.g. Ellis and DeMartini, 1995; Willis and Babcock, 2000; Heagney et al., 2007), yet constructed for approximately a quarter of the cost of commercially-available equivalents (Table 4). The total cost of the Reef Vision program, including the development and production of 12 BRUVs, training of volunteers and salary to fund the part-time employment (0.2 FTE) of a volunteer manager was ~AU$27,000. The estimated costs of a University-led equivalent program, involving the purchase of four commercially-available BRUVs and the travel and salary costs of undertaking one fieldtrip per month to collected videos from each artificial reef, were almost 50% greater at ~AU$55,000 (Table 4). Thus, in the case of the current study, employing a citizen science approach substantially reduced the cost of the project.

The use of an easy-to-use and commonly-owned small action camera, combined with in-person training made instances where volunteers required technical assistance minimal. This, together with the high resolution video produced, helped maintain participant engagement and reduced attrition. Engagement and management of volunteers was achieved via a closed group on Facebook containing 20 members (i.e. volunteers and project staff). On this private page, participants could share videos and photographs from their stills, experiences, troubleshoot and engage with the project managers. Throughout the year long study, members wrote 169 posts, which were 'liked' 685 times and generated 526 comments. Volunteers felt that 'capturing' a fish on the camera was a form of fishing. Several of them produced 'highlight reels' from the footage they collected and uploaded these to open Facebook groups that were typically related to recreational fishing and, in some cases also YouTube. Participating in the Reef Vision program was seen by volunteers as a way to 'give back' to the community and exponents of fishing, thus creating feelings of satisfaction, contentment, sense of achievement, fulfilment, pride and happiness, whilst also increasing ownership and stewardship over the artificial reefs.

While we consider that the citizen science approach (Reef Vision) detailed here could be used to monitor the fauna of other artificial reefs, there are some ways in which the methodology could be improved. Firstly, a larger pool of suitable volunteers is recommended as this reduces the risk of limited data collection during periods of undesirable weather and sea-state. Such a repository of participants would also reduce the impact of any unforeseen volunteer attrition. In the case of the current study, we consider that eight (rather than six) volunteers would be appropriate for monitoring an artificial reef of the size of those in Geographe Bay (Fig. 1).

Many studies on the fish fauna of artificial reefs have focused on the changes in community composition that occurred post-deployment and, as such, contain no data on the faunal assemblage prior to the deployment of the structure (e.g. Bohnsack and Talbot, 1980; Duffy-Anderson et al., 2003; Burt et al., 2009; Folpp et al., 2011; Becker et al., 2017). This baseline data is vital if the performance of the reef is to be measured against its aims and objectives. In the case of the current study, this would require the engagement of community during the planning stages of the artificial reef to ensure a spatially and temporally robust set of data are collected as a baseline. It is noteworthy that both Diplock (2010) and Streich et al. (2017) recommend a Before-After-Control-Impact (BACI) monitoring approach be employed to help elucidate the influence a new reef deployment has on local fish assemblages. The choice of a control site is critical, however, as the results of several studies have determined that the characteristics of the fish fauna associated with artificial reefs can differ markedly from those of adjacent natural reefs (Thanner et al., 2006; Burt et al., 2009; Folpp et al., 2013).

Conclusions

This study has demonstrated that citizen science can be an effective tool for monitoring the fish faunas of artificial reefs. The use of recreational fishers to collect BRUV video samples, but having the resultant footage analysed and interpreted by professional scientists, lowers fieldwork costs, circumvents some of the stigma around citizen science and increases community engagement. Reef Vision volunteers were able to collect enough data of sufficient quality to monitor the Bunbury and Dunsborough artificial reefs in Geographe Bay, south-western Australia. These data were extracted from the footage and used in robust univariate and multivariate analyses to determine that a soak time of 45 minutes was sufficient to capture 95% of the diversity and community composition of the fish fauna and detect spatial and temporal differences in those fauna. With the continuing deployment of artificial reefs around the world, the use of citizen science in monitoring can provide valuable data for researchers, managers and decision makers. Projects such as Reef Vision can also benefit volunteers and communities by enhancing social values, creating ownership over research projects and fostering stewardship of aquatic resources.

Acknowledgements

Gratitude is expressed to the recreational fishers and divers who participated in the Reef Vison program and to Andrew Rowland, Leyland Campbell, Andrew Matthews, Mark Pagano, Paul Lewis, Howard Gill, Thomas Bateman, Michael Tropiano and Stephanie Watts for their support and advice during the project. Whiteys Tackle and Camping, Dunsborough Outdoor Sportz and Coastal Water Dive are thanked for supplying bait and providing logistical support. This project was supported by Recfishwest and Department of Primary Industries and Regional Development through funding from the Recreational Fishing Initiatives Fund, the Fisheries Research and Development Corporation (FRDC 2013/221) on

behalf of the Australian Government and Murdoch University. This was conducted in accordance with Murdoch University Human Ethic Permit #2014/2005 and Animal Ethics Permit #O2626/14.

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Table 1. The total number of videos (> 1 h in length) received from Reef Vision volunteers for each of the Bunbury and Dunsborough artificial reefs in each month between October 2015 and September 2016.

Artificial reef	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Bunbury	3	14	5	8	7	6	4	5	1	5	1	5	**59**
Dunsborough	5	4	7	8	6	6	4	5	2	5	4	1	**52**
Total	**8**	**18**	**12**	**16**	**13**	**12**	**8**	**10**	**3**	**10**	**5**	**6**	**111**

Table 2. Mean MaxN abundance (N), standard error (SE), percentage contribution (%), cumulative percentage contribution (C%) of each species from the 24 videos recorded by BRUVs on the Bunbury and Dunsborough artificial reefs between October 2015 and September 2016. The number of videos in which each species was recorded (F) and the frequency of occurrence (%F) are also provided, as it the family to which each species belongs. Species representing > 5 % in terms of % or %F are highlighted in grey. * denotes that a species is targeted by recreational fishers.

		Abundance				Occurrence	
Species	**Family**	**N**	**SE**	**%**	**C%**	**F**	**%F**
Parapriacanthus elongatus	Pempheridae	21.21	18.80	29.51	29.51	2	8.33
Neatypus obliquus	Kyphosidae	9.46	2.31	13.16	42.67	15	62.50
Pseudocaranx spp.*	Carangidae	8.75	2.98	12.17	54.84	18	75.00
Coris auricularis	Labridae	8.17	1.27	11.36	66.20	22	91.67
Trachurus novaezelandiae	Carangidae	8.00	6.92	11.13	77.33	2	8.33
*Seriola hippos**	Carangidae	2.88	1.06	4.00	81.33	20	83.33
Parequula melbournensis	Gerreidae	1.83	0.42	2.55	83.88	15	62.50
Pempheris klunzingeri	Pempheridae	1.71	1.01	2.38	86.26	3	12.50
Anoplocapros amygdaloides	Aracanidae	1.83	0.34	2.55	88.81	19	79.17
Austrolabrus maculatus	Labridae	1.13	0.33	1.57	90.38	10	41.67
Diodon nicthemerus	Diodontidae	0.58	0.46	0.81	91.19	3	12.50
Chelmonops curiosus	Chaetodontidae	0.67	0.17	0.93	92.12	11	45.83
Parapercis haackei	Pinguipedidae	0.46	0.12	0.64	92.75	10	41.67
Myliobatus australis	Myliobatidae	0.58	0.13	0.81	93.57	12	50.00
Trygonorrhina fasciata	Rhinobatidae	0.54	0.15	0.75	94.32	10	41.67
*Pentaceropsis recurvirostris**	Pentacerotidae	0.33	0.14	0.46	94.78	5	20.83
*Arripis truttaceus**	Arripidae	0.25	0.25	0.35	95.13	1	4.17
Cheilodactylus gibbosus	Cheilodactylidae	0.29	0.11	0.41	95.54	6	25.00
*Glaucosoma hebraicum**	Glaucosomatidae	0.21	0.08	0.29	95.83	5	20.83
*Choerodon rubescens**	Labridae	0.25	0.09	0.35	96.17	6	25.00
Anoplocapros lenticularis	Aracanidae	0.21	0.08	0.29	96.46	5	20.83
Chromis westaustralis	Pomacentridae	0.17	0.17	0.23	96.70	1	4.17
Monocanthidae spp.	Monocanthidae	0.29	0.09	0.41	97.10	7	29.17
Suezichthys cyanolaemus	Labridae	0.21	0.08	0.29	97.39	5	20.83
Parapercis ramsayi	Pinguipedidae	0.21	0.08	0.29	97.68	5	20.83
Dasyatis brevicaudata	Dasyatidae	0.21	0.08	0.29	97.97	5	20.83
Chaetodon assarius	Chaetodontidae	0.13	0.09	0.17	98.14	2	8.33
Notolabrus parilus	Labridae	0.13	0.07	0.17	98.32	3	12.50
Tilodon sexfasciatus	Kyphosidae	0.17	0.08	0.23	98.55	4	16.67
*Chrysophrys auratus**	Sparidae	0.17	0.12	0.23	98.78	2	8.33
Pempherididae spp.	Pempherididae	0.08	0.08	0.12	98.90	1	4.17
Upeneichthys vlamingii	Mullidae	0.08	0.06	0.12	99.01	2	8.33
Trygonoptera mucosa	Urolophidae	0.08	0.06	0.12	99.13	2	8.33
*Platycephalus longispinis**	Platycephalidae	0.08	0.06	0.12	99.25	2	8.33
Aptychotrema vincentiana	Rhinobatidae	0.13	0.07	0.17	99.42	3	12.50
Trygonoptera personata	Urolophidae	0.08	0.06	0.12	99.54	2	8.33
Eubalichthys mosaicus	Monacanthidae	0.04	0.04	0.06	99.59	1	4.17
Apogon victoriae	Apogonidae	0.04	0.04	0.06	99.65	1	4.17
Orectolobus maculatus	Orectolobidae	0.04	0.04	0.06	99.71	1	4.17
Enoplosus armatus	Enoplosidae	0.04	0.04	0.06	99.77	1	4.17
Notolabrus angustipes	Labridae	0.04	0.04	0.06	99.83	1	4.17
Aracana aurita	Aracanidae	0.04	0.04	0.06	99.88	1	4.17
*Mustelus antarcticus**	Triakidae	0.04	0.04	0.06	99.94	1	4.17
*Achoerodus gouldii**	Labridae	0.04	0.04	0.06	100.00	1	4.17

Table 3. Mean squares (MS), percentage of the MS to the total (%MS), pseudo-F (*pF*) and significant level (*P*) for two-way PERMANOVAs tests on the (a) number of species, (b) total MaxN, (c) Simpson's diversity index and the fish faunal composition of the two artificial reefs in the two seasons. Significant differences are highlighted in bold. *df* = degrees of freedom.

(a) Number of species	***df***	**MS**	**%MS**	***pF***	***P***
Reef	1	**96.00**	**50.63**	**6.80**	**0.026**
Season	1	**73.50**	**38.76**	**5.21**	**0.034**
Reef × Season	1	6.00	3.16	0.43	0.516
Residual	20	14.12	7.45		

(b) MaxN	**df**	**MS**	**%MS**	***pF***	***P***
Reef	1	**10.07**	**65.88**	**22.76**	**0.001**
Season	1	**4.13**	**27.03**	**9.34**	**0.005**
Reef × Season	1	0.64	4.19	1.45	0.256
Residual	20	0.44	2.89		

(c) Simpson's index	**df**	**MS**	**%MS**	***pF***	***P***
Reef	1	**0.13**	**61.91**	**5.96**	**0.022**
Season	1	0.06	27.54	2.65	0.119
Reef × Season	1	0.00	0.18	0.02	0.892
Residual	20	0.02	10.38		

(d) Faunal composition	**df**	**MS**	**%MS**	***pF***	***P***
Reef	1	**3560**	**24.23**	**1.95**	**0.036**
Season	1	**5955**	**40.53**	**3.26**	**0.003**
Reef × Season	1	3348	22.79	1.83	0.065
Residual	20	1829	12.45		

Table 4. Approximate cost (AU$) of running the Reef Vision program with 12 volunteers (6 per artificial reef) compared to the estimated cost of a science equivalent program run by an Australian university. The science equivalent cost is based on a team of two research assistants using a boat and four BRUVs to collect four videos from each artificial once a month for a year. Note that neither budget includes the cost of video processing and data extraction and analyses, which should be comparable for both programs.

Costs	Reef Vision	Science equivalent
Operating		
BRUV frame	$5,172 (12 units)	$6,660 (4 units)
BRUV cameras	$3,828 (12 units)	$1,276 (4 units)
Bait	$1,440	$1,440
Consumables	$588	$2,400
Travel		
Training workshop	$610	$0
Fieldwork	$0	$21,870
Salary		
Volunteer management	$16,000	$0
Fieldwork	$0	$21,600
Total	**$27,638**	**$55,246**

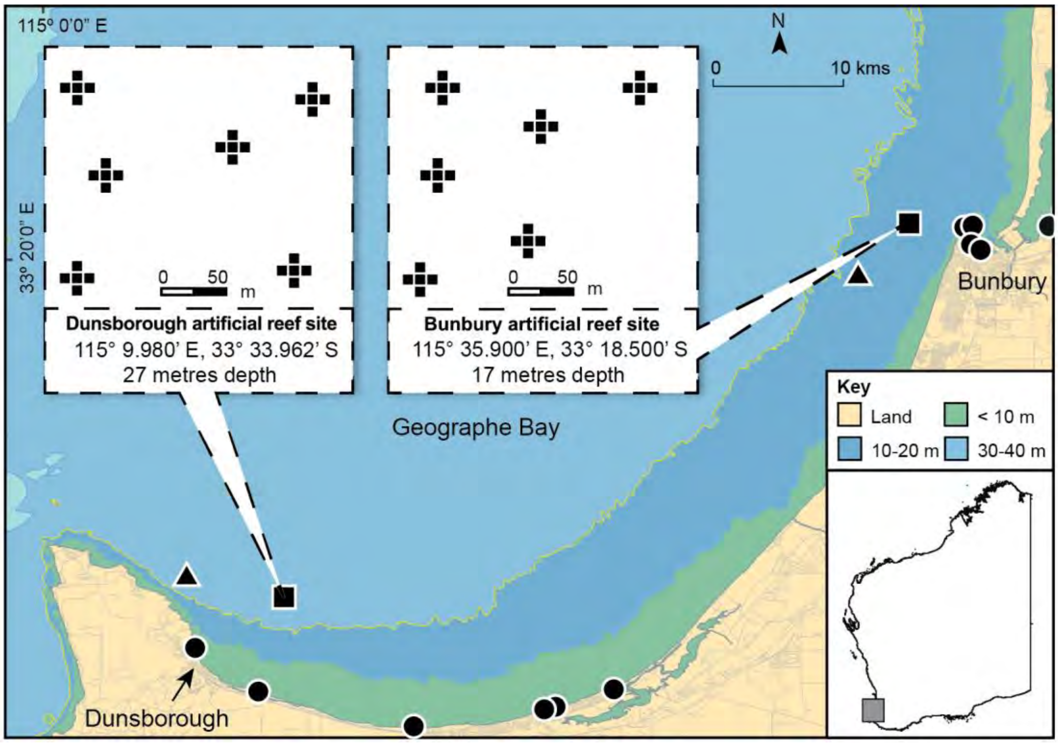

Fig. 1. Map showing the location of the Bunbury and Dunsborough artificial reefs in Geographe Bay and the configuration of their 30 concrete FishBox modules into six clusters. Grey square on inset denotes the location of Geographe Bay in Western Australia. ■, purpose-built concrete reef; ▲ sunken ship artificial reef; ●, boat ramp. Map modified from the Department of Primary Industries and Regional Development.

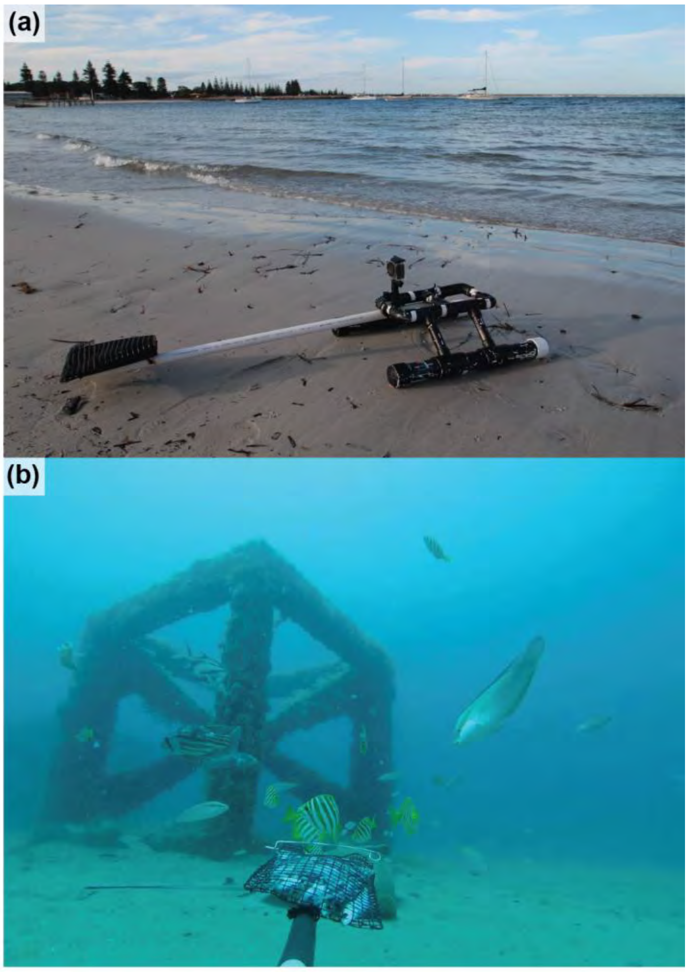

Fig. 2. Photographs of (a) the baited remote underwater video system supplied to Reef Vision participants and (b) a screenshot of footage collected from the Dunsborough artificial reef using the BRUV in (a). Footage in b shows 10 *Coris auricularis*, 10 *Neatypus obliquus*, 2 *Pseudocaranx* spp., 1 *Pentaceropsis recurvirostris*, 1 *Glaucosoma hebraicum* and 1 *Myliobatis australis*.

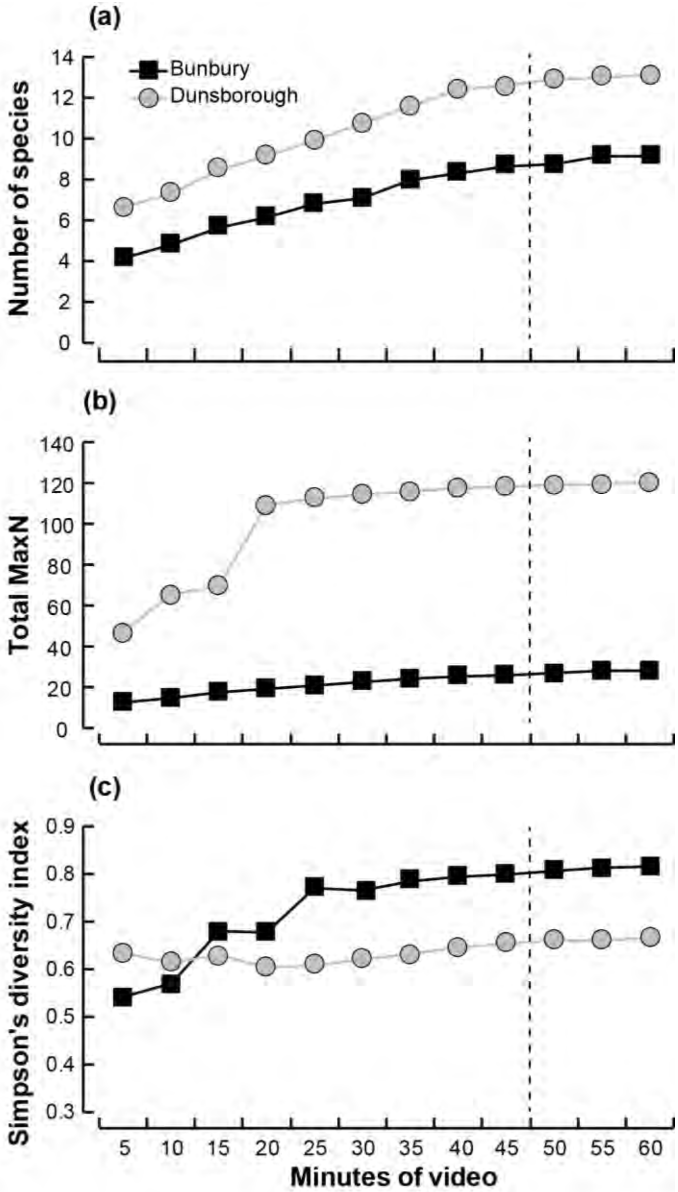

Fig. 3. Rarefaction curves for the (a) mean number of species, (b) total MaxN and (c) Simpson's diversity index from consecutive five minute intervals of BRUV footage recorded from the Bunbury and Dunsborough artificial reefs between October 2015 and September 2016. Vertical dashed line denotes 45 minutes.

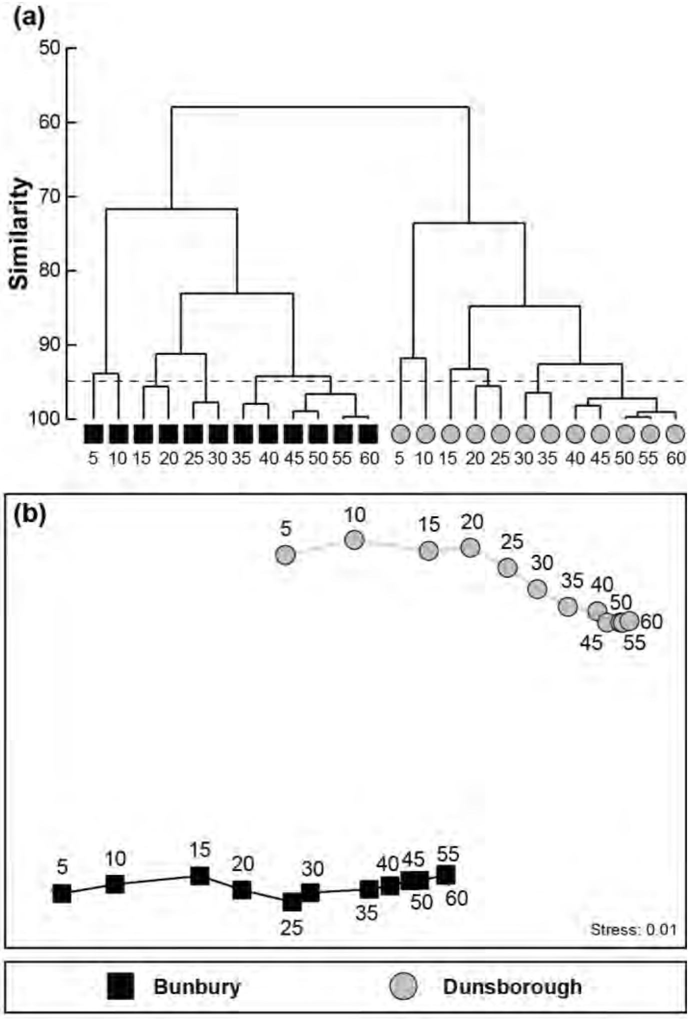

Fig. 4. (a) Cluster dendrogram and (b) nMDS ordination plot, derived from a Bray-Curtis resemblance matrix, constructed from the dispersion-weighted and square-root transformed and averaged MaxN abundances of each species recorded from consecutive five minute intervals of BRUV footage recorded from the Bunbury and Dunsborough artificial reefs between October 2015 and September 2016. Horizontal dashed line denotes a Bray-Curtis similarity of 95%.

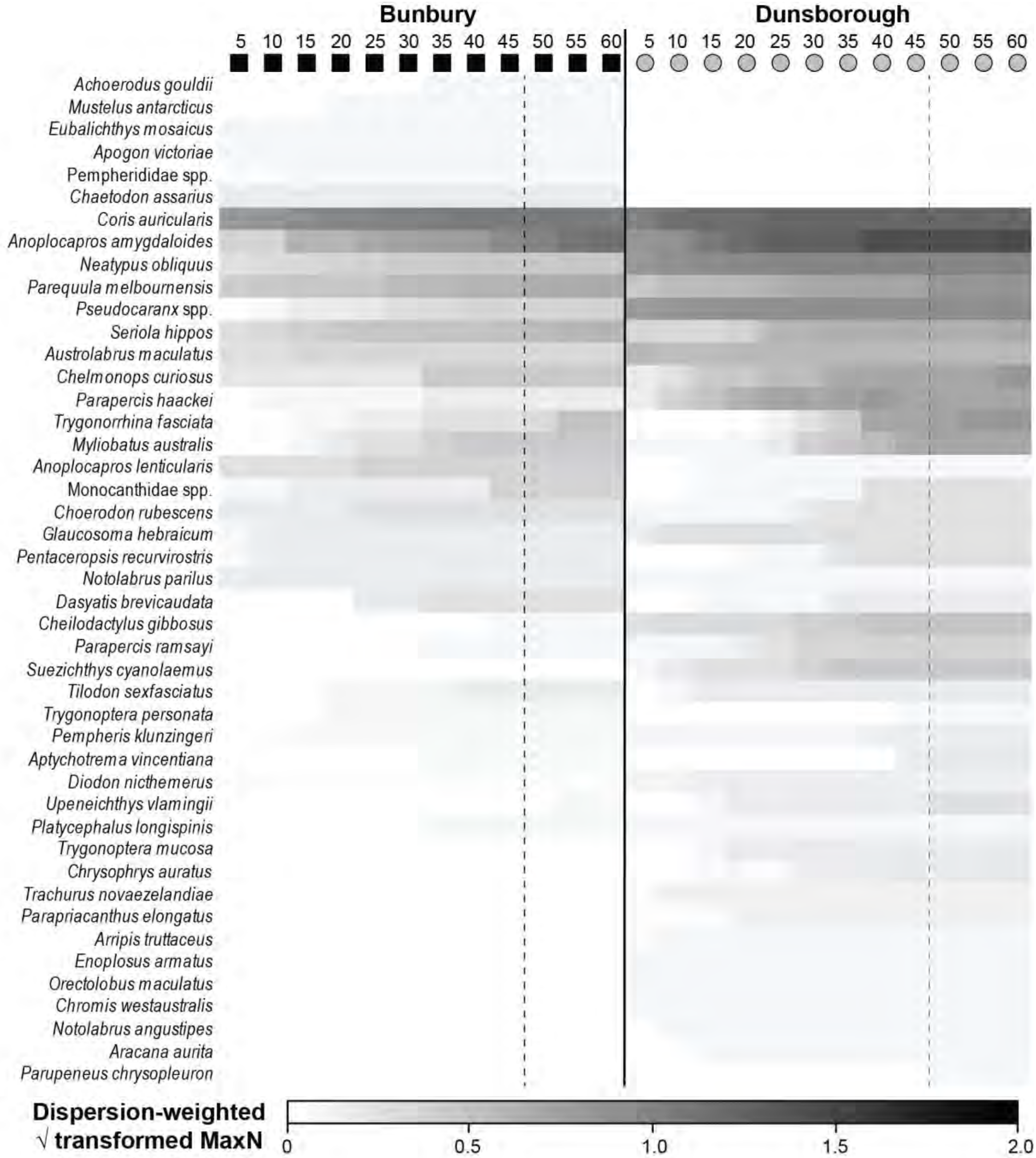

Fig. 5. Shade plot, constructed from the dispersion-weighted, square-root transformed and averaged MaxN abundances of each species recorded from consecutive five minute intervals of BRUV footage recorded from the Bunbury and Dunsborough artificial reefs between October 2015 and September 2016. Vertical dashed line denotes 45 minutes.

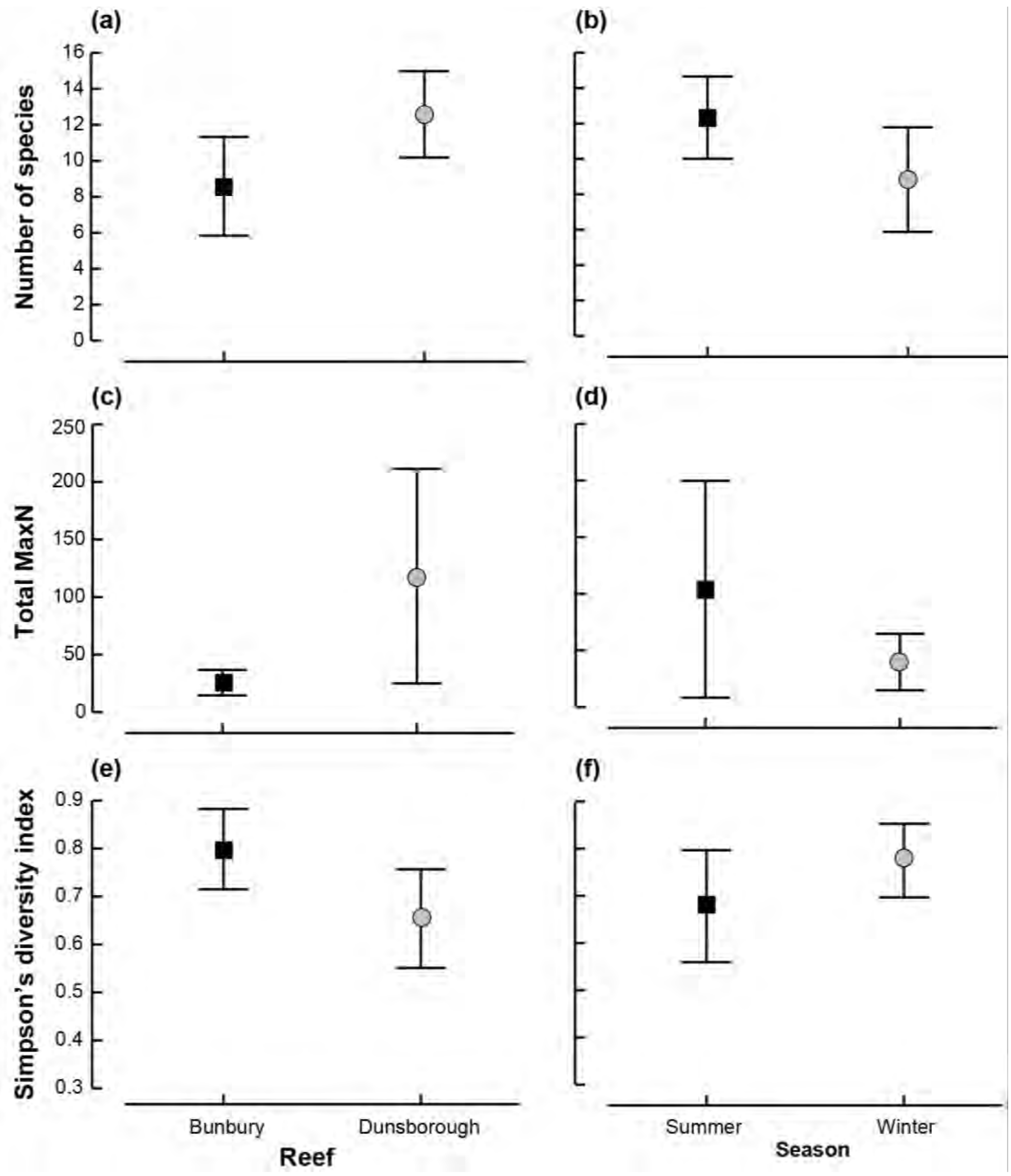

Fig. 6. (a, b) Mean number of species, (c, d) total MaxN and (e, f) Simpson's diversity index recorded between reefs and seasons. Error bars represent ± 95% confidence intervals.

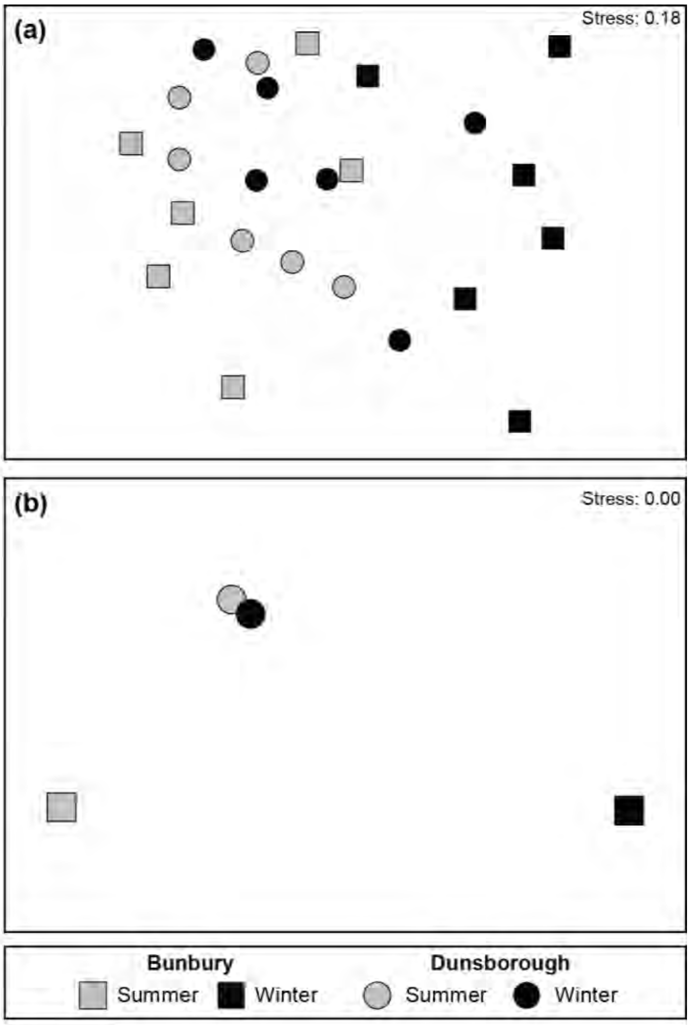

Fig. 7. (a) nMDS ordination plot, derived from a Bray-Curtis resemblance matrix, constructed from the dispersion-weighted and square-root transformed and averaged MaxN abundances of each species recorded from the Bunbury and Dunsborough artificial reefs between October 2015 and September 2016. (b) Centroid nMDS ordination plot, derived from a distance among centroids matrix, constructed from the above Bray-Curtis resemblance matrix.

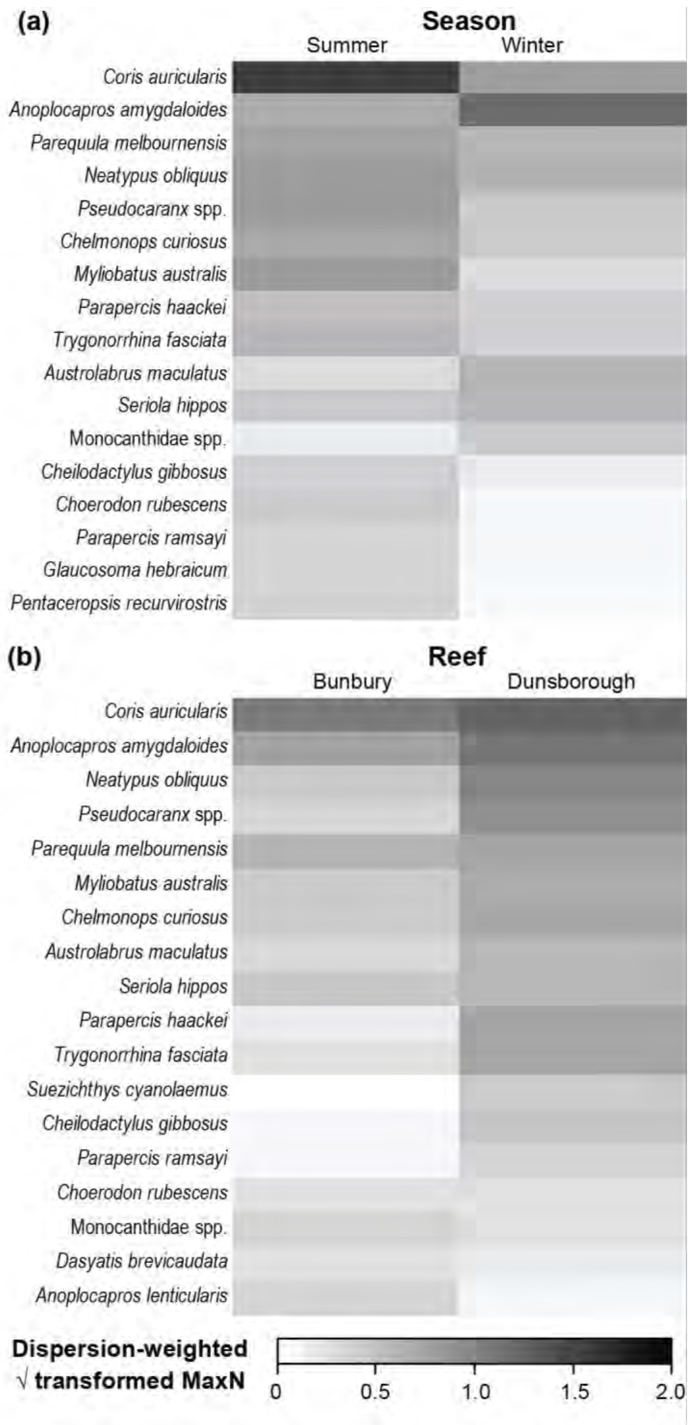

Fig. 8. Shade plots constructed from the dispersion-weighted and square-root transformed MaxN abundances of each species recorded from the Bunbury and Dunsborough artificial reefs between October 2015 and September 2016. MaxN abundances averaged for the (a) two seasons and (b) artificial reefs. Note only species that contributed ≥2.5% to the total number of fish to either reef or season are included.