Department of Agriculture, Fisheries and Forestry

Addressing knowledge gaps for the sustainable management of rocky reef fisheries in southern Queensland

FRDC 2008/015
Final Report
August 2013



Wayne Sumpton, Matthew Campbell, Mark McLennan,
Ian Brown, Kate Fraser, Stephen Wesche, Brigid Kerrigan

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July 2013

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Great state. Great opportunity.

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1. NON-TECHNICAL SUMMARY

2008/015 Addressing Knowledge Gaps for the Sustainable Management of Rocky Reef Fisheries in Southern Queensland.

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OBJECTIVES:

1 Determine key biological parameters required to sustainably and profitably manage the fisheries for key rocky reef fish species (particularly pearl perch and teraglin).

2 Quantify the post-release survival of common rocky reef species and investigate novel ways of enhancing post-release survival.

3 Determine the important habitats for rocky reef species and identify possible threats to those habitats.

4 Develop harvest strategy approaches that enable the sustainable management of rocky reef fisheries.

OUTCOMES ACHIEVED TO DATE:

The project outputs have contributed to or will lead to the following outcomes:

1. The key biological and fisheries parameters have been determined for pearl perch and teraglin and will be incorporated into future stock assessments enabling the improved monitoring and sustainable management of rocky reef species.

2. Estimates of short term post release survival have been derived for the three main target species of rocky reef species which can be used in future stock assessments. Methods of enhancing survival have also been determined and with extension to the fishing industry should result in enhanced release survival of each species.

3. Important habitat areas of pearl perch have been identified and the importance of Moreton Bay as a nursery area of juvenile snapper has been confirmed. The absence of pearl perch and teraglin from inshore estuarine areas such as Moreton Bay reinforce the importance of offshore habitat for these two species.

4. Project results will be communicated in collaboration with Fisheries Queensland through their usual communication network and strategies.

Historically, pearl perch and teraglin were secondary targets for demersal line fishers in south-east Queensland, with snapper the most commonly caught reef-associated species. However, declining snapper catch rates, combined with decreasing bag limits has seen pearl perch and teraglin catches increasing in the last decade. The prevalence of advanced Global Position System (GPS) and sonar technology has likely increased the efficiency of vessels accessing the Rocky Reef Finfish Fishery (RRFF), leading to increases in fishing power.

The pearl perch length and age frequency distributions skewed toward the minimum legal size of 35cm with most fish (~50-60%) caught from all sectors being between the MLS of 35cm to 50cm, with fish >50cm more common in waters between Fraser Island and Gladstone. Spawning fish were only observed from catches landed in November and December and there is still some uncertainty about the spatial and temporal extent of spawning. Sexual maturity in female pearl perch occurs at lengths 25-27.5cm and at about 3 years of age. Growth curves of male and female pearl perch differed significantly, with the oldest animal sampled being a 67cm, 22 year old female. Pearl perch were fully-recruited to the fishery at age 5 in 2009 and age 6 in 2010. Total instantaneous mortality estimates were $Z = 0.49$ in 2009 and $Z = 0.59$ in 2010. Empirical natural mortality (M) estimates ranged between 0.20 and 0.38. Based on the estimates derived during this study, combined with increasing fishing effort occurring in areas where spawning fish are found, we would categorise the pearl perch fishery as fully fished, with a possibility that the fishery is over-fished.

The fisheries biology of teraglin (*Atractoscion aequidens*) in Australia is significantly different to the presumed same species fished in South Africa (where it is known commonly as the geelbek). Preliminary genetic analysis suggests that teraglin in Australia may be a different species, although further work is needed to clarify this taxonomic position. Sexual maturity of teraglin in southern Queensland is reached at an age between 2 to 3 years of age and at an L_{50} of approximately 35cm and there is considerable spatial and temporal variation in reproductive parameters similar to patterns exemplified by other species in the same family (Sciaenidae). Teraglin spawn throughout the entire year with a peak in spawning, during the spring and summer. Estimates of fishing mortality are imprecise but indicate that teraglin are currently fully fished and possibly over-fished. Teraglin is a species that probably does not warrant future detailed attempts at age based stock assessment due to imprecise age estimation and difficulties associated with obtaining representative samples from each of the fishing sectors.

There is currently a paucity of relevant, Queensland-based data regarding the key fisheries and biological parameters for those rocky reef species considered incidental to snapper, pearl perch and teraglin in Queensland – samsonfish (*Seriola hippos*), amberjack (*Seriola dumerili*), yellowtail kingfish (*Seriola lalandi*), mahi mahi (*Coryphaena hippurus*), grass emperor (*Lethrinus laticaudis*), frypan bream (*Argyrops spinifer*) and cobia (*Rachycentron canadum*). Despite this, these species are increasingly targeted by commercial, recreational and charter fishers. Cobia and grass emperor, together, represent approximately 25% of total landings, by weight, in the Rocky Reef Finfish Fishery (RRFF). From information in the literature, yellowtail kingfish (shown to be overfished in New South Wales), amberjack, samsonfish and cobia are currently being managed with a minimum legal size (MLS) lower than the length-at-maturity. As such, these species require continued monitoring from AMU and the periodic analysis of logbook data to ensure the current management measures, including stringent in-possession limits, are protecting these species from overfishing.

Post-release survival of line-caught pearl perch was about 90%. The survival of throat- or gut-hooked pearl perch was significantly lower than those hooked in either the mouth or lip. Post-release survival was similar for both legal (≥ 35cm) and sub-legal (<35cm) pearl perch. Swim bladders of pearl perch rupture during ascent from depth allowing swim bladder gases to escape into the gut cavity. The gases continue to expand as the fish nears the surface, causing the alimentary tract to rupture near the anus, allowing the gases to exit the body cavity. The results of this study show that pearl perch are resilient (at least in the short term) to catch-and-release suggesting that post-release mortality would not contribute significantly to total fishing mortality. We recommend the use of circle hooks, fished actively on tight lines, combined with minimal handling in order to maximise the post-release survival of pearl perch but there is no need to treat this species to relieve barotraumas symptoms.

Short-term post-release survival of teraglin decreased with increasing depth with virtually 100% mortality when fish were caught in water exceeding 70m depth. A post-release survival of 40% was determined as the short-term experimental survival rate for this species (in water <50m deep) but it is recognised that this rate could be much lower depending on the actual handling practices employed by individual fishers. One of the features of teraglin biology which reduces the susceptibility of the population to post-release mortality is the higher abundance of smaller undersized teraglin in shallower water (<50m). In these depths they have a higher post-release survival, and the effects of barotrauma are not as severe. Barotrauma symptom relief treatment (by either venting or capsule release) is recommended for teraglin.

Previous studies have shown snapper post-release survival to be extremely low (30% – 45%) in depths similar to those fished in southern Queensland with a decrease in rates of survival for deeper waters. Snapper were found to have a short term post-release survival of 88% with no significant difference in survival rates for greater depths or size of fish (legal vs. sub-legal). Gut hooking and bleeding were found to be significant predictors of mortality. Traditional lateral venting techniques were shown to cause no harm and allowed fish to return to depth. We trialled a novel venting technique that was found to be an effective treatment for the relief of barotrauma symptoms. This technique was called "buccal venting" and involved piercing the everted stomach with an hypodermic needle (a practice previously not encouraged). Healing of stomachs was observed in 61% of fish that had been buccal vented. Short-term survival in buccal vented fish was not significantly different from fish vented in the traditional manner. In a large proportion of fish, the swim bladder was found to have healed within 3 days after capture.

The interpretation and analysis of "zero" catch records of a rocky reef species of interest (or groups of species) in recreational, commercial and charter logbooks and dairy data is an important analytical issue. The attribution of a zero catch to a fishing trip that had no chance of catching a particular species will severely bias catch rate estimates, (as will the elimination of zero catches from any analysis). Significant management changes for snapper including lowering of bag limits (from 30 to 4) and increases in MLS (from 25 to 35cm) have had an impact on recreational harvest rates effectively lowering both the mean and variance in harvest rate as these changes were introduced. Despite a long historical catch record for snapper via the Queensland Fish Board (QFB) records, this data source lacks sufficient information for either pearl perch or teraglin. Available evidence confirms that these data are still a useful historic indicator of the relative abundance of snapper, however, we believe that efforts should be made to determine events though time that may have impacted on the QFB records.

Pearl perch catch rates from the Gold Coast fishing charter fleet derived from the Australian Marine Life Institute (AMLI) data increased with depth while the opposite was the case for teraglin. Changes in the business operations of the charter fleet which saw movement towards shorter fishing trips and greater numbers of anglers per trip by some operators have altered the effective fishing effort in this fishery. While standardisation for these factors is simple in the AMLI data subset, it is difficult to standardise for these factors when analysing compulsory logbook information collected from the entire fishery where information regarding the number of anglers and fishing time are not mandatory. The AMLI sample of the Gold Coast fleet is still a representative sample of the snapper catch from the Gold Coast region but may be unrepresentative of the pearl perch catch due to the low number of catches of this species recorded in the database. In addition, recent trends that show the AMLI sampling targets vessels that operate in shallow water resulting in biases toward smaller teraglin and higher teraglin catch rates, while reducing the likelihood of catching pearl perch. Recent declines in participation rate in the AMLI program have also eroded the value of these data for the other main target rocky reef species as charter boat business conditions deteriorate further.

Baited Remote Underwater Video and Camera Stations were used to survey demersal fish communities over three broad benthic habitat types (sand, gravel and rocky reef) at two depth ranges (29 – 51 m and 52 – 75 m). A significant interaction between depth and habitat type implied that the differences between habitats were not consistent between the two depth ranges. As expected, fish species richness increased with the structural complexity of habitat. Juveniles and adults of the three main target species were rarely seen on sandy habitats despite juvenile pearl perch being sampled in the same areas with alternative sampling gears (trawls and traps). Adult snapper were seen at all depths and all habitat types but again were more abundant on the more structured habitats. We hypothesise that the lack of juveniles of pearl perch in samples is related to their seasonal utilisation of these habitats and to their nocturnal feeding activity. The pattern of differential seasonal use of open sandy habitats is consistent with the behaviour of snapper whose juveniles are seasonally vulnerable to capture on open less structured habitat. In contrast to snapper whose juveniles are abundant on inshore estuarine habitat, juveniles of both teraglin and pearl perch are restricted to oceanic offshore areas.

2. ACKNOWLEDGEMENTS

Members of the Fisheries Queensland Assessment and Monitoring Unit made an enormous contribution to this research through active involvement in all phases of the research from sample collection, through to processing of biological samples and analysis.

Ray Joyce was responsible for setting up the system of charter gathering for the Gold Coast charter fishery and has devoted considerable resources to collect and maintain the valuable catch and effort database. His tireless efforts directed at ensuring the long term viability of the Gold Coast Rocky reef fishery are to be particularly commended. We also thank the many owners, skippers and deckhands of the charter vessels that operate from the Gold Coast who so willingly provided much of the data collected by the AMLI. We are also grateful to a number of students of local universities who have assisted with data collection over the years.

Sean Maberly, DEEDI research vessel skipper made a great contribution to collection of BRUVS samples and the post-release survival research components of the research. Sean's contribution exceeded his role as a vessel skipper often providing insightful advice on various aspects of the research. Jeff Johnson of the Queensland museum also offered great assistance with the identification of fish species in our BRUVS/BRUCS surveys.

We would like also to thank the many commercial and recreational fishers who contributed to the research by providing samples of fish and allowing measurements of their catches. We would particularly like to thank Jeff Sorrell, David Moore, Peter Griffiths, Brendan Moore and members of the Bribie Island Sportfishing Club who aided in the capture of snapper and pearl perch as part of the post-release survival experiments. We also acknowledge the assistance of Bruce Sutton, Scott Butterworth, Greg Pearce, Ken O'Sullivan who provided pearl perch samples.

Dr Tony Courtney provided data on pearl perch relative abundance from trawl otter trawl surveys collected from previous FRDC research.

Many Fisheries Queensland staff also assisted throughout the project and we would particularly like to thank John Kung, James Webley, Steve Taylor and Bonnie Holmes for their contributions. Samples provided by fisheries observers, particularly Gavin Leese and Nathan Rowsell, were also appreciated. We are grateful for the assistance provided by the Research and Information Services team at the Primary Industries Building library. Specifically, we would like to acknowledge the patience and diligence of Zalee Crump, Pat Abbott, Mel Kippen, Paul Cottee and Diane Langford in providing prompt replies to the numerous requests for scientific papers throughout this project.

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3. BACKGROUND

During the last 20 years offshore recreational fishing effort for rocky reef species in southern Queensland has been increasing dramatically as a result of population growth and increasing boat ownership. The availability of advanced GPS and sounder technology as well as the use of braid lines and soft plastic lures has further increased the pressure on rocky reef fish stocks. At the same time commercial fishers with L1 endorsements (enabling commercial line fishing south of the Great Barrier Reef Marine Park) have been moving further north and into deeper water due to falling catch rates and other competitive pressures in the highly populated south-east corner of the state. There is now also anecdotal evidence that recreational fishers are likewise moving further north and to wider grounds where catch rates are superior to areas that have traditionally received considerable recreational fishing effort. This trend is expected to increase, as in the Gold Coast area alone (where localised depletion of stocks appears most critical) recreational boat ownership is expected to double in the next decade.

This localised depletion of rocky reef species was first identified as an issue in the mid 1990's after public consultations on rocky reef fisheries instigated by the then Queensland Fisheries Management Authority. Since then concerns have only heightened, particularly on the Gold Coast where increased recreational and charter fishing effort has been identified as an important contributor to declining catch rates and localised depletion. During this time it was also first recognised that stocks of snapper and possibly other rocky reef stocks required rebuilding.

Traditionally, snapper (*Pagrus auratus*) has been the main target species of the rocky reef fishery but recent declines in snapper catch have seen other species increasingly targeted. One of these targeted species is pearl perch (*Glaucosoma scapulare*) which is endemic to the east coast of Australia, and is a species that has many knowledge gaps despite some recent monitoring work in both Queensland and NSW. Anecdotal evidence has suggested that post-release survival of pearl perch is high given that most fish are seen to quickly return to depth after they are released, however recent experiences in Western Australia with a related species, the dhufish (*Glaucosoma hebraicum*) suggests that post-release survival may not be as high as previously thought. This is confirmed by the experience of Seaworld staff who have had great difficulty in ensuring the survival of pearl perch that they have captured and sought to hold in their marine Aquaria.

Another common target species, teraglin (*Atractoscion aequidens*) has been identified as a major discard mortality risk. Recent decreases in MLS have somewhat alleviated the discard mortality issue for teraglin but there are still uncertainties about the species fisheries biology given that features of the fishery and biology of the species, which has been documented in South Africa, appear vastly different to that on the east coast of Australia.

Despite a range of widespread concerns about the status of the rocky reef fishery, 2005 and 2006 saw a recovery in snapper catches amongst both the recreational and commercial sectors in some areas and this has reduced the concerns of some stakeholders. This recovery may be partially the result of management intervention which increased the MLS during 2003. This intervention was predicted to have flow on benefits noticeable two years after the increase. In addition, it is hypothesised by some that the effects of the current drought on the east coast of Australia could also be benefiting some marine species (particularly snapper) as it has increased the available habitat for juveniles due to increased salinity in estuaries that had previously been unavailable to the more oceanic species. Despite this apparent recovery the underlying concerns about localised depletion and hyperstability of snapper stocks and the largely unknown status of the other key species remain largely unaddressed. These concerns were highlighted in a recent snapper stock assessment conducted in 2006 (Allen *et al.* 2006). This assessment recognised some limitations in the available data and recommended a range of measures to improve the assessment and to improve the knowledge base on other rocky reef species. This current proposal and programs implemented by the DPI&F Assessment and Monitoring Unit (AMU) aim to address these limitations and data gaps.

The AMU currently provide information that is to feed into stock assessments for key rocky reef species (particularly snapper, pearl perch and teraglin). However these programs are in their infancy and mainly collect size and otolith samples of these species despite the fact that ageing protocols have not been developed or validated for any of the species other than snapper. In addition, the general fisheries biology of species such as pearl perch and teraglin remains largely unknown. AMU staff have recognised the need for research to assist in the development of cost effective monitoring practices for these species. They recognise that there is additional information that needs to be collected to add value to their sampling regimes and they recognise the need to ensure maximum synergy by working closely with researchers to maximise sampling as well as collection and analysis of biological material not currently being addressed by the AMU program. In particular, collecting monthly samples to assist in age validation and reproductive biology assessment. The Department of Agriculture, Fisheries and Forestry (DAFF) (previously QDPI&F) will also be formulating updated management arrangements in the rocky reef fishery beginning in 2014 and there is a need to ensure that knowledge gaps of the key rocky reef species are met.

As the research being proposed in this proposal has immediate management application a research steering committee will be established that will consist of Dr Brigid Kerrigan (reef line manager), Mr Eddie Jebreen (DAFF long term monitoring southern leader), Mr Geoff Weir (DAFF Observer Co-ordinator), Mr Ken O'Sullivan (commercial fisher), Mr Bill Corten (recreational fisher), Mr Ray Joyce (charter representative), Mr Mick O'Neil (stock assessment scientist) and Dr Wayne Sumpton (principal investigator). This committee will oversee progress in the proposed research and will be responsible for ensuring that research findings are quickly incorporated into the overall monitoring, assessment and management framework of the DAFF. It is recognised as essential that some flexibility is also maintained by the project team so that they are able to address emergent issues that may arise during the development of a management plan for this fishery.

Marine embayments such as Moreton Bay and Hervey Bay have been identified as important juvenile nursery areas for several rocky reef species, particularly snapper, and there have been concerns expressed that incidental trawl discard mortality of juvenile snapper and possibly other rocky reef species may have detrimental effects on fish stocks (Sumpton and Jackson, 2005). In addition, spatial trawl closures in Moreton Bay which were designed to minimise the impact of trawling on snapper may be ineffective due to inappropriate timing of the closures.

Dr Sumpton has already been liaising with Dr John Stewart and other colleagues from NSW who are researching rocky reef species and it is considered vital that linkages are maintained between the two jurisdictions to ensure maximum benefit to both states. This project will continue the dialogue and collaboration that has already been taking place between researchers and managers in both Queensland and NSW.

References:

Allen, M.S., Sumpton, W.D., O'Neill, M.F. and Courtney, T (2006). Stochastic Stock Reduction Analysis for Assessment of the Pink Snapper Fishery, Queensland, Australia. Department of Primary Industries and Fisheries Assessment Report.

Sumpton, W.D. and Jackson, S. (2005) Incidental trawl capture of juvenile snapper (Pagrus auratus) reduces yield of a sub-tropical line fishery in Australia: An assessment examining habitat preference and early life history characteristics. Fisheries Research 71:335-347.

4. NEED

Recreational rocky reef fishing effort is concentrated in the densely populated southern part of Queensland and there have been increasing concerns of localised depletion of rocky reef species at a time when there are also increased competitive pressures on commercial line fishers in this area.

DAFF Queensland will shortly be reviewing management arrangements for the rocky reef fishery and this proposed research will directly feed into this management process by addressing high priority QFRAB, ReefMAC and ReefSAG research needs. These priorities include determining the critical habitats of all life history stages of rocky reef species, improving our understanding the fisheries biology and population dynamics of rocky reef species (particularly pearl perch and teraglin).

A recent assessment and MSE (Allen *et al*. 2006) and subsequent review by Dr Carl Walters suggested recruitment over-fishing of snapper and recommended several research and monitoring initiatives to ensure sustainability of species taken in the rocky reef fishery. Some of the monitoring requirements (e.g. age structured sampling of snapper) are already being addressed as core business of the DAFF Queensland long term monitoring program but other research priorities including estimating discard mortality and identifying ways of reducing this mortality are yet to be addressed.

In addition, despite recent declines in trawl effort in Moreton Bay and elsewhere, the impact of the incidental trawl capture of snapper (and other rocky reef species) has been shown to be substantial (Sumpton *et al*. 2005). There is a need to work closely with industry and other stakeholders to examine the importance of different habitats and to minimise the impact of fishing practices on juvenile rocky reef species.

Management utilisation of the results of this research will be ensured by the involvement of Brigid Kerrigan (current DAFF Queensland reef-line fishery manager) as a co-investigator, and a steering committee involving representatives of all key stakeholders.

5. OBJECTIVES

5.1 Determine key biological parameters required to sustainably and profitably manage the fisheries for key rocky reef fish species (particularly pearl perch and teraglin).

5.2 Quantify the post-release survival of common rocky reef species and investigate novel ways of enhancing post-release survival.

5.3 Determine the important habitats for rocky reef species and identify possible threats to those habitats.

5.4 Develop harvest strategy approaches that enable the sustainable management of rocky reef fisheries.

6. METHODS

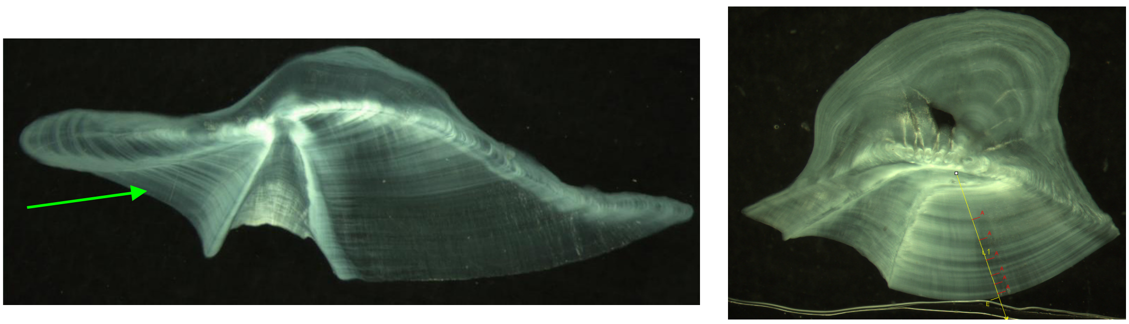
6.1. Biological and Fisheries Parameters of Key Rocky Reef Species

Pearl perch and teraglin samples were collected as part of the rocky reef fish monitoring program conducted by the Assessment and Monitoring Unit (AMU) of Fisheries Queensland. Samples were collected from commercial fishers, recreational fishers, charter operators and seafood processors as part of the routine sampling that started in 2006. Sampling takes place in south east Queensland from Baffle Creek, just north of Bundaberg, to the News South Wales-Queensland border. Samples are collected opportunistically year-round providing vital information for use by Fisheries Queensland in determining the status of these fisheries.

To supplement the AMU sampling, project staff obtained pre-recruit pearl perch in order to provide information on juveniles, specifically regarding growth and the lower bounds of growth curves that are lacking from fishery-dependent sampling where minimum legal size restrictions are in place. Further, teraglin samples collected during a previous study (Sumpton *et al*., 1998) were analysed, as were samples collected by the Australian Marine Life Institute.

Pearl perch and teraglin gonads were staged macroscopically in the laboratory when project staff either collected samples or assisted in the processing of samples collected by AMU. The lengths at which 50% of the female teraglin and pearl perch reached sexual maturity (L_{50}) was determined by fitting a logistic curve to the proportion of females with gonads at stages II to V for given total lengths. Once staged, female gonads were weighed and Gonosomatic Index (GSI) was calculated to determine reproductive seasonality.

The age of pearl perch and teraglin was assessed according to protocols developed by AMU (Fisheries Queensland, in press). In summary, sagittal otolith pairs were removed, washed and dried. One otolith was then blocked in polyester resin and set aside until the resin had completely cured. Once cured, a thin section (0.3mm) was taken through the focus with a diamond-edged circular saw. The section was then mounted on a glass slide using polyester resin for microscopic examination. Mounted otoliths were examined using a dissecting microscope and reflected light on a matt-black background. Nominal ages were assigned according to the number of opaque zones between the primordium and the distal edge of the otolith (see Figure.6.1.1). Edge-type was also recorded and classified as new, intermediate or wide, according to the width of the translucent material between the distal edge of the otolith and the last opaque zone.



(a) (b)

Figure 6.1.1 a) Sectioned pearl perch otolith with primary reading area highlighted; b) sectioned otolith from a 6+ year old teraglin.

Each fish was assigned a birthday of January 1 so that the corrected age was calculated as the additive of the number of opaque zones and the number of days after January 1 that the fish was caught. That is, for example, a fish with 4 opaques zones caught on the 30 June would have a corrected age of 4.5 years. The von Bertalanffy growth parameters k and L_∞ were estimated using least-squares techniques, by plotting total length against corrected age.

Estimates of total instantaneous mortality, *Z*, for pearl perch and teraglin were derived using age-length keys (ALK's) from length frequency data generated from AMU sampling. *Z* was determined by regressing frequency against age, with the first point of the regression determined by the first fully-recruited age class. Natural mortality, *M*, estimates were derived using three empirical methods.

For both species, we conducted simple yield per recruit analysis based on growth curves derived from our research and empirical estimates of natural mortality. Growth estimates used in the analysis were those derived using all data for each species. Changes in yield were estimated for a range of natural mortality estimates and MLSs. Mean weights at age were those derived from the von Bertalanffy growth curves and standard length-weight regressions.

AMU primarily focuses on sampling snapper, pearl perch and teraglin. Samples from other rocky reef species are collected opportunistically and, as such, these data are not comprehensive. For the purposes of the current project, we have searched the literature for relevant fisheries information on the incidental rocky reef species – samsonfish, amberjack, yellowtail kingfish, mahi mahi, grass emperor, frypan bream and cobia.

6.2. Post-Release Survival and Ways of Enhancing Survival of Line Caught Rocky Reef Species

Experimental site selection

Fish were captured from a range of sites for these experiments. Areas offshore from Double Island Point and Moreton Island were targeted based on depths and catch likelihood. Capture sites at Double Island Point ranged in depth from 37 – 50 metres whilst depths offshore from Moreton Island ranged from 51 – 180 metres (Figure 6.2.1). Teraglin were caught in waters offshore from Moreton Island. For the experiments carried out in the shallower waters at Double Island Point large cages were used whilst, due to logistical considerations, onboard tanks were used for the experiments carried out in the deeper waters offshore from Moreton Island.

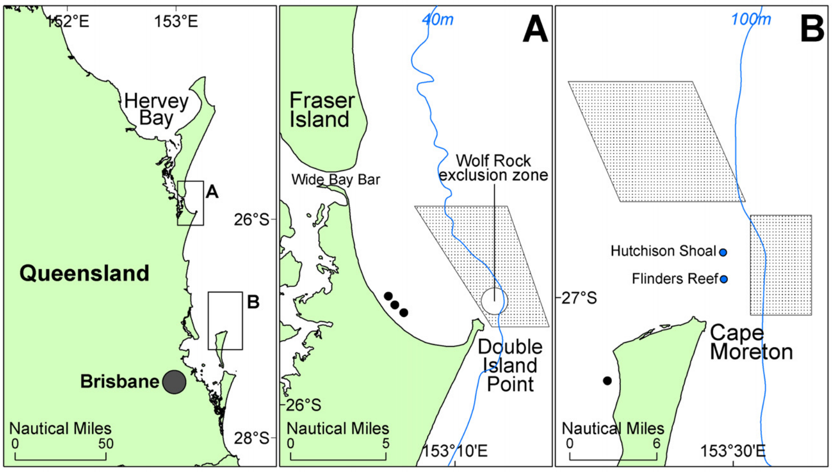


Figure 6.2.1 Location of post-release survival experiments. (A) The Double Island point area was the location for the shallow experiments; (B) The Moreton Island area was the location of the deep experiments. The black circles represent the location of the cages when used and the shaded areas represent the fishing grounds.

Double Island Point - Pearl Perch and Snapper

Post-release survival was assessed using the vertical enclosure cages or "socks" described by Brown *et al.* (2010), similar to those described by Render and Wilson (1996) (Figure 6.2.2. details Appendix 3.5)

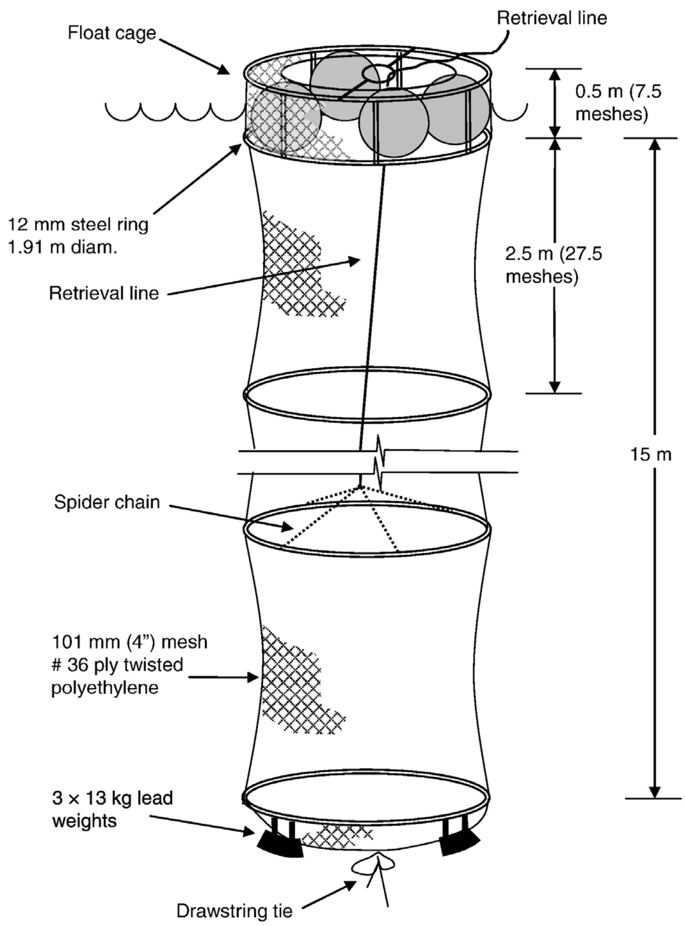


Figure 6.2.2 The vertical enclosure or "sock" used to quantify the post-release survival of *G. scapulare* and *P. auratus* at the Double Island Point site.

Pearl perch and snapper were angled from the Fisheries Research Vessel (FRV) *Tom Marshall*, a 14.5m aluminium diesel-powered catamaran, and a 5.8m aluminium centre cab, MV *Makaira.* Fish were captured using conventional recreational fishing gear (details Appendix 3.5) Once caught, relevant data were recorded including species, time of day, hook location, hooking-related injuries, capture depth and external signs of barotrauma. Pearl perch and snapper over 20cm total length were kept to ascertain post release survival. Snapper that displayed the particular barotrauma symptom of the stomach protruding into the mouth (buccal cavity) were assigned a treatment in the order they came on board and treated (or not depending on experimental protocol). Treatments were lateral venting (Florida Sea Grant 2005, Brown *et al*. 2010); "buccal" venting where their stomach was pierced to let the trapped swim bladder gasses escape; or they had no treatment and were used as controls (details Appendix 3.7). In some instances the stomach was accidently pierced with the hook point or snapper would bite down piercing the everted stomach and release the trapped swim bladder gasses. Observations of the hook point piercing the stomach were recorded as buccal vented with any observations of the fish biting down and piercing the stomach being recorded as "self" buccal vented.

Figure 6.2.3 Snapper caught in 60 metres being buccal vented

Each fish was then tagged using a numbered Hallprint™ T-bar tag and placed in a holding container supplied with flow-through seawater. Two 1.4 t polyethylene holding tanks were located on the stern deck of the *Tom Marshall*, while a modified and plumbed 110-litre insulated fish box acted as the holding tank on the *Makaira*. Approximately 45 minutes after the first fish had been placed in a holding tank, the fish caught on the *Tom Marshall* were transferred to the holding tank aboard the *Makaira* before all fish were transported to a pre-determined sock for release. Once at the sock, tag number, the time since capture (i.e. surface interval) and the release condition of each fish were recorded. This procedure was repeated until fishing ceased for the day and repeated on subsequent days. Fishing was carried out over three days, with each sock containing the catch from separate days. At the end of 3 days in captivity fish were retrieved and placed in a 1.4 t holding tank, assessed for vitality and tag numbers recorded.

Cape Moreton – Teraglin, Pearl Perch and Snapper

Given the distances of the fishing grounds from the sheltered waters required to deploy the socks, two methods were employed to hold captured fish from the Cape Moreton area. For the purposes of the deep water experiments, this sock was modified by removing the middle section so that it was five metres deep. All fishing took place aboard the *Tom Marshall* using conventional hook and line as described in detail in Appendix 3.5. Captured fish were tagged and treated to relieve barotrauma symptoms (if required by experimental protocol) before being placed in the holding tanks. Once fishing was complete each day, the fish were either left in the holding tanks for a period of 2-3 days or removed to the modified sock, depending on the weather conditions and the distance to the sock. At the completion of the experiment all surviving fish were killed by placing in chilled seawater (Rowland *et al*., 2006) for later dissection and examination in the laboratory along with those that had died during the experiment (Appendices 3.5; 3.6; 3.7).

Laboratory techniques

In the laboratory, all fish were dissected and examined to investigate organ damage as a result of capture and barotrauma. Teraglin were firstly assessed in terms of the firmness of their gut as either “soft”, “medium” or “hard”. The former was recorded when the stomach area was flaccid and this condition was always associated with a ruptured swimbladder and a lack of air in the gut cavity. A “hard” stomach was recorded when the gut was well distended from its normal position and a force of approximately 1 kg applied to it failed to distort the gut more than 1 cm. “Medium” was anything between these two extremes. Upon dissection the sex, gonad stage and a subjective gut fullness index (empty to full) were recorded. Internal organs, particularly the liver, pancreas, gut and swimbladder were then examined and any abnormality recorded. In the case of swimbladder this involved measuring the maximum size (±2 mm) of the rupture(s) using vernier callipers. The position of the rupture(s) was recorded in terms of relative position along the length of the swimbladder. Haemorrhaging was also recorded. Male teraglin are known to "croak" with the aid of sonific muscles and this characteristic was used in the field to discern males from females (and non-croaking males). Upon dissection of fish in the laboratory and relating the sex of fish back to field observations of noise production it was observed that a significant proportion of males did not make any sound on being landed and thus sex discrimination in the field was incompletely determined.

Pearl perch and snapper were assessed in a slightly different manner. Before dissection, each fish was immersed in water and air was injected into the gut cavity, via a small-bore hypodermic needle, to provide information regarding the likely escape route of swim bladder gases during capture. Fish were then dissected carefully, in order to ensure the swim bladder remained intact. The swim bladder was examined and the presence/absence of a perforation was recorded, as was the size, shape, any signs of healing and the location of the perforation, as a distance from the anterior edge of the swim bladder as a percentage of its length. If no perforations were located, the swim bladder was injected with air, via the small-bored hypodermic needle to assess whether the swim bladder had healed and to detect the location of any perforation not located by the first inspection. In addition and to investigate the consequences of buccal venting the stomachs of snapper were examined for holes, any signs of healing or infection and if they had returned to a normal position. If the stomach appeared to be healed it was dissected out and pressurised with a syringe to test if healing had occurred (Appendices 3.5; 3.6 and 3.7).

Fishery observations - Teraglin

Teraglin examined in these trials were predominantly sampled in offshore waters adjacent to the Gold Coast and Stradbroke Island. All fish were caught from line fishing vessels (5 -14m in length) including recreational and charter vessels using rod and reel and a range of different gear types in terms of line thickness, hook and sinker sizes. There was no experimental control over the gear type used by these fishers and the skill level of anglers varied dramatically, particularly those fishing on board charter vessels. Depth of capture ranged from 20m to 100m but most fishing was restricted to reefs corresponding to areas known commonly as 24 fathom, 36 fathom and 42 fathom reefs. For analyses, depths have been grouped into three depth ranges: 30 to 49m (shallow) 50 to 79m (medium) and 80 to 109m (deep) corresponding to the commonly known depth stratified fishing areas recognised by fishers. When teraglin were caught they were released using one of a number of techniques. These were either released without further treatment, laterally vented using a hypodermic syringe, released with the aid of a release capsule, had their abdomens massaged to presumably burst the swimbladder and release gases or they were launched head first into the water to force them from the surface.

(a) (b)

Figure 6.2.4 (a) Photo of the release capsule used to release teraglin (snapper in the photo) and other rocky reef fish in field trials conducted in southern Queensland. (b) Snapper swimming out of capsule at depth.

When accompanying recreational and charter fishers, all fish caught were broadly assessed for barotrauma symptoms using the same system as used in the controlled experiments. The total length of each fish was measured to the nearest centimetre. Fish studied were within the size range of 33 to 79cm although the majority observed and/or dissected were undersized (33 – 38cm).

The apparatus used for "capsule release" was a bell-shaped device made from soft nylon trawl-mesh, formed around an upper (30cm in diameter) and a lower steel hoop (45 cm square hoop) (see Figure 6.2.4). When a fish was released and was seen to float on the surface the device was placed over the fish which was then lowered to an appropriate depth with an attached line, whereupon the fish - with its swim bladder re-compressed – was presumably able to swim free. This sort of device has been described in the literature (e.g. see Bruesewitz *et al*. 1993), but there is little evidence of its having been used directly for barotrauma relief (except in Western Australia) rather than as a control against which the effectiveness of other methods such as venting could be assessed.

Post-release survival was assessed using generalised linear modelling (GLM) via a binomial distribution with a logit link function, where vitality – a binomial variable with 0 = dead and 1 = alive – was the response variable. Water depth and fish length were transformed from continuous variables into categorical variables, with depths and size transformed into different categorical factors depending on species (see Appendices 3.5, 3.6 and 3.7 for details). The effects of several qualitative factors on survival were also tested including: signs of barotrauma present (none, exophthalmia, swollen gut cavity, everted stomach); the presence of bleeding (none, light, heavy); hook location (lip, mouth, throat, gut, outside mouth); holding facility (sock, modified sock, holding tank); and the presence of any injuries (none, eye, gill, jaw, moderate scale loss and heavy scale loss). Experiment number (1–6) was also added to the model in order to assess the spatial and temporal variability in post-release survival across all experiments. The final model was determined using the "rsearch" function in Genstat (2011), whereby the initial model contained all factors, some of which were removed via backwards elimination until an appropriate model is found based on the adjusted correlation coefficient (adjusted R^2). The final model, therefore, consisted of depth, size and any other factor found to have had a significant effect on post-release survival.

Three further GLMs were used to determine the effects of the aforementioned factors on the size of swim bladder perforations, signs of healing of these perforations and the presence of barotrauma symptoms. The first GLM tested the effects of relevant factors on perforation size in millimetres via a normal distribution with an identity link function while the second GLM tested the effects of relevant factors on the presence of healing of swim bladder perforations – a binomial variable with 0 = no healing present and 1 = healing present – via a binomial distribution with a logit link function. The third GLM tested the effect of relevant factors on the presence of barotrauma symptoms – a binomial variable with 0 = no barotrauma symptoms and 1 = barotrauma symptoms present – via a binomial distribution with a logit link function. Again, the "rsearch" function in Genstat (2011) and backwards elimination were used to identify the most appropriate model. Full details can be found in Appendices 3.5, 3.6 and 3.7.

Long term survival

In addition to the short term experiments we investigated long term survival using the large tag-and-release SunTag dataset to shed light on factors influencing the relative survival of recreationally-caught snapper and pearl perch in Queensland. The database is administered by InfoFish P/L, whose principal, Mr W Sawynok, made the relevant data available to this Project in February 2012.

A mixed-model analysis was used to determine whether initial capture depth and/or body size had an appreciable effect on the probability of the fishes being recaptured. As it is possible that angler behaviour and experience may influence the survival rate of the captured fish, we used a generalised linear mixed-model (GLMM) analysis (Schall 1991) in GenStat 14 (2011). Recapture was a binary score (recaptured or not recaptured), and length category and depth category the two predictor variates (factors). 'Angler' was included in the model as a random variate, because of the large number of anglers who contributed to the dataset, and (with a few outstanding exceptions) the relative sparseness of observations attributed to an individual angler.

Because the numbers of observations for both fish size (length) and initial capture depth were highly variable across the range, classification of both variates and subsequent pooling of classes was essential prior to analysis. A similar methodological approach was taken to investigate the effect of barotrauma on recapture rates. Both GLMM and GLM were used, with (initially) angler as the random variate and capture depth and fish size fixed effects, where appropriate, and barotrauma signs as the binary response variate. Full details can be found in Appendix 3.4.

6.3. Habitat of Rocky Reef Species

We approached the determination of key rocky reef species habitats from two fronts, firstly by examining the historical trawl surveys that reported fish bycatch in waters of southern Queensland, and secondly by conducting our own underwater video camera and still camera surveys of selected habitats in the region. Detailed presentation of these two aspects of the project can be found in Appendix 3.8 and 3.9 for the trawl and camera surveys respectively.

Methods - Historic Trawl Surveys

The data collected from three separate trawl surveys of bycatch in the eastern king prawn (EKP) fishery were analysed to determine soft trawlable habitat utilisation by rocky reef fish species in south-east Queensland. Two of these surveys were completed as part of the FRDC-funded project *Bycatch weight, composition and preliminary estimates of the impact of bycatch reduction devices in Queensland's trawl fishery* (Courtney *et al.*, 2007) and were conducted in deep water (>90m) and shallow water (<90m) outside Moreton Bay. The third survey was designed to improve the understanding of the distribution and abundance of Sygnathids (seahorses, seadragons, pipefish and pipehorses) – hereafter referred to as "the Sygnathid survey" (Dodt, 2005). Although these surveys were not designed to measure the abundance of rocky reef fish they provide information regarding the distribution of fish species, particularly juveniles of demersal species that inhabit soft substrate during part of their lifecycle.

Shallow water EKP Survey

A commercial trawler, which towed triple-gear (three nets) as commonly used in the EKP fishery was chartered for 10 nights in October 2001. Only catches from the two outside nets were analysed. The nets had headline lengths of 12.8m (7 fathoms) and a mesh size of 50.8 mm (2 inch). Mesh size in the codends was 45mm. 59 trawl shots were undertaken resulting in samples being obtained from 118 individual net trawls. Trawl length was approximately 53 minutes, at 2.4knots. On completion of each trawl, the bycatch from each net was placed into baskets and weighed, before being placed into storage boxes in the vessel's freezer. In the laboratory, bycatch species were identified to species level, counted and weighed. The length of a maximum of 20 randomly-selected individuals of each species was also recorded.

Deep water EKP Survey

Sample collection and laboratory protocols for the deepwater survey were similar to those for the shallow water survey described above. However, this survey tested the effects of a square mesh codend in the deepwater EKP fishery in July 2002. As is standard in the deepwater trawl fishery, larger nets were used in the survey (22m headline length as opposed to the 12.8m headline length used in the shallow water survey). Again, three nets were used, with catches from the outside nets analysed. Mesh size was 50.8mm in the body of the net and 47mm in the codend. This survey resulted in 65 shots and 130 samples of bycatch.

Sygnathid survey

The Sygnathid survey was conducted in 2005 using standard commercial trawling gear (Dodt, 2005). Trawl shots were only one nautical mile in length and approximately 27 minutes duration. Net configuration was the same as that used in the shallow water EKP survey. As both outside nets were identical, catches were pooled and overall catch rate per shot were analysed. Bycatch catches were converted to catch rates using the methods described above.

For all surveys the data presented in the results are the standardised catch of each species converted to numbers as well as weight in grams per unit of trawled area (hectare).

Methods - Camera surveys

The two surveys used to assess habitat utilization of the rocky reef species will be hereafter referred to as the "BRUVS survey" and the "BRUCS survey". The former used Baited Remote Underwater Video Stations (BRUVS) with video cameras facing across the sea floor. The Baited Remote Underwater Camera Stations (BRUCS) survey used multiple still images collected using vertically facing still cameras.

BRUVS Survey – Sunshine Coast

Baited Remote Underwater Video Stations (BRUVS) were used in an area of continental shelf adjacent to the Sunshine Coast, Queensland, between 29 and 75 m depth (Figure 6.3.1). This study area was selected because it supports populations of commercially and recreationally important line fishing species and previous trawl surveys have sampled juvenile pearl perch, teraglin and snapper in these areas. Sampling was conducted from a 14.5 m Fisheries Research Vessel *Tom Marshall* in late autumn/early winter (May – July 2011) to take advantage of high underwater visibility that is a result of the typically low levels of phytoplankton at that time of year. Three habitat types were sampled, categorized broadly as sand, gravel, rocky reef (Figure 6.3.2) with an additional "kelp" habitat defined after analysis of the videos showed that this habitat was sampled. This particular area of Queensland's continental shelf supports many types of vegetated and biogenic benthic habitat, however the choice of these three broad habitat types enabled the representation of a rough gradient of complexity with sand being the simplest habitat, followed by gravel and finally rocky reef as the most structurally complex habitat. Shallow samples were those taken from 29 – 51 m depth, and deep samples were from 52 – 75 m depth.

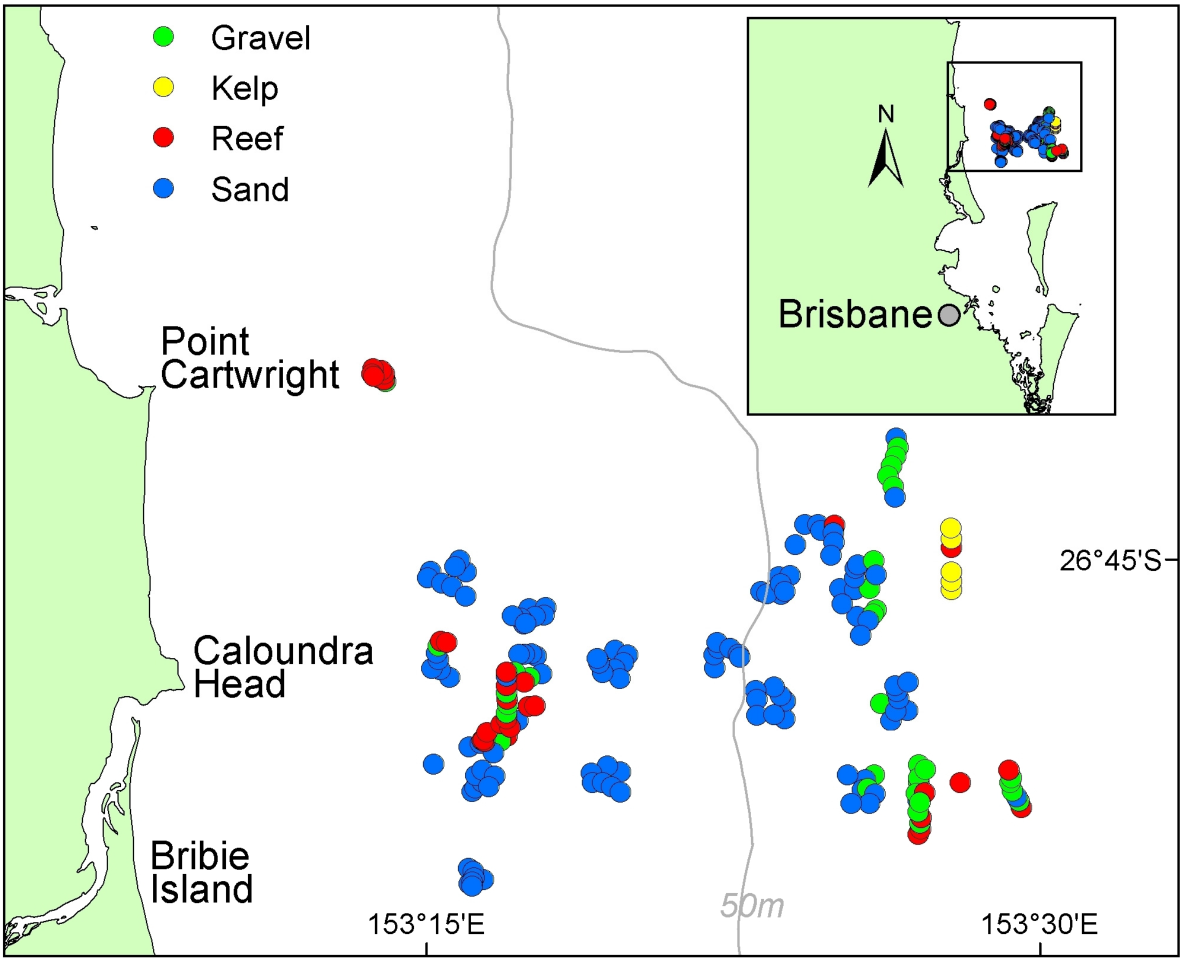
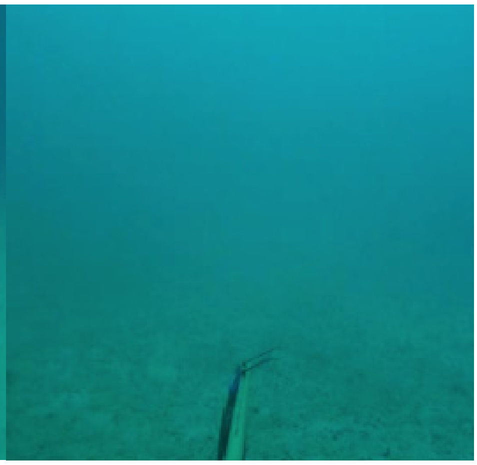


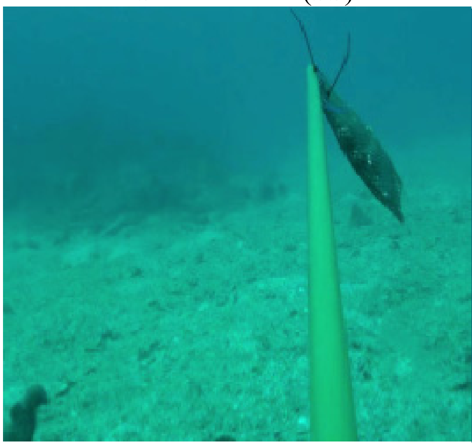
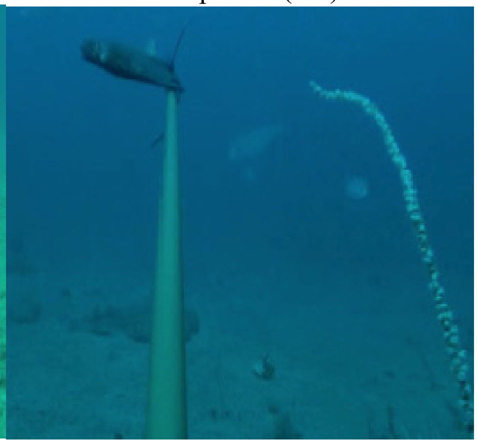
Figure 6.3.1 The location of the 185 BRUVS deployments. The 50 m depth contour is shown offshore from the coast. Deep samples were taken offshore from this contour and shallow samples taken closer to the coast. Colours represent the different habitat types.

Eight BRUVS were used in the study, each comprised of a single Sony HDR-CX100E digital video camera with (x0.6) wide-angle lens in a custom built PVC underwater housing, attached to a trestle-shaped frame that rested on the substrate when deployed (Figure 6.3.3). A semi-rigid bait arm of electrical conduit held a plastic mesh bag containing approximately 1 kg of crushed pilchards (*Sardinops neopilchardus*) 1.5 m in front of the camera lens

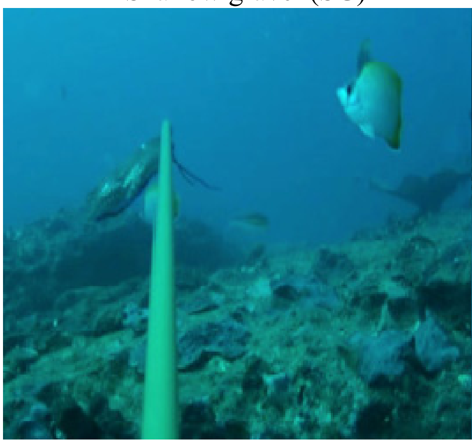
Videos were analysed using Event Measure ™ software. Due to inaccuracies in topographic maps and the inability of the seabed classification system to determine exact habitat type, some habitat types were under-represented and a balanced experimental design was not achieved. Of 187 video samples used in the final analysis: 69 were shallow sand, 8 shallow gravel, 24 shallow rocky reef, 47 deep sand, 25 deep gravel, 9 deep rocky reef and 5 deep kelp. The relative abundance of fish species in a single sample (1 hr video) was estimated by MaxN, the maximum number of individuals of that species seen together in any one frame on the entire tape (Cappo 2007). MaxN is a useful and conservative index of relative abundance, as it removes the possibility of repeatedly counting individuals that leave and re-enter the field of view.

Shallow sand (SS) Deep sand (DS)

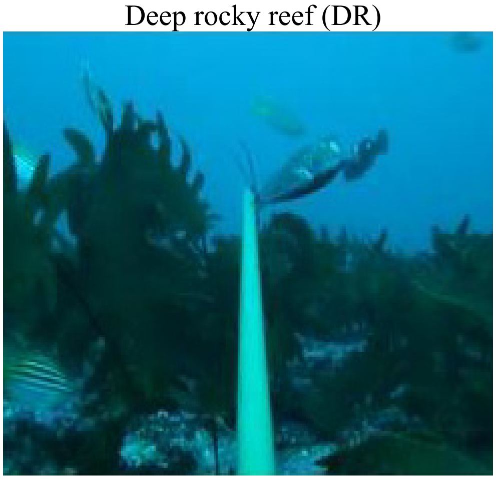



Shallow gravel (SG) Deep gravel (DG)




Shallow rocky reef (SR) Deep rocky reef (DR)

Figure 6.3.2 Representative photographs of the seven different depth/habitat sample groups. (Still shots extracted from videos using Event Measure™. NB quality of image was far higher in videos).



Deep kelp (DK)

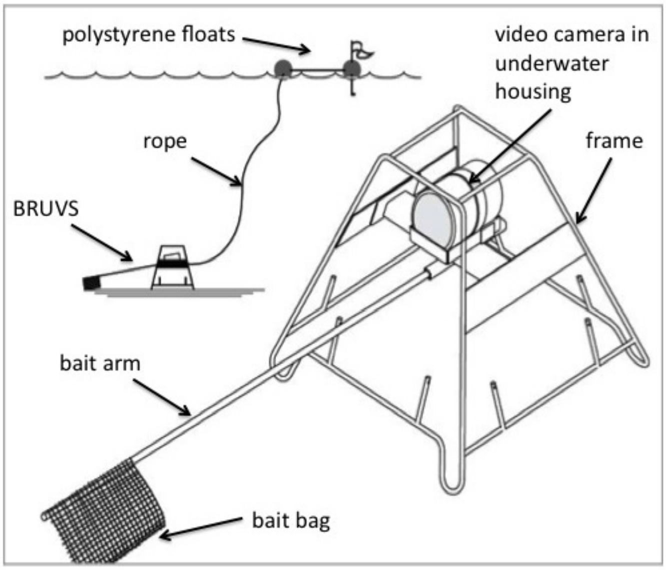


Figure 6.3.3 Baited Remote Underwater Video Station (BRUVS) (modified after Stowar *et al*., 2008), showing position on the sea floor and details of the bait arm and bag, camera housing and frame.

Raw abundance data for each habitat and depth range were plotted for six fish species (*Pagrus auratus, Glaucosoma scapulare, Choerodon venustus*, *Saurida undosquamis, Atractoscion aequidens, Pentapodus paradiseus* and *Nemipterus theodorei*). These data were analysed using binomial and gamma mixed model generalized linear models with logit of MaxN as the dependent variable and depth and habitat type as factors.

BRUCS Survey – Moreton Island and Stradbroke Island

The two 'areas of interest' chosen were located in two broad near-shore oceanic areas outside Moreton Bay (i) east of South Passage and (ii) east of Jumpinpin (Figure 6.3.4). These were selected because of reasonably closely situated Marine National Park, Conservation Park, Habitat Protection and General Use zones, and un-zoned areas, which overlapped to some extent and also the areas represented habitat that supported crab populations. No specific rocky reef habitats were sampled as the main focus of the research was sampling of sand habitats that were likely to contain crabs. In addition, the use of gear set on a bottom trotline would have snagged on any bottom structures. Despite this both sand and gravel areas were sampled as were a range of different vegetation types.

The cameras used in these surveys were still image cameras facing vertically downwards and mounted on a frame 1.6m above the seafloor but their utility was limited by the fact that the images were "still" images collected using a vertically facing still camera. Such a system made the accurate identification of some fish species difficult due to both the movement of the fish causing blurred images, as well as the inherent difficulty in identifying fish from a dorsal rather than lateral aspect. Sampling at each survey site consisted of deploying 10 pieces of apparatus (typically 4 pots, 4 dillies and 2 camera frames (BRUCS) clipped in random order onto a trotline at 50 m intervals. The BRUCS were programmed to shoot one frame each minute, with a total set time of an hour (typically 60 frames). Crushed pilchards (*Sardinops neopilchardus*) were also used as bait (usually 3 pilchards per bait bag) for each apparatus.

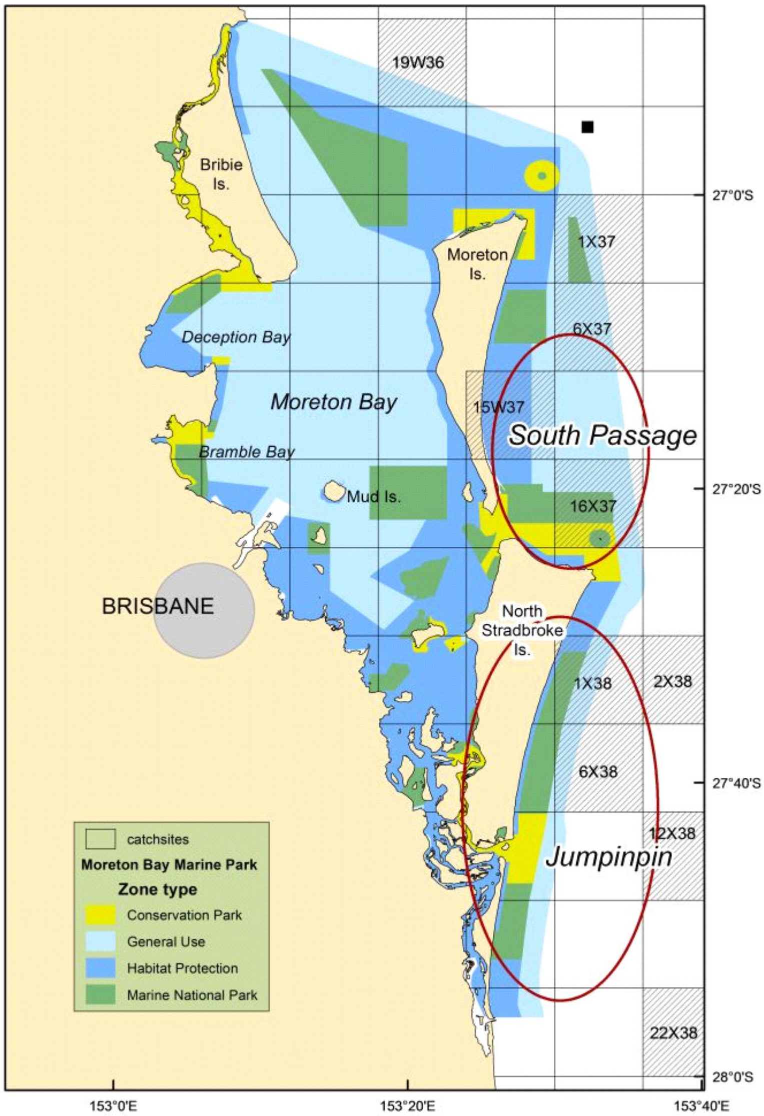


Figure 6.3.4 The two sampling areas (South Passage and Jumpinpin), showing the new MBMP zoning and AMU spanner crab survey 6x6 min sub-grids (labelled squares). Green zones are closed to all forms of fishing. Yellow zones are recreational line fishing zones, while light green and blue zones are open to line fishing.

6.4 Development of Harvest Strategies for Rocky Reef Fisheries

The catch of a fishery is often an important parameter in many fishery assessments and a critical data requirement in most harvest strategies. Species landed in the rocky reef fishery are accessed by three sectors (commercial, recreational and charter) complicating the accurate and precise estimation of catch and effort due to different reporting requirements for each sector and the general lack of a consistent long term series of precise catch estimates for the recreational sector. This section of the report assesses the catch and other fisheries information available from each of the fishing sectors and discusses the development of appropriate harvest strategies for the three main target rocky reef species. Detailed analyses and discussion of these data are presented in Appendices 3.10 to 3.12.

We firstly assess the logbook data provided by the commercial and charter sectors. The various recreational surveys are then presented prior to a final discussion of a subset of data obtained from a sample of the Gold Coast charter sector (known as the Australian Marine Life institute Data (AMLI data)) which has been used in recent stock assessments of the snapper fishery.

Historically, pearl perch *Glaucosoma scapulare* and teraglin *Atractoscion aequidens* were secondary targets for offshore line fishers in south-east Queensland, with snapper *Pagrus auratus* the most commonly caught reef-associated species. However, a decline in catch rates of snapper, combined with decreasing bag limits for charter fishers, has seen pearl perch and teraglin catches increasing in the last decade.

Methods - Compulsory Commercial and Charter Catch and Effort Data

To obtain indices of abundance, commercial and charter catch rates derived from compulsory logbooks were standardised using generalised linear mixed models incorporating both random and fixed terms. The catch rate standardisation quantified variation in catch rates according to a number of spatial and temporal terms. Linear mixed models were used to adjust the catch rates of pearl perch and teraglin from the commercial and charter sectors, each containing both random and fixed terms. In each model, the response variable was the catch per vessel in kilograms per day in the log scale. The fixed terms included year, month and the spatial component, CFISH Grid. In order to minimise variation in catch rates according to CFISH Grid, those grids with less than 20 days of effort over the period where logbooks were in operation were excluded from the analysis.

Restricted Maximum Likelihood (REML) analyses were performed using Genstat (2008) statistical software. Year and Month were included in all models, as adjusted means were required for these factors, while CFISH grid was also included in each model. Individual terms were included according to their effect on the deviance term generated by the REML procedure in Genstat (2008), an approximation of the Akaike Information Criteria (AIC). Corresponding snapper catch was omitted from the model if the REML calculated a positive parameter estimate for this term (David Mayer, personal communication). The lunar covariates were omitted if their effect on catch rates were not statistically significant (i.e. $P > 0.1$).

Methods - Recreational Catch and Effort Information

<u>Information prior to 1990</u>

Apart from reports of snapper catches made by early naturalists (Welsby), historical catch data for the Rocky Reef Finfish Fishery (RRFFF) have not been collated until the establishment of the Queensland Fish Board (QFB) in the 1930's.

The QFB maintained catch records between 1936 and 1981. Recreational fishers were also able to market fish through the Fish Board up until the late 1980's and there is uncertainty about the proportion of the commercial catch that was sold through the Fish Board, since in some areas many commercial fishers directly marketed their catch outside the Fish Board. There are no Fish Board records of teraglin, although it is likely that teraglin were included in the generic category of Jew, which was predominantly mulloway. Given the similarity in current catch trends of snapper and pearl perch over recent years it would seem reasonable to assume that catches of pearl perch mirrored those of snapper. However we would advise caution as pearl perch are generally found further offshore than snapper and thus their fishery may have been more likely to develop later than snapper.

Fish Board records are used extensively as an index of change in catch over time for a number of species for which quantitative stock assessments are used. While there may be some issues surrounding the use of these data as an index of commercial catches for the reasons previously stated, they have proven to be a good index for some species. In the case of barramundi, good correlation has been obtained between environmental flows and Fish Board records of catch, suggesting the utility of the data for that species at least (Halliday and Robins, 2007). Of the three rocky reef species being studied in this report only snapper is reported consistently in fish board records and as such we were unable to readily find any historical recreational catch data for either teraglin or pearl perch prior to the 1990's.

<u>Research surveys after 1990</u>

Recreational catch information has also been gathered by a number of on-site research surveys but only two have provided information on the rocky reef species being discussed here. These surveys and their results are described in detail in Ferrell and Sumpton (1997) and Sumpton (2000) and in Appendix 3.11. They were both random stratified catch (and catch rate) surveys of recreational boat anglers returning to seven different access points (boat ramps) during daylight hours from Tweed Heads to Mooloolaba over a 12 month period during 1994/1995 and also 1999. Effort information was assessed using aerial surveillance during the first survey but no overall effort estimates were obtained during the later survey.

RFISH program surveys (Diary and phone Surveys:- 1996/7, 1998/9, 2001/2 and 2004/5)

State-wide surveys of recreational anglers using telephone surveys to estimate participation followed by a year long diary program to estimate recreational catches have been conducted at regular intervals in Queensland. Telephone surveys have been conducted in 1996, 1998, 2001 and 2004, with diary programs conducted the following year with the co-operation of a sample of anglers identified from the phone surveys. Generally, more than 4500 angler volunteers have contributed to each of these surveys but many discontinued their diaries throughout the survey year.

National recreational surveys (Diary and phone surveys:- 2000 and 2010)

There have been a further two recreational fishing surveys, using methodologies similar to the RFISH surveys described above, but with greater contact with diary participant in order to reduce recall bias and increase accuracy of reported catch information. The first survey was in 2000 as part of a wider national survey while the most recent survey used identical methods. The main difference between these two surveys and the other RFISH surveys was the greater contact maintained with fishers

RFISH program (Bus route survey of Moreton region:- 2007/08)

Readers are referred to Webley *et al.* (2009) for a complete discussion of this survey and its methodology although it is based on standard and well established techniques that are applied widely throughout the world to assess recreational fisheries. It is important to note that this survey was designed to collect information from vessels that left from, and returned to, boat ramps in southern Queensland during daylight hours only. In addition, it did not collect any catch or effort information from vessels that were moored at private jetties or marina berths. In southern Queensland effort from this part of the fishery most likely contributes a significant (but unknown) proportion of the total fishing effort. Likewise, no information was collected from fishers returning from their fishing trips during night time hours. Once again, these fishers can contribute a significant (but again unknown) proportion of the effort on rocky reef species. This limitation is applicable to all the historical research surveys that have used onsite methods to estimate rocky reef fish catch rates as none have been able to address either the night-time or fishing “platform” issues identified above. There have been attempts to assess the night time catches but logistic and safety constraints precluded their completion (Ferrell and Sumpton 1997). It is clear that any estimate of total catch or effort from this survey would clearly underestimate the total catch of many species fished in the area.

Catch rates obtained from surveys conducted at different times over the life of a fishery can provide valuable information on the relative abundance of a particular species providing all features contributing to changes in the fishery can be factored into the analysis. In this regard it is important to factor in both the impact of management as well as standardising for changes due to technology and other factors.

Methods - Gold Coast Charter Fishery - Australian Marine Life Institute (AMLI) data

As part of an ongoing independent fisheries monitoring program, the Australian Marine Life Institute (AMLI) have been collecting fish catch, effort and environmental data from a sample of the Gold Coast charter boat fleet since 1993. This normally involved an observer (usually Mr Ray Joyce) checking and measuring the catch of line fishing charter vessels at the wharf after the completion of each fishing trip. Information on fishing activities including number of anglers on board, fishing time, bait and fishing location were recorded as well as a range of environmental data including water temperature, current speed and direction, wind speed and sea conditions on the fishing grounds.

The collection of this observer-based fisheries data on a daily basis coupled with the recording of abiotic information enabled an assessment of the factors affecting rocky reef species catches by way of a Conditional General Linear Model (CGLM). To account for the inflated numbers of zeros in the catch two-part generalised linear models were fitted using GenStat v11.1. A binomial generalised linear model with the logit link (McCullagh and Nelder 1989) was used to model the proportion of zeros and the gamma distribution, with the log link, was used to model the non-zero catch. The final model terms for all species were:- year + location + month + depth + current speed + sea-conditions + day/night.

For both species we conducted simple yield per recruit analysis based ojn growth parameters derived from our research and empirical estimates of natural mortality. Changes in yield were estimated for a range of natural mortalities and minimum legal sizes. Mean weights at age were those derived from the von Bertalanffy growth curves and standard length-weight regressions.

7. RESULTS/DISCUSSION

7.1 Biological and Fisheries Parameters of Key Rocky Reef Species

A total of 14,348 pearl perch and 7,966 teraglin were measured by Fisheries Queensland Assessment and Monitoring Unit (AMU) in the period 2006 to 2012. Pearl perch length frequency distributions from all sectors are skewed heavily (Figure7.1.1a), with most fish caught from all sectors being between the MLS of 35cm to 50cm TL. In all sectors, proportionally few fish > 55cm TL are caught, although the commercial sector catch more larger fish than the other two sectors. A similar trend is observed in the teraglin catch (Figure 7.1.1b), with the commercial sector catching proportionally more large fish (>50cm TL).

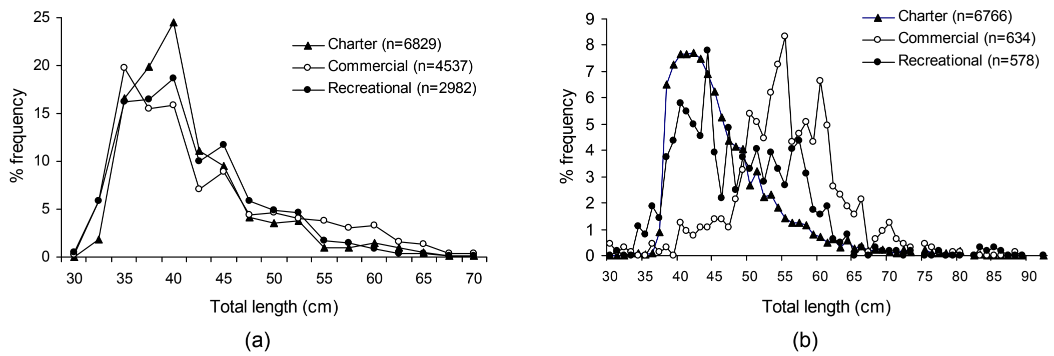


Figure 7.1.1 Catch length frequencies of a) pearl perch and b) teraglin caught by commercial, recreational and charter fishers for all sampling regions and years between 2006 and 2011 as part of the Assessment and Monitoring unit's fishery-dependent sampling of the Queensland Rocky Reef Finfish Fishery.

In areas where fishing has traditionally occurred, such as those offshore from the Gold Coast, Sunshine Coast and Brisbane, the size of pearl perch caught is generally less than 50cm TL in all sectors (Figure 7.1.2). Larger fish (>50cm) were more common in the more northern regions (Fraser Offshore and Rockhampton Offshore).

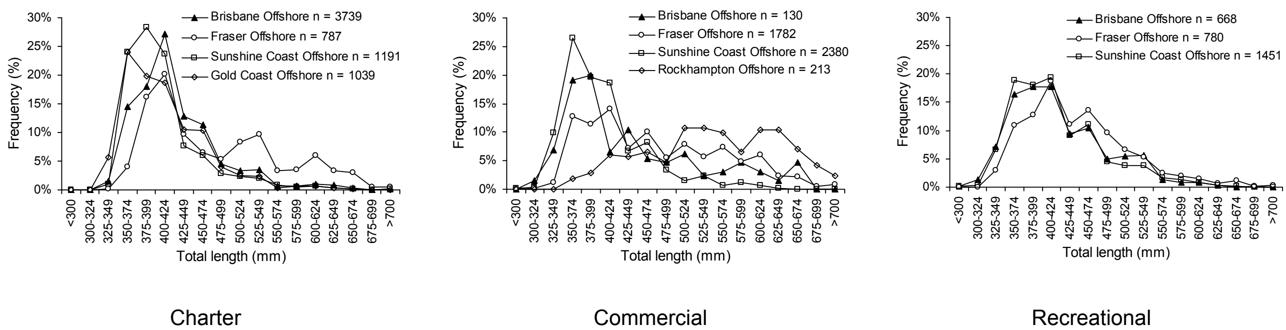


Figure 7.1.2 Pearl perch length frequency distributions by sector and AMU sampling region for the period January 2007 to December 2011. Note: those regions with n < 100 were excluded.

Regional teraglin size structures were strongly influenced by the catch from each sector, with the Gold Coast catch dominated by just-legal fish targeted by charter vessel (Figure 7.1.3a and Figure 7.1.3b). The teraglin catches from the remaining AMU sampling regions were dominated by both commercial and recreational catches, resulting in a higher proportion of larger fish. The teraglin length frequency distribution of the Gold Coast charter fishery demonstrate a strong depth-related size stratification of the catch with larger individuals being taken in deeper water further offshore (Figure 7.1.3c).

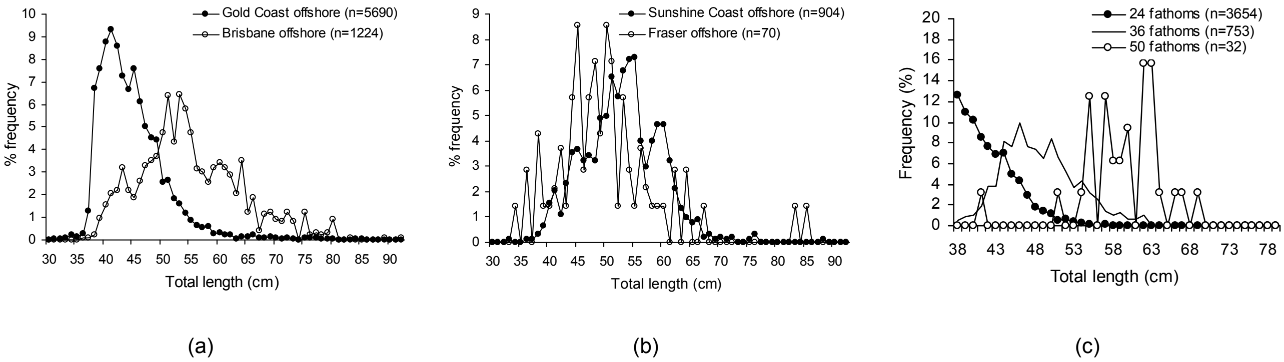


Figure 7.1.3 Teraglin length frequency distributions as a function of AMU sampling region (a and b); and c) depth from the Gold Coast charter fishery.

Size at 50% maturity (L_{50}) in female *G. scapulare* was found to be in the 25-27.5cm size class and all female *G. scapulare* were mature in the size class 42.5 – 44.9cm. No females were mature in any size class less than 22.4cm (Figure 7.1.4a). 99.99% of female *G. scapulare* mature at the MLS of 35cm. Pearl perch GSI was highest in April, averaging 1.70% (s.e. = 0.28), and lowest in the winter months, although sample sizes were low in the months January to April. GSI was lowest in August (0.31%; s.e. = 0.03), before increasing through spring Figure 7.1.4b).

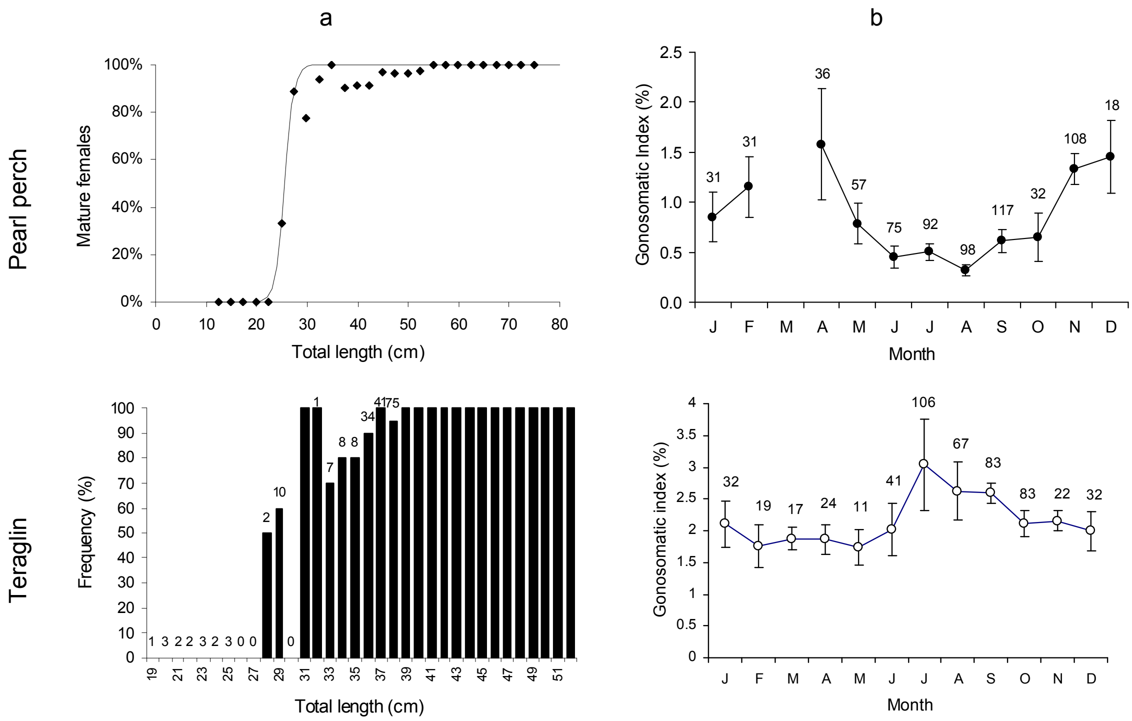


Figure 7.1.4 (a) Percent frequency occurrence of mature (stages 2-5) female pearl perch and teraglin as a function of total length (mm); and (b) Mean monthly gonosomatic indices for female pearl perch and teraglin sampled from January 2009 to December 2010.

All teraglin greater than 38cm TL were classified as mature. However, the L_{50} was imprecisely defined due to the sampling of low numbers of fish smaller than 34cm (Figure 7.1.4a). GSI in teraglin were found to have peaked in July (Figure 7.1.4b), although these data show few statistically significant differences among the monthly means. Immature (Stage I) and undeveloped/resting (Stage II) pearl perch ovaries were more likely to occur in the winter months (Figure 7.1.5a), while spawning fish (Stage V) were only observed in November and December. A high proportion of pre-spawning (Stage IV) ovaries were present during February, suggesting that there may be two spawning periods, although sample sizes were low during the early part of the year. Apart from August, pre-spawning (Stage IV) ovaries were present in samples collected year-round. In teraglin, pre-spawning (Stage IV) ovaries were present year-round (Figure 7.1.5b), with no spawning (Stage V) fish caught during the period March – July.

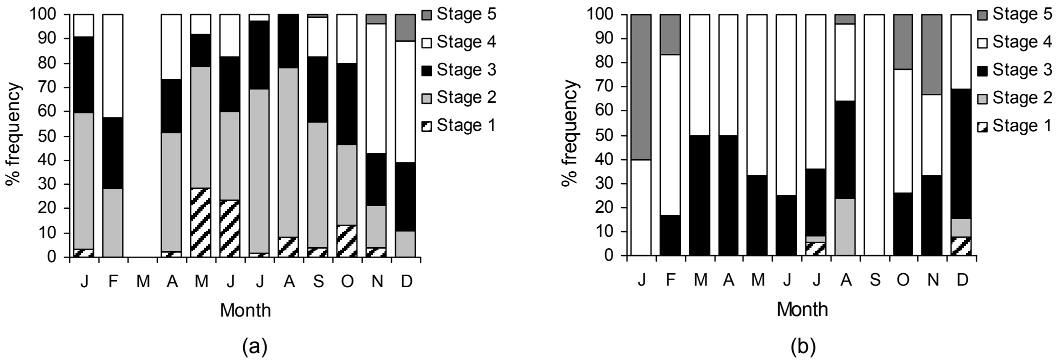


Figure 7.1.5 Percent frequency of occurrence of gonad stage for pearl perch (a) and teraglin (b) from 2009 and 2010.

From the combined age-length data from 2009 and 2010 (Figure 7.1.6a), pearl perch are between 3 and 7 years old at the MLS of 35cm TL. The von Bertalanffy growth parameters were found to be L_∞ = 706.8mm, k = 0.156yr^{-1} and t_0 = -0.502yr for 1118 pearl perch sampled during 2009 and 2010. The oldest animal sampled was 22 years old, with 108 (9.6%) older than 10 years old. Wide edges were present in all months (Figure 7.1.6a), as were new edges. The oldest teraglin sampled were likely over 15 years old, whilst some two year old fish had recruited to the fishery. Growth of teraglin was best described by the von Bertalanffy growth parameters k = 0.343, L_∞ = 626mm, t_0 = -0.877 (Figure 7.1.6b). A high proportion teraglin exhibited new bands during the summer and early autumn (Figure 7.1.7b).

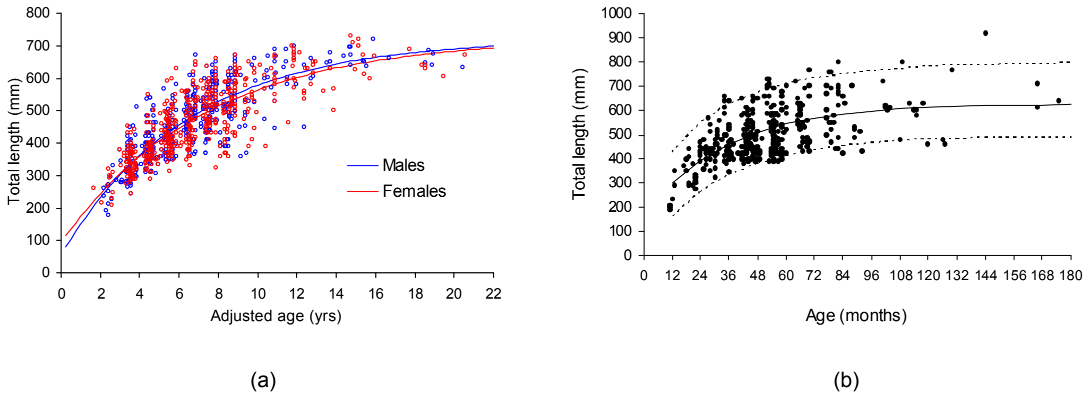
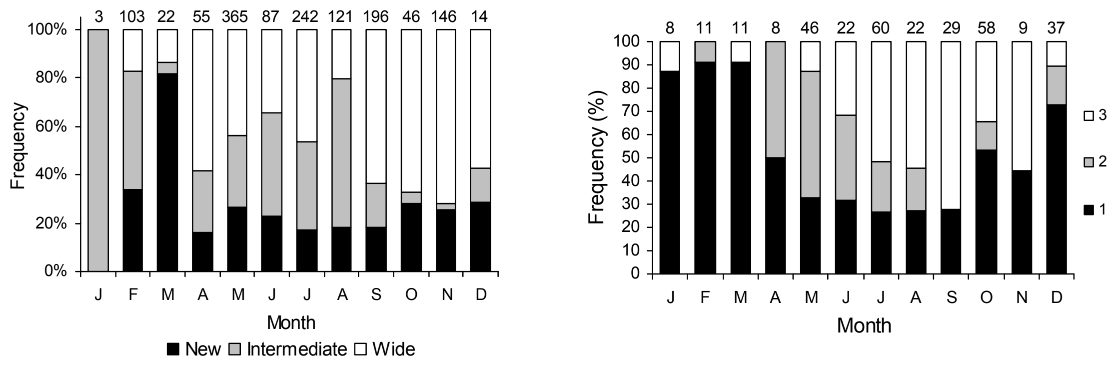


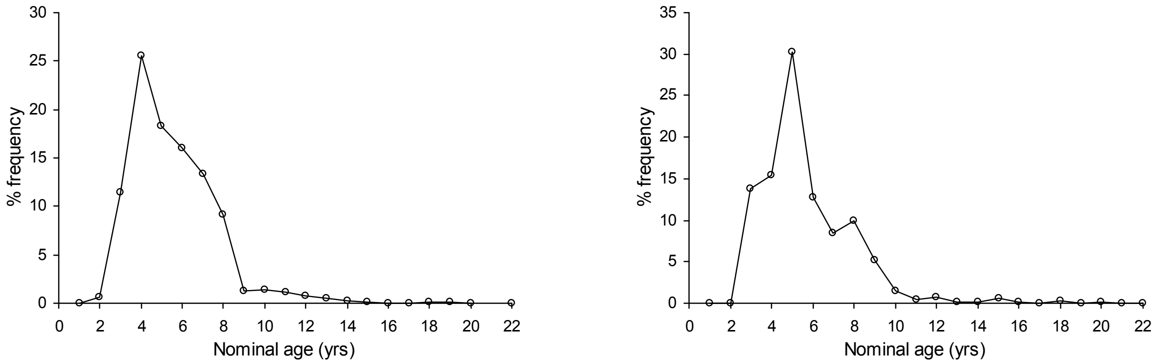
Figure 7.1.6 von Bertalanffy growth curves for a) pearl perch and b) teraglin sampled by AMU during 2009 and 2010.



(a) (b)

Figure 7.1.7 Temporal change in otolith edge rating for a) pearl perch and b) teraglin base on samples collected by AMU during 2009 and 2010.

The length composition of pearl perch caught by commercial, recreational and charter fishers indicated that age frequency distributions of pearl perch were truncated, with 3 – 9 year old fish accounting for 94.9% and 95.9% of all fish caught in 2009 and 2010, respectively (Figure 7.1.8). Pearl perch were fully-recruited to the fishery at age 5 in 2009 and age 6 in 2010. Total mortality estimates ranged from 0.49 to 0.59, depending on the first fully-recruited size class and the maximum age included in the regression. Estimates of natural mortality ranged from $M = 0.2$ to $M = 0.22$



(a) (b)

Figure 7.1.8 Pearl perch age structures for the years a) 2009 and b) 2010 across all sectors and AMU regions.

Examples of teraglin age structures of the sampled commercial, recreational and charter catches are shown in Figure 7.1.9. These show that catch is generally dominated by smaller and younger fish between 2 and 5 years old. The commercial sector had a higher proportion of older fish reflecting the obvious selectivity for larger fish. The first fully recruited age class to the fishery was the 4th year class. Based on fish aged four being the first fully recruited age class to the fishery estimates of total mortality ranged from 0.52 for the commercial fishery up to 1.02 for the charter sector with the recreational estimates being closer to those of the charter sector.

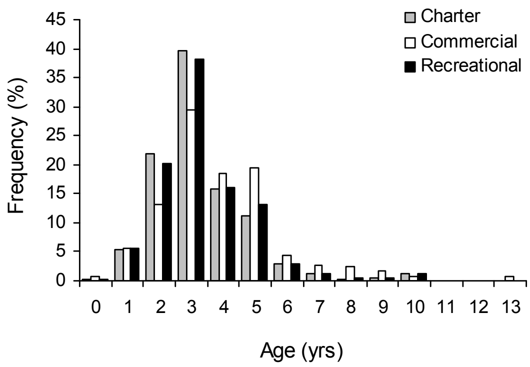


Figure 7.1.9 Unweighted age structures of teraglin derived from the catch of charter, commercial and recreational fishers using an age length key constructed from all age and length data collected during 2009 and 2010.

Commercial logbook data indicated that cobia, grass emperor, amberjack and yellowtail kingfish are important rocky reef species landed by the three sectors accessing the fishery. Table 7.1.1 summarises important biological information for the incidental rocky reef species. Cobia are reportedly a very fast growing species, growing to a metre in length within 3 years. Cobia have been found to have a length-at-maturity (L_{50}) of 783mm FL, close to the current Queensland MLS of 85cm TL. GSI is highest in October/November, with spawning occurring between September and June.

Grass emperor are serial spawners during January and February and grow to approximately 60cm. In recent years, the catch of grass emperor has increased as a proportion of total catch in the commercial sector, representing approximately 13% of total catch by weight.

Table 7.1.1 Summary of von Bertalanffy growth parameters (L_∞ and k), length-at-maturity (L_{50}) and fishing mortality (F) as a proportion of the instantaneous rate of natural mortality (M) published in the scientific literature for the incidental RRFF species. Refer to text for source of data.

Species	L_∞ (mm) FL	k (yr^{-1})	L_{50} (mm) FL	F/M ratio
Samsonfish	♂ 1,139; ♀1,279	♂0.240; ♀0.188	831 FL; 888 TL	0.31
Amberjack	♂ 1,746; ♀1,351	♂ 0.19; ♀ 0.22	705 – 1071	0.37
Yellowtail kingfish	1,840	0.054	834	2.58 – 5.60
Mahi mahi	1,289	1.27	457	1.22
Grass emperor	592	0.23	226	0.95-1.71
Frypan bream	524	0.224	372	0.69
Cobia	♂ 1,162; ♀ 1,243	♂ 0.53; ♀ 0.47	783 FL	1.43

Amberjack are the largest member of the family Carangidae and are found throughout the world, with L_∞ estimated at greater than 1.3m for females. GSI was highest in the spring months. One study also found that all fish older than 9 years were female.

Yellowtail kingfish aged 1 year were found to be 350mm FL, and 828mm FL at age five in one study, with a length-at-maturity L_{50} = 834mm in New South Wales. This is much higher than the current Queensland MLS.

There is considerable information about the snapper fishery and as well the biology of snapper in Queensland. The current study has added to our understanding of the two next most important rocky reef species, pearl perch and teraglin, as well as improving some of the available information relevant to the assessment of the snapper fishery. We believe that apart from snapper and pearl perch none of the other species of rocky reef fish warrant age-based assessment as catches are relatively small and distributed across three diverse fishing sectors, resulting in difficulties regarding representative catch sampling. We would argue that this conclusion is supported by the issues we have seen in teraglin sampling and variation in the derived fisheries parameters for this species.

The Fisheries Queensland Assessment and Monitoring Unit (AMU) currently collects information opportunistically on a range of minor rocky reef species in addition to snapper, pearl perch and teraglin. In many cases this involves the measurement of catch size structures at boat ramps, fish processors and commercial catches but in other instances biological material (otoliths) is also collected for possible future analysis. The latter is not analysed further as there is often doubt about sample size and associated issues given the catch of the minor rocky reef fish species. We would recommend that the specific objectives and costs associated with the continued collection and processing of biological samples be reviewed for the minor rocky reef fishery species, with resources best used in the collection of biological information for snapper and pearl perch only. The written protocols and procedures in place for the collection of information, as well as laboratory and analytical protocols of the AMU are comprehensive and are clearly best-practice. The attainment of various sampling targets where representative and statistically robust sampling fractions are obtained for each sector and region given the levels of catch in each of the sampling strata is a challenging objective. We would argue that the ability to investigate the composition of individual catches within each stratum would aid in the ability to determine possible bias.

We have more confidence in our assessment of the pearl perch fishery given greater accuracy and precision in most of the fisheries parameters that were derived as part of the current research. In addition, post-release survival is higher than expected, based on previously published information on a congeneric species prior to this research. Our estimates of total mortality suggest that this species is currently fully-fished and possibly overfished but yield per recruit analysis shows that the MLS is set at the optimum size. However, there is no certainty that this MLS coupled with current bag limit restrictions will eliminate the risk of future recruitment overfishing. Pearl perch is a species that requires careful monitoring to avoid concerns in the future, particularly since the snapper fishery is classified as overfished and there have been recent increases in the catch of pearl perch at a time when snapper catches are declining. Unfortunately pearl perch status assessments suffer from the fact that catch curve analysis was used under the assumption of constant recruitment, an assumption clearly violated by the presence of a strong 4 year old cohort in 2009. One of the reassuring features of the pearl perch age distributions is their similarity (particularly in terms of fish <10 years old) to those derived in the mid 1990's. The parameters derived for teraglin are less precise and probably even more prone to bias given the different size structures among the three fishing sectors. The lack of older age classes for teraglin in the catch from both charter and recreational sectors has a large impact on the estimates of total mortality, effectively inflating the estimates of total mortality (*Z*). If age structure derived from the commercial sector were representative of the population there would be less concern about the status of the teraglin fishery in Queensland.

For teraglin the relatively high *k* confirms that this species has a very high initial growth rate, until sexual maturity is reached at a relatively early age (2 or 3yrs). This rapid growth rate and early maturity are features of teraglin biology that may counter the negative effects of the poor post-release survival rates derived during the current research. It is widely accepted that relatively fast growing and highly fecund species such as teraglin are resilient to fishing pressure and the threat of overfishing. Despite this, some members of the sciaenid family (particularly larger species that attain a length in excess of 1m) have been listed as critically endangered (Sadovy and Cheung 2003). These include the Chinese Bahaba (*Bahaba taipingensis*) and the Totoaba (*Totoaba macdonaldi*) which have been severely overfished in their native Chinese and Californian waters respectively. White seabass, a congeneric of teraglin, in California have also been subject to over-fishing and it is therefore prudent to exercise caution when it comes to the teraglin fishery.

7.2 Post-Release Survival and Ways of Enhancing Survival of Line Caught Rocky Reef Species

Pearl Perch

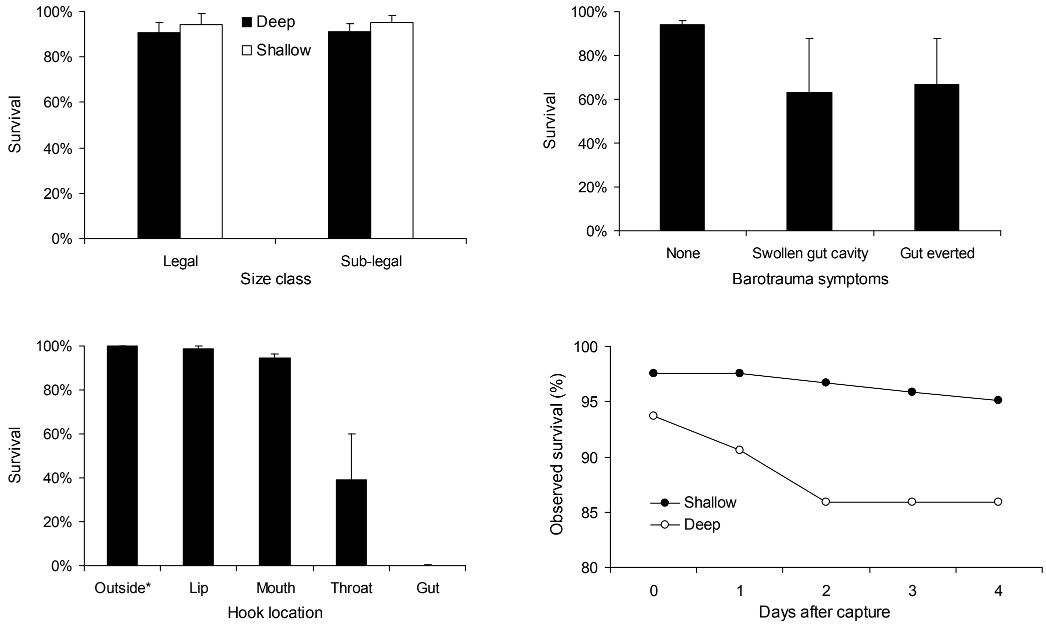


Figure 7.2.1 Post-release survival of pearl perch as a function of depth, size, hook location upon capture, observed barotrauma symptoms and days after capture. *Outside represents hooks located outside the mouth upon capture.

A total of 186 individuals were used to assess the post-release survival of pearl perch. Overall short term survival was excellent at 93.6%. Larger fish survived as well as smaller fish with no significant difference in survival between legal and sub-legal fish (MLS is 35cm TL). Factors that affected post-release survival of pearl perch included depth, hook location and the presence of barotrauma symptoms. Pearl perch caught from deep (≥ 80m) had a slightly lower survival then those fish taken from shallow (< 80m) waters (91.16% vs. 94.87%). Nearly all fish were hooked in either the lip or mouth. Of the fish hooked in either the throat or gut, survival was significantly lower with neither of the gut-hooked fish surviving ($n = 2$) and only 38.93% of throat-hooked fish ($n = 7$) surviving. Pearl perch with obvious barotrauma symptoms (6.5%, $n = 12$) were less likely to survive with survival rates between 63% and 76% (Figure 7.2.1).

Healing of the perforations in the swim bladder was observed in 48.9% of pearl perch dissected. Fish size, water depth and the time held after capture significantly ($P < 0.05$) affected the incidence of the healing of swim bladder perforations acquired during capture. The incidence of healing was significantly higher in fish caught in deeper water ($P = 0.010$) and for sub-legal ($P = 0.014$) pearl perch, while the incidence of healing was higher in animals kept for longer periods. Note that the high rates of healing observed occurred within 3 days or less depending on time in captivity. Full details can be found in Appendix 3.5.

Teraglin

All teraglin caught during the controlled experiments showed signs of barotrauma regardless of depth of capture. Short-term post release survival of teraglin was poor and survival decreased with increasing capture depth. In shallower waters (40-50m) survival was highest at 60% dropping to 10% for those fish captured from deeper waters (75-85m). Survival of sub-legal (<38cm) teraglin was also significantly greater than larger fish (approximately 60% survival compared with 40% survival of larger fish). While sex was not a significant effect there was a trend towards a lower survival of females in comparison to males (Figure 7.2.2).

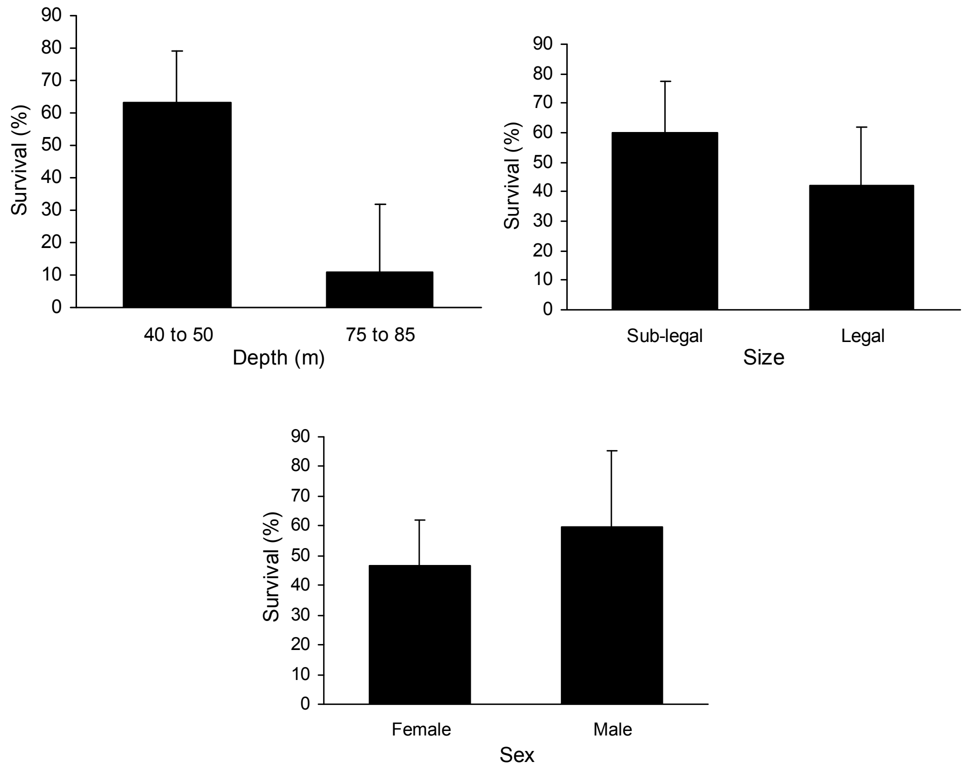


Figure 7.2.2 Model predictions of post-release survival of teraglin caught in two depth and size categories. Vertical bars are 95% confidence intervals.

Only 4 of the 7 fish (57%) that were observed croaking on capture survived and these fish were caught in both deep and shallow areas. Subsequent dissection indicated that they were all males, all but one of which had a ruptured swimbladder. While there were too few croaking males caught to statistically test the effect of "croaking" the size of the holes in the swim bladders of these fish were quite small being between 1mm and 15mm in maximum dimension. While we had originally hoped to identify the sex of teraglin on the basis of their croaking this was quickly proven to be inconsistently determined in the field as not all males made a croaking sound on capture.

Similar results were obtained in the fishery-dependent component of the project. Despite a wide variation in the release mechanisms used by line fishers there was clearly a strong depth related effect on the "survival potential" depending on treatment and depth of capture (Figure 7.2.3). Only 16 fish were released in water exceeding 70m in depth but none of the vented or control fish "survived". One of the three capsule-released fish was also not seen to resurface following release by capsule suggesting that it may have survived and been able to swim away. Other techniques used by charter boat operators to enable teraglin to swim away included massaging the stomach (presumably to vent gases from a ruptured alimentary canal) and launching the fish head first into the water so that it was forced well below the surface, but none had enough replication or experimental control to allow the statistical analysis of their individual effects. However, at times it was noted that fish treated in these ways were at least able to swim out of sight. On some vessels these methods were very effective with success rates over 60% on some trips and depths.

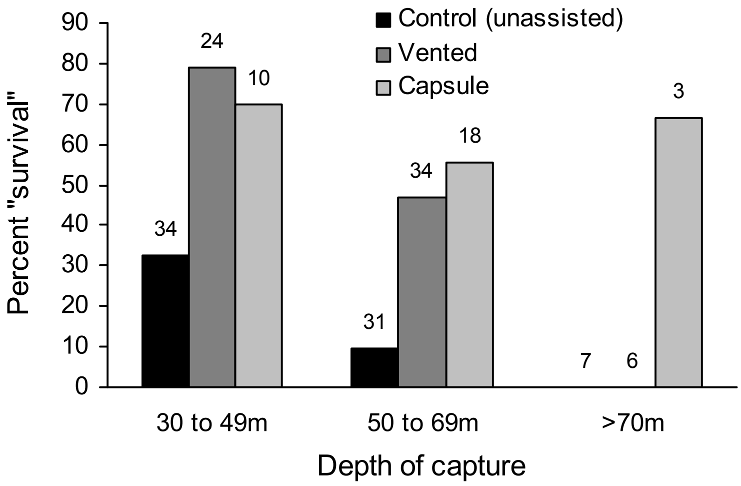


Figure 7.2.3 Effect of two barotrauma relief techniques on the percentage of teraglin that were able to swim away out of sight after capture and release from various depth ranges. Sample sizes are shown above each bar. For capsule release percentages are those fish that did not float back to the surface after release.

A qualitative observation that was consistent across all observer trips was that the majority of "croaking" teraglin (presumably males) were able to be returned to water unassisted when they were caught in water less than 50m deep. We initially presumed these were males that had their swimbladders intact; however, as noted earlier 6 of 7 fish that were observed croaking in our controlled experiments had ruptured swimbladders.

All fish (both male and female) caught in water greater than 70m had ruptured swimbladders with the size of the rupture increasing with depth. Other physiological effects of barotrauma observed were rupturing of veins in the liver (4% of fish) and corneal bleeding (13% of fish). Total voiding of the stomach was observed in 77% of fish and none of the fish caught in the controlled experiments were able to have air expelled from their bodies when pressure was exerted along their gut indicating that there had been no (major) rupturing around the anus or other area from which air could escape. Healing of the swim bladder was observed in 25% of the fish dissected where mesenteric tissue had formed a partial seal allowing the retention of swim bladder gasses. Full details can be found in Appendix 3.6.

Snapper

Short term post-release survival for snapper caught in this study was 88%. Not all snapper caught showed signs of barotrauma (23%). In some instances anglers observed swim bladder gasses in the form of bubbles rising with the fish from depth and the captured fish would then present with no barotrauma symptoms. All fish were used in the model to ascertain overall survival. However, due to the uncertainty of how and where swim bladder gases were escaping, snapper that exhibited no barotrauma symptoms were excluded from the analysis of treatment (venting, etc) effects. Notably, there was no difference in survival between untreated fish (controls) that showed barotrauma symptoms compared to those that did not show barotrauma symptoms and were therefore excluded from the analysis. The proportion of fish that did not display any barotrauma symptoms was the same across all depth classes (23%). Size of fish and depth of capture did not significantly affect survival (Figure 7.2.4a). Hook location (Figure 7.2.4b) and bleeding (66% survival) were significant factors affecting survival with 4 of the 5 gut hooked fish dying (2% of catch). While treatment was found to be a significant factor affecting overall survival, analysis showed no significant differences between treatments. However a trend towards lower survival for vented fish was observed (Figure 7.2.5).

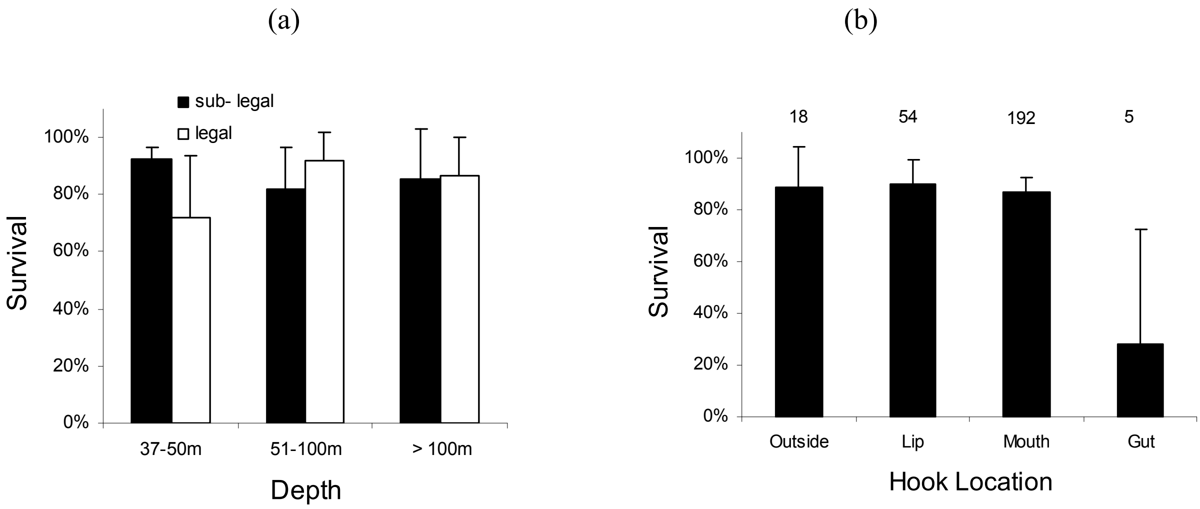


Figure 7.2.4 Predicted survival of snapper. (a) For sub-legal and legal snapper in 3 depth classes. (b) Hook location. Error bars are 95% confidence intervals.

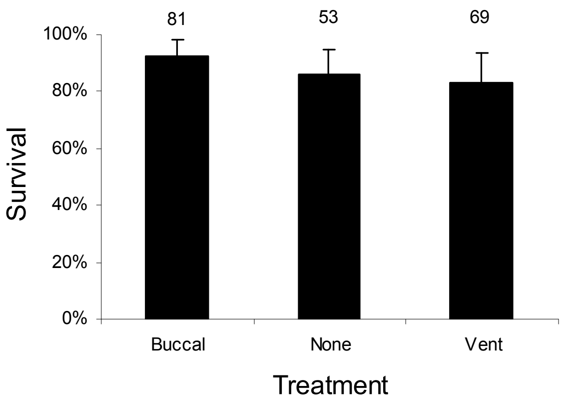


Figure 7.2.5 Predicted survival for each treatment Error bars are 95% confidence intervals.

No factors from the dissections were found to have affected survival. Rupturing of the swimbladder occurred at the rete mirabile in 46% of the snapper examined. The size of the rupture was generally larger for fish taken in the deeper depth class. However, rates of healing could not be ascertained as the fish kept in the 15 metre deep socks re-ruptured the swim bladders when retrieved at the end of the experiments. For snapper kept in the 5 metre deep sock observed healing rate of the swim bladder was 61%. Only 3% (n=7) of snapper dissected showed no signs of a rupture in the swim bladder.

For snapper that exhibited stomach prolapse the dissections revealed that the stomach had returned to a normal position within the gut cavity for 64% of fish, with this increasing to 73% for vented fish. For snapper that were not vented (Buccal, Self and No treatment) the stomach was often slightly inverted, and clenched around the site of any wound in the stomach. The stomachs of snapper that were buccal vented (including those that "self" buccal vented) were found to have healed in 61% of cases. Two fish that had not been buccal vented had stomachs that displayed healed wounds similar to those displayed by buccal vented fish. Signs of infection were found in only 4% (n = 3) of the buccal vented fish when dissected.

During experimental trials swim bladder gas was observed bubbling from the vent of snapper floating in the on-board tanks. Of the fish dissected 19% showed air bubbles from the vent when pressurised and placed under water. Full details can be found in Appendix 3.7.

Long term survival

The SunTag dataset relating to the two species, extracted in February 2012, comprises 14,782 records of snapper tag releases and 2,550 pearl perch tag releases. 876 tagged snapper and 50 tagged pearl perch were recaptured, representing gross recapture rates of 5.9% and 2.2% respectively. Some snapper had been recaptured more than once (the maximum recapture number was 4) with only two pearl perch re-captured on more than one occasion. For both species 'recapture' (i.e. survival) probability increased substantially with increasing body size, with recapture probabilities ranging from <1% for fish less than 25 cm to >5% for fish greater than 35 cm in length. The likelihood of snapper exhibiting signs of barotrauma increased with depth and fish size with the mean probabilities, after adjustment for angler effects, increasing from effectively zero in the shallowest depth range (<10 m) to about 16% in the deepest range (>50 m). Not surprisingly, the release condition assigned by anglers to fish at release is a significant predictor of recapture/survival. Most of the reported movement was highly localised, with 83.6% of the recaptures occurring within 1 km of the release point. Only 25 (2.9%) had moved 20 km or more, and four (0.5%) had moved 100 km or more. Full details can be found in Appendix 3.4.

Discussion

The three rocky reef species that we assessed for line fishing post-release survival showed very different responses and vulnerabilities to barotrauma-related injuries. While we only assessed short-term post-release survival (<3 days) we are confident our results are accurate given most post-release survival studies show that a high proportion of post-release mortalities occur in the first 1-3 days.

We also acknowledge that there are considerable differences among some studies even when dealing with the same species. In many cases this is due to logistic limitations and variations in the apparatus and experimental conditions used to assess survival. In other instances it is also likely related to subtle (and therefore difficult to measure) differences in the process of initially catching and handling the fish. While scientists may be able to recommend best handling protocols, it is difficult to duplicate or simulate the range of handling practices employed across the various sectors that access a resource. That is why assessments often choose a range of post-release survival estimates to test. In some ways it can be argued that our open socks artificially enhance survival because they protect fish from predators. On the other hand holding fish in shallow tanks where they are unable to return to a suitable depth would clearly impact on potential survival.

In terms of levels of resilience to barotrauma, our results clearly indicated a decreasing level of resilience from pearl perch to snapper to teraglin. Pearl perch has very high post-release survival and does not require relief of barotrauma symptoms. Both teraglin and snapper require some form of barotrauma relief, particularly for teraglin which exhibits low post-release survival (although higher than previous anecdotal reports suggested). Buccal venting appeared to do no harm to snapper and the high incidence of healing observed suggests that this is a viable alternative to traditional venting techniques for this species, although further research is required to confirm this, particularly in fish greater in size than the maximum legal size – anglers are allowed one fish over 70cm TL.

An interesting result of our analysis of the ANSA long term tagging data was that the recapture rate of snapper was about 3 times that of pearl perch. One interpretation that could be drawn from this is that post-release survival of pearl perch is much lower than snapper. However, we would not support such a conclusion as we have previously analysed two species (scarlet sea perch and saddletail sea perch) with very different short-term post-release survival but which had similar overall recapture rates (Brown *et al.* 2008). A range of different factors can contribute to differential recapture rates across species. These include tag shedding, tagging induced mortality as well as spatial and temporal variations in both tagging effort and subsequent general fishing effort from which the tag recaptures are reported. For example, a high proportion of the tagged snapper that were recaptured as part of the co-operative tagging program, were tagged, released and recaptured in Moreton Bay, a relatively shallow area subject to very high levels of angler fishing effort, resulting in relatively high snapper recapture rates and artificially inflating the survival rates mentioned above, compared to pearl perch.

7.3. Habitat of Rocky Reef Species

Results/Discussion - Historic Trawl Surveys

Shallow water EKP survey

Pearl perch (*Glaucosoma scapulare*) were present in 47 of the 204 (23%) trawls sampled in the shallow water EKP fishery during the fishery bycatch project. Average pearl perch catch per hectare was 0.876 individuals and 13.87 grams. Pearl perch were distributed across the sampled area from the Southport Seaway, north to Noosa. Depth ranged from approximately 25m (14 fathoms) to 91m (50 fathoms). The pearl perch caught during the bycatch project were generally small juvenile, averaging 6.2cm FL. The largest concentrations of pearl perch in the shallow water EKP fishery were located in approximately 70m (35 - 40 fathoms) in areas adjacent to North Stradbroke and Moreton Island (Figure).

Snapper (*Pagrus auratus*) (average length of 117.5mm FL) were caught in approximately 1% of net trawls with catch rates of 0.424 $g.ha^{-1}$ and 0.006 $individuals.ha^{-1}$. No teraglin were reported in any of the surveys analysed

Deep water EKP survey

Pearl perch were present in only 24 of the 201 (12%) net trawls sampled in the deep water EKP fishery (Figure 7.3.1). Average pearl perch catch rate was 0.023 $individuals.ha^{-1}$ and 5.929 $g.ha^{-1}$. Depth ranged from approximately 91m (50 fathoms) to 190m (104 fathoms). The pearl perch caught in the deepwater were larger, averaging 187mm FL.

Snapper were also caught in the deep water EKP fishery in approximately 0.5% of net trawls with an average length of 180mm FL. Snapper catch rates in the deepwater EKP fishery were 0.205 $g.ha^{-1}$ and 0.001 $individuals.ha^{-1}$.

Sygnathid survey

Pearl perch were present in 11 of the 87 (12%) trawls sampled during the Sygnathid survey with an average catch rate of 0.02$g.ha^{-1}$ and 0.08 $individuals.ha^{-1}$. The pearl perch caught during the survey had a mean fork length of 68mm and only one snapper was caught during the survey.

We further examined the literature for results of other surveys conducted in Moreton Bay and found no reports of either pearl perch or teraglin.

Prawn trawling is associated with relatively soft substrates of sand and/or mud. As such, the results of the trawl samples detailed in this chapter indicate that the only major rocky reef species associated with such substrates outside of Moreton Bay are pearl perch and, to a much lesser extent, snapper. Sumpton and Jackson (2005) reported that significant numbers of juvenile snapper were caught by trawlers in Moreton Bay, yet very few are caught in the adjacent offshore king prawn fisheries. This suggests that once snapper leave Moreton Bay, proportionally more inhabit hard ground that is not accessible to prawn trawlers.

No teraglin were caught in the 600+ net trawls included in the current analysis. This indicates that juvenile teraglin do not inhabit the soft, trawled substrates in the sampling area. It is likely that they either settle on hard substrates as fry or recruit from areas south of the sampling area. During the project we received some samples of juvenile teraglin from trawlers fishing shallow waters off the Gold Coast and anecdotal reports from trawl operators suggest that thy are more common further south in NSW waters.

In contrast, pearl perch appear to be a relatively common species on trawl grounds between Noosa and Southport, particularly in depths of around 60 metres. The highest concentrations occur around Cape Moreton and Point Lookout. Pearl perch use these shallower habitats as juveniles approximately 60mm in length. This was confirmed by a blue swimmer crab (*Portunus pelagicus*) fisher, who reported he had caught a large number of juvenile pearl perch in crab pots. Pearl perch were encountered in 23% of samples, the 41st most frequently encountered species in the shallow water EKP fishery. However, they were less frequently encountered in the deep water EKP fishery.

We found larger pearl perch in trawl samples from soft substrates in deeper water. It is difficult to ascertain if the larger fish are present in the deeper areas year-round or if the fish caught during the July 2002 deep water EKP survey are the same cohort as those caught in the October 2001 shallow water EKP survey. The derived growth curves for pearl perch (see Appendix 3.1) suggest that this may be the case indicating a common behaviour among fish of moving to deeper water with age.

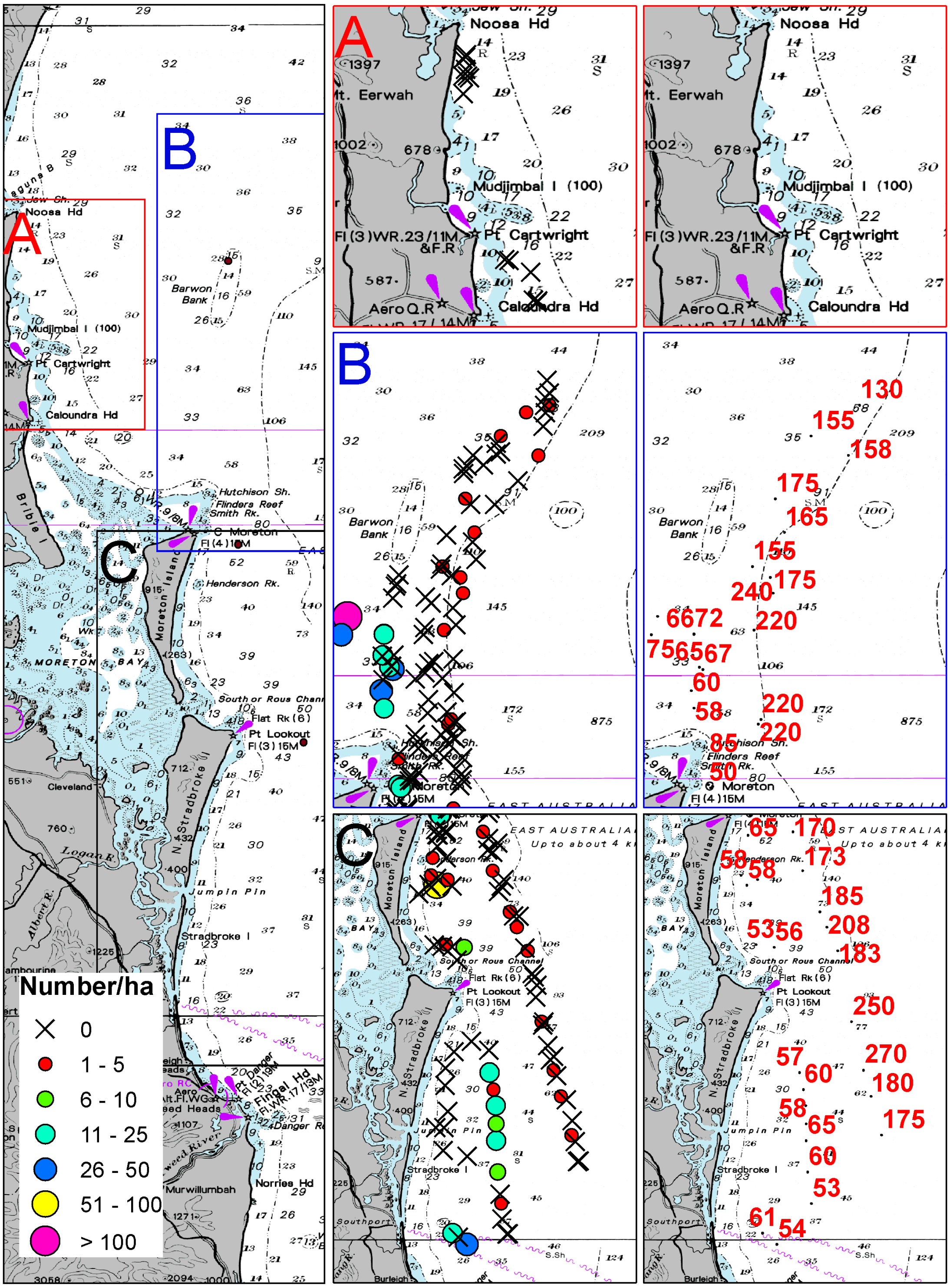


Figure 7.3.1 Catch rate of pearl perch, caught by commercial trawlers throughout a project assessing the bycatch composition in Queensland's east coast otter trawl fishery (Courtney *et al.*, 2007). Average catch rates of pearl perch in the shallow water EKP fishery (<91m) were 13.8g.ha^{-1} and 0.876 individuals.ha^{-1} and 5.9g.ha^{-1} and 0.023 individuals.ha^{-1} in the deep water EKP fishery (>91m).

Results/Discussion – Camera Surveys

BRUVS Survey – Sunshine Coast

A total of 125 species of demersal fish from 44 families were recorded in the 187 BRUVS samples collected on the Sunshine Coast continental shelf. Of the three main fishery targeted rocky reef species, snapper, pearl perch and teraglin, only snapper were present on all habitat types in both deep and shallow water (Figure 7.3.2). The frequency of occurrence of snapper was significantly different between all habitat/depth groups, and this species was most abundant in deep rocky reef habitats. No small juvenile snapper (<20cm) were seen in any of the BRUVS samples. There were also no juvenile pearl perch (<20cm) seen on any of the BRUVS with the majority of fish exceeding 25cm in length. Pearl perch were most abundant in deep rocky reef habitat and were absent over shallow sand and gravel, with significantly different frequency of occurrence between all habitat/depth groups. The relatively high standard error for this species reflects both the small sample size but also the relatively wide range in MaxN. Teraglin was recorded in only one of the 187 samples, a deep gravel site.

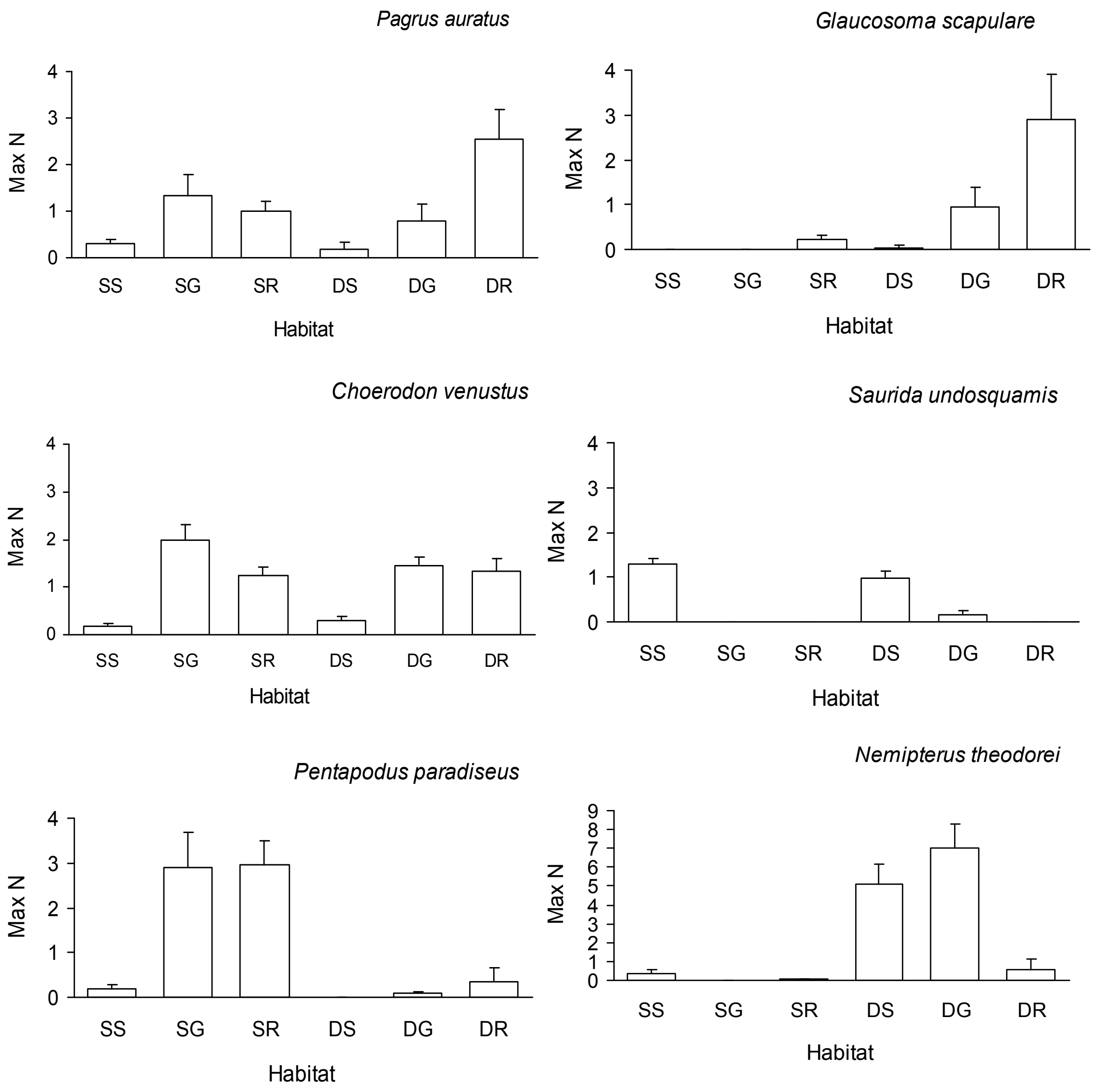


Figure 7.3.2 Relative abundance distribution of six relatively common species (mean and standard error) in BRUVS samples off the Sunshine Coast, Southern Queensland. (SS Shallow Sand, SG Shallow Gravel, SR Shallow Reef, DS Deep sand, DG Deep Gravel, DR Deep Reef).

Choerodon venustus and *Saurida undosquamis* were the two most frequently occurring species in the study, occurring in 76 and 74 of the 187 samples respectively. *Choerodon venustus* which is also an important fishery species was recorded in all habitat types in both deep and shallow water but was more common on the more structured habitat types of reef and gravel. *S. undosquamis* was recorded only over shallow sand, deep sand and deep gravel habitats. Most footage viewed on sand habitat had a MaxN of either one or two for this species, reflecting a fairly ubiquitous and consistent distribution across these habitats. *Pentapodus paradiseus* occurred in 35 of the 187 samples and over all habitats with the exception of deep sand. Relative abundance of *P. paradiseus* was similarly high over shallow gravel and shallow rocky reef, and lower over shallow sand, deep gravel and deep rocky reef. *Nemipterus theodorei* was recorded in 54 of the 187 video samples over all habitats except shallow gravel was highest in deep samples (both sand and gravel) where it was the dominant species.

<u>BRUCS Survey – Moreton Island and Stradbroke Island</u>

The analysis of the BRUCS was limited to determining MaxN for only two species of fish – snapper and pearl perch. From a general qualitative perspective there were clearly both spatial and temporal relationships among the crab assemblages and these are described by Brown (2012). It was rare to see either snapper or pearl perch in the same images as crab species although there were apparently no visible differences in the habitat types in the images. Both species were more frequently associated with coarser sediment sometimes with associated sparse macroalgae and other organisms. The highest MaxN for snapper was 16 while for pearl perch it was only 4. Figure 7.3.3a & 7.3.3b shows the relative abundance of both species in the sampled areas over the two years of sampling. These results are broadly similar to those identified from the BRUVS samples taken on similar habitat further north off the Sunshine Coast which shows some fish on the sandy less structured habitats but more commonly on the more structured rocky reef habitats.

None of the fish sampled were classified as juveniles and in fact over 70% of pearl perch observed were above the current MLS. The opposite was the case for snapper with the majority being less than 35cm although two large individuals (>50cm) were observed on sandy habitat that had a very patchy cover of macroalgae.

Despite the fact that teraglin are a common reef fish in the area of Jumpinpin we were unable to consistently identify this species in images. Snapper and pearl perch were not observed in either year of the BRUCS surveys in the Jumpinpin area as well despite the fact that reefs are located in similar close proximity to those off southern Moreton Island. Characterization of the bottom types indicated that the sediment types where both pearl perch and snapper were recorded were gravel sites rather than sand. It was interesting that many of the areas sampled were characterized on maps as being areas of reef yet they had little complexity and on numerous occasions BRUCS landed on sand and gravel substrates in a similar result to the BRUVS analysis conducted further north off the Sunshine Coast.

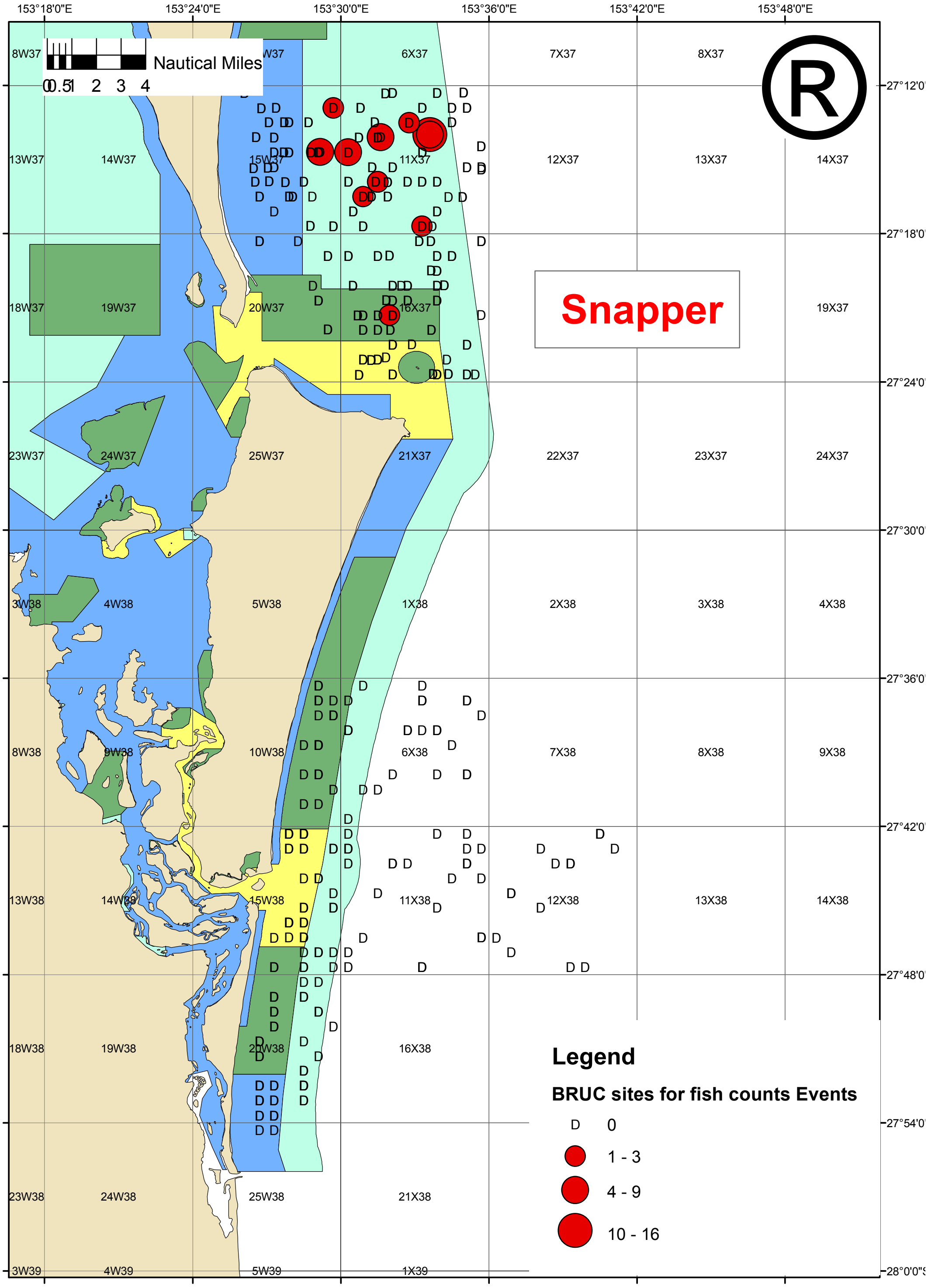


Figure 7.3.3a Relative abundance (MaxN) of snapper (*Pagrus auratus*) on BRUCS conducted during October to December in 2009 and 2011.

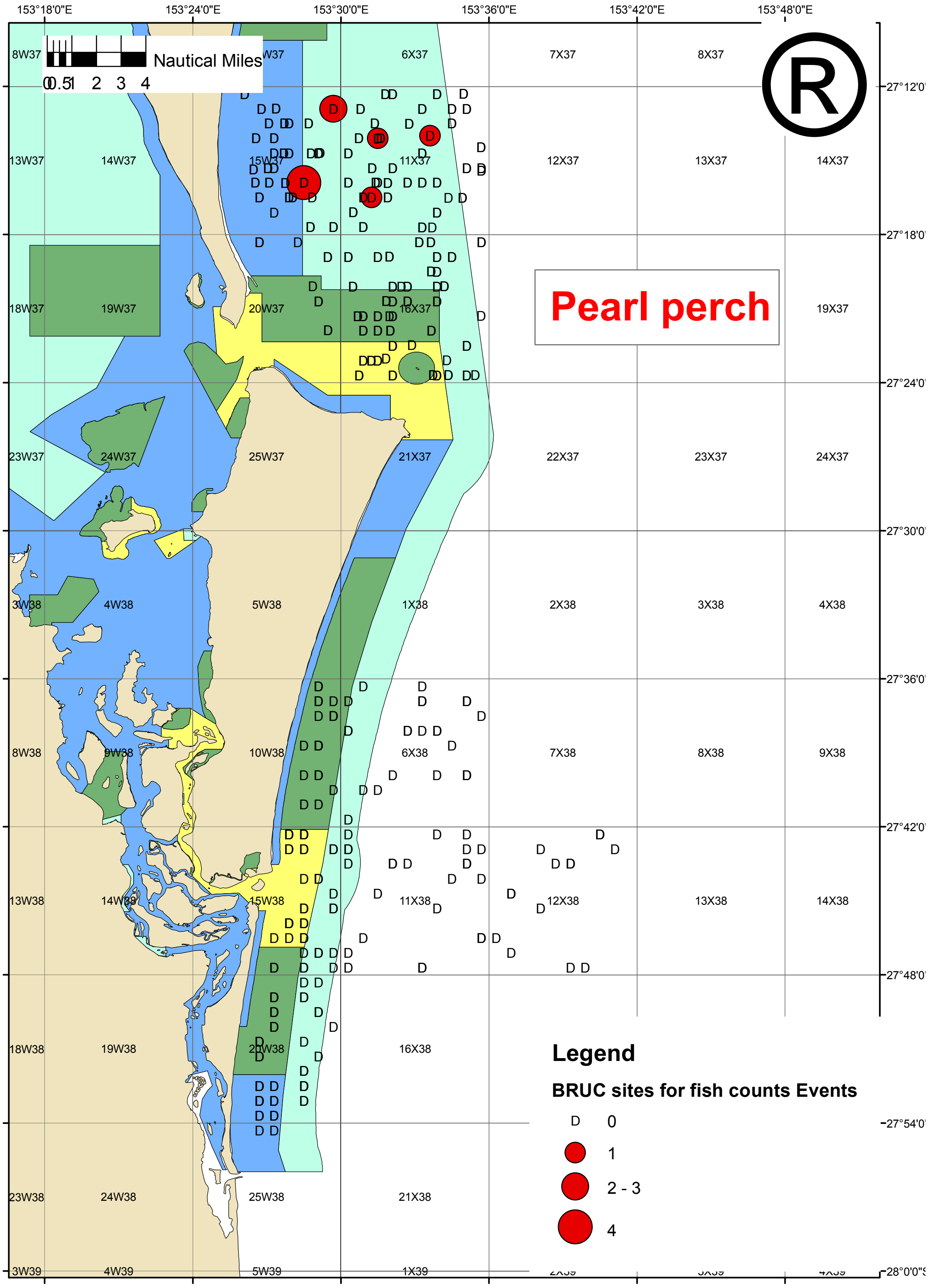


Figure 7.3.3b Relative abundance (MaxN) of pearl perch (*Glaucosoma scapulare*) on BRUCS conducted during October to December in 2009 and 2011.

General Discussion

Juveniles of the most important species fished in the area were rarely seen in either the BRUVS or BRUCS samples despite adults of those species being represented in samples. This could be due to the seasonal availability of some of the species. Juvenile snapper for example, are known to be strongly seasonal in Moreton Bay when using trawl sampling due partially to gear selectivity as well as related to purely the seasonal abundance of 0+ year old snapper which tend to be more abundant during the austral spring and summer (Sumpton and Jackson 2005). It was surprising that juvenile pearl perch were not seen in any BRUVS samples taken off the Sunshine Coast. The area chosen represented an area where juveniles had previously been identified in crab pots as well as otter trawl samples. Research in Western Australia on the closely related *Glaucosoma hebraicum* has likewise failed to sample many small juveniles in trawl, trap or BRUVS surveys despite considerably more sampling effort than was undertaken by the present study. Juvenile *G. hebraicum* have only recently been seen by divers in relatively shallow water in WA (Paul Lewis WA Fisheries, personal communication).

Larger pearl perch were more abundant in the deeper areas and were absent from the sand habitat, a result conflicting with expectations of the previous trawl surveys where juveniles were trawled in the same areas sampled by the BRUVS. This could be due to their generally more cryptic nature, the seasonal nature of their abundance on different habitats or even small scale diurnal behaviours. Trawl samples were taken during the evenings and it is possible that juveniles of this species may move off reef areas to forage in sandy habitat at night where they may also enter the pots of commercial blue swimmer crab fishers. Their large eye suggests that they may be more of a nocturnal predator, an observation further supported by fishers who often report elevated catch rates when fishing for this species at night.

Snapper were also found at both depth ranges and in all habitats although more were seen on the more complex gravel and reef habitats compared with the sand. Snapper are more ubiquitous across the region and have a higher relative abundance than all other species of fisheries importance (apart from venus tuskfish). This feature of their ecology confirms that their catch rates are more likely to reflect the relative abundance of the species, more so than species that have a highly patchy distribution such as pearl perch and teraglin. The lack of juvenile teraglin was expected given the relative paucity of these fish in previous trawl samples conducted in the region and lack of reports of their capture by fishers in all sectors. We still cannot be certain about the habitat relationships of this species as we were unable to accurately identify teraglin in the still camera BRUCS used in the southern part for the survey area where the relative abundance of this species is known to be greatest.

In the present study significantly different assemblages of demersal fishes were found in association with different habitat types in both deep and shallow water, and certain species were found to be important in defining assemblages associated with only one particular habitat type and depth range. These patterns were operating at relatively fine spatial scales at both the community and individual species levels. This is of course well known to experienced fishers who are aware of these differences and who target particular reefs or fine scale fishing locations (GPS marks) because they are known to be preferred sites for individual species. These “hot spots” are known to vary dramatically over the scale of less than 100m even on the presumed same habitat and these observations suggest that while habitat complexity may be a broad surrogate, patterns at the individual species level may be more complex.

Pearl perch, for example, were found in shallow rocky reef, deep rocky reef, deep gravel and deep sand habitats, however it was only found to be an important species causing similarities between the assemblages found at deep rocky reef sampling sites. Thus deep rocky reef areas may potentially be used as predictors of the likely occurrence of pearl perch, which may enable fisheries managers to determine zoning plans to best ensure future fisheries production of this species. If habitat is to be accurately used as a surrogate for ichthyofauna, the precision and spatial resolution of topographic maps, the fine scale composition and configuration of habitat types relative to each other and taxa-specific biological information must all be considered (Anderson *et al.* 2009). We note that variations in relative abundance of species at all spatial scales on essentially the same habitat can result in “habitat” based surrogates offering differential protection for individual species. The current Moreton Bay Zoning plan clearly has significantly different impacts on the three target species investigated here, having the greatest protective benefit for snapper whose juveniles are particularly abundant in Moreton Bay where protection is offered by the closures.

7.4. Development of Harvest Strategies for Rocky Reef Fisheries

Results/Discussion - Compulsory Commercial and Charter Data

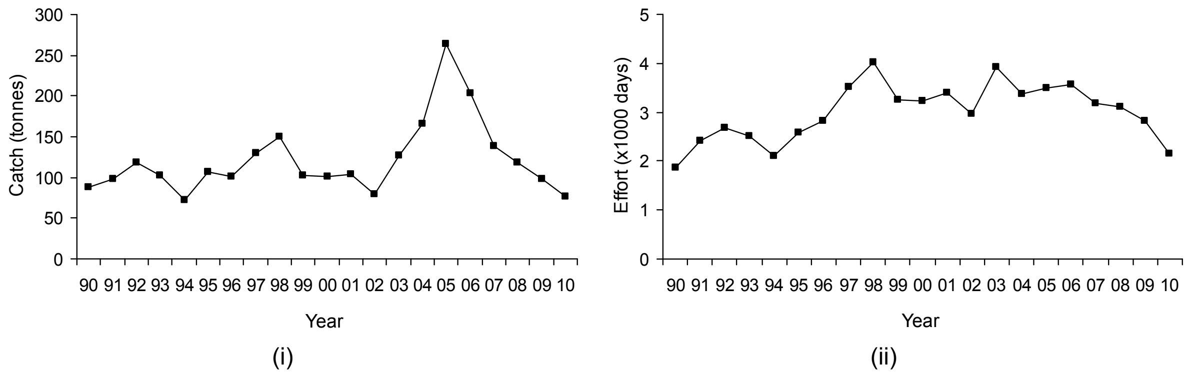


Figure 7.4.1 Catch (i), in tonnes, and effort (ii), in 1000's of days, for snapper in the RRFF from logbook data.

Total snapper catch averaged approximately 100 t until 2002, before significant increases in catch in 2003, 2004 and 2005 (Figure 7.4.1). Although snapper accounted for the highest proportion of catch by commercial and charter operators in the RRFF, the snapper catch has decreased as a percentage of total catch (Figure 7.4.2) in recent years. Snapper catch in both sectors was approximately 40% o the total catch of the RRFF in 2010, down from in excess of 80% at the start of the respective logbook periods.

The catches of teraglin and pearl perch, as a percentage of total catch, have remained relatively stable in both sectors (Figure 7.4.2). Since 2000, pearl perch have comprised approximately 20% of the catch in both sectors, while teraglin are of less importance to the commercial sector (<5% of total catch since 2000) compared to the charter sector (~10%). The catch of the traditionally incidental RRFF species has increased over time in both sectors (Figure 7.4.3). Cobia have become an increasingly important target species in both the commercial and charter sectors in recent years, while the catch of grass emperor and amberjack has also increased since 2000.

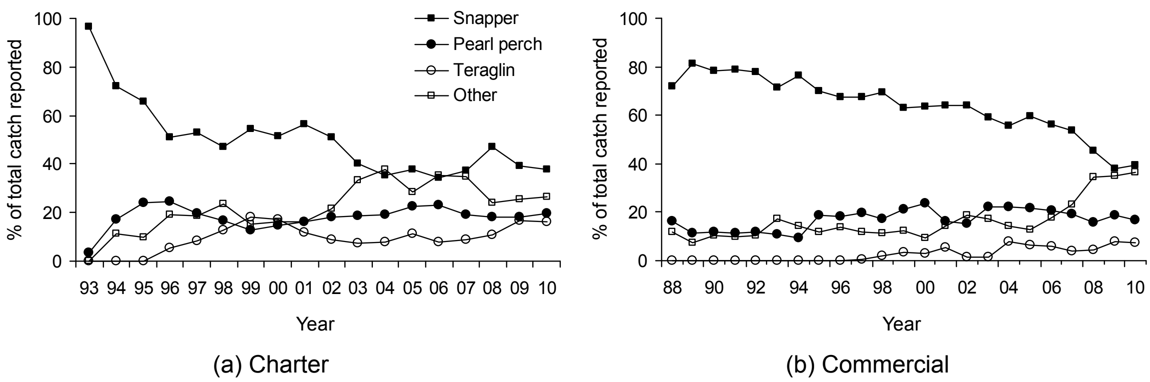


Figure 7.4.2 Percentage of total catch landed by line in the charter and commercial sectors by species from logbook data.

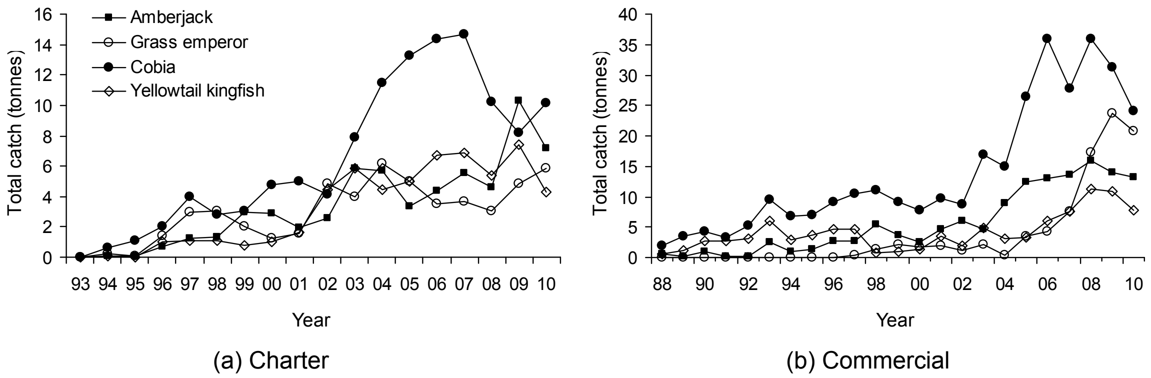


Figure 7.4.3 Total catch (in tonnes) of traditionally incidental species ("Other" species in Figure 3 Percentage of total catch landed by line in the charter and commercial sectors by species from logbook data.

The REML analysis showed that the catch rates of pearl perch and teraglin from the RRFF were significantly affected by temporal and spatial factors. The temporal factors, year and month, and the spatial factor, CFISH grid, were all found to significantly affect the catch rates of pearl perch and teraglin from the charter sector. In the commercial sector, the temporal factors had a significant effect on the catch rates of pearl perch and teraglin, while the spatial component had no significant effect ($P = 0.67$). Lunar phase was found not to have had any significant effect on the catch rates of pearl perch and teraglin in either sector. Further, there was a positive correlation between daily catches of pearl perch and teraglin and their associated snapper catches and, as such, this lunar variable was excluded from all analyses.

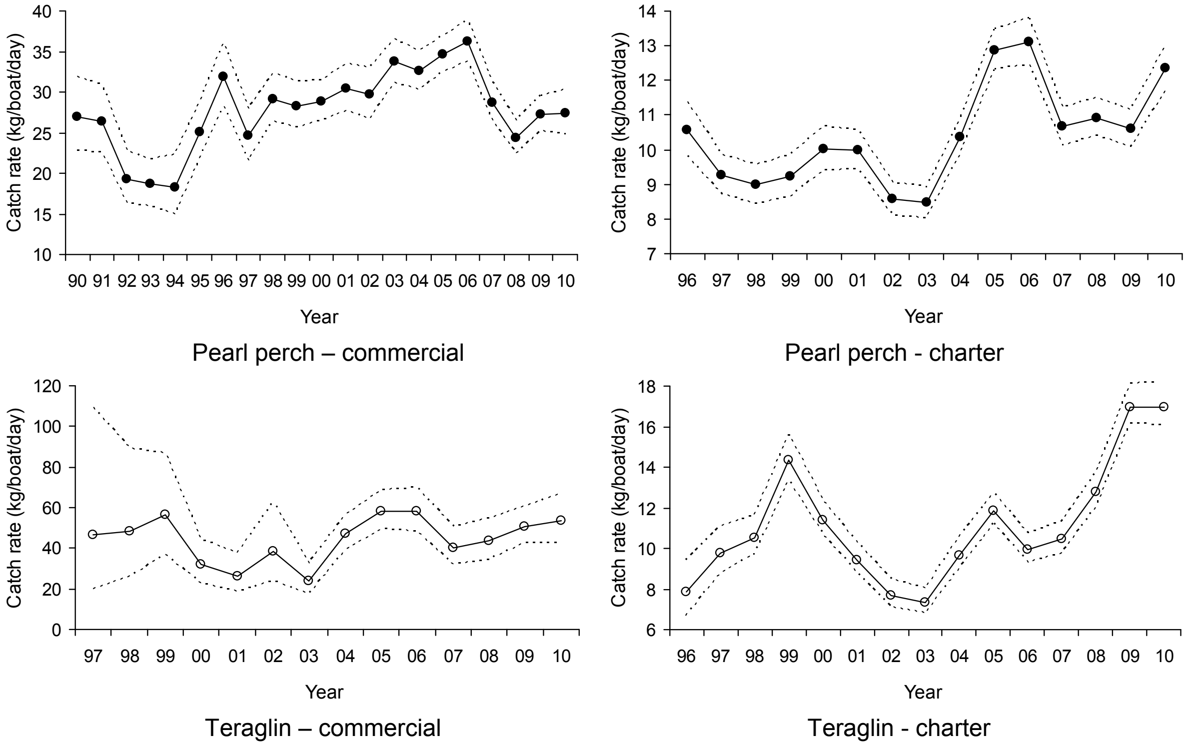


Figure 7.4.4 Bias-corrected back-transformed mean pearl perch and teraglin catch rates (in kg/boat/day) from the charter and commercial sectors of the RRFF. Dotted lines represent 95% confidence intervals.

Pearl perch catch rates from the commercial sector increased from 18.2 kg/boat/day in 1994 to 36.2 kg/boat/day in 2006, before decreasing to approximately 27kg/boat/day during the period 2007-2010 (Figure 7.4.4). Catch rates were highest in April and October and lowest during February. Pearl perch catch rates from the charter sector remained at 9-10 kg/boat/day until 2001, before decreasing to 8.5

kg/boat/day. Catch rates then increased to 13.1 kg/boat/day in 2006, followed by a decrease to 10.7 kg/boat/day during 2007-2009. In 2010, the catch rate of pearl perch from the charter sector increased to 12.3 kg/boat/day. Catch rates were higher from April, May and June.

Teraglin catch rates from the commercial sector have been relatively stable since 1997 while the charter sector catch rates have increased since 2003, reaching 17 kg/boat/day in 2009 (Figure 7.4.4).

Campbell *et al*. (2009) analysed snapper catch rates as part of a stock assessment finding that snapper were either fully-fished or overfished noting that the commercial catch rates were hyperstable and thus not a good indicator of stock abundance. Since 2007, catch rates of snapper have continued to decline in the commercial sector. The decrease in snapper catch was evident in both the commercial and charter sectors from logbook data, with snapper catch decreasing as a proportion of total catch.

In the commercial sector, reductions in snapper catch rates have occurred concurrently with significant increases in fuel price and, despite the use of increasingly efficient outboard engines, this has led to fishers accessing fishing grounds closer to their home port. This is evident from logbook data, with inshore CFISH grids receiving increasing levels of fishing effort since 2000. In these grids, fishers can target wrecks, pinnacles and other favourable habitat known to hold large populations of cobia, yellowtail kingfish and pearl perch, traditionally considered as incidental catch by fishers targeting snapper. Further, some fishers target grass emperor on gravel and low relief reef areas, close to shore off the Sunshine Coast. These behaviours allow fishers to maximise profit by minimising fuel and other costs. This behaviour is evident from the logbook data, with the catch of these species increasing in recent years.

Additionally, some commercial rocky reef fishers have diversified into adjacent fisheries, particularly the deepwater line fishery targeting bar cod *Epinephelus ergastularius*, blue-eye trevalla *Hyperoglyphe antarctica*, hapuka *Polyprion oxygeneios* and bass grouper *Polyprion americanus* (Sumpton *et al.*, 2013) and other species managed under the Coral Reef Finfish Fishery (CRFF) in waters north of Noosa. Specialised techniques have been developed by fishers to target these high value species, with some fishers using bottom discrimination software on computers to identify likely habitat.

Commercial rocky reef fishers are accessing these fisheries due to the high likelihood of large catches of species with high market value, but the effect of this increase in effort on the sustainability of the deepwater stocks, in particular, is unknown.

A complicating factor in the analysis of catch rates derived from logbooks relates to changes in the reporting behaviour of commercial fishers, as a consequence of changes to the Queensland Line Fishery Logbook, over time. Successive versions of the commercial Queensland Line Fishery Logbook have made provision for the reporting of more species. All versions of the Queensland Line Fishery Logbook up to July 2004 had snapper as the only rocky reef fish, with fields for coral reef fish and mackerel and three "Other" fields. In 2004, the fourth version of the Queensland Line Fishery Logbook (LF04) had provision for the reporting of both snapper and pearl perch and two "other" rocky reef fish. The fifth version (LF05), in operation since 2007, had provision for the reporting of all rocky reef fish. In addition, various investment warnings have increased the incentive to falsify logbook records.

Although the catch of species such as yellowtail kingfish, grass emperor and amberjack has increased since 2000, the annual catch of pearl perch and teraglin, as a proportion of total catch, have remained relatively stable in both the commercial and charter sectors. Despite this, observed pearl perch and teraglin catch and effort have increased in both the commercial and charter sectors.

Standardised commercial pearl perch catch rates increased after 1994 through until 2006, most likely as a result of several factors. Firstly, as was the case for the snapper fishery, commercial fishers utilised highly efficient four-stroke and fuel-injected two-stroke outboard engines, allowing fishers to increase their range and access offshore reefs that were previously only lightly-fished. This, combined with the increased use of affordable, highly-sophisticated GPS and sonar equipment allowing fishers to accurately identify likely fish-holding habitat, improved the commercial fishers' ability to locate and exploit aggregations of pearl perch well offshore. Developments in fishing gear and specialised baits have further increased effective fishing effort.

Secondly, the shift away from targeting snapper, as a result of decreasing catch rates, saw fishers targeting pearl perch with resultant increases in catch rates. Although pearl perch were considered as bycatch during the early years of the logbook programme, commercial fishers realised the marketability of pearl perch and began expanding into locations known to produce quantities of pearl perch. Although caught over rocky reef with snapper, pearl perch are also known to inhabit areas adjacent to rocky reef, specifically in areas supporting wire weed (Gorgonid soft corals) and similar organisms. Such areas are now targeted by all sectors, with one such area near Hutchison's Shoal referred to as Pearl Perch Alley. Further, wrecks and pinnacles, known to hold large populations of pearl perch, are easily targeted using the GPS and sonar equipment discussed above.

Marriott *et al*. (2011) reported similar catch rate trends for commercially-caught West Australian dhufish (*Glaucosoma hebraicum*) from southern Western Australia, to those from the current study. However, these authors reported that the addition of factors relating to the uptake of colour sounders, GPS and electric reels significantly affected dhufish catch rates after using a mixed model analysis. Marriott *et al*. (2011) suggest that the adoption of these new technologies over time resulted in a divergence between the observed commercial dhufish catch rate and abundance. In an attempt to quantify the effects of the adoption of colour sounders and GPS on pearl perch catch rates in the current study, a preliminary analyses was undertaken using data collected by Sumpton *et al.* (in press). These data quantified the proportion of fishing effort where colour sounders and/or GPS units were used by recreational anglers and were collected as part of a survey of recreational anglers accessing the rocky reef fishery in southern Queensland. The addition of an index of the use of technological advancements in the REML analysis revealed that the pearl perch catch rate data from the current study would be significantly lower than those presented in Figure 7.4.4, with similar trends produced to those for the Marriott *et al*. (2011) study. The collection of information regarding the adoption of fishing-related technology by commercial fishers will be undertaken prior to the next snapper stock assessment scheduled for 2014 to ensure these data can be used to produce more accurate standardised catch rates.

Further, Jones and Luscombe (1993) reported on the effect of the adoption of fish-finding technology on the catch rates of snapper in the South Australian Scalefish fishery. These authors attributed a 5-50% increase in snapper catch rates caught over natural reefs to the installation of colour sounders.

Teraglin were of much less importance to commercial fishers compared to pearl perch with teraglin accounting for only approximately 3% of total RRFF landings. The lack of catch prior to 2004 may be a result of the format of the Queensland Line Fishery Logbook, with only two fields available for rocky reef fish, as discussed above. The commercial catch rates of teraglin are highly correlated to the catch rates of snapper reported by Campbell *et al*. (2009) up until 2007, with teraglin catch rates increasing annually since this time. This suggests that, unlike pearl perch, teraglin have remained an incidental catch of fishers targeting snapper in rocky reef areas where significant populations of teraglin are located.

Recent increases in commercial teraglin catch rates during a time when snapper catch rates are decreasing, suggest that some commercial fishers have targeted teraglin. Teraglin are relatively easy to target given their propensity to form dense schools over rocky reef (Sumpton *et al.*, 1998). Once aggregations are located, large catches are possible, with 6.7% of all teraglin catches being greater than 100kg. As with pearl perch, advances in fish-finding technologies, along with the increased availability of high quality bait, have contributed to increases in catch rates.

The analysis of snapper catch rates from the charter sector by Campbell *et al*. (2009) revealed that catch rates declined from 1999 to 2007, while increases in catch rates of pearl perch and teraglin were evident over this period. Further, the catch of amberjack, grass emperor, cobia and yellowtail kingfish have increased since the introduction of the Queensland Commercial Fishing Tour Logbook, with cobia catch increasing almost exponentially in the period 2001-2005.

Pearl perch and teraglin catch rates from the charter sector increased after the management changes in 2003. As with the commercial fishery, the introduction of more sophisticated GPS and sonar technology, combined with the shift away from targeting snapper, has also contributed to these increases. The inclusion of covariates describing the uptake of GPS and colour sounders, as discussed by Marriott *et al*. (2011), would likely result in decreasing catch rates of both species in the charter sector.

Although the catch rates of pearl perch and teraglin are likely to have been affected by the fish finding technologies discussed earlier, the fishing gear used by anglers accessing the RRFF via charter operations has also likely affected catch rates. It is, therefore, prudent to quantify the effects of these advancements in gear-related technology in order to provide better estimates of fishing power associated with these factors.

The pearl perch and teraglin catch rates show that 2003 was a poor year for both these species in the charter sector. However, during the subsequent 2-3 years, catch rates increased significantly. This also occurred in the recreational and charter snapper fishery as reported by Campbell *et al*. (2009). The fact that the catch rates of these rocky reef species increased in the years immediately after the management changes described earlier were introduced suggests that the changes contributed to the increase in catch rates for these years.

In the case of teraglin, the decrease in the MLS from 45cm to 38cm would have resulted in an increase in the number of individuals caught, particularly in the commercial fishery where fishers are not restricted by bag limits. However, the teraglin catch rate in the charter sector increased by approximately 30%, most likely as a consequence of the existing bag limit of 5 per angler per day and the decrease in the average weight of the smaller fish targeted after the decrease in minimum legal size. Increases in the teraglin catch rates from the charter sector since 2007 are likely due to charter operators concentrating effort on inshore reefs where smaller teraglin are caught in large numbers. Although these fish are smaller, charter anglers are able to catch their bag limits easily once a school is found.

From the REML analyses, CFISH grid, Year and Month significantly affected catch rates in all models, apart from CFISH grid in the commercial teraglin analysis due to the low number of grids in which commercial fishers landed teraglin. Ideally, the spatial resolution of logbook data should be enhanced, with only a small percentage of current logbook records containing site (6 x 6 nautical miles) information. This could be achieved using GPS technologies interfaced with electronic logbooks like those used in Salmonid fisheries in Canada. In this fishery, commercial fishers use electronic tablets interfaced with a GPS receiver to record catch and location information before reporting the information via email to the management agency (Ron Goruk, Fisheries and Oceans Canada, personal communication). Such information in RRFF would provide important information regarding locations, depths and time fished during a fishing day. At present, the location information is at a resolution of 30 x 30 nautical miles which, in south-east Queensland, may incorporate catches landed in depths ranging from 20m to 150m. The imposition of such management measures, however, is unpopular with fishers. As such, it is important to extend the benefits of such systems to fishers including the ease in recording information using drop-down menus, etc, decreasing times to fill-out logbooks, reports of catch information for use by the fisher (fishing diary) and sending the logbook information via email negating the need to send paper-based information.

In conclusion, pearl perch and teraglin catch rates have increased in both the charter and commercial sectors. This was driven by a reduction in the catch rates of snapper, a consequent redirection of fishing effort onto these two species and increases in fishing power attributable to advancements in fish-finding and fish-catching technologies. Further research should focus on quantifying the effects of these advancements on catch rates. Logbook information has shown that snapper catch has decreased in the last 10-12 years in both the commercial and charter sectors, with the landings of amberjack, cobia, yellowtail kingfish and grass emperor increasing during this time. The targeting of pearl perch and, to a lesser extent, teraglin will have ramifications for the populations of these species.

Results/Discussion – Recreational Catch and Effort Information

Research surveys after 1990

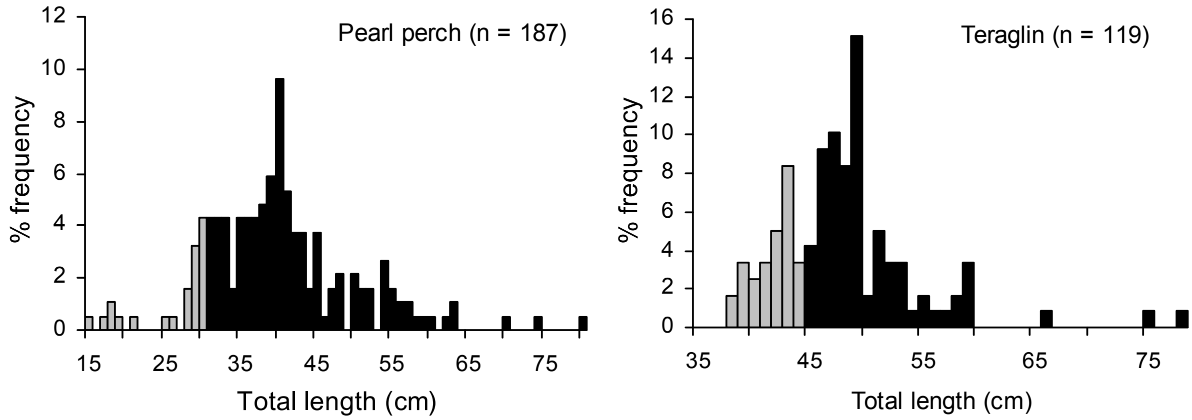


Figure 7.4.5 Length frequency of recreationally caught pearl perch and teraglin during on site boat surveys of line fishers during 1994 and 1995. Grey bars indicate fish that were smaller than the 1993 MLS.

While there were not large numbers of pearl perch or teraglin measured during these surveys the size frequency distributions (Figure 7.4.5) broadly reflect those obtained from other recreational and charter samples obtained during more recent years by the AMU (See Appendices 3.1 and 3.2). The relatively small proportion of undersized fish of both species during the 1994/95 survey was partially a reflection of the absence of these fish from Moreton Bay (an area of high fishing effort). The minimum legal size had also only recently been set for both species at 30cm for pearl perch and 45 cm for teraglin. Snapper showed even higher proportions of undersized fish retained particularly for those fishers who fished inside Moreton Bay (Ferrell and Sumpton, 1997). Subsequent surveys conducted during 1999 showed that compliance had increased dramatically and it was hypothesised that the high levels of undersized fish during the 1994/95 survey was related more to a time lag needed for the regulation changes to be communicated effectively to the recreational sector rather than an ongoing compliance issue (Sumpton, 2000).

RFISH program surveys (Diary and phone Surveys:- 1996/7, 1998/9, 2001/2 and 2004/5)

The most recent Recreational Fishing Information System (RFISH) diary survey, conducted in 2005 indicates that approximately 328,000 snapper and 148,000 pearl perch were harvested (caught and kept) by recreational fishers in Queensland in 2005 (Table 7.4.1). Obviously, successive increases in MLS have impacted on the average size of fish in the catch and this is particularly the case for snapper where MLS has increased from 25 to 35cm from 1993 to 2003. The average weight used for the 1997, 1999 and 2002 surveys was based on the figure estimated from research conducted during the mid 1990's and is the most precise due to the high sampling intensity and large numbers of fish recorded from all sectors and there were no changes in MLS between 1994 and 2002. The 2005 estimate is the one for which we have the least confidence as it is based on a figure derived during 2006. The full impact of the increase in MLS that occurred just over a year prior to the survey would also have impacted over the 2 years immediately after the increase as selectivity and growth effects influenced the resultant size structure of the catch.

The differences in the RFISH figures indicate that the number of pearl perch caught decreased by approximately 30% between the 1999 and 2002 surveys. A similar reduction can be seen in the number of fish harvested while the proportion of fish released appears to have remained stable.

Table 7.4.1 Estimated recreational catch of snapper and pearl perch from the 1997, 1999, 2002 and 2005 RFISH diary surveys (Insufficient teraglin were reported by diarists to enable the reliable estimation of total catch). Relative standard errors (%) shown in brackets.

Snapper	1997	1999	2002	2005	2008[#]
Number caught	1 327 000 (6.9%)	1 284 000 (9.0%)	1 253 135 (6.6%)	1 218 000 (8.2%)	164 953
Number released	750 000 (6.7%)	757 000 (9.2%)	956 695 (7.3%)	891 000 (8.2%)	127 654 (17.1%)
Number harvested	577 000 (8.6%)	527 000 (10.4%)	296 440 (7.6%)	328 000 (9.7%)	37 299 (24.9%)
Harvest weight (tonne)	519[a]	474[a]	267 [a]	525 [b]	

Pearl perch	1997	1999	2002	2005	2008[#]
Number caught		109 000 (21.8%)	74 000 (13.9%)	356 000 (14.2%)	16 906
Number released		44 000 (31.1%)	32 000 (16.6%)	208 000 (15.9%)	11 622 (42.1%)
Number harvested		65 000 (18.1%)	42 000 (13.8%)	148 000 (13.2%)	5 284 (39.9%)
Harvest weight (tonne)		76[c]	50[c]	192[d]	6.8[d]

[a] Using an average weight of 0.9 kg per fish based on the average weight of a snapper caught during research conducted from 1994 to 1996.
[b] Using an average weight of 1.6 kg per fish, estimated from charter logbook data.
[#] Estimates for the 2008 survey are only for boats launching from the Moreton region (refer Webley *et al.* 2009).
[c] Using an average weight of 1.2 kg based on catches measured during the mid 1990s.
[d] Using an average weight of 1.3 kg based on catches of pearl perch from 2006 to 2010

None of the RFISH recreational surveys sampled sufficient teraglin to provide a reliable estimate of total catch for this species. RFISH diary respondents have reported fewer than 200 of these fish in any given survey period, confirming the minor importance of this species compared to other species of rocky reef fish.

The issue of whether catch rates determined from the early RFISH surveys represent an accurate index of abundance is hotly discussed and the determination of an appropriate sampling frame is difficult to determine for some species. It is obviously no use including the “zero” catch of fishers who have no chance of catching a particular species. It is a well known fact that many species’ distributions are heavily clumped rather than distributed uniformly throughout the fishing grounds, even on their favoured habitat. The utility of these surveys is very much species dependent but the fact that the majority of the survey respondents lived and fished in southern Queensland means that species such as snapper are more likely to be representatively sampled, although the notion of a representative sample is difficult to determine and requires a through understanding of the sampling frame as well as detailed knowledge of how that frame was sampled.

This is less of a problem for species such as snapper that are found over the widest range of habitats compared with either teraglin or pearl perch (see Appendix 3.9). Fishers are also able to target particular species depending on the type of bait/gear that they use. There are different methodologies applied to the various recreational catch estimates that further complicate the interpretation of trends. For some species (such as snapper) where different data sets reinforce each other there can be increased confidence in the estimates derived from these surveys. This may not be the case for all species. One of the apparent anomalies in the RFISH data was the large catch of grassy sweetlip in 2005. Whether this represents better targeting or greater availability of this species is unknown, but the fact that this species is one that is used to characterize a rocky reef fisher is important in determining the overall catch rates, as it was often caught without an associated catch of snapper.

An analysis of the catch of diarists showed that 35% of those who caught grassy sweetlip did not catch any snapper at all throughout the period they completed their diaries. This percentage of fishers was reduced to 17% and 22% respectively for those fishers who caught pearl perch and teraglin but did not catch snapper. It is thus clear that spatial and temporal fishing patterns as well as targeting practices of anglers can affect the likelihood of catching particular species or groups even though the individual species may be classified as "a rocky reef species". We modelled different ways of deriving catch rates based on a range of assumptions about what constituted a fishing trip capable of catching a rocky reef species. These ranged from only including catches that reported a particular species of interest to the most expansive assumption where catches of all trips that recorded one of the species defined as a rocky reef species were used to calculate catch rates. Under these scenarios catch rate estimates varied by over an order of magnitude for each of the three species (Table 7.4.2) but snapper was still the most precise estimate, reflecting the high targeting preference, higher abundance and more widespread distribution of this species. The variance was obviously further increased when released fish were included in the catch rate estimates and this effect was proportionally greater for snapper, reflecting the high release rate for that species.

Table 7.4.2 Estimated ranges of catch rates (fish per trip) obtained from recreational catches recorded in RFISH diaries from 1997 to 2005. Highest rate is average of all fish caught on trips when any of the particular species were either retained or released. Low catch figures are averages for all catches where any one of the 10 rocky reef species were caught.

Species	1997	1999	2002	2005
Teraglin	5.25 - 0.56 x 10^{-3}	4.33 - 0.95 x 10^{-3}	6.03 - 0.80 x 10^{-3}	2.74 - 0.24 x 10^{-3}
Pearl perch	3.32 - 1.54 x 10^{-3}	3.95 - 1.39 x 10^{-3}	4.31 - 1.42 x 10^{-3}	5.16 - 2.16 x 10^{-3}
Snapper	6.24 - 15.32 x 10^{-3}	6.02 - 14.88 x 10^{-3}	6.05 - 10.44 x 10^{-3}	5.64 - 7.45 x 10^{-3}

National recreational surveys (Diary and phone surveys:- 2000 and 2010)

Results from the National Recreational and Indigenous Fishing Survey (NRIFS), undertaken in 2000, indicated that the Queensland recreational sector harvested 232,000 snapper. Snapper catch in Queensland was the third highest all any state comprising 18% of the national snapper catch. Reliable estimates of pearl perch and teraglin were not available from the 2000 NRIFS survey as they were grouped with a number of other species. The NRIFS snapper harvest estimate is approximately half the RFISH-estimated catch for 1999 and also significantly less than the 296,000 RFISH-estimated harvest for 2002.

At the time of drafting this report a more recent recreational survey (2010/11) was currently being analysed and reported. This survey utilised similar methods to the earlier NRIFS survey (Phone and diary survey) but more contact was maintained with fishers in order to minimise recall bias.

General Discussion – Recreational Catch and Effort Estimation

There are 10 fish that are classified as rocky reef species for management purposes. These species include the three primary target species by management and the AMU as the following: snapper (*Pagrus auratus*), pearl perch (*Glaucosoma scapulare*), teraglin (*Atractoscion aequidens*). Secondary rocky reef species include samsonfish (*Seriola hippos*), amberjack (*Seriola dumerili*), yellowtail kingfish (*Seriola lalandi*), mahi mahi (*Coryphaena hippurus*), cobia (*Rachycentron canadum*), grass emperor (*Lethrinus laticaudis*) and fryingpan snapper (*Argyrops spinifer*). Despite this classification there are other species, particularly those managed under the Coral Reef Finfish Fishery (CRFFF) which are probably more likely to be encountered when fishing some southern rocky reefs. Example of these species include venus tusk fish, pigfish and various lutjanids, lethrinids and serranids, which were often seen in association with snapper during our BRUVS surveys (see Appendix 3.9) and research ramp surveys as well as recorded in logs of commercial L1 fishers that hold CRFFF "other species" quota. This often causes confusion;

particularly amongst recreational fishers who access both rocky reef and coral reef species caught in the same locations but which have different management arrangements. We have already described how many of the diary respondents caught species classified as rocky reef species in isolation from each other and many clearly "specialised" in a small suite of particular species. Grassy emperor in particular was a common species taken by offshore line fishers in southern Queensland often without catching other rocky reef species, suggesting habitat segregation. Pelagic species including mahi mahi, *Seriola* spp. (amberjack etc) and cobia were often caught without recording other rocky reef species.

The numbers of snapper reported by RFISH diarists is over an order of magnitude higher than pearl perch with relative standard errors reflecting the higher precision of any snapper estimates compared with other species, adding confidence to the estimates of the recreational catch for at least this rocky reef species.

The stratification of the earlier RFISH surveys which results in sampling being distributed according to fisher population density effectively means that the majority of diary participants are from the high population districts of southern Queensland. This results in even more accurate and precise catch estimates of species such as snapper and other species where the catch is largely restricted to more southerly waters where a high proportion of diary participants would be fishing.

The attribution of a zero catch to a trip that had no chance of catching a particular species will severely bias catch rate estimates. Including catches for trips such as these that have no possibility of catching a particular species may result in grossly deflated catch rate estimates. Likewise, only including catches when a species is actually caught has the potential of over-estimating sustainability, as unsuccessful trips that may have targeted that species are eliminated from the analysis and hyperstability of catches and catch rates becomes more likely. When a stock is in decline it is more likely that the number of such zero catches would increase. It is well known that it is possible to target some species of rocky reef fish while at the same time having a low probability of catching some of the other species. Different fishing techniques are often very species specific and sometimes size selective as well. The fact that we have shown that snapper in particular are more widely distributed on the fishing grounds over a range of habitats (see Appendix 3.11) confirms demersal fishing in many areas of the southern rocky reef fishery still has a high probability of catching this species. While a thorough analysis of this was beyond the scope of this report it is important to recognise that determining what constitutes a fishing trip likely to catch a particular species of interest is critical and warrants careful consideration and scenario modelling in any stock assessment that seeks to use catch rates as an index of stock abundance.

The handling of zero catches is not as problematic for the 1995/95 on-site survey data as the assumption is that interviews of fishers at boat ramps were obtained from a random sample of all fishers who were fishing offshore irrespective of their targeting behaviour. Effort estimates were obtained from counts of offshore fishing boats independent of the catch survey and also independent of any targeting preference. Thus, these catch rate estimates are less likely to be biased. Other on-site surveys that have adequate design would similarly provide better estimates of catch rates and would also be more likely to produce more accurate and precise estimates of released fish as recall bias would be reduced.

Bag limit changes will clearly influence the resultant catch rates obtained in any form of survey and based on catch rates obtained prior to the introduction of the 5 bag limit for teraglin and pearl perch, the former species is the one most likely to be impacted as it had the highest proportion of fishing trips where catches exceeded 5 per person. In some cases, catches of more than double the bag limit were reported in earlier surveys prior to the lowering of the bag limit. This observation of some individual high catches has also been reported in the charter fishery on the Gold Coast where very large catches were historically reported (Ray Joyce personal communication). This same level of relatively high catches was also reported, particularly for snapper where the bag limit (even when it was as high as 30 fish per person) was regularly achieved by some anglers (Ferrell and Sumpton, 1997). Pearl perch appears less of a problem here as recreational catch rates of this species appear never to have been of the same order as snapper and thus catch rate estimates through time are less prone to bias caused by reducing bag limits.

Bag limits being exceeded causing biased catch rate estimates are less of a problem when harvested fish as well as released fish are included to determine the catch rate as opposed to a harvest or retained catch rate. However, both precision and accuracy are often compromised when releases are included, largely due to recall bias. Fishers are less likely to remember a fish that they released, particularly if the numbers released are greater than the numbers caught. This is particularly relevant for the species we are considering here, all of which can be released in large numbers depending on the area fished and time of year. Analysis of the raw data from each of the earlier RFISH surveys showed that it was not uncommon for anglers fishing in inshore waters to release greater than 20 snapper per trip. In contrast, numbers of teraglin and pearl perch released were not as great, again confirming the importance of snapper.

We had little confidence that the design and intensity of the earlier RFISH surveys had any ability to provide reasonable estimates of any of the fishery parameters for teraglin in terms of either catch or effort. Likewise onsite surveys encountered few individuals of this species and QFB records of this species are indeterminate. The fact that so few are reported indicates that this is probably not a priority species. We are still uncertain about the historical importance of this species as some personal commercial logs of this species showed very large catches suggesting that at least in areas in south Queensland it was once a more important species than its current low catch status would suggest. The QFB records do not provide any evidence to confirm this, as teraglin was probably included in the generic "Jew" category.

Catch estimates for the other secondary species of rocky reef fish also suffer from relatively high relative standard error, apart from grassy emperor which has clearly been a species that has increased in popularity in recent years in both the commercial and recreational sectors.

The 2005 estimates of recreational catch are often questioned as being grossly overestimated. While there may be some issues in the average weight of fish of some species used to expand catch rates to overall harvest weights due to the proximity of the survey to management changes (largely changes to MLS) made in 2003, ongoing data collected by the AMU and other sources add confidence to these weighting factors. Likewise, 2005 was also a very high catch year when virtually all forms of fishery data were examined, including CFISH data. Of greater concern is the disparity between catch and release of some species across the 2002 and 2005 surveys. We did not have access to the weighting factors used to scale these estimates but this warrants further investigation given differences in the raw sampled data on catch rates.

Results/Discussion - Gold Coast Charter Fishery - Australian Marine Life Institute (AMLI) data

There has been a decline in the contribution of the main target species (snapper) to the overall catch on the Gold Coast, since 1993 (Figure 7.4.6). The proportion of the pearl perch catch ranged from 2% to 14%, with higher proportions recorded in earlier years (1994 to 1997). Teraglin varied in importance more than the other two species between 7% to over 50% with the value of this species to the charter fleet peaking in more recent years.

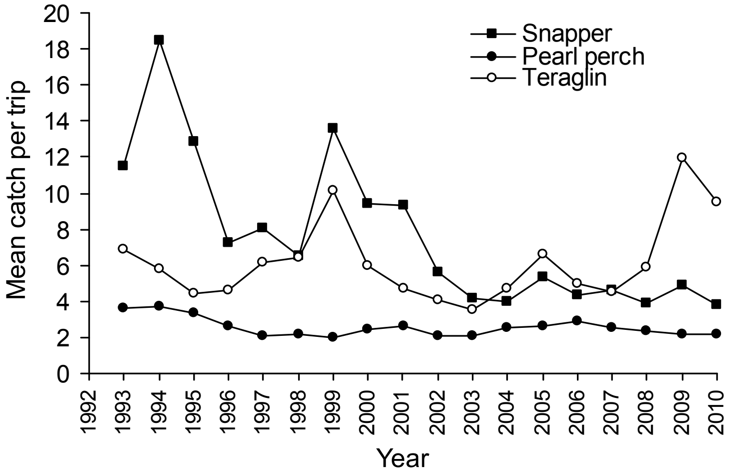


Figure 7.4.6 Standardised catch rates (fish/per trip) of the Gold Coast offshore charter fleet from 1993 to 2010.

Pearl perch catch rates were lower than the other two species and have slowly declined over time with much less variation than the other two species. Seasonality in catch rate was likewise not consistent amongst the three species although summer had generally the lowest catch rates for all species. Snapper catch rates were generally higher during the late autumn and winter months with a clear peak in July. Lowest catch rates for snapper were during the late summer. Teraglin had a bimodal seasonal distribution with the highest catch rates in spring and autumn with a trough corresponding to the peak in snapper catches in mid-winter. The warmer months had the lowest pearl perch catches and this species' catch rates peaked in autumn and spring.

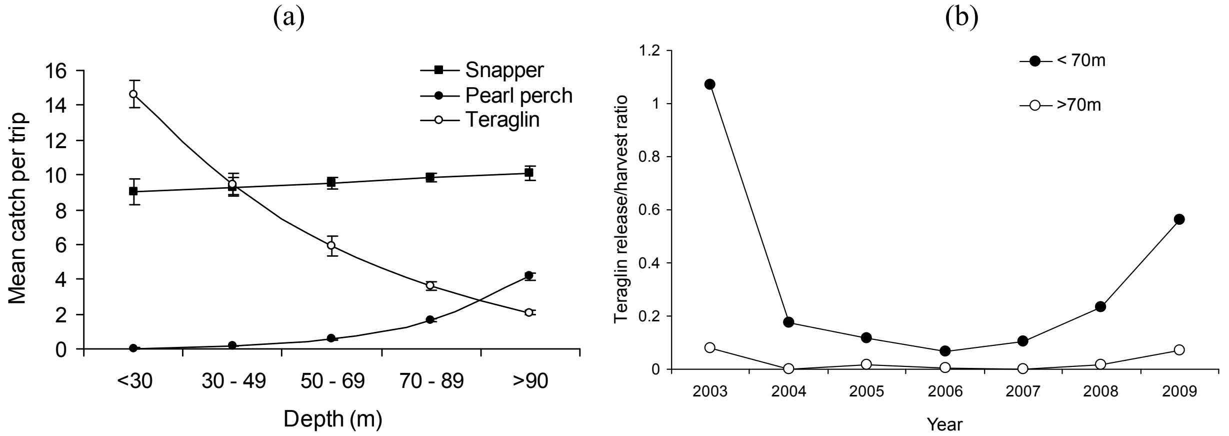


Figure 7.4.7 Model predictions of (a) mean catch rates relative to depth of the Gold Coast offshore charter fleet from 1993 to 2010. (b) ratio of the number of teraglin released compared with the number retained (harvested) from a sample of Gold Coast charter vessels fishing two depth ranges. NB – MLS was reduced from 45 to 38cm in 2003.

The effects of decreasing the MLS on teraglin can clearly be seen in Figure 7.4.7b where the release ratio declined in 2004. It is interesting to note that in recent years the ratio of release to retained teraglin has again increased as increasing numbers of smaller fish continue to be landed by the Gold Coast charter fleet. The release rate was also dramatically higher in water less than 70m deep reflecting smaller size of this species in shallower waters closer to shore.

The fishing operations of many of the Gold Coast charter fleet have changed dramatically over the last 20 years with a trend to fishing shallower water as well as reducing average time on the fishing grounds and increasing the average number of anglers per boat (Figure 7.4.8). Some of these trends have been quite dramatic with average depth fished declining by over 25% from 77m to 55m.

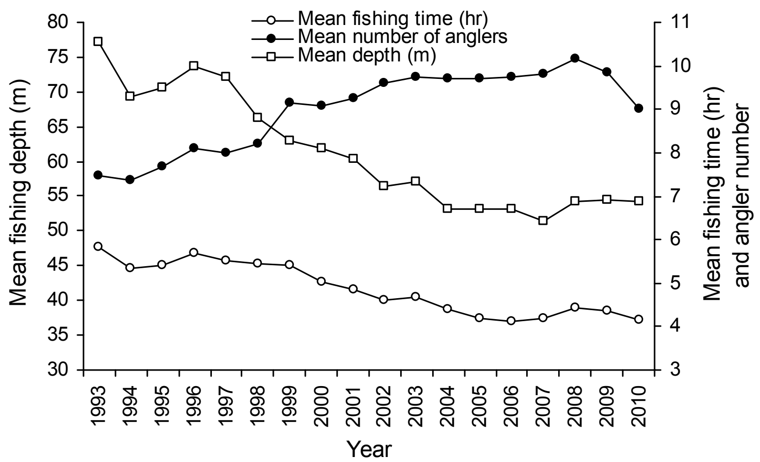


Figure 7.4.8 Change in various trip characteristics of the AMLI sample of the Gold Coast charter fleet since 1993.

The pearl perch discard ratio also suggests recruitment of smaller pearl perch to the fishery occurs during the autumn months when the release rate peaks (Figure 7.4.9). The large confidence intervals, particular during autumn, suggest considerable annual variation and lack of any consistent statistical trends apart from the significantly lower release rates that occur during the summer months when they are half those of the April to June period.

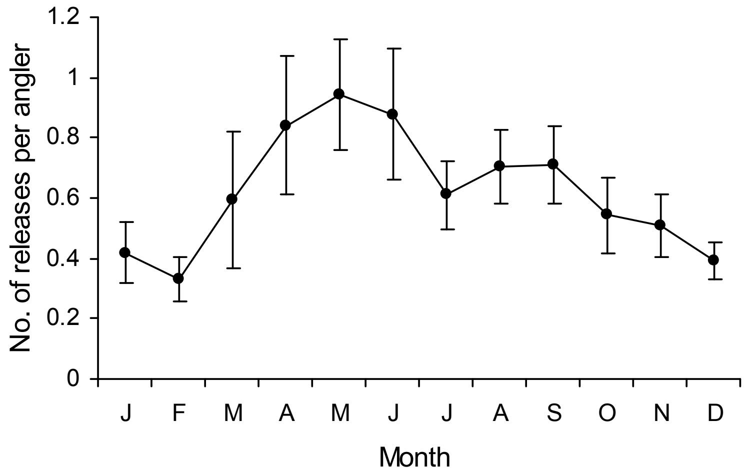


Figure 7.4.9 Monthly variation in the number of pearl perch released per angler on AMLI sampled charter boats fishing on the Gold Coast between 2004 and 2009. Vertical bars are 95% confidence intervals.

The AMLI data are not particularly representative of the pearl perch catch as there are many trips where this species is not recorded largely because the charter skippers fish closer to shore in order to reduce fuel and other costs. Pearl perch are known to be more abundant in the deeper areas (>30m) of the fishery on the Gold Coast and elsewhere in their distribution. Economic conditions can therefore clearly influence catch rates. This may not necessarily relate to any particular change in abundance or other sustainability issues for these species, but be more related to targeting preferences. Recent change to the dynamics of the sampled fleet in terms of fishing time and number of anglers further exacerbate this issue. While data standardisation can adjust for these issues it is more difficult to incorporate important factors such as depth effects into models if these data are not available.

Large numbers of teraglin are regularly reported by Gold Coast charter operators and this is one species that may be representatively sampled by this fishery. While teraglin are caught in all depth ranges with high catch rates of smaller fish in shallower water, larger fish are commonly found deeper. Standardised catch rates from the Gold Coast Charter fleet may therefore provide a useful index of relative abundance for teraglin, particularly if fishing operation of vessel skippers remains fairly consistent through time.

Likewise at a finer scale, seasonal change in the unadjusted species composition in the fishery of the Gold Coast only partially reflects the differential seasonal availability of species. While some species may be caught all year round fishers will take advantage of the seasonal availability of fish such as cobia and target such species even when traditional "bread and butter species" such as teraglin and snapper are still available. This ability of the fishery to selectively target species when they are available is a limiting factor when considering changes in catch rate and the use of catch rates as indices of abundance, at least on small spatial scales. Catch rates for species such as pearl perch may decline in the short term merely because charter operators are targeting other species. This issue of targeting is a significant problem in this and other fisheries, and one which is difficult to address under current catch reporting and other business arrangements. The use of fishery dependent data such as the AMLI data is thus useful to validate trends evident from other data sources.

It is widely accepted that a small subset of a fleet can still exhibit catch rates that are representative of the catch of the entire fleet or more importantly their catch rates may provide a useful index of a species relative abundance. These vessels should characteristically be those that are fairly long-term participants whose effort can at least be standardised so that a reasonable time series of annual indices can be calculated from their catches. It is still an area of contention whether the Gold Coast charter fleet meet these criteria as the nature of the fleet has changed over recent time both in terms of targeting preferences as well as areas fished. The movement to half day charters by some operators as well as competitive business pressures has seen changes to fishing practices among many operators. The global financial crisis and increasing fuel prices caused many structural changes in the fishery as operators sought to further minimise costs and remain viable. The data showing the changes in catch rates with depth suggest that for both teraglin and pearl perch these changes could have a dramatic effect on catch rates. This would be further exacerbated by the varying size structure with depth for many species, particularly teraglin which are smaller in shallower water and caught at higher catch rates in these areas.

Changes in fishing power of vessels are also known to have a dramatic effect on catch rates which is why fishing effort data has to be standardised in order to obtain a reliable index of a species' relative abundance. The sampled charter fleet on the Gold Coast has exemplified dramatic changes in response to a number of influences including:- changes to areas fished in response to species availability as well as deteriorating business and other economic conditions. It is possible to account for many of these variations in our assessment models; however, the data needed to standardise are not always available for the entire charter fleet in Queensland where data is reliant on compulsory logbook information. The observed reduction in fishing time and the increase in numbers of anglers are clearly a reflection of the need to maintain business viability in the face of rising cost pressures. The effect of these two changes could cancel each other as one is an effective increase in effort while the other is an effective decrease. Analysis of the total effect, however, showed that the effect of both was to cause an overall effective decline in effort. It is recognised that changes in fishing characteristics may be partially driven by changes in the sampled vessels (as operators enter and leave the fishery) and there were clearly changes in the characteristics of individual vessels that were maintained throughout the study period.

Longer term analysis of catch data, as yearly averages, still provides a better index of abundance as it is unlikely that the nett effect of changing targeting practices would leave species such as snapper, pearl perch and teraglin as less than fully exploited in the region given high overall levels of general fishing effort in the region.

The compulsorily collected CFISH charter data do not contain information on length of fishing trip or effective fishing hours and there is a limited number of records where the number of anglers is recorded. If there are changes in any of these parameters over time due to economic circumstances (or other reasons) then the lack of these data may hide changes in effective effort since what constitutes "a day's effort" may vary dramatically over time. The Gold Coast charter fleet clearly exemplifies this fact as night time fishing trips and the longer full day trips have been replaced by two trips per day by some operators. The range of practices that individual businesses adopt is clearly diverse and discussions with many charter operators have confirmed this. The current recording practices in the CFISH logs therefore clearly lack precision and may also offer biased assessments over time if conditions change and are unaccounted for in any assessment.

The Gold Coast charter fleet (and charter businesses generally) have been resilient in terms of taking advantage of the seasonal availability of particular species by changing to targeting these species. Under climate change scenarios which predict strengthening of the EAC and the latitudinal movement of species ranges there will be an expected shift of tropical species such as lutjanids and lethrinids further south to the Gold Coast fishery. At the same time temperate species such as snapper, pearl perch and teraglin may become less abundant as they are already at the northern extreme of their distributions in southern Queensland and their ranges are expected to move south. The species most at risk from a Queensland perspective is teraglin as this species has the most restricted northerly distribution and may be further displaced south by any climate change impact.

Yield per Recruit Analysis

Pearl perch discard mortality is low and growth parameters used indicate that for the most likely levels of fishing mortality (F = 0.15 to 0.35), yield is maximised at around the current MLS of 35cm (Figure 7.4.10). This analysis supports the current MLS for this species under current fishery conditions.

For teraglin, estimates of *M* ranged from 0.295 to 0.305. Given the *Z* estimates derived from catch curve analysis range from 0.51 to 1.02, and the higher post-release survival estimates from the experiments conducted as part of the current project, yield is maximised across a range of natural mortality estimates when the MLS is 35cm TL (Figure 7.4.11).

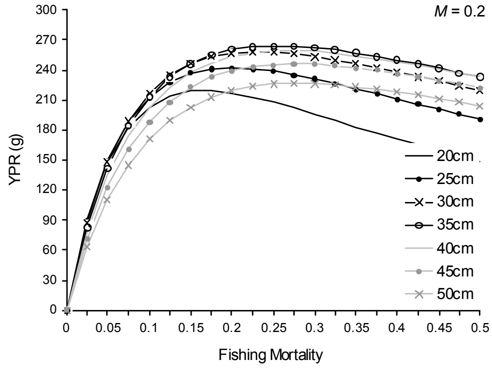


Figure 7.4.10 Change in yield per recruit of pearl perch at a range of different minimum legal sizes (MLS) for various levels of fishing mortality and natural mortality estimate of *M* = 0.2.

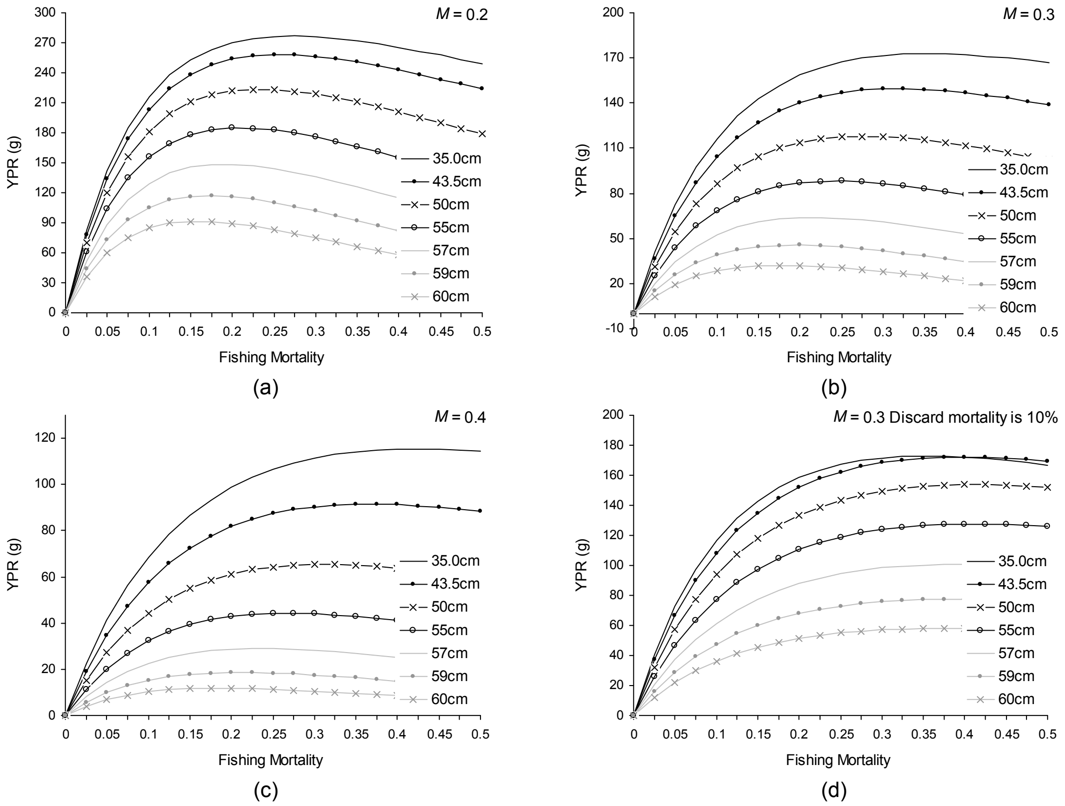


Figure 7.4.11 (a) to (c) Change in yield per recruit of teraglin at a range of different minimum legal sizes (MLS) for various levels of fishing mortality and three levels of natural mortality and 60% discard mortality of undersized fish. (d) Effect of lower discard mortality (10%) on yield.

Development of Harvest Strategies for Rocky Reef Fisheries – General Discussion

As an index of abundance, catch rate data are only sufficiently robust for snapper. Catch and effort data for both pearl perch and teraglin have only been recorded since logbooks were made mandatory for commercial fishers in 1988 and for charter operators in 1996. As such, unlike snapper, these species lack a long-term catch and effort data series. This is also the case for the minor incidental rocky reef species.

The use of snapper trends from Queensland Fish Board records as an historic surrogate for pearl perch in particular is not advised as the depth distribution (and other information) of this species suggests that its fishery may have developed more recently, even more so than teraglin. Most fisheries in southern Queensland were developed by fishers moving further away from port as local stocks became depleted and catch rates fell. The blue swimmer crab fishery is a recent example where fishing effort was limited to western Moreton Bay until the 1960's when it spread more widely throughout Moreton Bay before eventually expanding to offshore waters off Bribie Island during the 1980's with subsequent further offshore development during the 1990's. Since catch rates of pearl perch are generally higher in deeper water (>60m) and many of the productive pearl perch fishing grounds are well offshore it was probably not until the widespread use of sophisticated depth sounders and GPS during the 1990s that saw the rapid expansion of the pearl perch fishery. Nowadays, pearl perch is a significant component of the recreational and commercial catch, rivalling snapper in some regions as the primary target species in some years and generally showing an increasing proportional contribution to the total catch at the expense of snapper.

The fact that catch and effort data are only available for the commercial and charter sector is a limitation to the successful development of more accurate assessments. Our analysis of the commercial CFISH data has also highlighted the impacts of management changes and investment warnings on the accuracy of the reported data. There is currently no capacity to regulate and monitor the catch from the recreational sector on an annual basis, yet this sector is responsible for the highest proportion of rocky reef catch. High relative standard errors of RFISH recreational catch estimates for rocky reef species other than snapper and pearl perch reduce the confidence in our ability to track changes in recreational catch for all but these two rocky reef species. Analysis of the Australian Marine Life Institute data highlighted how changing business conditions can impact on the ability of data to track real change in fisheries.

Summary of Commonwealth 4 tiered assessment system

– Tier 1: robust quantitative assessment
– Tier 2: preliminary quantitative assessment
– Tier 3: estimates of fishing mortality (F) from catch curves (age/length data)
– Tier 4: trends in Catch Per Unit Effort (CPUE)

We would not advocate the consideration of any rocky reef species (other than snapper) for either Tier 1 or Tier 2 assessments (in the terminology of the Commonwealth Harvest Strategy Policy - see above). In the last 6 years snapper has undergone two stock assessments with the next assessment due to be completed in 2015. Further, regular Tier 1 assessments involving management strategy evaluation are a feature of the current management arrangements of that species. It is not our intention to update that assessment here, we only note this project has provided information that will be used to update the next snapper assessment, particularly the post-release survival rates.

The adoption of a biomass-based harvest strategy comes with an increasing cost burden in terms of the monitoring and assessment framework that needs to be maintained in order to obtain accurate and precise assessments of stock status.

The added complication in the management of this fishery is the extent to which it is accessed by the recreational and charter sectors. While estimates of the charter catch are better defined because of the compulsory logbook system, no such system is in place to accurately assess the catch of recreational anglers on a regular basis and annual catches must be inferred from estimates derived from periodic state-wide recreational estimates, conducted every few years.

The recent establishment of a maximum legal size limit for snapper will complicate the derivation of vulnerability schedules in future stock assessment as there is no formal process for evaluating the impact of this measure (other than within the model). Likewise the recent reduction in bag (in-possession) limit, from five to four, will further complicate the catch rate estimation. While modelling catch rate as harvest rate plus release rate can mitigate some of the problems associated with the impacts of changes in bag limit and MLS, estimates of total catch (including releases) do not remain unbiased. The number of fish released is often poorly defined and subject to recall bias more so than in the case of harvest estimates. We have also shown that changes in management arrangements can operate to alter vulnerability in the short term and often management changes will take some time before a new equilibrium is reached in terms of both the size structure of the catch and catch rates. This was noticeable in our analysis of the teraglin charter data collected from the Gold Coast, where the lowering of the MLS from 45 to 38cm initially caused a reduction in release rates (as expected), but over time, as the fishery established a new equilibrium, release rates again began to increase as smaller fish became more vulnerable to capture.

An estimate of Maximum Sustainable Yield (MSY) is available for snapper but no estimate is available for either pearl perch or teraglin nor do we believe that with the current data it is possible to obtain an accurate and precise estimate in the short term. Despite the relative wealth of data for snapper, there is considerable uncertainty around the estimate of MSY due largely to uncertainties in the estimation of virgin biomass. There is however, increased confidence in the derivation of the ratio of current biomass to virgin biomass.

Currently reference points used in performance measurement for the RRFFF are based on catch rates as well as levels of mortality. Only snapper has an additional biomass-based reference point derived from a quantitative stock assessment which is a useful indicator of stock status. We would recommend the definition of target and limit reference points in terms of overall total mortality (Z) rather than biomass in the case of all RRFFF species, except snapper, where biomass is also used. Stakeholders were critical of biomass-related reference points when management options were discussed during the public consultation phase of the last snapper stock assessment completed in 2009; the concepts behind mortality estimates are likely to be more easily understood by stakeholders. The lack of a long term catch series for pearl perch or the other RRFFF species restricts the ability to conduct comprehensive stock assessments on these species.

We argue that the current suite of management controls which involve size and bag limits are still appropriate given the rocky reef fishery is predominantly recreational, where strategies involving arrangements such as quotas or other output controls are difficult to formulate, monitor and manage.

8. BENEFITS AND ADOPTION

This project was designed primarily to be of assistance to fisheries managers and stock assessment scientists involved in ensuring the sustainability of Queensland's rocky reef line fishery. It was also designed to improve the post-release survival of key rocky reef species and aid in the extension of best handling and treatment techniques to fishers.

The estimates of post-release survival for snapper will be particularly useful in the upcoming stock assessment of snapper due in 2014. Previous estimates of post-release survival used in stock assessment models lacked precision and accuracy as they were based on experiments which had some inadequacies. The estimates of short-term post-release survival for snapper derived during the current project, using improved experimental procedures, are over twice those derived previously. Stock assessment scientists indicate that there is a strong desire to use all the information generated by this project to add precision and accuracy to future fishery models. The confirmation of high post-release survival for pearl perch and the identification of treatments that can enhance the post-release survival of teraglin are positive messages that will be extended to the wider fisheries community and will aid in future stock status assessments.

Commercial and charter catch data summarisation and standardisation routines generated by the project are now incorporated in the regular performance measurement reviews for the rocky reef fishery, conducted annually by Fisheries Queensland.

We have further highlighted the need for rationalisation of the ongoing monitoring and assessment of the rocky reef fishery. We have recommended that Fisheries Queensland restrict the species monitored to snapper and pearl perch in the short-term - monitoring resources are best used to reduce the uncertainty around the growth parameter and mortality estimates of snapper and pearl perch rather than devoting limited resources collecting information on, for example, teraglin and cobia. We have also recommended changes to the sampling strategy for pearl perch in order to gain more representative samples and better information on the spatial and temporal scale of pearl perch spawning. Project staff will continue to work with the Assessment and Monitoring Unit over coming months to complete ageing and sampling protocols.

Habitat relationships are still not fully established. Our habitat surveys confirmed the relatively small spatial scale at which individual species abundance can change. We have shown that snapper and pearl perch were observed on a range of habitats in a range of depths, despite their known association with rocky reef, although these two species are more associated with structured habitat.

The impact of changing business conditions on the collection of representative catches in the charter sector has been highlighted, with most charters conducted on inshore grounds, biasing age/length structure sampling, particularly for teraglin.

We have formulated communication material that will be extended to the three fishing sectors accessing the rocky reef fishery. Recommendations for improving post-release survival have been communicated to the various fishery participants via the communications unit of Fisheries Queensland.

The final outcomes and recommendations of this project are yet to be communicated and discussed with the project steering committee. However, once FRDC approval is given to this report the final steering committee meeting will be convened to present findings and discuss future options for incorporating the information collected by the project into stock assessments and management arrangements.

9. FURTHER DEVELOPMENT

While not a priority in terms of the overall economics and management of the fishery in Australia, the taxonomic position of teraglin also needs to be determined in relation to the South African geelbek and other members of the family. This is a relatively simple task that warrants research attention at some stage in the future.

The actual written ageing protocol for pearl perch is still to be formulated but staff involved in this project will continue to work with the AMU to develop protocols for the representative sampling, ageing and analysis of pearl perch, in particular. In this regard, it is important that representative catches are obtained from the more northerly parts of the distribution of pearl perch and that reproductive information continues to be collected to enable important spawning regions to be more accurately determined.

The influence of errors in ageing and various analytical processes leading up to the derivation of fisheries parameters has received considerable research attention largely at the level of individual analytical processes such as age length keys, errors in growth estimation etc. While guidelines exist for appropriate fisheries sampling design and the management of errors, the incorporation of uncertainty and potential for bias at all stages of the procedures used in the estimation of growth and mortality would be beneficial.

Very little relevant Queensland-based research has been conducted on the incidental rocky reef species, particularly the grass emperor, the catch of which has increased significantly in the commercial and charter sectors since 2008. We recommend that further research is required to ensure the current MLS of 25cm TL is appropriate in relation to the length-at-maturity of grass emperor in Queensland.

We recommend that future research should attempt to determine differences in catch rates and other fishery parameters for daytime versus night time anglers, as well as catch rates of fishers using trailerable vessels leaving and returning from ramps versus catch rates of fishers from privately moored vessels (those that cannot be surveyed from boat ramps). Further, we recommend that, in conjunction with current methods for estimating recreational catch rates, novel methods should be developed to accurately determine the catch of rocky reef fish by the recreational sector. Further research should also focus on quantifying the effects of the use sophisticated GPS and sonar technologies in the RRFF to enable the derivation of more accurate catch rate trends for snapper in stock assessments.

There is clearly a need to further refine methods of ameliorating the effects of barotrauma on rocky reef fish. Although we have determined that the short-term post-release survival of snapper, pearl perch and teraglin, long term survival studies are complicated by a range of logistical difficulties. The variability of post-release survival estimates for a range of species in the scientific literature confirms the difficulty in adding precision to post-release survival estimates.

We are loathe to recommend buccal venting as a general technique given that we have only established its efficacy in the short-term for one species of fish – pink snapper. The process of piercing an everted digestive tract to release swimbladder gases has historically had widespread disapproval, but we have found little scientific evidence to discount it as a means of relieving barotrauma symptoms. The main evidence appears to come from the "belief" that damage to the digestive tract would cause infection which would only become evident in the medium to long term. Estimation of long-term mortality related to barotrauma and subsequent infection is a logistically-difficult task as the practice of holding and feeding deepwater fish *in situ* or in aquaria have a number of disadvantages. Despite this, the process of piercing an everted gut with a hook is an attractive option for barotrauma relief providing it does not cause additional mortality. This is an area also warranting further research and possible extension to the fisheries community should this technique improve the post-release survival of rocky reef fish. The technique of venting fish by piercing near the anus (as is currently the practice in the live coral trout fishery) may also require further investigation as a more generally acknowledged and recommended technique. The alimentary canal of pearl perch was found to naturally rupture near the vent when brought up from depth and still had good short-term survival. The relief of barotrauma symptoms by anal venting would also reduce the probability of inadvertent organ damage caused by lateral venting since there are fewer vital organs around the cloaca. In contrast, the area used to insert a needle for lateral venting has many vital organs in the vicinity, including the heart and liver.

Swimbladder healing and physiological recovery from barotrauma injury is an area that, at present, is poorly understood. It is essentially an area of academic interest rather than important from a fisheries management perspective. However, a better understanding of the potential to heal may provide more general guidance on the likelihood of the post-release survival of species that have not been assessed comprehensively in field experiments but have anatomical similarities regarding the swim bladder.

While we have not established significant size-related mortality for snapper, we assessed few fish greater than 70cm. If the recently introduced recreational in possession limit of one snapper over 70cm results in very high discard rates, it will be necessary to investigate post-release survival of snapper of this size in future.

Scant information is available on the post-release survival of amberjack. These fish have recently become the target of a catch-and-release sport fishery and have a bag limit of 2. As such, we recommend the post-release survival of amberjack be assessed using the methods detailed in the current study.

Small scale spatial and temporal changes in individual species distributions as well as the composition of the associated fish communities even on the same habitat types can vary dramatically. Areas that are classified in Marine Park zoning, for example, as the same habitat type can support vastly different benthic communities, making the effect of Marine Park zones difficult to evaluate without any "before and after" comparison. Marine protected areas as part of the Moreton Bay Marine Park offer some protection to juvenile and adult snapper but likely do little to conserve either pearl perch or teraglin. Both these species are absent from Moreton Bay and other estuarine areas. The seasonal utilisation of these soft substrate habitats is still not defined.

The distinction between management arrangements of coral reef and rocky reef fish creates confusion, particularly in southern Queensland. In the south, a wide range of both coral reef and rocky reef species are caught on the same fishing grounds. The range of species observed during our BRUVS surveys clearly exemplify this point as does the analysis of the commercial and charter logbook data. This is less of an issue in north Queensland where species such as snapper, pearl perch and teraglin are not common, and the offshore demersal fishery is truly a coral reef fishery. Attempts should be made to bring the management arrangements of rocky reef and coral reef species into line.

Data generated by this project are stored in a secure Microsoft Access database administered by the DAFF, Queensland on a server located at the Ecoscience Precinct in Brisbane. The DAFF will make project data available on the Internet as per the FRDC data management policy.

10. PLANNED OUTCOMES

We have provided estimates of key biological parameters (growth rate, reproductive parameters, size structure, age structure, mortality estimates for both pearl perch and teraglin as well as providing less detailed information (largely from the literature and an analysis of logbook data) for the minor rocky reef species such as cobia and grassy emperor. These will be used in stock status deliberations, performance management assessment and future stock assessments.

Estimates of short-term release survival have been derived for the three main target species (pearl perch, teraglin and snapper). Survival estimates for snapper will be used in the next snapper stock assessment due in 2015. High release survival of pearl perch confirm the resilience of this species to line capture (providing best handling practises are maintained) and the low release survival of teraglin is somewhat mitigated by the size stratification with depth of this species, as smaller individuals are more commonly caught in shallow water where survival is better.

We would envisage that ongoing extension of the results of our post-release survival research to the wider community and the adoption of best handling and treatment practices will increase the overall post-release survival of the rocky reef species studied here. We see further positive benefits providing our preliminary results regarding the efficacy of "buccal venting" can be further confirmed, developed and possibly extended to other species.

We have also provided a number of specific recommendations for improving the monitoring of rocky reef fisheries. Project staff will continue to work with the Assessment and Monitoring Unit to provide more precise and accurate estimates of various sampling, ageing and analytical parameters to achieve a more cost effective monitoring program and improved fisheries information systems.

Yield per Recruit modelling has confirmed that current management by minimum legal size is appropriate for pearl perch and teraglin and current harvest strategies involving minimum legal sizes optimise fishery yields for these two species.

This research will result in improved levels of confidence in the outputs of stock assessment models for snapper given we have improved the level of precision and accuracy in some of the inputs to the assessment model for that fishery. This will be of benefit when communicating information on stock status to various fishery stakeholders in the future.

11. CONCLUSIONS AND RECOMMENDATIONS

The broad conclusions of the project related to the achievement of the specific project objectives are detailed below. Objective specific recommendations are also provided.

Objective 1 Determine key biological parameters required to sustainably and profitably manage the fisheries for key rocky reef fish species (particularly pearl perch and teraglin).

- We have provided estimates of the important fisheries parameters needed for the sustainable management of the teraglin and pearl perch fisheries in terms of growth, mortality rates, and reproductive parameters and confirmed that both species are likely to be currently classified as fully-fished or over-fished.
- The accuracy and precision of fisheries parameters are higher for pearl perch than for teraglin.
- The catch of rocky reef species other than snapper, pearl perch and teraglin exhibit significant spatial and temporal variation, resulting in "patchy" sampling and limitations regarding stock assessment information. This reduces their value as species for detailed assessment and also reduces the confidence in the results of risk assessments.

- The existing management measures for teraglin and pearl perch are adequate given the current fishery conditions. However, for yellowtail kingfish, samsonfish, amberjack and cobia, the current MLS is most likely lower than the length-at-maturity.

Recommendations

1. Concentrate rocky reef fish monitoring resources on snapper and pearl perch and consider removing teraglin from the list of primary rocky reef species being monitored.

2. Ensure spatially and temporally representative samples of snapper and pearl perch are obtained from the commercial fishery in particular.

3. Review existing monitoring and assessment protocols for collecting and processing fisheries information for "minor" rocky reef species (cobia, amberjack etc) with a view to reducing biological material processing costs.

4. Continue to collect reproductive information (specifically macroscopic gonad staging) for pearl perch and extend the sampling period to include summer to better define spatial and temporal spawning patterns over the entire extent of the fishery.

5. The Assessment and Monitoring Unit should record catch location information at the finest spatial scale possible and to the level of individual fisher whenever possible in order to better understand possible spatial and temporal bias in sampling strategies and to more precisely determine pearl perch spawning areas.

Objective 2 Quantify the post-release survival of common rocky reef species and investigate novel ways of enhancing release survival.

- The post-release survival (or at least an estimate of relative survival) of pearl perch, teraglin and snapper has been quantified and recommendations made for reducing the effects of barotrauma on fish survival.
- Pearl perch has a vey high post-release survival (>90%) and we do not recommend any treatment for this species.
- Snapper post-release survival is also higher (88%) than previously determined but we would recommend treatment for barotrauma for this species using a release capsule or buccal venting.
- Post-release survival of teraglin is low (<50%) and depends on a range of factors, but can be improved by treating fish either by venting or using a release capsule.
- We have trialled alternative ways of treating fish for barotrauma but believe that long-term survival should be assessed before the technique we describe as "buccal venting" is widely advocated across the fishery or recommended for use on other species.
- Analysis of recreational tag and recapture data for snapper and pearl perch supports some of the conclusions drawn from the short-term controlled post-release survival experiments. However, in some circumstances they provide biased estimates due to the usual logistical problems associated with tag and recapture studies (e.g. tag loss, tag-induced mortality, under-reporting)

Recommendations

1. Extend and communicate best handling and barotrauma treatment procedures to all sectors using Departmental communication strategies.

2. Use updated estimates of short term release survival obtained during this research in the next snapper stock assessment due for completion in 2015.

Objective 3 Determine the important habitats for rocky reef species and identify possible threats to those habitats.

- While we have not quantified with any great precision the important habitats across the region we have confirmed the importance of estuarine/embayment habitats for snapper and the more offshore distribution of pearl perch and teraglin (and the absence of the latter two species from estuarine habitats).
- We have not been able to identify juvenile teraglin habitat although we have confirmed that the size/depth stratification that occurs on the Gold Coast is unlikely to extend to waters further north as few smaller fish are seen in these areas.
- The relative rarity of teraglin in trawl survey by-catch suggests that this species may rely on very shallow habitats not sampled during this study and previous trawl surveys or that the juvenile biomass is distributed in more southerly waters of NSW.
- While our BRUV survey failed to detect juvenile pearl perch we hypothesise, based on samples collected from commercial crab fishers and trawl surveys, that this species utilises soft substrate habitats similar to snapper, but outside Moreton Bay. Like snapper, these habitats may only be seasonally important.
- The lack of pearl perch, snapper, and teraglin on soft habitats off North Stradbroke Island and South Stradbroke Island suggests a general lack of fisheries productivity from this region. However, the lack of temporal replication in sampling reduces the level of confidence in this conclusion.
- Current Moreton Bay Marine Park Zoning provides a greater benefit for snapper than for either pearl perch or snapper.

<u>Recommendations</u>

1. Encourage further research to determine recruitment dynamics of rocky reef species and specifically the dynamics of the East Australian Current and other oceanic processes on rocky reef fisheries. We have a far better understanding of coral reef dynamics compared with the dynamics of rocky reefs.

Objective 4 Develop harvest strategy approaches that enable the sustainable management of rocky reef fisheries.

- Snapper is currently the only species for which a Tier 1 assessment and harvest strategy (in terms of Commonwealth fisheries policies) is appropriate.
- Pearl perch is currently assessed via a Tier 3 approach (age-based fishing mortality estimates) which is appropriate in the short-term.
- Teraglin should be discontinued as a primary species for assessment and monitoring with resources being devoted to collecting more accurate and precise data on snapper and pearl perch.
- The monitoring of total fisheries mortality on an annual basis for both snapper and pearl perch should continue and will become even more useful when sufficient years of data are available to conduct a more detailed cohort analysis.
- Management of pearl perch, teraglin and snapper by output controls such as MLS is an appropriate harvest strategy given the scale of the fishery and the different sectors that access the resource.

<u>Recommendations</u>

1. Maintain existing size limits for both pearl perch (35cm) and teraglin (38cm).
2. Update snapper stock assessment as a matter of priority using additional age structure information collected by AMU and incorporating the release survival estimates derived by the current research.

3. Incorporate effects of fishing technology (GPS, sounders etc) into catch standardisation protocols. These data are being collected as part of related research being conducted by the University of Queensland and by DAFF as part of research into the deepwater line fishery (FRDC Project 2010/053).

4. Quantify the impacts of the recently introduced maximum size of snapper on mortality estimates and sustainability of the snapper fishery. This can be achieved by including questions regarding specific releases of large snapper into future RFISH surveys and other surveys of recreational fishers.

5. Modify charter logbooks to obtain more detailed information on fishing characteristics such as fishing time to enable better standardisation of catches.

6. Work with industry to generally improve the quality of commercial logbook data provided by commercial line fishers.

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13. APPENDIX 1. INTELLECTUAL PROPERTY

The research was for the public domain. The report and any resulting manuscripts and extension material are intended for wide dissemination and promotion.

14. APPENDIX 2. STAFF

Dr Wayne Sumpton (Principal Investigator)

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15. APPENDIX 3. DETAILED INFORMATION USED TO ADDRESS PROJECT OBJECTIVES

The following appendices provide more detail on the achievement of project objectives than is provided in the main body of the report. They are written as a series of smaller chapters that deal with discrete components addressing the more general project objectives. Each appendix contains a summary of the findings as well as a justification of the methods, detailed results and a discussion of their implications.

Appendices 3.1 to 3.3 relate to the first project objective and describe the parts of the project that derived the key biological information for rocky reef fisheries, particularly pearl perch and teraglin.

Appendices 3.4 to 3.7 address the post release survival issues of the main targeted rocky reef species. Appendix 3.4 examines the long term survival of pearl perch and snapper using ANSA tagging data, while appendices 3.5 to 3.7 deal with the experimental approach we took to address short-term release survival issues of pearl perch, teraglin and snapper respectively.

Appendices 3.8 and 3.9 relate to the third project objective, which is an investigation of the habitat of rocky reef species, while the final 3 appendices (3.10 to 3.12) consider the additional information that is important for developing harvest strategies for the sustainable management of rocky reef species.

APPENDIX 3.1 BIOLOGICAL AND FISHERIES INFORMATION FOR MONITORING AND DEVELOPING HARVEST STRATEGIES FOR PEARL PERCH (*Glaucosoma scapulare*) IN SOUTHERN QUEENSLAND

Summary

Pearl perch samples were collected by the Queensland Government's fisheries Assessment and Monitoring Unit (AMU), supplemented by research sampling, and assessed for various biological information. The length frequency distributions of pearl perch sampled were skewed toward the minimum legal size (MLS) of 35cm (but less so than other RRFF species), with most fish (~50-60%) caught from all sectors being between the MLS of 35cm to 50cm. In areas where fishing has traditionally occurred, such as the areas offshore from the Gold Coast, Sunshine Coast and Brisbane, fish size was generally less than 50cm in all sectors, with fish >50cm more common in waters between Fraser Island and Gladstone. Immature and undeveloped/resting female pearl perch ovaries were more likely to occur in the winter months, while spawning fish were only observed from catches landed in November and December. Fifty percent of female *G. scapulare* were mature in the size range 25-27.5cm, with all female pearl perch mature at the MLS of 35cm. Gonosomatic Index peaked in December, averaging 1.45% and was lowest in the winter months. Growth curves of male and female pearl perch were significantly ($P < 0.05$) different with the von Bertalanffy growth parameters were found to be L_∞ = 720.8mm, k = 0.154yr^{-1} and t_0 = -0.520yr for males (n=455) and L_∞ = 723.7mm, k = 0.137yr^{-1} and t_0 = -0.1001yr for females (n=512) sampled during 2009 and 2010. The oldest animal sampled was 67cm, 22 years old female. 9.6% of fish were older than 10 years. Age frequency distributions of *G. scapulare* were truncated, with 3 – 9 year old fish accounting for 94.9% and 95.9% of all fish caught in 2009 and 2010, respectively. Pearl perch were fully-recruited to the fishery at age 5 in 2009 and age 6 in 2010. Total instantaneous mortality estimates were Z = 0.49 in 2009 and Z = 0.59 in 2010. Empirical natural mortality (M) estimates ranged between 0.20 and 0.38. Older, larger pearl perch were caught in waters between Fraser Island and Gladstone, with the majority of spawning and pre-spawning females caught in this area. This confirms earlier studies that suggested that pearl perch migrate northward to spawn. Increasing fishing pressure in these areas, combined with the fact that pearl perch are long-lived and slow growing, indicate that this species may be vulnerable to overfishing. Based on the mortality estimates derived during this study, we would categorise the pearl perch fishery as fully-exploited, with a possibility that the fishery is over-fished. As such, we recommend that AMU increase sampling of pearl perch caught in the areas from Fraser Island to Gladstone and record macroscopic gonad stages.

Introduction

Pearl perch *Glaucosoma scapulare* are distributed from Port Jackson, New South Wales northwards to waters off Rockhampton (McKay, 1997) in depths to at least 200 metres (Sumpton, unpublished data). *G. scapulare* are a highly-prized table fish (McKay, 1997; Grant, 2002), with catches of 34.7 t, 32.6 t and 23.4 t landed by the recreational (Recreational fishing surveys), commercial (logbook data) and charter (logbook data) sectors, respectively, in 2010. These landings are second only to snapper *Pagrus auratus*, the iconic sparid seen historically as the primary target species in Queensland's Rocky Reef Finfish Fishery (RRFF). *G. scapulare*, one of four Glaucosomatids found in Australia, are a schooling species occurring close to submerged reefs (McKay, 1997) and adjacent areas, particularly those where wire weed (Gorgonid soft corals) occurs (Grant, 2002).

Little is known about the fisheries biology of *G. scapulare* apart from a preliminary study (Sumpton *et al.*, 1998), which suggested they were a slow growing, long-lived fish in accord with the congeneric West Australian dhufish *G. hebraicum* (Hesp *et al.*, 2002) and North-west jewfish *G. buergeri* (Newman, 2002), attaining 70cm TL and 7.3kg in weight (Grant, 2002).

Historically, fishers targeted known reefs located via landmarks in order to catch *P. auratus*, with other reef-associated species such as *G. scapulare*, yellowtail kingfish *Seriola lalandi* and cobia *Rachycentron canadum* caught incidentally. However, with the increasing availability of affordable, advanced GPS and sonar technologies and the localised depletion of inshore reefs, fishers began fishing further offshore and northwards to previously unfished areas. At the same time, the catch rates of *P. auratus* in the recreational sector declined significantly (Campbell *et al.*, 2009) prompting more stringent management measures such as decreasing bag limits and increasing minimum legal sizes.

The declining *P. auratus* catch rates, combined with reductions of the in-possession (≈bag) limits for recreational anglers, saw fishers diversifying and targeting areas where *G. scapulare* congregate, including gravel and wire weed substrates adjacent to rocky reef, as well as wrecks. This has led to increasing pressure on *G. scapulare* in recent years and, given their longevity and relatively slow growth rates, concerns exist regarding the long-term sustainability of the species (John Stewart, personal communication).

The species' longevity and resultant long reproductive life are thought to ensure the stock through periods of poor recruitment (Stewart, 2011). However, age-class truncation may decrease the resilience of *G. scapulare* through such periods by reducing the reproductive potential of the population (Stewart, 2011). Preliminary age structures derived for the Queensland commercial fishery in 1995/6 showed that very few large, older fish were caught which has been attributed to a migration to spawning grounds at the northern extreme of the species' range, although there is currently no evidence to confirm this. The recent expansion of the RRFF into the northern range of *G. scapulare*, along with increased sampling coverage in this area, discussed below, will facilitate the testing of hypotheses regarding any northward spawning migration(s).

In response to a Stochastic stock reduction analysis of *P. auratus* conducted by Allen *et al*. (2006) which showed that this species was being overfished and highlighted concerns for other rocky reef species, Fisheries Queensland began sampling the catches of rocky reef fish, including *G. scapulare*, as part of its routine fisheries monitoring program.

The management arrangements for the RRFF recently received criticism from stakeholders as a result of legislation introduced in March, 2011, due to the fact that *P. auratus* was found to be overfished in the most recent stock assessment (Campbell *et al.*, 2009). The management review called for a range of options to reduce catch in the RRFF including a six week closure (for *P. auratus*, *G. scapulare* and teraglin, *Atractoscion aequidens*), quotas for commercial and charter fishers and reductions in the in-possession (~bag) limits for recreational anglers. Stakeholders nominated a perceived lack of accurate data as major limitation of the assessment models. This has reinforced the need for up-to-date and accurate data that are collected, collated and analysed transparently, in order to add accuracy and precision to model outcomes and increase the confidence with which rocky reef fish stocks can be managed.

In Queensland, the only biological data available are from a preliminary report (Sumpton *et al.*, 1998) that biological and population structure information from samples collected as part of the FRDC-funded research project *Assessment of the fishery for snapper (*Pagrus auratus*) in Queensland and NSW* (FRDC Report 93/074). This report provided preliminary information on the growth, reproduction and mortality of pearl perch, generated from fishery-dependent sampling but was limited by the lack of younger fish for growth analysis and low numbers of samples for reproductive information. The current project was initiated to update this information, specifically regarding growth, ageing and reproduction, so that this information can be used in forthcoming stock assessments.

This chapter directly addresses Objective 1: "Determine key biological parameters required to sustainably and profitably manage the fisheries for key rocky reef fish species", specifically regarding pearl perch.

Methods

Pearl perch samples were collected as part of the rocky reef fish monitoring program conducted by the Assessment and Monitoring Unit of Fisheries Queensland. Samples are collected from commercial fishers, recreational fishers, charter operators and seafood processors as part of the routine sampling that started in 2006. Sampling takes place in south east Queensland from Baffle Creek, just north of Bundaberg, to the News South Wales-Queensland border (see Figure 1). The sampling protocols are summarised in the document by Fisheries Queensland (2010). This program aims to collect representative length data to estimate length structure as well as samples from which to obtain length, sex and age data.

Samples are collected opportunistically year-round with the purpose of, for example, constructing age structures via age-length keys (ALK's) to determine mortality rates.

To supplement this sampling, project staff obtained pre-recruits, 0+ and 1+ animals, to provide information on juveniles, specifically with regard to growth and the lower bounds of growth curves that are lacking from fishery-dependent sampling where minimum legal size restrictions are in place. Additional biological samples were also collected from various sources, including commercial fishery samples and fish from the post-release survival experiments detailed in Appendix 3.5.

Morphometric information

Samples collected by project staff were used to develop fork length-total length conversions given that AMU record only fork length. Linear regressions were performed in Genstat (2011) to generate the regression equation $\text{Total length} = \beta_0 + (\beta_1 \times \text{fork length})$.

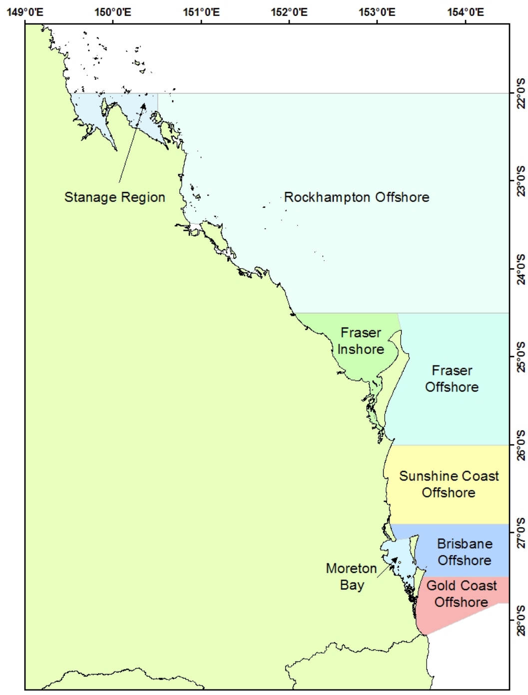

Figure 1 Location of Assessment and Monitoring Unit sampling regions taken from Fisheries Queensland (2010)

Reproduction

Gonads were staged macroscopically in the laboratory in accordance with Mackie *et al*. (2009). The staging system used is summarised in Table 1. Gonads were staged in this manner when project staff either collected samples or assisted in the processing of samples collected by AMU.

The lengths at which 50% of the females reached sexual maturity (L_{50}) were determined by fitting a logistic curve to the proportion of females with gonads at stages II to V (see Table 1) for each 2.5cm length (TL) class. Once staged, female gonads were weighed and Gonosomatic Index (GSI) was calculated using the following equation:

$$\text{GSI} = \frac{\text{Gonad weight (g)}}{\text{Total weight (g)}} \times 100$$

In accord with Hesp *et al*. (2002), mean monthly GSI was calculated using only individuals greater in size than the L_{50} calculated above.

Table 1 Simplified macroscopic staging classification for female *G. scapulare* ovaries as described by Mackie *et al*. (2009).

Stage	Description of ovaries
0 – Unknown gender	Small translucent ribbons, sex indistinguishable.
I – Immature	Ovaries thin and firm, pale or translucent pink.
II – Resting	Ovaries more rounded, pale pink or red. No oocytes visible. Approximately 1/4 - 1/3 length of body cavity
III – Developing	Ovaries enlarged, pale orange or pink, blood vessels noticeable. Oocytes visible, small. Approximately 1/3 – 2/3 length of the body cavity.
IV – Developed	Ovaries enlarged, orange or yellow but not speckled. Oocytes large and clearly visible.
V – Spawning/Spent	Ovaries much enlarged, translucent pale orange. Hydrated clear oocytes visible giving speckled appearance. Blood vessels prominent. Alternatively, ovaries bloody and flaccid (spent).

For samples collected by AMU, where frames were collected from fishers and processors, a total weight (g) was calculated from fork length (cm) using the following equation from Sumpton *et al*. (1998):

$$\text{Weight} = 0.04 \times \text{Fork length}^{2.787}$$

Age and growth

The age of *G. scapulare* was assessed according to protocols developed by AMU (Fisheries Queensland, in press). In summary, sagittal otolith pairs were removed, washed and dried. One otolith was then blocked in polyester resin and set aside until the resin had completely cured. Once cured, a thin section (0.3mm) was taken through the focus with a diamond-edged circular saw. The section was then mounted on a glass slide using epoxy resin for microscopic examination.

Mounted otoliths were examined using a dissecting microscope and reflected light on a matt-black background. Nominal ages were assigned according to the number of opaque zones between the primordium and the distal edge of the otolith (see Figure 2). Ages were then corrected by assigning a birthday of all fish to January 1 so that, for example, a fish with 4 opaques zones caught on the 30 June would have a corrected age of 4.5 years. That is:

$$\text{Corrected age} = \text{nominal age} + \frac{(\text{no. days after January 1 individual was caught})}{365}$$

Edge-type was also recorded and classified as new, intermediate or wide, according to the width of the translucent material between the distal edge of the otolith and the last opaque zone.

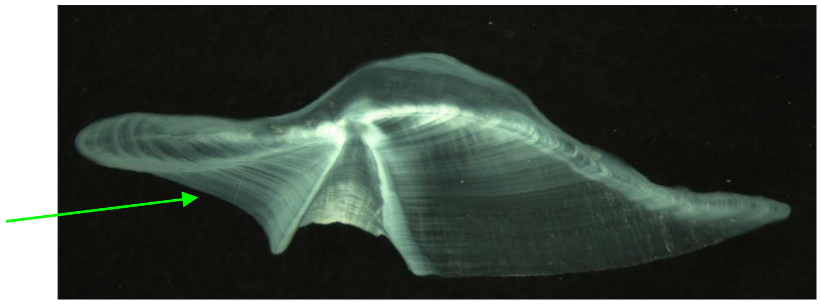

Figure 2 Sectioned pearl perch otolith with primary reading area highlighted.

The birth date of 1 January was allocated given the proportion of Stage 5 gonads observed in samples and the increasing GSI in the months October to December (see Figure 6 and Figure 7b).

The von Bertalanffy growth parameters k and L_∞ were estimated using least-squares techniques as described by Haddon (2001), whereby the expected total length of each individual, given the corrected age is:

$$E(L_i) = L_\infty\left(1 - e^{-K(t_i - t_0)}\right) + \varepsilon_i$$

where $E(L_i)$ is the expected total length of the ith individual in mm, L_∞ is the average maximum length in mm, k is the growth rate parameter, t_i is the corrected age of the ith individual, t_0 is the age at zero length and ε_i is the normal error term. The von Bertalanffy growth parameters k, t_0 and L_∞ were estimated using non-linear regression in Genstat (2011) by minimising the sum of the squared difference between the expected length and the observed length. Further, 95% confidence intervals were also derived for the von Bertalanffy growth curves using the following equation:

$$-1.96 \times \sqrt{s^2 + se_\mu^2} < \mu < 1.96 \times \sqrt{s^2 + se_\mu^2}$$

where s^2 is the variance from the model and se_μ is the standard error about the predicted mean lengths-at-age and μ is the predicted mean length-at-age .

In accord with Silberschneider *et al*. (2009), growth parameters of males and females caught between January 2009 and December 2010 were compared via an analysis of residual sums of squares using methods described by Chen *et al*. (1992).

Mortality

Estimates of total instantaneous mortality, Z, were derived using methods described by Ricker (1975), as used by Silberschneider *et al*. (2009). Total instantaneous mortality rates were derived across all sectors for the years 2009 and 2010. Length frequency data generated from AMU sampling, together with the length-weight conversion above, were used to determine the mean weight of *G. scapulare* caught in the commercial, charter and recreational sectors. Total catch for the charter and commercial sector was determined using logbook data described in Appendix 3.10 and weighted by AMU sampling region (see Figure 1), while estimates derived by McInnes (2008) were used to determine total catch for the recreational sector.

The total catch of each sector was then divided by the respective mean weight of *G. scapulare* to determine the total number of fish caught. Annual length frequency distributions, as proportions in 25mm size classes, were then applied to these data to derive a length frequency distribution for each sector. Age-length keys for 2009 and 2010, derived using length-at-age data, were then applied to determine age frequencies. The frequencies were then converted to percentages before being transformed via a natural logarithm.

Linear regressions were then fitted to age versus the natural logarithm data, the slopes of which approximated the total instantaneous rate of mortality. The age frequency distributions were assessed to determine the age at which *G. scapulare* were fully recruited to the fishery, with these values used as the minimum age for the linear regressions. A range of ages were assessed for the maximum age used in the linear regressions and depended on sample sizes in the older age classes.

Natural mortality, M, was estimated using the empirical equation reported by Hoenig (1983), i.e. $M = e^{1.44 - 0.982\ln(t_{\max})}$, with the value of t_{max} varying due to variability in ageing the oldest fish collected. The method reported by Pauly (1980), that is $\log M = -0.066 - 0.279 \log L_\infty + 0.6543k + 0.4634 \log T$, where L_∞ and k are the von Bertalanffy growth parameters derived during the current project and T is the mean annual temperature, was also used to estimate M. Further, the method derived by Jensen (1996) which approximates M as 1.5 times the von Bertalanffy growth parameter k, was also investigated.

Results

1076 individuals were measured in order to establish a fork length/total length relationship. Individuals ranged in size (FL) from 65mm to 690mm. The linear regression generated in Genstat (2011) accounted for 99.9% of the variance, with the linear regression equation taking the form:

$$\text{Total length (mm)} = 0.831 + [1.0504 \times \text{Fork length (mm)}]$$

A total of 14,348 pearl perch were measured by AMU in the period November 2006 to April 2012, ranging in size from 24cm TL to 82cm TL. A total of 6,829, 4,537 and 2,982 individuals were sourced from charter operators, commercial fishers and recreational fishers, respectively (see Figure 3). The length frequency distributions from all sectors are skewed heavily, with most fish caught from all sectors being between the MLS of 35cm to 50cm TL. In all sectors, proportionally few fish > 55cm TL are caught, although the commercial sector catch more larger fish than the other two sectors (Figure 4).

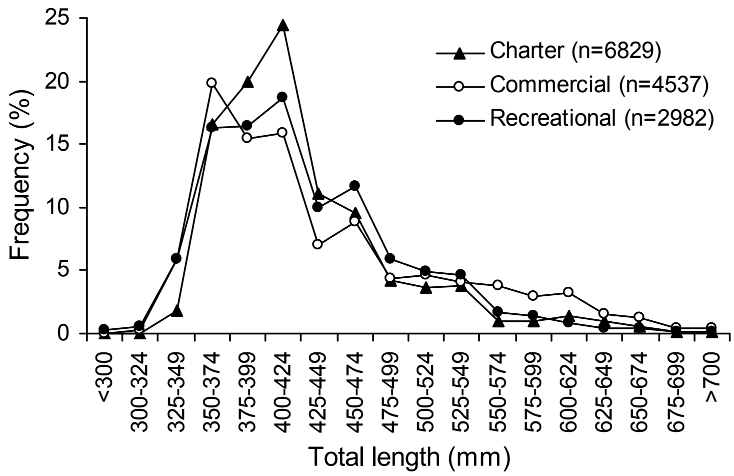

Figure 3 Pearl perch length frequency distributions for each sector across the period 2006 – 2012, as part of the Assessment and Monitoring unit's fishery-dependent sampling of the Queensland Rocky Reef Finfish Fishery.

In areas where fishing has traditionally occurred, such as those offshore from the Gold Coast, Sunshine Coast and Brisbane, fish size is generally less than 50cm TL in all sectors (Figure 5). Larger fish (>50cm) were more common in the more northern regions (Fraser Offshore and Rockhampton Offshore, see Figure 1).

For the purposes of analysing the frequency of occurrence of female gonad stage (Figure 6), Stage I *G. scapulare* ovaries were grouped with ovaries from fish of unknown sex. Immature (Stage I) and undeveloped/resting (Stage II) ovaries were more likely to occur in the winter months, while spawning fish (Stage V) were only observed in November and December. A high proportion of pre-spawning (Stage IV) ovaries were present during February, suggesting that there may be two spawning periods, although sample sizes were low during the early part of the year. Apart from August, pre-spawning (Stage IV) ovaries were present in samples collected year-round.

Size at 50% maturity (L_{50}) in female *G. scapulare* was found to be in the 25-27.5cm size class (Figure 7a) and all female *G. scapulare* were mature in the size class 42.5 – 44.9cm. No females were mature in any size class less than 22.4cm (Figure 7a). The logistic regression suggests that the proportion of mature female *G. scapulare* increased rapidly between the size classes 22.5-24.9cm TL and 30-32.4cm TL, with 99.99% of female *G. scapulare* mature at the MLS of 35cm.

GSI was highest in April, averaging 1.70% (s.e. = 0.28), and lowest in the winter months, although sample sizes were low in the months January to April. GSI was lowest in August (0.31%; s.e. = 0.03), before increasing through spring (Figure 7b).

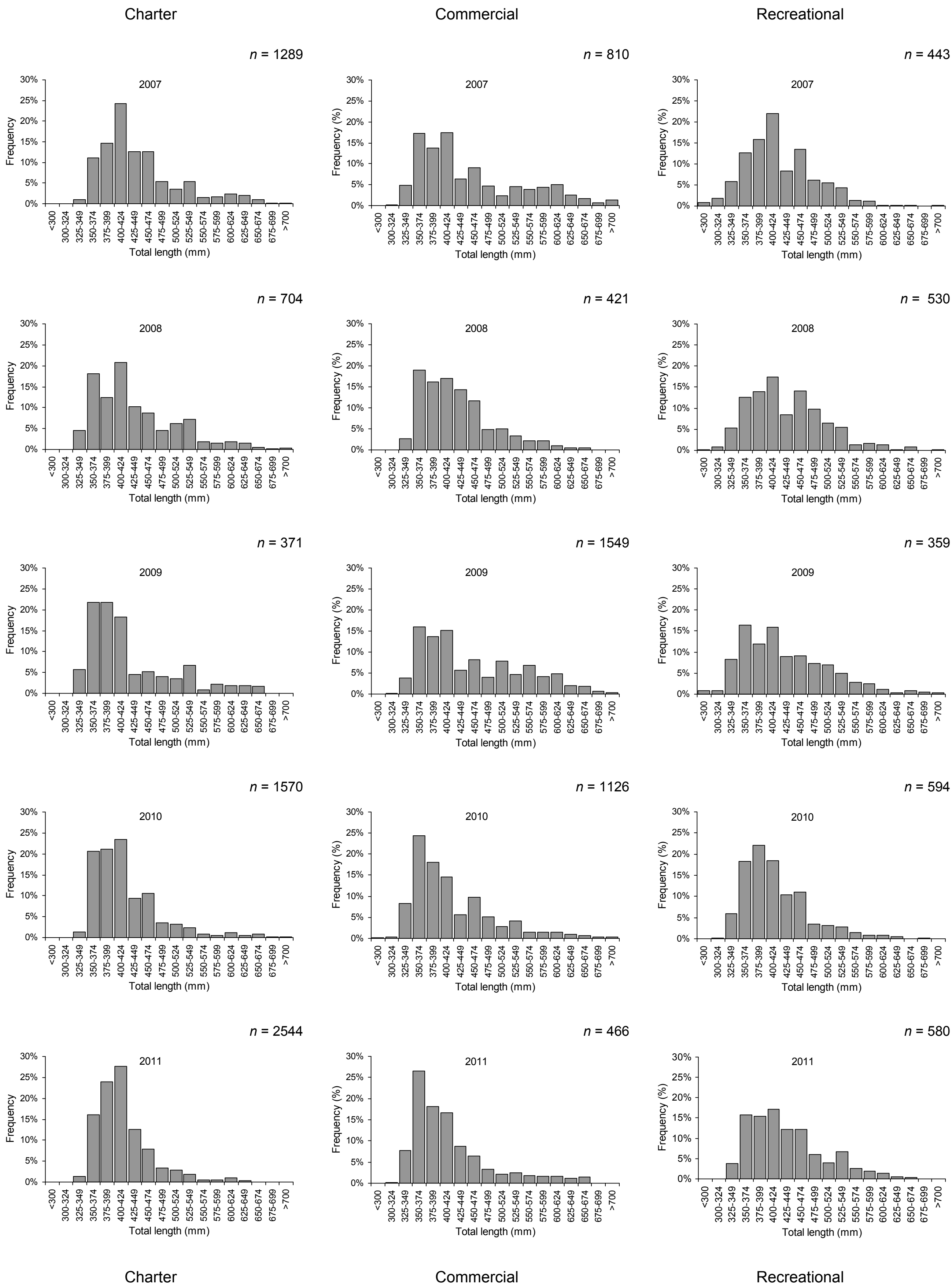

Figure 4 Pearl perch length frequency data by year and sector, across all AMU sampling regions, for the period January 2007 to December 2011.

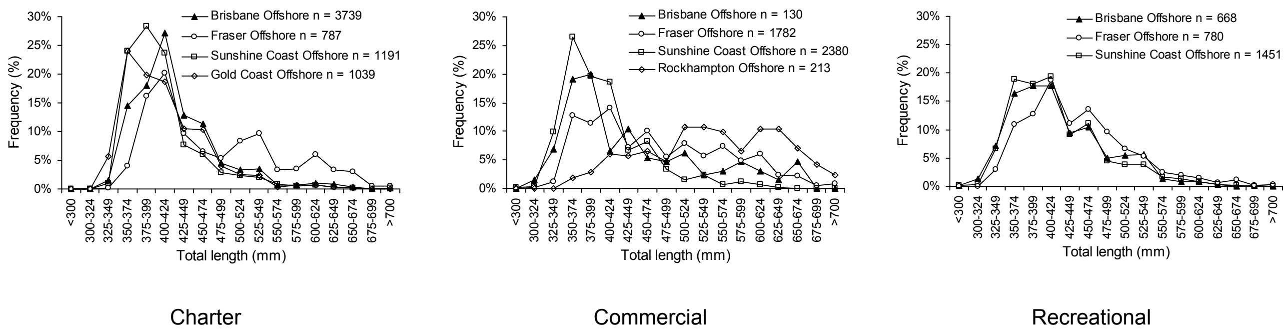

Figure 5 Pearl perch length frequency distributions by sector and AMU sampling region for the period January 2007 to December 2011. Note: those regions with n < 100 were excluded.

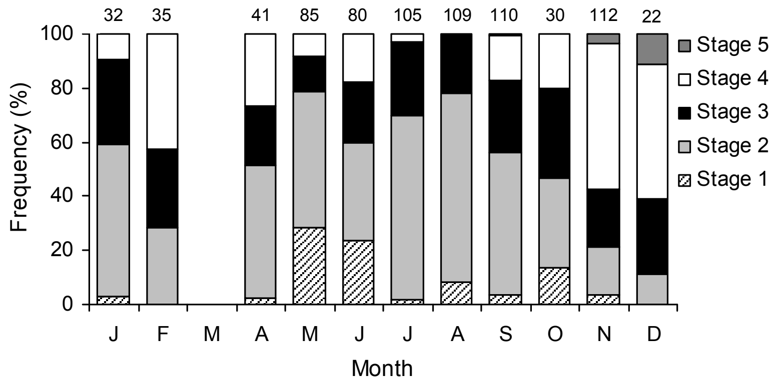

Figure 6 Percent frequency of occurrence of gonad stage for pearl perch from January 2010 to December 2010. Gonads were classified in accord with Mackie *et al.* (2009), see Table .

From the combined age-length data from 2009 and 2010 (Figure 8), *G. scapulare* are between 3 and 7 years old at the MLS of 35cm TL. The von Bertalanffy growth parameters were found to be L_∞ = 706.8mm, k = 0.156yr^{-1} and t_0 = -0.502yr for 1118 *G. scapulare* sampled during 2009 and 2010. The oldest animal sampled was 22 years old, with 108 (9.6%) older than 10 years old. There was a significant difference in growth between male and female G. *scapulare* (Figure 9, ARSS; $F_{3,3}$ = 307, P < 0.01). Females were found to grow more slowly and to a slightly larger size, with the L_∞ parameter found to have had the most influence on the difference between the sexes. Wide edges were present in all months (Figure 10), as were new edges.

The length composition of *G. scapulare* caught by commercial, recreational and charter fishers indicated that approximately 53% and 67% of fish were between the MLS of 35cm and 45cm in 2009 and 2010, respectively. Further, 5.4% and 3.6% of *G. scapulare* caught in Queensland were greater in size than 60cm TL in 2009, and 2010, respectively. Age frequency distributions of G. scapulare were truncated, with 3 – 9 year old fish accounting for 94.9% and 95.9% of all fish caught in 2009 and 2010, respectively (Figure 11c and Figure 11d).

G. scapulare were fully-recruited to the fishery at age 5 in 2009 and age 6 in 2010 (see Figure 11e and Figure 11f). Total mortality estimates ranged from 0.49 to 0.59, depending on the first fully-recruited size class and the maximum age included in the regression. Estimates of natural mortality were: M = 0.2 or M = 0.22 based on Hoenig's (1983) empirical formula, using $t_{\max}$ = 22 and $t_{\max}$ = 20, respectively; between M = 0.40 and M = 0.37 using the Pauly (1980) method, with mean annual temperature of T = 25°and T = 22°, respectively; and M = 0.23 using the Jensen (1996) method.

We conducted simple yield per recruit analysis based on growth curves derived from our research and empirical estimates of natural mortality. Assumptions of the model are (a) closed population (b) constant natural mortality for all recruited age classes (c) constant annual recruitment (d) knife edged gear selectivity; and (e) constant fishing mortality after the age of recruitment. Obviously, these are assumptions that are rarely met but these types of analysis can be useful for fisheries such as this that are managed by minimum legal size regulations.

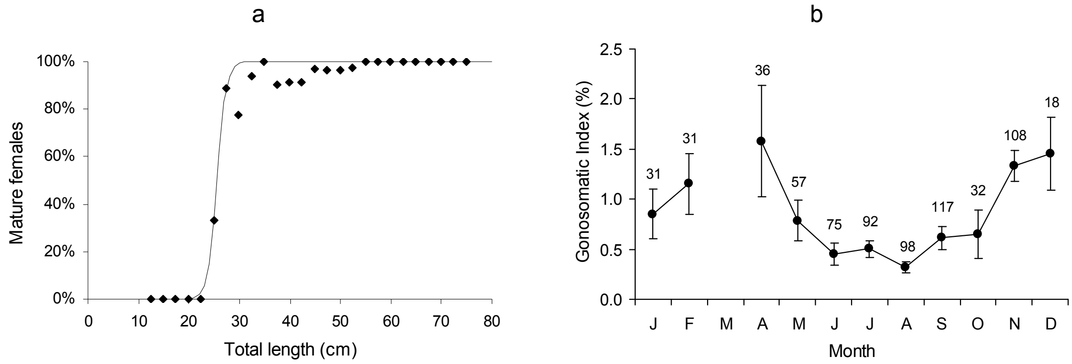

Figure 7 (a) Percent frequency occurrence of mature (stages II-V) female pearl perch as a function of total length (mm). L_{50} is in the size class 25 – 27.5cm TL. (b) Mean monthly gonosomatic indices for female *G. scapulare* greater than L_{50} = 27.5cm TL, sampled from January 2009 to December 2010 as part of the Assessment and Monitoring unit's fishery-dependent sampling of the Queensland Rocky Reef Finfish Fishery, supplemented by samples provided by project staff (n = 693). Error bars represent 95% confidence intervals for each mean.

Growth estimates used in the analysis were those derived using all data (regardless of sex). Changes in yield were estimated for a range of natural mortality estimates as well as a range of sizes at first capture (MLS). Mean weights at age were those derived from the von Bertalanffy growth curves and standard length-weight regressions. Changes in yield were investigated under a range of different growth and natural mortality scenarios but we present data for our "best" estimate of growth and for three natural mortality estimates that cover the range of likely levels as assessed by empirical formulae. Obviously a faster growth rate would result in a greater yield than slower growth scenarios and also allow for a greater capacity to sustain lower minimum legal sizes.

We have included post-release survival of 90% (see Chapters 6). We set this so that fish were available to the fishery at age 3 (and we assume all these were released). We also assumed that no fish above the minimum legal size were released.

Pearl perch discard mortality is low (10%) and growth parameters used were (t_0 = -0.197, k = 0.137, $L\infty$ = 723mm). The models indicated that for the most likely levels of fishing mortality (F = 0.15 to 0.35), yield is maximised at around the current MLS of 35cm (see Figure 12) with the expected increase in yield for larger MLS's if natural mortality is lower than that derived from empirical formulae (M=0.2). Likewise predicted yields increase marginally with smaller MLS's if natural mortality is higher than predicted. In conclusion, the analysis supports the current MLS for this species under current fishery conditions.

Discussion

Opaque zone (increment) formation in *G. scapulare* has been found to occur through spring and completed by late summer/autumn. The edge analysis from the current study somewhat confirms this with a higher proportion of "new" edges in February/March. However, edge interpretation was difficult in *G. scapulare*. The first opaque zone was also difficult to interpret in some individuals. The small individuals sourced from a blue swimmer crab (*Portunus pelagicus*) fisher confirm that the first increment is likely formed in the summer after being spawned. Opaque zones were generally broad and diffuse, with subsequent opaque zones becoming narrower toward the distal edge, particularly in older fish. Similar patterns were found in the congeneric *G. buergeri* as reported by Hesp *et al*. (2002).

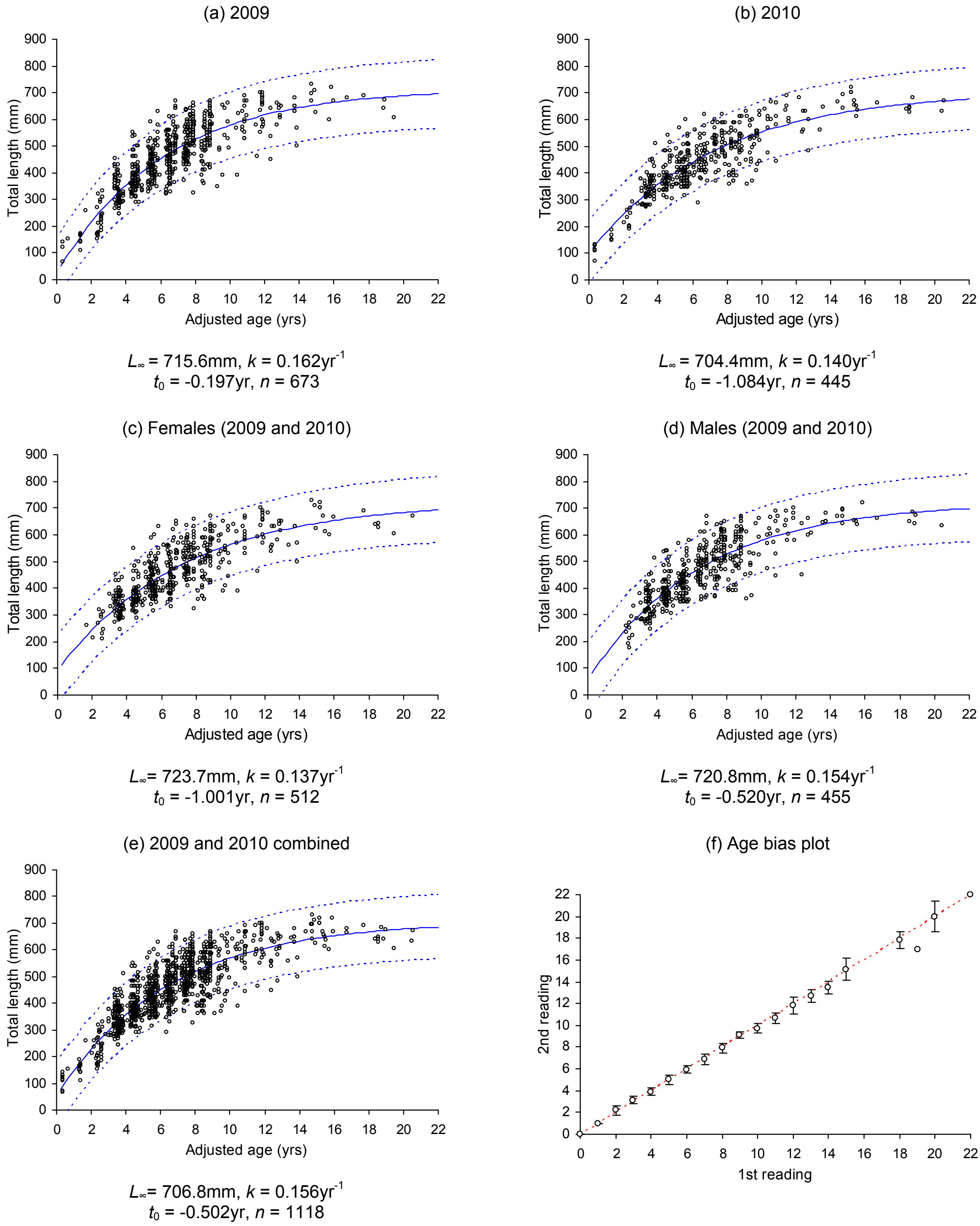

Figure 8 (a) – (e) von Bertalanffy growth curves for *G. scapulare* caught from January 2009 to December. Dotted lines represent 95% confidence intervals. (f) Age bias plot for 362 *G. scapulare* read by project staff (MC), where points are the mean increment count of the second reading. Error bars represent one standard deviation. Dotted line represents the 1:1 equivalence line.

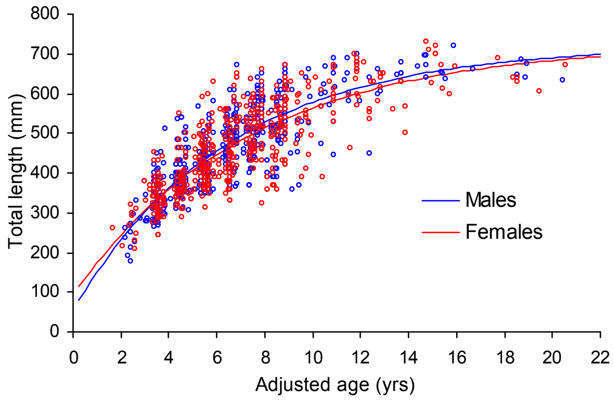

Figure 9 von Bertalanffy growth curves for *G. scapulare* caught from January 2009 to December 2010.

The growth and age information confirm that *G. scapulare* is relatively long-lived (>20 years) and slow growing (L_∞ = 706.8mm and k = 0.156yr^{-1}) species. This is in accord with estimates for *G. scapulare* in NSW of L_∞ = 667.5mm, k = 0.2yr^{-1} (John Stewart, personal communication). The congeneric *G. hebraicum* are slower growing (k = 0.11yr^{-1}) with a higher asymptotic mean maximum size with L_∞ = 929mm and attain an age of 41 years (Hesp *et al.*, 2002). Further, Newman (2002) reported the growth parameters for the congeneric *G. buergeri* were L_∞ = 512.7mm, k = 0.139yr^{-1}. Growth rates of *G. scapulare* in Queensland are higher than those caught in New South Wales, which is attributed to the influence of higher water temperatures in the northern range of this species (John Stewart, personal communication). Approximately 46% of growth to L_∞ is achieved at the MLS of 35cm TL, while 75 % of growth to L_∞ is achieved at approximately 8.5 years and 53cm TL. *G. scapulare* at the MLS of 35cm TL are most likely to be 3-4 years old. Sumpton *et al.* (1998) reported that three year old *G. scapulare* represented 12% of fish caught, similar to the representation of this age class in the current study despite MLS increasing to 35cm TL.

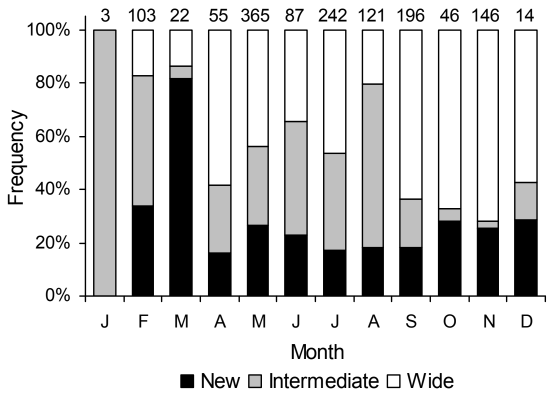

Figure 10 Frequency of edge-type classified as new, intermediate or wide, according to the width of the translucent material between the distal edge of the otolith and the last opaque zone

The growth curves for males and females were significantly (P < 0.05) different, with females growing slower and to a larger size (Figure 2.9). This is in contrast with the congeneric *G. hebraicum*. Hesp *et al.* (2002) reported that male *G. hebraicum* (1025mm) grow larger than females (929mm). Further, Newman (2002) reported that there was no significant difference in the growth rates of female and male *G. buergeri*.

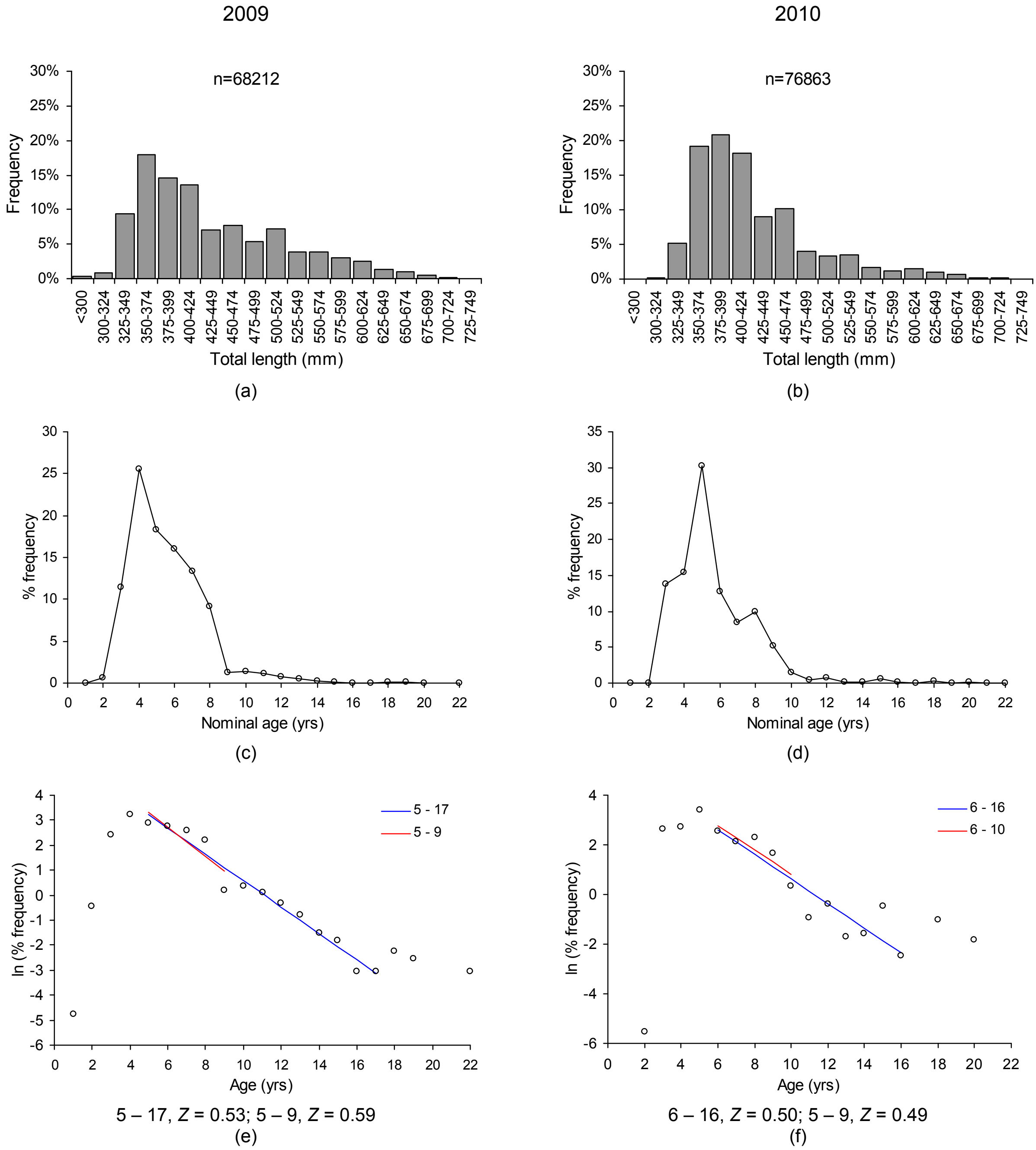

Figure 11 Length (a and b) and age (c and d) composition of commercial, recreational and charter *G. scapulare* catches combined for 2009 and 2010, respectively. Linear regressions fitted to the natural logarithms of the age compositions given in (c) and (d), the slopes of which approximate the instantaneous rates of total mortality, *Z*, for (e) 2009 for ages 5 – 17 and 5 – 9 and (f) 2010 for ages 6 – 16 and ages 6- 10.

The length and age structures generated from the current study are similar to those reported from preliminary samples collected from the commercial sector in the mid 1990's (Sumpton *et al.*, 1998) with fish generally less than 60cm TL and 9 years of age dominating catches (Figure 11a-d). However, the recent expansion of the fishery to the areas off Fraser Island and northward to grounds off Rockhampton (Figure 1) has resulted in larger fish appearing in AMU samples (Figure 5). This, to some extent, supports the hypothesis that the low incidence of large *G. scapulare* in samples collected during the 1990's was due to spawning migrations to areas at the northern boundary of their range. Further, 158 of the 176 (~90%) pre-spawning fish (Stage IV, Figure 6) and 10 of the 15 spawning fish (Stage V) sampled were caught in the Rockhampton Offshore and Fraser Offshore regions (Figure), suggesting that this area may, indeed, be an important area for spawning. No pre-spawning ovaries (Stage IV, Figure 6) were present in samples from the Brisbane Offshore and Gold Coast Offshore regions (Figure 1). However, it is difficult to state with certainty that *G. scapulare* spawn only in the area north of Fraser Island or whether, for example, pre-spawning fish move into deeper waters off southern Queensland to spawn and are not available to the fishery, accounting for the lack of Stage IV and Stage V female ovaries in samples collected during the current and previous studies.

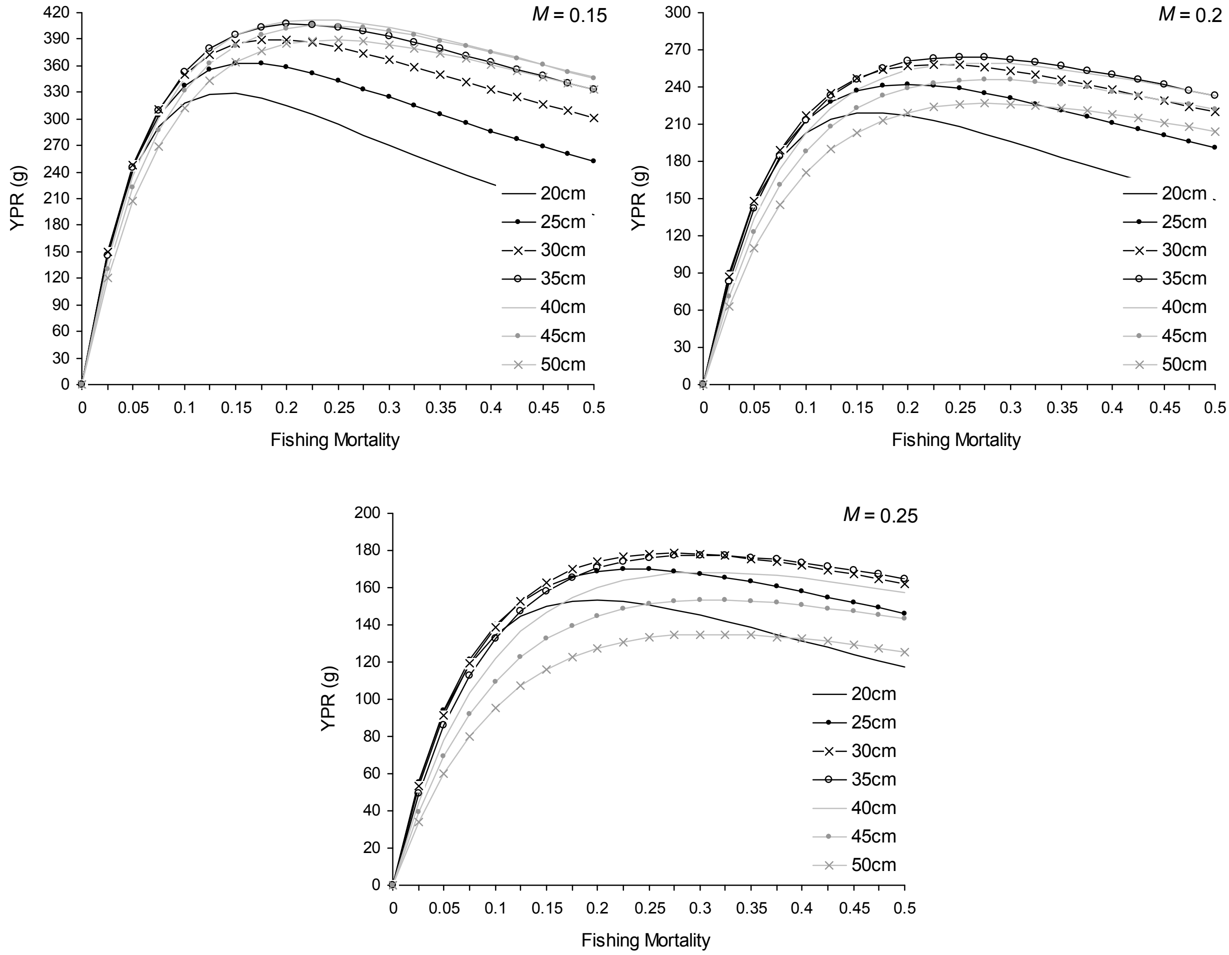

Figure 12 Change in yield per recruit of pearl perch at a range of different minimum legal sizes (MLS) for various levels of fishing mortality and three levels of natural mortality

Total instantaneous mortality estimates (*Z*) derived in the current project ranged from 0.37 to 0.51 based on the linear regressions in Figure 11. Given the estimates of the instantaneous rate of natural mortality (*M*) based on two of the three methods used, the *G. scapulare* fishery is likely at a point where fishing mortality exceeds natural mortality and is, therefore, fully-exploited. Newman (2002) reported estimates of *M* at 0.2 for the congeneric *G. buergeri*. This author states that the Pauly (1980) estimate of *M* was inappropriate for *G. buergeri* as it was difficult to get accurate temperature data for 100-200m water depth. This is an issue for using this method to estimate *M* for *G. scapulare* as their range, in terms of depth and latitude, varies significantly.

Given the high catch rates of *G. scapulare* in 2005 (see Appendix 3.10 for discussion), it is reasonable to assume that the spawning biomass was probably high in that year, giving rise to subsequent strong year classes. This is obvious in the age frequency distributions with four year old fish being the most prevalent year class in 2009 (Figure 11c). This strong age class is maintained in 2010, with five year old *G. scapulare* representing the most common age class (Figure 11d). Total instantaneous mortality estimates for *G. scapulare* from the current study are lower than those reported by Sumpton *et al*. (1998) although, as stated previously, that study failed to source older animals. The sampling of fish from the northern part of their range during the current study resulted in fish ≥ 9years representing approximately 5% of total *G. scapulare* catch in the Queensland RRFF. Given that total instantaneous mortality rates were generated using similar methods, the increase in the catch of older animals during the current study would account for the decrease in total instantaneous mortality compared to those reported by Sumpton *et al.* (1998). The fact that that total mortality is greater than natural mortality indicates the fishery is fully-fished. However, the strong age class first observed in 2009 as 4 year olds, then as five year olds in 2010 violates the steady state equilibrium assumption of constant recruitment necessary when deriving mortality estimates from catch curve analyses (Newman 2002). As such, we recommend the use of other methods to determine mortality estimates such as cohort analysis.

As discussed in Appendix 3.10, more fishing effort is being applied in the northern range of *G. scapulare*, as a consequence of improving GPS and fish-finding technology. Given the results from the current study, and those from a previous study (Sumpton *et al.*, 1998), that spawning fish are only found in the area Fraser Island to Gladstone, the increasing fishing effort in this area may be cause for concern regarding long-term sustainability. It is, therefore, prudent to maintain the sampling of individuals for reproductive information, particularly in the northern part of this species' range.

Further, Stewart (2011) states that age-class truncation, evident in the current study (Figure 11c and Figure 11d), may decrease the resilience of *G. scapulare* through periods of poor recruitment by reducing the reproductive potential of the population. This would be of concern in the current study if the age distribution were composed of samples of equal size across all regions. This is obviously not the case, however, and the age-class truncation evident in the current study is possibly a function of under-sampling the more northern regions, rather than a lack of large animals in the population. It would be prudent, therefore, to increase the sampling of catches from the areas adjacent to and north of Fraser Island.

Should any increased sampling reveal that older, spawning fish are not more frequently caught in these areas, Stewart (2011) suggests remedial management actions to increase the number of older animals in the population including the introduction of no take marine protected areas (NTMPAs). Kleczkowski, Babcock *et al*. (2008) and Watson, Harvey *et al*. (2007) both reported that NTMPAs were beneficial to the congeneric *G. hebraicum* with higher numbers found inside the protected areas. However, NTMPAs are extremely unpopular with recreational fishers in Queensland and the benefits they provide are questioned (Hilborn and Kearney, 2012).

Stewart (2011) suggests that the introduction of a Maximum Legal Size would also be beneficial. This would be a far more palatable alternative, compared to the establishment of NTMPAs, should modelling suggest that the establishment of a maximum legal size. In 2011, the number of *P. auratus* over 70cm was restricted to one per person per day for recreational and charter anglers in Queensland in order to protect the highly-fecund larger fish. The results from the post-release survival experiments detailed in Appendix 3.5 suggest that *G. scapulare* are resilient to capture-and-release and such measures would likely achieve the desired outcome of protecting older, spawning animals should modelling indicate this to be beneficial.

Gonosomatic Index (GSI) of *G. scapulare* was generally low in winter (Figure 7b), in accord with a preliminary study (Sumpton *et al*., 1998). GSI increased during spring and peaked at 1.45% in December. A peak in GSI also occurred in April but was more variable. Pre-spawning (Stage IV) female *G. scapulare* gonads were caught in all months, with immature /undeveloped female ovaries (Stage 0 and Stage I) present in higher proportions during winter. Female *G. scapulare* were found to mature below the MLS of 35cm TL at approximately 25-27.5cm TL, in agreement with Sumpton *et al.* (Sumpton *et al.*, 1998), corresponding to fish aged 2-3 years (Figure 8e). Given that spawning females were most common in December and immature fish were most common in March, the allocation of the January 1 as the birth date for ageing is appropriate.

The sample sizes from the months January-March and October-December reflect that sampling of rocky reef fish by AMU occurs mostly through the winter months in response to the higher *P. auratus* catches at this time. We have shown that *G. scapulare* spawn in summer and, as such, it would be beneficial to sample *G. scapulare* during this time. The growth characteristics derived during the present study, combined with increasing fishing pressure, indicate that *G. scapulare* are vulnerable to over-exploitation. It is recommended, therefore, that AMU continue collecting reproductive information from *G. scapulare* samples, particularly fish caught at the northern boundary of their range from Fraser Island to waters off Gladstone in central Queensland. If such information confirms the presence of localised spawning areas, then appropriate management measures may be required to protect these areas. Historically, *G. scapulare* have not been the subject of any age- or length-based stock assessment modelling. However, the information generated during the current project is appropriate for use in such assessments, particularly cohort analysis, providing the precision and accuracy of various parameters can be maintained and improved into the future. The lack of historical (pre-1990) catch rate information (see Appendix 3.10) and irregular and imprecise recreational catch estimates are significant impediments to this.

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APPENDIX 3.2 BIOLOGICAL AND FISHERIES INFORMATION FOR MONITORING AND DEVELOPING HARVEST STRATEGIES FOR TERAGLIN (*Atractoscion aequidens*) IN SOUTHERN QUEENSLAND

Summary

The biology of teraglin (*Atractoscion aequidens*) in Australia is significantly different to the presumed same species fished in South Africa (where it is known commonly as the geelbek). Preliminary genetic analysis suggests that teraglin in Australia may be a different species to that fished in South Africa i.e. *Atractoscion aetlodus* (Gunther 1867), although further work is needed to clarify this taxonomic position. Sexual maturity of teraglin in southern Queensland is reached at an age between 2 and 3 years of age and at an L_{50} of approximately 35cm. There is considerable spatial and temporal variation in reproductive parameters similar to patterns exemplified by other species in the same family (Sciaenidae). This is significantly different to the situation in South Africa where geelbek mature around 5 years and a size of greater than 80cm. Teraglin spawn throughout the entire year in southern Queensland but there is evidence of a peak in spawning during spring/summer, however the low numbers of larger fish sampled may have been influencing this result. The oldest fish sampled was estimated to be 14 years old and 92 cm in length and fish in their second year of life were recruiting into the line fishery. There was no significant difference in the growth rate between the sexes but there is evidence of schooling by sex, as individual catches are sometimes dominated by a particular sex. The relatively small size of the fishery coupled with the different size structures of the catch from each fishing sector (commercial, recreational and charter) creates difficulties in determining unbiased and precise total mortality estimates. Ageing is also inaccurate and imprecise further eroding the utility of age based assessments. The relatively high fecundity, extended spawning period, and early onset of maturity are features that provide some protection to the teraglin fishery and lower its risk of unsustainability. Teraglin is a species that does not warrant future detailed attempts at age based stock assessment due to imprecise age estimation and difficulties associated with obtaining representative samples from each of the fishing sectors. In addition the lack of accurate spatially- and sector-explicit catch information precludes the derivation of weighting factors for representative age assessment. Historical information suggests that much larger and older individuals were once common in the fishery but this does not appear to be the current situation. From a Queensland perspective, teraglin is a species where any range shift as a result of climate change may restrict catches as most teraglin are taken south of the Sunshine Coast.

Introduction

Atractoscion aequidens (known commonly as teraglin in Australia and geelbek in South Africa) is an important commercial and recreational line caught fish within the family Sciaenidae. It has previously been reported as one of the few sciaenid species with separate populations in the Atlantic and Pacific oceans (Sasaki, 1989). The species is found in the east Atlantic Ocean along the eastern, southern, western and northwest coasts of Africa (Druzhinin and Filatova, 1979; Sasaki, 1989; Griffiths and Hecht 1995,. On the west coast of Africa it has been recorded on the Arguin Bank (Degroot and Nijssen, 1971) and from the Gulf of Guinea southwards to Cape Agulhas (Fischer *et al.,* 1981*;* Van der Elst, 1981*).* On the African east coast they are reported from Cape Agulhas to Southern Mozambique (van der Elst, 1981; Fischer and Bianchi 1984) and also in the Gulf of Aden (Druzhinin & Filatova, 1979).

In Australia, the presumed same species is found in offshore coastal waters off the east coast with the majority of the catch landed between Sydney (33° S) and Rockhampton (22° S)(Sasaki 1989) where they are reported to grow to a weight of 19.5 kg (Grant 1985) and are fished by both commercial and recreational line fishers (Kailola, 1993). Teraglin are absent from the west coast of Australia. From a Queensland perspective the vast majority of the catch today is taken south of Fraser Island (24° 40'S) and particularly in the most southerly waters south of the Sunshine Coast.

Other closely related Sciaenids of local fisheries importance to Queensland include the mulloway or the jewfish (*Argyrosomus japonicus*) and the black jewfish (*Protonibea diacanthus*). In contrast to teraglin, mulloway are a euryhaline species generally found in shallower inshore reefs and estuaries growing to a reported weight of 61kg (Grant 1985). Both species are thought to prey on suprabenthic, pelagic and demersal organisms (Smale 1983) and appear to favour off the bottom feeding at and after dusk, along with diurnal vertical migrations of prey (Pollard 1978, Grant 1978). Black jewfish (*Protonibea diacanthus*) are also line fished, particularly in north Queensland where their range does not overlap with teraglin, but like teraglin, black jewfish is known to be particularly vulnerable to barotrauma (Phelan 2008). There is considerable overlap in the distributions of mulloway and teraglin with both being caught in nearshore oceanic waters of southern Queensland and there is probably considerable misidentification of the two species.

There have been no studies conducted in Australia on teraglin despite considerable research effort on other members of the family (Phelan 2008, and references contained therein). Neira *et al*.(1988) reported a total of 11 teraglin larvae caught entering Lake Macquarie and within coastal waters off Sydney in February suggesting that like mulloway, estuarine environments may be important for juvenile teraglin. Despite this observation, trawl surveys and other fishing surveys conducted in Moreton Bay and other open estuarine systems in Queensland have not reported catches of teraglin although adults and juveniles of mulloway are very commonly recorded in these estuarine areas. Juvenile teraglin are however reported in trawl surveys in offshore waters but not in large numbers (Courtney *et al*., 2007). On the east coast they are fished in two state jurisdictions (Qld and NSW) where current management measures including MLS are relatively consistent (38cm TL in both).

Studies conducted in South Africa have found that mature geelbek (the presumed same species) exhibit a spawning migration similar to tailor (*Pomatomus saltatrix*) (Garrett, 1988), travelling north to spawn, and the Agulhas current carries eggs and juveniles south (Garret 1988; Griffiths and Hecht, 1995). Griffiths and Hecht 1995 found that the area of the southeast Cape was utilised as a nursery area where juveniles feed on mysids until progressing to larger prey such as anchovies. At maturity (5-9+ years) they then migrated in spring inshore and long-shore north to the spawning grounds dispersing back offshore over the spawning grounds over summer (Griffiths and Hecht 1995). Whitely (1966) states that adults are distributed within Queensland in winter and in the summer months they move further south, suggesting a behaviour similar to South Africa. If their behaviour was indeed similar on the east coast of Australia then the expectation is that southern Queensland would be an important seasonal spawning and possible nursery area. However, at present there is little information to support the theory that teraglin migrate locally on the east coast Australia and limited information on other aspects of their biology, other than concern over post-release survival.

Anecdotal evidence also indicates that teraglin (like black jewfish in northern Australia) may have a high post-release mortality and are further vulnerable because of their schooling habits and high vulnerability to line fishing. Post-release mortality of teraglin is described in Chapter 7 but these aspects of their biology raise concerns about the sustainability of the fishery, particularly given observed overfishing in sciaenid fisheries overseas. As an example, another closely related sciaenid (*Atractoscion nobilis*) underwent a decline during the 1980's with subsequent management intervention resulting in recent recovery (Pondella and Allen, 2008) of the species in its endemic Californian waters. Recent stock assessments have also heightened local sustainability concerns for snapper (Allen *et al.* 2006, Campbell *et al.* 2008) and it is reasonable to assume that since teraglin is accessed by the same fisheries that target snapper it may also be under considerable fishing pressure.

All these features heightened concerns over the sustainability of the *A. aequidens* fishery, particularly given the lack of biological and fisheries information on the species and the apparent differences between South African and Australian populations. This chapter describes the biological characteristics of the Australian *A. aequidens* and compares these to the presumed same species studied by Griffiths and Hecht (1995) off the coast of South Africa. We also assess the ability to collect long-term representative data needed to manage this fishery.

Methods

Biological information on teraglin were obtained from three sources. Firstly, from an earlier FRDC project - No 93/074 (Ferrell and Sumpton 1997) that opportunistically collected some biological information on teraglin during the period 1993 to 1996 due to the overlapping nature of the snapper and teraglin fisheries (although none of the teraglin data were analysed at the time). Secondly, from data collected by the Australian Marine Life Institute who collected limited biological information in addition to catch information on teraglin at various time periods since 1993. Finally, the Queensland Fisheries Assessment and Monitoring Unit (AMU) have also been collecting catch size structure information and otoliths from teraglin fishers since 2006 and these data were further supplemented by the research team involved in this present research. Overall, samples were collected from the southeast Queensland between 24° 00'S to 28° 30'S but most samples (>80%) were taken between 27° 00'S to 28° 30'S.

Data from the earlier FRDC project consisted of otolith and gonad material collected opportunistically from the fishery as well as samples collected from dedicated research fishing trips. Data from this source covered the entire spatial extent of the fishery and included catches from all sectors (commercial, charter and recreational).

The AMLI data were restricted to the Gold Coast charter boat fishery for *Atractoscion aequidens* (see also Appendix 3.11 for biological analysis were taken periodically between August 1992 and 2011. On days when charter boat sampling took place total lengths (TL) of fish from complete catches were measured (± 1 cm). Biological material (including otolith and gonad samples) were taken at times from samples of fish when charter fishers returned to the wharf at the completion of their fishing trip.

Samples collected from commercial fishers, recreational fishers, charter operators and seafood processors as part of the routine sampling by the LTMP of Department of Agriculture, Fisheries and Forestry were also analysed. This program aims to collect representative length, sex and ageing data from rocky reef species by structured year-round sampling of all fishing sectors. Teraglin is one of the three primary species of rocky reef fish assessed by the AMU, the other two being snapper and pearl perch. Members of the current research team also supplemented these samples with additional material obtained independent of the AMU. In some cases these fishers were subsequently included in the AMU sampling protocols.

Total length was the standard fish measurement recorded although other measures were taken at times to allow the conversion of various morphological measures to a common unit of measurement. Minimum legal sizes in Queensland are also specified as total lengths which were recorded with the caudal fin extended to its fullest. Whilst not being the standard way of measuring total length, it is the method adopted by the Queensland Boating and Fisheries Patrol, the agency responsible for enforcing the Queensland Fisheries Act. During the earlier FRDC research total lengths were recorded in this way but in all other cases the more common method of measuring total length with the fin placed in its "natural position" was the measure adopted. The morphology of the caudal fin in teraglin only results in small errors (<2%) between the two methods of total length measurement but we have not further adjusted total lengths in this study.

Laboratory procedures for otolith extraction and ageing were identical to those reported for pearl perch (see Appendix 3.2) apart from multiple sections being required due to the morphology of the teraglin otoliths which made visual recognition of the focus impossible due to otolith thickness and opacity. Typically two or three serial sections were taken with the one closest to the focus used for subsequent ageing. Processing of samples collected during the 1990's was virtually identical to these procedures as it involved embedding (usually the left otolith) in polyester resin and sectioned along a transverse plane through the focus to a thickness of approximately 300 – 400µm using similar Buehler isomet diamond saws to those currently used. Sections were mounted on glass microscope slides using polyester resin prior to viewing and ageing under reflected light with a compound microscope and image analysis software.

For the samples collected during the 1990's, two independent readers each counted the alternating opaque hyaline zones, without any reference to fish size. This procedure was repeated after a period of at least 14 days had elapsed. Each reader also assigned a value of readability and distance of opaque otolith margin from the edge (Tables 1 and 2). If fewer than 3 readings of age coincided, and the otolith had a readability of less than 3, the otolith was rejected and not included in further analysis. To determine periodicity of growth zone deposition, the percentage frequency of the position of the opaque otolith margin was plotted on a monthly basis. Otoliths collected since 2006 were processed under standard protocols used by the Fisheries AMU (see Appendix 3.1 for details) but in the case of teraglin, ages were derived from agreed age estimates of two highly experienced otolith readers (WS and SW).

Age increments were determined according to the number of completed opaque zones between the focus and the distal edge of the otolith (see Figure 1) when viewed under reflected light. These nominal increment counts were then further corrected by adjusting for month of capture and edge classification to determine the age class to which the fish belonged but we chose January 1 as the birthday. This was complicated by the lack of a well defined spawning period (see later results). The biological age in months was then determined using the assigned age class according to the following equation.

$$A_m = (\text{Age class x } 12) + (C_m - B_m)$$

Where: A_m = biological age (in months); C_m = capture month; B_m = birth date (1 January).

For otoliths collected since 2006, edge-type was classified as new (1), intermediate (2) or wide (3), according to the width of the translucent material between the distal edge of the otolith and the last opaque band (see Appendix 3.1).

Beamish and Fournier's (1981) Index of Average Percentage Error (IAPE) was used to assess reader precision.

$$\frac{100}{N}\sum_{j=1}^{N}\left[\frac{1}{R}\sum_{i=1}^{R}\frac{|X_{ij}-X_j|}{X_j}\right]$$

where N is the number of fish aged, R is the number of times each is aged and X_{ij} is the ith age determined for the jth fish.

Growth curves were fitted to the length at age data, using the von Bertalanffy equation:

$$L(t) = L_\infty (1\text{-}e^{-k(t - to)})$$

where $L(t)$ is the total length at time t, L_∞ is the asymptotic length, k is the growth rate parameter, t_0 is the age at zero length.

Table 1 Otolith rating describing distance of opaque band in relation to edge of sectioned otolith (Sumpton *et al.* 1998). Equivalent rating system used by the AMU is shown on parentheses after the description.

Edge Increment Rating	Description
1	Opaque band on edge of section otolith (1 or New)
2	Opaque band or part thereof just clear of edge (2 or Intermediate)
3	Opaque band at least half of own width, clear of edge (2 or Intermediate)
4	Opaque band clear of edge full width of band (3 or Wide)

Table 2 Otolith rating describing readability of sectioned otoliths (Sumpton *et al.* 1998). The AMU system is not strictly comparable to this system.

Rating	Description
1	Otolith uninterpretable.
2	Bands present but uninterpretable
3	Clear bands present but multiple interpretations possible
4	Clear bands, single interpretation probable
5	Perfect banding, only one interpretation possible

Sub-samples representative of all size classes of fish were weighed to the nearest 5g and a length weight relationship determined. The resulting equation allowed for the weights of the remaining sample to be calculated. In the laboratory, fish were dissected, sexed and the gonads assigned a macroscopic maturity stage (Table 3). After associated fat had been removed, the gonads were weighed to the nearest 0.1g and gonosomatic indices were derived (Griffiths and Hecht 1995) (see Table 3). Seasonal reproductive activity was established by calculating the monthly percent frequency of each maturity stage for sexually mature female fish. These fish were staged macroscopically according to a modified classification system outlined by Griffiths and Hecht (1995). In addition a monthly gonosomatic index (GSI) was calculated according to the following equation GSI = (gonad weight/ fish weight) x 100. Where total fish weight was not available an approximation was derived from the length/weight relationship.

Table 3 Classification and description of the macroscopic gonad maturity stages of teraglin (Modified from Griffiths and Hecht, 1995).

Stage 0. Juvenile
Gonads are transparent thread-like structures and are unsexable.
Stage 1. Immature or resting
Testes are extremely thin, flat and pinkish white colour. Ovaries appear as thin translucent orange tubes. Eggs are not visible to the naked eye.
Stage 2. Active
Testes are wider, triangular in cross section and beige in colour. Sperm is present if the gonad is cut and squeezed gently. Eggs become visible to the naked eye as tiny yellow granules in a gelatinous matrix. There is very little increase in the diameter of the ovary.
Stage 3 Developing.
Testes become wider, deeper and are mottled and creamy beige in colour. They are also softer in texture, rupturing when pinched lightly. Besides the obvious presence of sperm in the main sperm duct, some sperm is also present in the tissue. Ovaries become larger in diameter and opaque yellow in colour. Clearly discernible eggs occupy the entire ovary.
Stage 4. Ripe
Testes are still larger in cross section and softer in texture. They become creamier in colour due to considerable quantities of sperm. The ovaries are larger in diameter as a result of an increase in egg size. There is considerable vascularisation of the ovary.
Stage 5. Ripe/running
Both the testes and the ovaries are now even larger in cross section. They are extremely delicate at this stage and rupture easily when handled. The testes are uniformly cream in colour and the ovaries are amber. Most of the eggs are large (>1.2mm in diameter) and transparent. Eggs and sperm are exuded freely when pressure is applied to the abdomen of the whole fish.
Stage 6. Spent
Testes are shrivelled in appearance and a mottled beige and cream in colour. A little viscous semen may still ooze from the genital pore when pressure is applied to the abdomen. Ovaries are bloodshot and considerably reduced in diameter.

Histological samples of gonads were also taken from a proportion of fish. Subsamples of approximately 2 grams were taken from the centre of ovaries of female teraglin and sectioned using standard Hematoxylin and eosin stain procedures. Ovaries were staged according to the most advanced group of oocytes present in the section.

Size at sexual maturity is usually determined by calculating the percentages of mature and immature gonads observed for fish of given size classes during the spawning season (Elder, 1976; Hecht and Baird, 1977; Standard and Chittenden, 1984; Buxton and Clark, 1992 in Griffiths and Hecht, 1995). In line with the studies of Griffiths and Hecht (1995) mature fish were those classified with active gonads stage 2 and above. We concentrate here on female gonad development and reproductive biology since female reproductive parameters are usually considered in stock assessment models in preference to males because female energy investment in reproduction is usually higher than males (West 1990) and the development of ovaries is more indicative of spawning activity.

We also investigated the size and age structure of the catch from all sectors and derived "pseudo" estimates of total mortality of teraglin using catch curves following the derivation of catch age structures using age length keys. All the ageing data collected during 2009 and 2010 were used to construct a single age length key which was then applied to the weighted and unweighted size structure information under various assumptions. We acknowledge the use of a single age length key for different years and regions is problematic but the lack of sufficient ageing data within particular years necessitated a compromise. We stress that estimates of total mortality described are not considered to be actual population estimates due to discrepancies between the catch age structure and that of the underlying population of teraglin being fished. Natural mortality, *M*, was estimated using a number of empirical equations

Hoenig (1983) $M = e^{1.44 - 0.982 \ln(t_{max})}$

Hoenig (1983) $M = -\ln(0.05)/T_{max}$ where T_{max} = maximum age

Pauly (1980) $\log M = -0.066 - 0.279 \log L\infty + 0.654 \log k + 0.463 \log T$

Samples of smaller (<30cm TL) teraglin were also collected opportunistically from commercial trawlers operating in the area as all line fishing sectors noted that small teraglin were rarely caught on line fishing gear (at least in the areas where adults are line fished).

Results

There were no differences in the external morphology of males and females although a proportion of males made a croaking sound upon capture consistent with the behaviour of other members of the family Sciaenidae. The length weight relationships derived from a subsample of 325 fish did not differ significantly (P>0.05) between the sexes and as such the combined relationship was calculated as

$$\text{Weight} = 0.0309 \text{ Fork Length}^{2.662} \ (R^2=0.980).$$

Other morphometric relationships were also derived to enable comparisons with studies where fork length or other morphometrics were used or when fork length was only measured in this study.

Fork Length (FL) = 0.939 Total length (TL) (R^2 = 0.993)

Standard length (SL) = 0.855 Fork length (FL) (R^2 = 0.862)

Table 4 Numbers of teraglin measured from catches harvested by each fishing sector, and number of otoliths collected during the period 2006 to 2011 (Figures not adjusted for sub-sampling and unrepresentative sampling).

Year	Number of teraglin measured			Total lengths	No. otoliths
	Charter	Commercial	Recreational	measured	collected
2006	239	10	33	282	9
2007	721	87	27	835	39
2008	339	148	110	597	84
2009	**1372**	**123**	**122**	**1664**	**162**
2010	**1646**	**153**	**137**	**2073**	**233**
2011	2459	91	149	2699	77
Total	6776	612	578	7966	604

The majority (>85%) of lengths collected by the AMU and the research group since 2006 were obtained from the charter fishing sector reflecting the importance of the species to that sector (see Appendix 3.10 and 13 and Table 4). Otolith collections were supplemented by the research team during 2009 and 2010 and these were the only years where greater than 100 otoliths were collected for age structured analysis.

During other years insufficient fish were sampled to develop age length keys or provide a representative weighted estimate of the catch age structure of any sector without relying on an age length key generated using otoliths of fish collected in a different year.

Table 5 highlights the extent of the under-sampling of commercial catches from the Gold Coast in particular, as well as the decreasing importance of the species in the more northerly part of its range.

Table 5 Catch (tonnes) of teraglin recorded in CFISH logbooks of commercial and charter fishers for the various AMU sampling regions during 2009 and 2010.

AMU region	Charter		Commercial	
	2009	2010	2009	2010
Rockhampton Offshore	0.013	0.048		
Fraser Offshore	1.002	0.312	0.438	0.302
Sunshine Coast Offshore	2.686	2.565	2.709	1.719
Brisbane Offshore	4.118	4.625	1.401	2.766
Moreton Bay	1.845	1.425	1.554	2.140
Gold Coast Offshore	9.997	4.604	16.081	11.966
Total catch	19.661	13.579	22.183	18.892

Despite the fact that recent catch size structured information was obtained from a total of 7966 fish from all three fishing sectors, over 6 years, stratified by 4 main regional areas there were insufficient samples to enable the statistical analysis of trends in the mean size of fish caught, largely due to unbalanced and incomplete coverage and aliasing problems in the analysis. For example, most charter lengths in some years were restricted to Gold Coast offshore where there were few commercial samples.

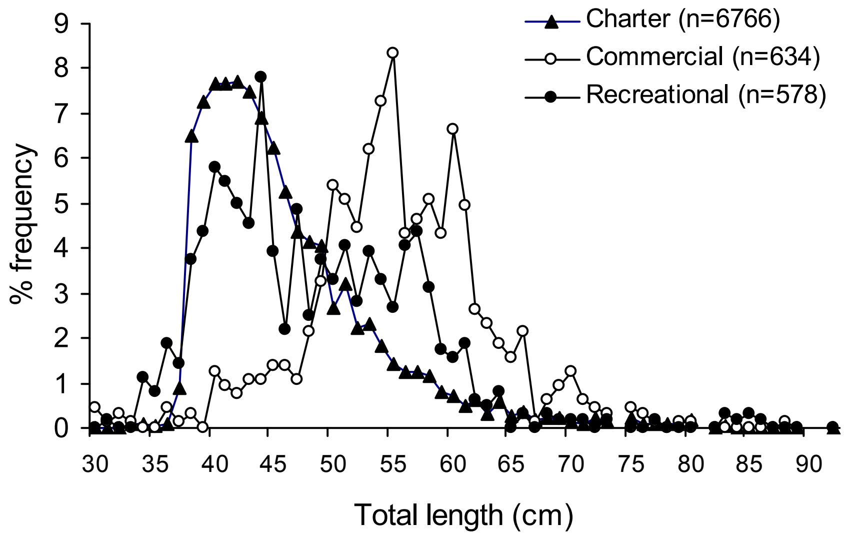

Figure 1 Catch length frequencies of teraglin caught by commercial, recreational and charter fishers for all sampling regions and years between 2006 and 2011.

The vast majority (>90%) of measurements taken by the AMU were deemed representative of the catch but all length frequency figures presented in this chapter have been adjusted by removing unrepresentative catches and adjusting the length classes for sub-sampling of the catch when this took place. The largest fish sampled was 92 cm but there were relatively few fish greater than 75cm in the sampled catch of any sector (Figure 1). There were significant differences ($P < 0.05$) in the mean size of the teraglin caught among the various sectors with the average size of fish in the sampled commercial catch (mean = 55 cm) being almost 20% larger than either the charter (mean = 46 cm) or recreational (mean = 48cm) sectors. Historic samples collected during the 1990's were likewise similar in size structure to those collected more recently reflecting the trend of smaller fish being taken by the charter fishery, although the minimum legal size prior to 2003 was 45 cm for teraglin (Figure 4a). Over 20,000 snapper and pearl perch were measured from commercial catches predominantly from waters North of Cape Moreton during the period 1993 to 1996 but fewer than 50 teraglin were reported in these catches.

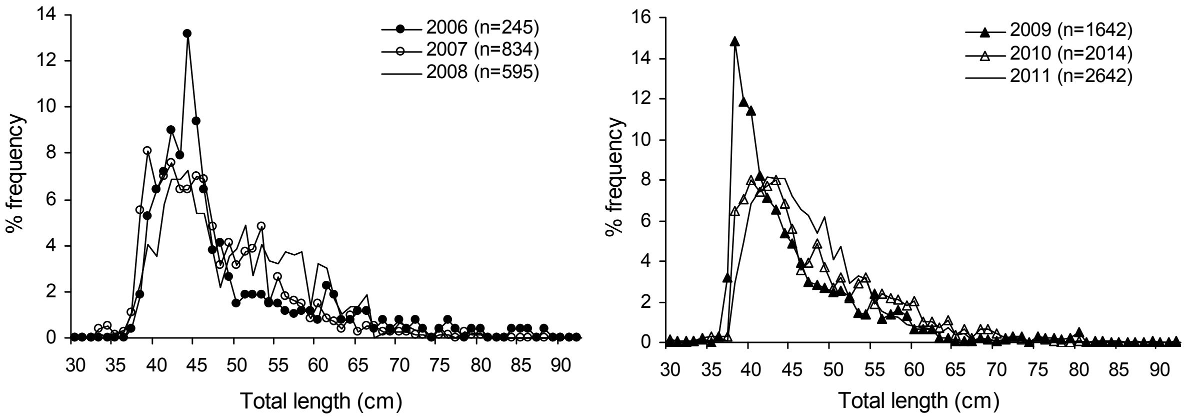

Figure 2 Annual catch length frequencies of teraglin caught between 2006 and 2011 summed across all three fishing sectors and sampling regions.

Annual variation was swamped by the oversampling of smaller fish from the charter sector but there was still considerable annual variation in the size structure of the catch with 2007, 2008 and 2011 having a higher proportion of larger individuals in the sampled catches (Figure 2). It is interesting that the 2011 had a higher proportion of large individuals when it was the year that also had the highest proportion of charter catches which have previously been shown to be dominated by smaller individuals.

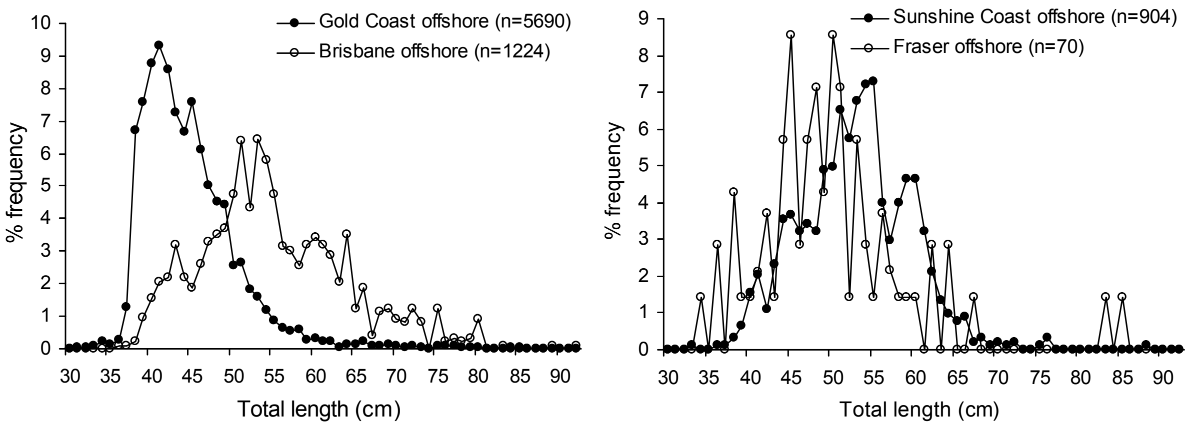

Figure 3 Regional catch length frequencies of teraglin caught from the Gold Coast to Fraser Island summed across all years and fishing sectors.

Regional size structures were strongly influenced by the different size structures derived from the catches of the three different fishing sectors with the Gold Coast being dominated by the charter boat catches where fish were on average considerably smaller than either of the other sectors (Figure 3). Brisbane offshore, the Sunshine Coast and Fraser offshore had a higher proportion of both commercial and recreational catches which resulted in a higher proportion of larger fish in the overall unweighted catch size structures. None of the teraglin monitoring data were recorded at a level that would allow the identification of the individual catches of fishers (due to confidentiality reasons) nor was it possible to record depth of capture of the various catches because a large proportion of the samples were obtained from fish processors. However, information collected from the Gold Coast charter fishery enabled depth stratified size structures to be derived for at least a subset of that sector (Figure 4). These data clearly demonstrate a strong depth related size stratification of the catch with larger individuals being taken in deeper water further offshore (at least on the Gold Coast). Prior to the lowering of the MLS both the 24 fathom reefs and 36 fathom reefs had virtually identical catch size structures. When the MLS was lowered in 2003, depth differences in size structure became more apparent reflecting the higher relative abundance of smaller fish in shallower waters. While there were some small fish caught in the deep areas (50 fathoms), fish caught further offshore were generally much larger and catch rates were lower (reflected in the small sample size measured at these depths).

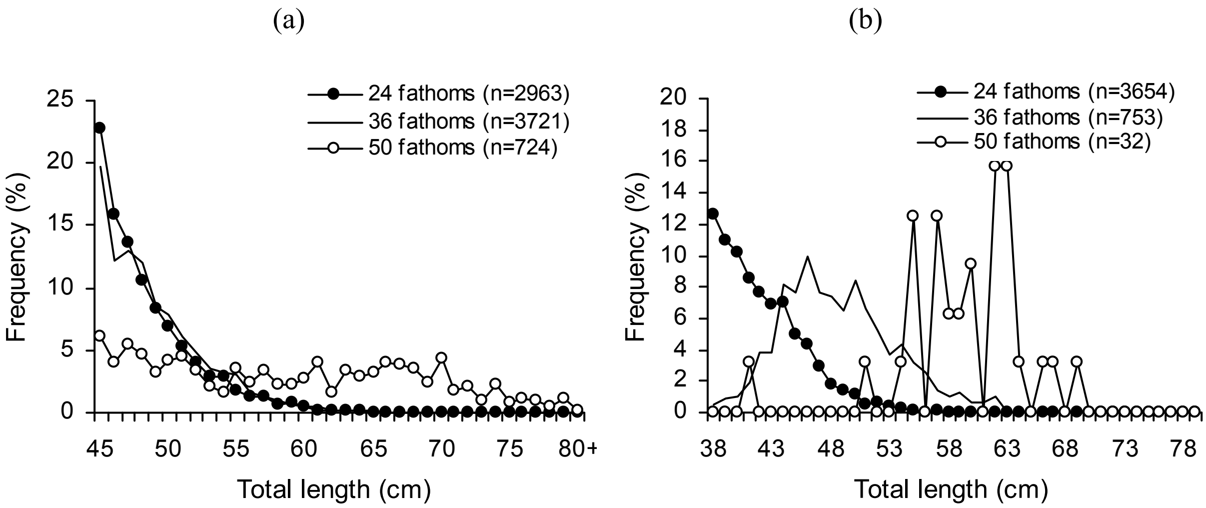

Figure 4 Depth related size frequencies of teraglin caught by the Gold Coast charter fishery from (a) 1999 to 2002 and (b) from 2003 to 2009. Sample sizes at each depth are shown in brackets. Note that the minimum legal size up to 2003 was 45cm and subsequently it was decreased to 38 cm. All fish below these sizes were removed from the analysis.

Age and growth

Teraglin otoliths were typical of the Sciaenidae, being relatively dorso-ventrally thickened in comparison to most other species and with the focus unable to be seen through the whole otolith. Figure 5 shows two sections that exemplify the multiple banding patterns and complex edge interpretation issues of this species. The inability to determine the focus of the otolith when viewing the blocked whole otolith necessitated multiple sections being required in order to obtain a section close to the focus for interpretation and ageing. Growth curves were derived in a number of ways including assuming no birthday and interpreting only increments without adjustment for birthday and edge interpretation through to analysis assuming a January 1 birthday and adjusting the age with the aid of month of capture and edge interpretation. However, the imprecision in edge interpretation resulted in age adjustments using edge assignments being discontinued.

(a) (b)

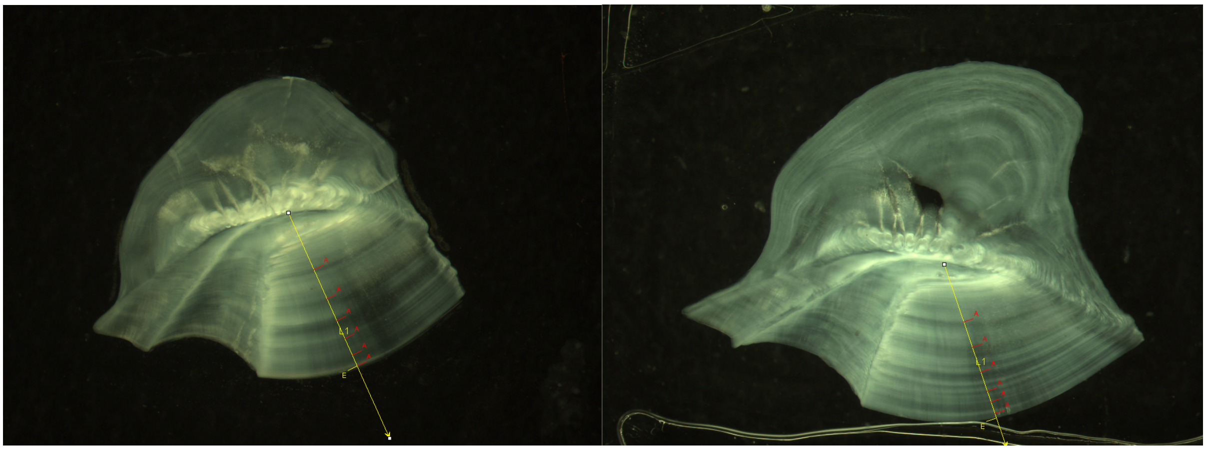

Figure 5 Scanned images of sectioned teraglin otoliths showing (a) relatively clear banding and (b) evidence of double banding.

The IAPE score for teraglin increment counts was 6.3% while the IAPE for edge classification was 19.5% suggesting a relatively low level of precision in both age estimation and edge interpretation. Despite this, repeated increment counts of a subsample of 150 otoliths read by the same reader at an interval of 30 days showed no evidence of systematic bias in interpretation but increasingly less precision when interpreting older individuals (Figure 6).

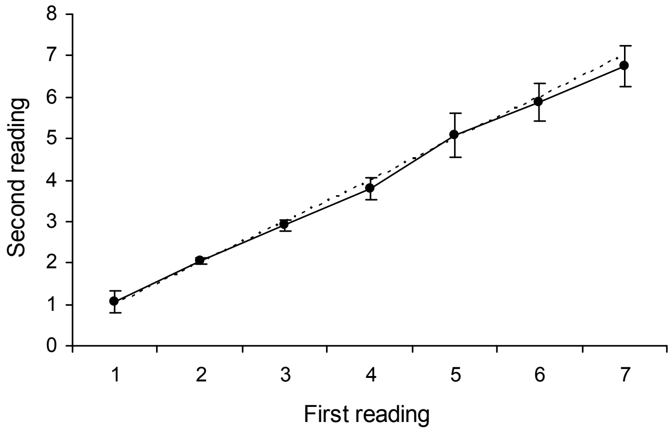

Figure 6 Age bias plots for teraglin (Mean increment counts and 95% confidence intervals of second reading compared with the first reading). The 1:1 equivalence line is shown as a dashed line.

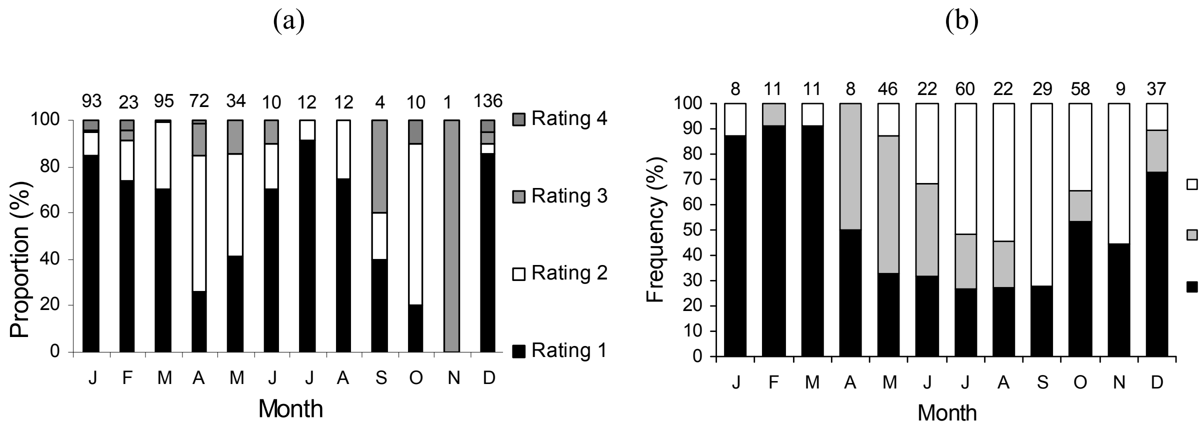

Figure 7 The temporal change in otolith edge rating for *Atractoscion aequidens* based on (a) historic otolith collection (1993 to 1996) describing the distance of opaque bands in relation to edge of sectioned otolith (b) based on otoliths collected during 2009 and 2010. Refer to Table 3.2 for explanation of rating system. NB Historic sample was not re-evaluated in terms of edge classification.

Edge interpretation of teraglin otoliths from the 1990's showed an inconsistent pattern of edge assignment (Figure 7a) with opaque edges being recorded throughout the year and evidence of two edges being formed (or at least interpreted), one during the winter and the other during the summer. In contrast, edge interpretation was more consistently assigned during the most recently collected and aged samples. Due to the fact that double banding was recognised and incorporated in the most recent analysis, we were able to distinguish between these bands, particularly as it related to the recognition of the "wide" edge classification. The most recent edge interpretations show a high proportion of new bands also being categorised during the summer and early autumn (Figure 7b). However, it needs to be recognised that sample sizes were low (<20 individuals) during some of the summer months.

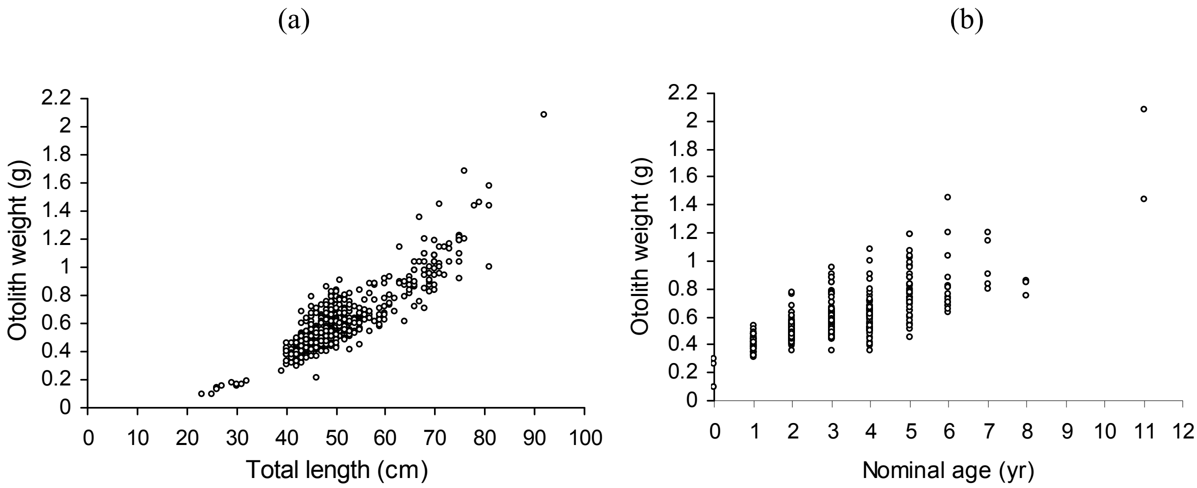

Figure 8 Relationship between (a) otolith weight and fish length and (b) otolith weight and assigned age for teraglin. Data collected during 1993 to 1996.

Due to the difficulty in sectioning and interpreting teraglin otoliths, the otolith weight was also investigated to see if it provided a useful index of age and the relationship between weight and fish length is shown in Figure 8a along with the relationship between otolith weight and estimated age (Figure 8b). The relationship between age estimate and otolith weight was particularly imprecise with considerable overlap in the weights across different aged fish. Fish of a given otolith weight could be spread across over 5 age classes.

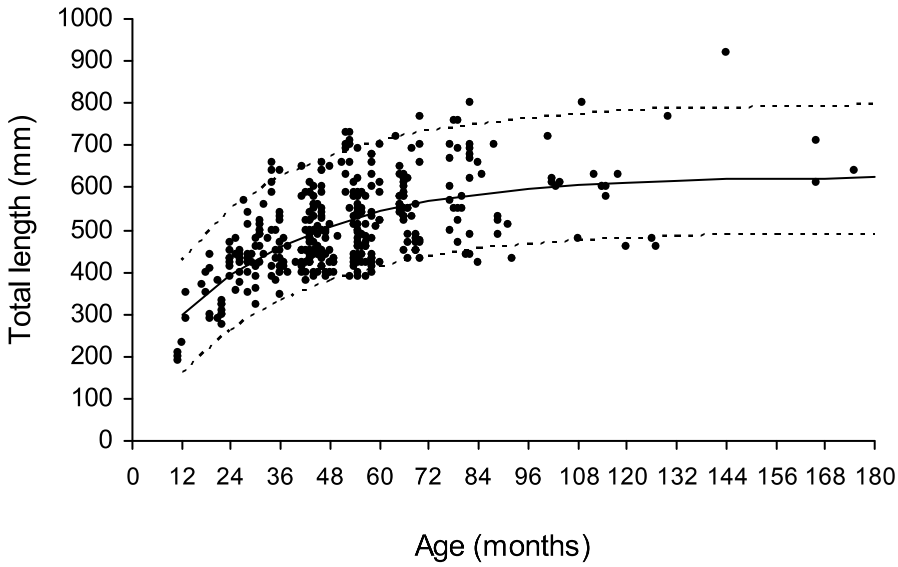

Figure 9 Age length relationship for teraglin with fitted von Bertalanffy growth curve and 95% confidence region.

The oldest fish sampled had 14 increments and were likely over 15 years old with some fish in their second year of life recruiting to the fishery. Log-ratio tests showed no significant difference between the growth curves for male and female teraglin but the sample size was not large enough to statistically determine minor differences in growth parameters between the sexes. Growth of teraglin was best described by the following von Bertalanffy growth parameters $k = 0.343$, $L_{\infty} = 626$mm, $t_0 = -0.877$ (Figure 9).

<u>Reproduction</u>

Overall, sex ratios did not differ significantly from 1 (chi-square = 2.632, df =1, $P>0.05$) and length frequency distributions were also not significantly different (Kolmogorov–Smirnov test $D = 0.187$, $P>0.05$) between males and females. Despite this, the sex ratio of individual catches often differed significantly, being dominated by one sex sometimes by up to an order of magnitude.

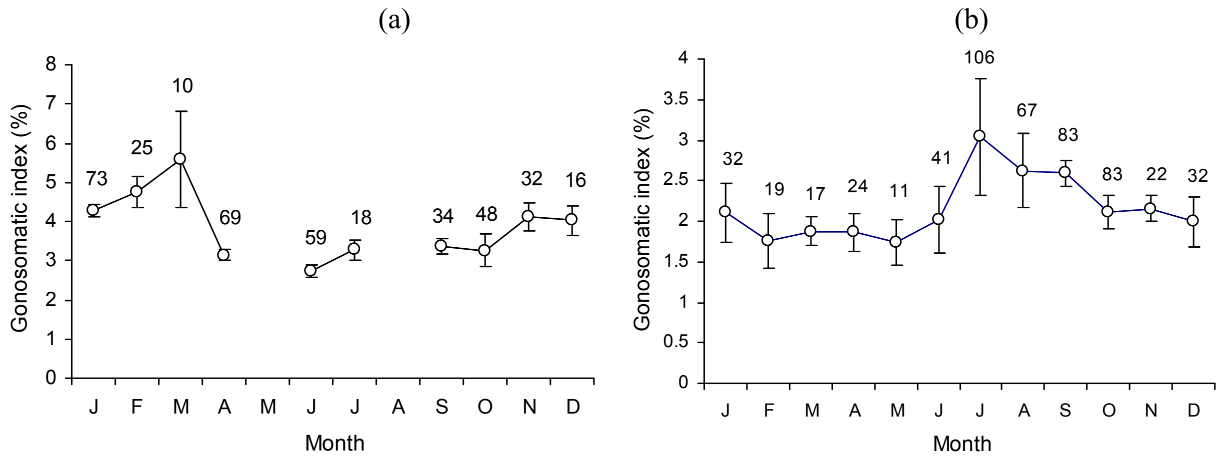

Figure 10 Mean (± 95% confidence intervals) gonosomatic indices of female teraglin collected (a) from southern Queensland during 1993 to 1996 (b) from southern Queensland during 2010 and 2011. Sample sizes are shown above each bar.

Gonosomatic indices did not vary dramatically throughout the year but there were considerable differences between the seasonal reproductive stages shown by the present study and earlier periods when reproductive data were collected during the 1990's when the Gold Coast charter catch was assessed for reproductive stage (Figure 10). The size of fish sampled during the earlier study was significantly greater than the most recent study reflecting the size selectivity of the Gold Coast charter fleet and lowering of MLS that occurred in 2003.

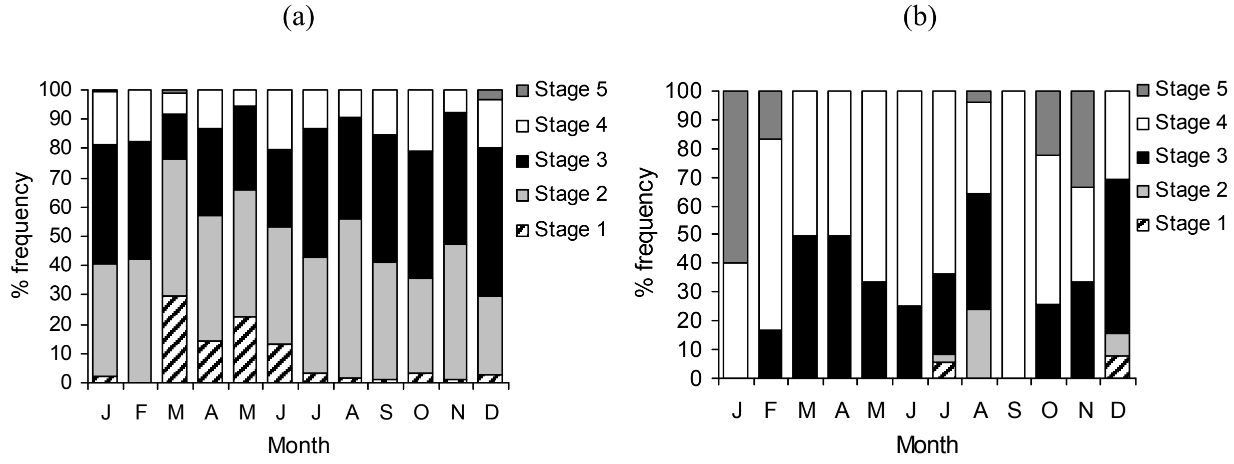

Figure 11 Percent frequency of various gonad stages of female teraglin retained by the Gold Coast charter fishery (a) between 1998 and 2001and (b) from the commercial and recreational sector between 2009 and 2010 covering the entire fishery.

Samples collected exclusively from the Gold Coast charter fishery showed that some teraglin spawned throughout the year (Figure 11a) with inconsistencies determined using data collected in the 1990's to the present in terms of the months that had highest proportions of maturing and spawning fish. The most recently collected reproductive data also show few statistically significant differences among the monthly average GSI's despite the fact that there was considerable variation in the GSI during July and August.

The smallest mature female sampled was 28cm TL (Figure 12a). This female was 2 years old and had a GSI of 2.1%. All fish greater than the current MLS were classified as mature but the L_{50} was imprecisely defined due to the sampling of low numbers of fish smaller than 34cm (Figure 13).

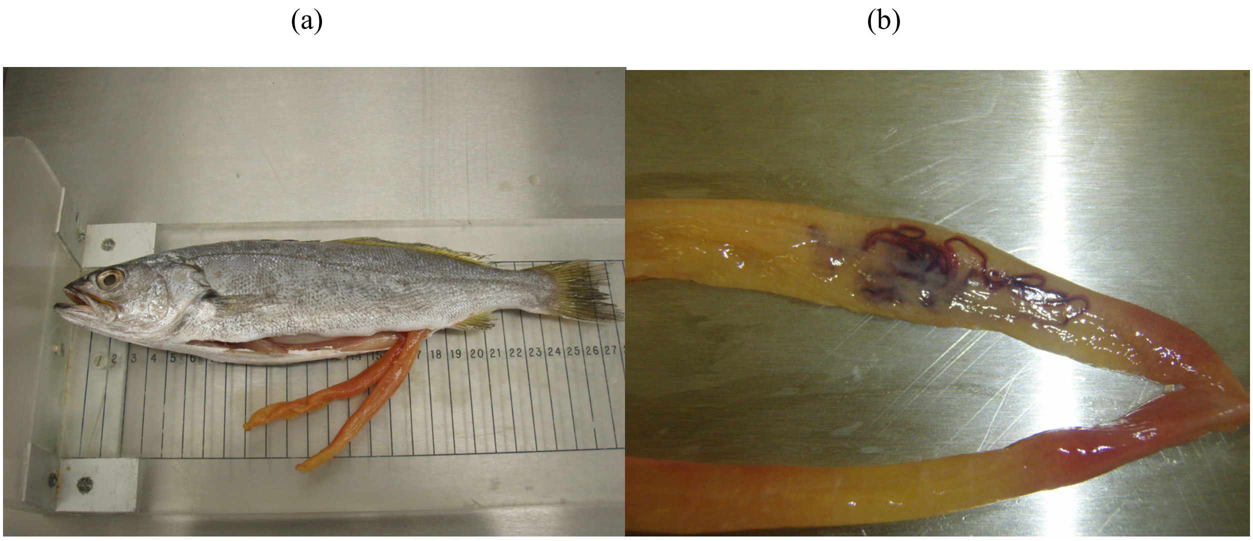

Figure 12 (a) A 28cm female teraglin caught of the Gold Coast in September 2010 showing mature/resting gonads. (b) Gonad of 30 cm female teraglin showing parasitic nematodes.

Nematodes were present in the gonads of approximately 2% of female fish examined (Figure 12b) and prevalence was as high as 30% in some individual catches.

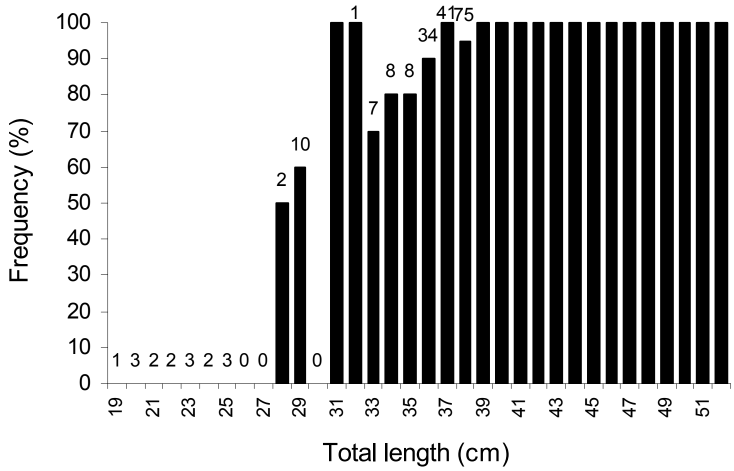

Figure 13 Estimated size at maturity (L_{50}) of female teraglin

Fisheries Statistics

Examples of age structures of the sampled commercial, recreational and charter catches are shown in Figure 14. These show considerable variation among the sectors but the sampled catch is generally dominated by smaller and younger fish between 2 and 5 years old. Fish above the minimum legal size had as few as 1 increment and were therefore most likely in their second year of life (although the majority of fish with only one increment were below the MLS). The commercial sector had a higher proportion of older fish reflecting the obvious selectivity for larger fish shown in Figure 1. The first fully recruited age class to the fishery was the 4th year class. Estimates of "total mortality" (Z) derived from these age structures demonstrate the wide variation that would be achieved depending on the catch weighting strategy adopted (Table 6). Based on fish aged four being the first fully recruited age class to the fishery estimates of total mortality ranged from 0.52 for the commercial fishery up to 1.02 for the charter sector with the recreational estimates being closer to those of the charter sector. We stress that these estimates are not "real" population estimates of total mortality as there is considerable doubt about how representative the catch of any of the sectors is of the age structure of the population being fished (see later discussion). The information available to weight the regional catches from each sector is also poorly defined.

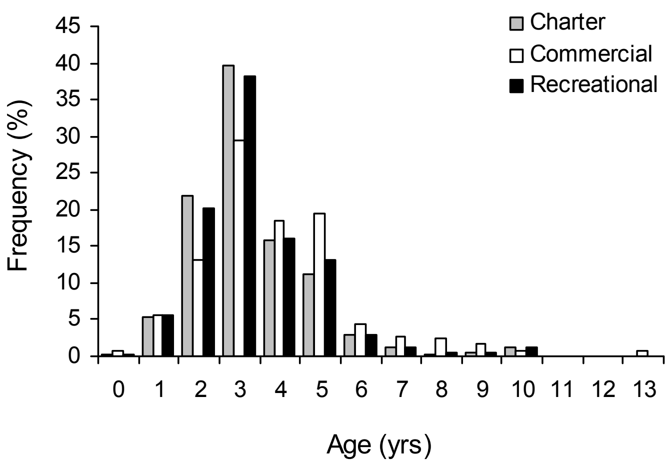

Figure 14 Unweighted age structures derived from the catch of charter, commercial and recreational fishers using an age length key constructed from all age and length data collected during 2009 and 2010.

Table 6 Estimates of total mortality (*Z*) from catch curves assuming age 3 and 4 (in parentheses) as the first fully recruited age classes and ages 8 to 10 as the last age for fitting the regression.

Sector	Instantaneous total mortality estimates		
	Age 10	Age 9	Age 8
Charter	0.64 (0.58)	0.82 (0.82)	0.96 (1.02)
Commercial	0.53 (0.54)	0.51 (0.52)	0.56 (0.59)
Recreational	0.64 (0.59)	0.80 (0.81)	0.89 (0.95)

The youngest ages should theoretically be used because larger and older teraglin are usually caught further offshore (particularly off the Gold Coast) and may not always be available to elements of the fishery therefore violating the assumptions of a closed fishery and one with constant fishing mortality after the age at first capture but it also runs the risk of overestimating mortality. It is clear that levels of mortality vary dramatically depending on how the regressions are calculated.

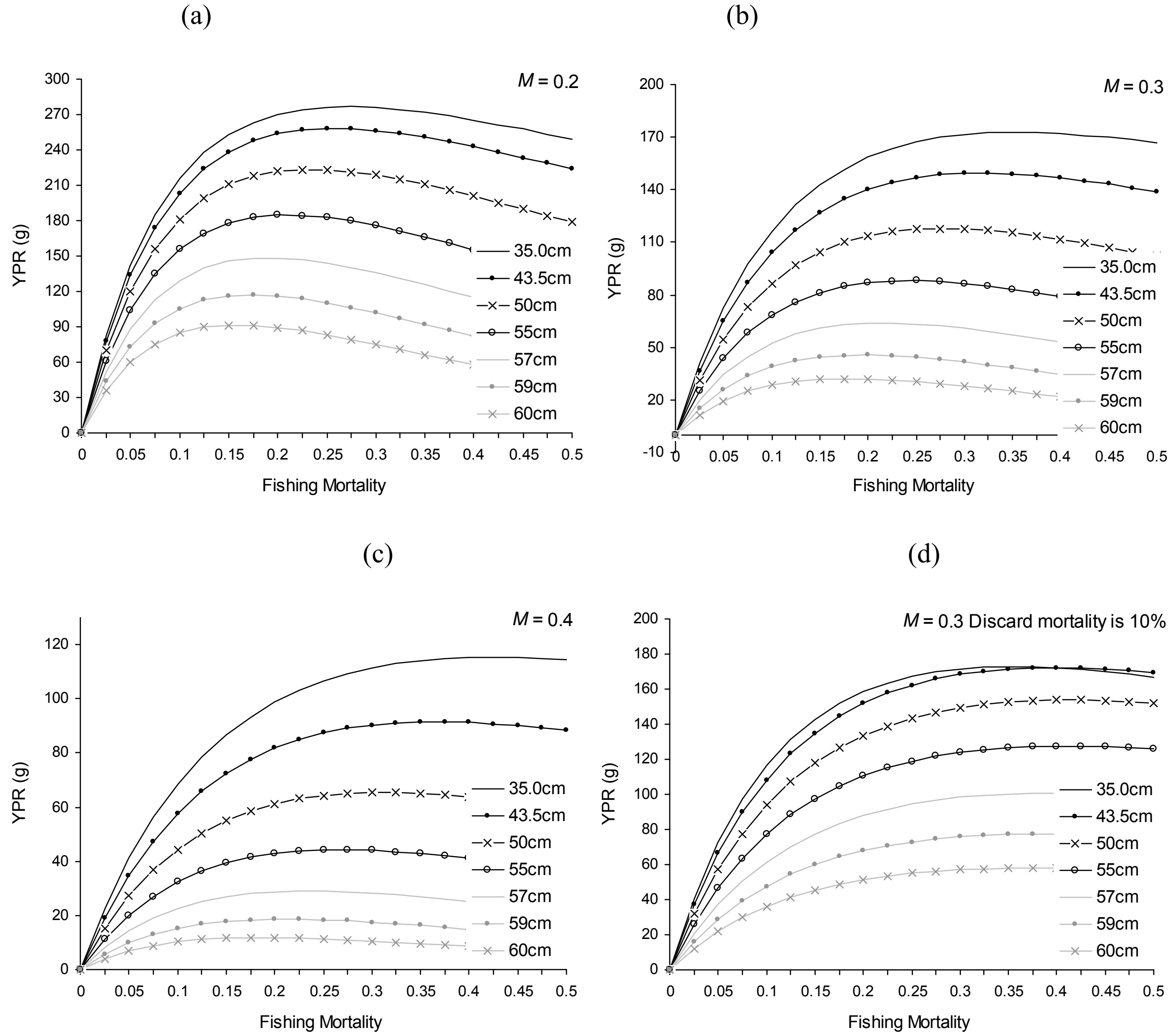

Figure 15 (a) to (c) Change in yield per recruit of teraglin at a range of different minimum legal sizes (MLS) for various levels of fishing mortality and three levels of natural mortality and 60% discard mortality of undersized fish. (d) Effect of lower discard mortality (10%) on yield.

Given growth parameters and reproductive information, estimates of natural mortality were derived using an average water temperature of 22°C and the growth parameters derived in the current research estimates of *M* ranged from 0.305 (Pauly) to 0.295 for Hoenig (1983). Given the *Z* estimates derived from catch curve analysis range from 0.51 to 1.02 depending on assumptions, fishing mortality is likely to be less than natural mortality only based on commercial sampling and for when age 10 was the maximum age used in the regression suggesting that this fishery is likely to be currently at least fully fished and possibly overfished. We again stress that we have low confidence in the extent to which these parameters are unbiased population estimates.

We conducted simple yield per recruit analysis of teraglin (see Appendix 3.1 for methods and assumptions). Growth estimates used in the analysis were those derived using all data (regardless of sex). Changes in yield were investigated under a range of different growth and natural mortality scenarios but we present data for our “best” estimate of growth and for three natural mortality estimates that cover the range of likely levels as assessed by empirical formulae. Obviously a faster growth rate would result in a greater yield than slower growth scenarios and also allow for a greater capacity to sustain lower minimum legal sizes.

We have included post-release survival of 40% (See Appendix 3.6). We set this so that fish were available to the fishery at age 2 (and we assume all these were released). We also assumed that no fish above the minimum legal size were released.

Teraglin growth was less precisely estimated than pearl perch but the following growth parameters (t_0 = -0.383, k = 0.343, L_∞ = 626mm) were used to produce the yield curves presented in Figure 15. The assumption is that discarding occurs two years earlier than the first fully recruited age class and the discard mortality of fish between the size at which they are vulnerable and the MLS is 60%. All parameters of teraglin were known with less accuracy and precision than those of pearl perch. As expected with such high discard mortality yield models suggest that fish should be taken at relatively small sizes in order to maximise yield at all probable levels of natural mortality. Obviously reducing sizes to less than the MLS increases the risk of reducing the spawning biomass, as the size at maturity is currently just under the MLS of 38 cm. We have included a figure that shows the impact of a higher post-release survival (or lower discard mortality) on fishery yields (Figure 15d) that shows higher yields and less of an impact of changing the MLS. The results of teraglin are strongly influenced by the rapid initial growth and the slower growth once maturity is reached. This has the effect of yield being very sensitive to quite small changes in the size of capture for fish younger than 5 years old, and for this reason we have less confidence of the results of the YPR analysis for this species.

Discussion

The age and growth data for teraglin in Australia put it as a much faster growing species than in South Africa and with a significantly lower L_∞ and higher *k*. There are also fewer older fish on the east coast of Australia. The lack of larger individuals in our fishery was a severe limitation to the accurate estimation of growth in this species. This underrepresentation of larger and older fish in the samples as well as the paucity of smaller fish resulted in a lower L_∞ and higher *k* than would normally be expected for this species.

The plotting of temporal changes in the otolith marginal increment analysis (time of ring formation) reveal a clear trend of opaque edge recognition during January and December and gradually declining to low frequencies between April and October. These results illustrate that opaque rings were laid down during spring/summer therefore validating the use of otoliths and subsequent annuli as a means of ageing *Atractoscion aequidens*. Earlier interpretations of otoliths analysed during the 1990’s recognised double bands with one laid down the same time as assessed in the most recent analysis but also a second band recorded during the winter. We were able to distinguish between these bands in the latter analysis. We hypothesise that these two growth checks are associated with a winter growth check and the spring/summer spawning period. We also recognise that gonad development throughout the year and the apparent extended spawning period would further complicate the interpretation of otoliths and determination of accurate and precise age estimates.

It has been proposed that otolith weight can be used to estimate the age of fish (Pawson 1996) since otolith growth is often independent of somatic growth and continues after fish have reached their maximum size (Francis *et al.,* 1992). Although a relationship between otolith weight and age exists, the overlapping of mean otolith weights of particular adjacent age classes illustrates high variation in otolith weight per age class. This variation is indicative of the common phenomenon where slow-growing fish have heavier, larger otoliths than faster growing fish of the same length (Campana 1990, Francis *et al.,* 1992). Therefore, due to the high variation of otolith weight at age*,* the use of otolith weights as an alternative means of ageing would not be recommended for this species.

Sexual maturity as defined by stage 3 gonads is achieved at two to three years of age at a length between 28 and 40 cm. This is at least half the size of geelbek in South Africa where sexual maturity occurred at an age of five years and a fork length of approximately 90cm (Griffiths & Hecht 1995). Samples of fish under 35cm (1-2 year old fish) are under-represented in our samples and therefore an accurate estimate of the length at 50% maturity is not precisely determined. Nonetheless sexually mature fish were well represented in fish that were less than 35cm and the smallest mature fish was only 28 cm in total length.

Plotting of the gonosomatic index of female *Atractoscion aequidens* indicates a relatively stable line with only slight fluctuations and peaks during summer with no consistent and peak spawning event. Similarly the monthly proportion of various stages of gonad development of female *A. aequidens* indicates that stage 3 and 4 gonads are observed throughout the year suggesting that, unlike the African stocks that experience a spawning peak during late winter/spring the Australian *A. aequidens* are serial spawners with an extended, and less defined, spawning season. The staging data do, however provide more evidence of a seasonal spawning peak than do the GSI data. Actual spawning fish were rarely seen across all seasons in southern Queensland with a likely peak during spring and summer. The relatively low number of fish at these advanced maturity stages in our samples suggests that *A .aequidens* may leave the fishery to spawn or that hydration occurs over a relatively short time period when fish are not vulnerable to line capture. Alternatively samples were possibly collected that were not representative of the reproductive state of the population. Immature or resting (stage 2) gonads indicating the onset of sexual maturity also occurred within the 20-30cm size classes. These fish are much smaller compared to the African species where onset of sexual maturity occurred at five years at a fork length of 87cm (Griffiths & Hecht 1995). These growth and reproductive differences between the South Africa and Australia fisheries give further weight to the two fisheries catching different species.

In addition, the size frequency distribution of geelbek in South Africa is strongly bimodal in some areas with the more northerly part of the fishery being unimodal and consisting mostly of larger spawning fish greater than 80cm in length. In some areas (e.g. South Cape) the South African catch size structures are similar to those of the Queensland charter fishery but we found no evidence of bimodal size structures or any evidence of areas where larger individuals (>80cm) were caught in the absence of smaller size classes.

In general, the Queensland fishery is based on smaller and younger fish that mature earlier and grow faster than in South Africa. However, given the geographic isolation of these populations, the widely differing maximum lengths and ages, as well as reproductive differences between this sciaenid in Australia and South Africa it is likely that with genetic analysis there will be future taxonomic revision of this “group”. Farmer (2008) has likewise noted differences between mulloway in South Africa and the presumed same species on the west coast of Australia. The absence of teraglin from Western Australia would suggest that the likelihood of teraglin and geelbek being the same species is even more remote than mulloway.

The catch size structures confirm some of the anecdotal information that shows sections of the charter fishery are targeting inshore areas while the commercial sector is fishing in deeper water where teraglin tend to be a larger size. Catch information collected from the recreational fishery is indicative of one that is fishing a wider range of depths, since the size structure of the catch contains a higher proportion of larger fish than the charter sector. It is somewhat surprising that very few larger older teraglin were sampled from any sector as some historic reports suggest that the species was once fished at a much larger size than is currently the case. It was rare to sample teraglin greater than 5kg in weight despite the fact that Grant (2002) notes that teraglin "are commonly seen to 11kg and are known to attain 19.5 kg". We saw no evidence of "common catches" of individual fish above 5kg. If these historic reports are correct then teraglin would appear to be growth overfished (regardless of the application of any yield per recruit modelling) or larger fish are no longer found on the fishing grounds at the northern end of the species range and may have contracted their range further south. Alternatively, historic reports may have confused teraglin with mulloway; the latter are known to reach sizes well over 20kg in Queensland waters (Grant 2002). While no fish larger than 92cm were sampled during this research there are still reliable anecdotal reports of specimens exceeding one metre in length being taken at times over the last few years (Ray Joyce personal observation). As mentioned earlier, Griffiths and Hecht (1995) found latitudinal related size stratification with much larger fish at the northern extreme of their range in South Africa and strongly bimodal distributions. While we only sampled at the northern end of the species range in Australia, research conducted in NSW covering the southerly distribution of teraglin has likewise found fewer larger fish and no evidence of bimodal size distributions (John Stewart, personal communication). We must conclude that misidentifications of teraglin and mulloway are largely responsible for these reporting anomalies.

There are a number of features of both the fishery and the analytical procedures associated with ageing and data interpretation that preclude teraglin as a good candidate for future detailed stock assessment modelling or fishery dependent monitoring. Firstly (as discussed in Appendix 3.10 to Appendix 3.12), it is only a relatively minor fishery for recreational and commercial rocky reef fishers with annual commercial catches of less than 30 tonnes, although it is a significant component of the southern Queensland charter fishery.

Secondly, the fact that there is population size stratification with depth of teraglin also complicates both the collection of representative catch data as well as data interpretation. While it is relatively easy to sample the catch of the charter sector in particular, it is doubtful whether any cost effective catch sampling would produce a representative sample of the entire population due to the targeting of inshore areas by some operators. Business conditions and other factors change the areas that charter (and other) fishers will operate, thus affecting the resultant size of fish sampled. As an example, in an attempt to reduce fuel costs some fishers are centring their fishing operations closer to shore (see Appendix 3.12). In these locations catch rates can be quite high but size of fish is on average much lower than when fishing further offshore where the converse is the case. Currently, the AMU are oversampling the charter sector with over 80% of fish measured being derived from this sector when the catches of the commercial and recreational sectors are of a similar magnitude and thus should receive proportionally similar sampling effort.

There is currently insufficient power to reliably estimate the recreational catch of this species due to low numbers recorded by recreational diarists. The most recent estimate of recreational teraglin catch derived for 2011 was only around 5 tonne with a relative standard error of 77.5% suggesting a very low level of precision. The lack of accurate and precise recreational catch information thus restricts the ability to weight catches appropriately for this species.

The routine sampling conducted by the AMU was unable to obtain sufficient samples from either the commercial or recreational sectors to enable the construction of representative size or age structures. On the other hand it was relatively simple to obtain size structured information from samples of catches of the charter sector given the importance of this species to that sector. Without representative samples from these sectors any estimates of total mortality derived from age structures would be biased. This is caused by a number of things including the under-representation of larger and older fish in age length keys in addition to the inability to obtain accurate and precise estimates of catch for the recreational sector and the likely biased estimates of population size structure sampled from the charter sector. The current age length key used in this analysis clearly under-represents the larger and older fish in the population and insufficient samples were obtained on an annual basis causing a "smoothing" of any catch age structures, particularly at the older extreme of the age distributions. Despite the difficulty in obtaining commercial catches from these areas there is still a relatively high level of reported commercial catch from these areas.

While it is possible to rescale sampling strategies of the AMU to target fishers who catch teraglin, such a change involves considerable extra cost. Members of the research team working with the AMU program spent time, independent of the AMU sampling program, to supplement samples during 2009 and 2010 but were unable to significantly increase the number of teraglin collected for biological sampling (e.g. otoliths) from the commercial and recreational sectors without increasing bias. It was possible to collect information from the occasional very large catch but these were often heavily size stratified being composed of predominantly large or small fish covering a relatively narrow size range. Examination of historical observer records of commercial line catch from the 1990’s showed that teraglin made up less than 1% of the rocky reef catch of some commercial fishers fishing for rocky reef species. Catches from commercial fishers working north of Moreton Island were particularly small, and this is the region where most of the commercial rocky reef fishery line effort is now targeted. Commercial line fishing effort off Stradbroke Island and the Gold Coast is now relatively light and this is the area where teraglin abundance appears to be the greatest. It is of little value obtaining multiple catches from only one or two fishers unless there is certainty that these catches are representative of the overall catch.

In addition, age structured modelling is complicated by the lack of accuracy and precision of the age estimates themselves. The processing of teraglin otoliths involves multiple sections in order to obtain a section from which an age estimate can be obtained. Even with multiple sectioning the thickness of the sectioning blade (250 microns) often results in the focus of the otolith being destroyed and the “best” section is often far from the focus and thus not ideal for ageing. Observations of serial sections sometimes showed that multiple interpretations of the sections were possible, so that one section was scored as having greater or lesser bands than an adjacent section of the same otolith. The precision of any age estimate is further diminished by the difficulty in assigning a birthday for this species. The extended spawning season and limited ability to determine spawning or settlement without the analysis of daily rings at a considerable extra cost reduces the precision of any derived age structures.

Due to all these complications we would not recommend that teraglin be considered for further detailed monitoring and assessment. Since teraglin is a species that is most important to the charter sector, it may be still informative to collect information on the species composition of the charter catch and associated size structure including teraglin as one of a suite of species examined for that sector. Such monitoring would only be of value if details of the depth of capture were also recorded as we have shown that changing business conditions can impact on the catch size structure and species composition as operators target different depths and fishing areas.

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APPENDIX 3.3 BIOLOGICAL AND FISHERIES INFORMATION FOR THE MINOR ROCKY REEF SPECIES IN SOUTHERN QUEENSLAND

Summary

There is currently a paucity of relevant, Queensland-based data regarding the key biological parameters for the those rocky reef species considered incidental to snapper, pearl perch and teraglin in Queensland – samsonfish (*Seriola hippos*), amberjack (*Seriola dumerili*), yellowtail kingfish (*Seriola lalandi*), mahi mahi (*Coryphaena hippurus*), grass emperor (*Lethrinus laticaudis*), frypan bream (*Argyrops spinifer*) and cobia (*Rachycentron canadum*). Despite this, these species are increasingly targeted by commercial, recreational and charter fishers. Cobia and grass emperor, together, represent approximately 25% of total landings, by weight, in the Rocky Reef Finfish Fishery (RRFF). From information in the literature, yellowtail kingfish (shown to be overfished in New South Wales), amberjack, samsonfish and cobia are currently being managed with a minimum legal size (MLS) lower than the length-at-maturity. As such, these species require continued monitoring from AMU and the periodic analysis of logbook data to ensure the conservative management measures, including stringent in-possession limits, are protecting these species from overfishing.

Introduction

As discussed in Appendix 3.10, snapper (*Pagrus auratus*), pearl perch (*Glaucosoma scapulare*) and teraglin (*Atractoscion aequidens*) are the three most important species in the RRFF, in terms of total harvest. As a percentage of the total line-caught rocky reef catch in each sector, these three species accounted for 39.7%, 16.9% and 7%, respectively, in the commercial sector and 37.2%, 19.6% and 16%, respectively, in the charter sector, during 2010. The remaining species classified as rocky reef fish – samsonfish (*Seriola hippos*), amberjack (*Seriola dumerili*), yellowtail kingfish (*Seriola lalandi*), mahi mahi (*Coryphaena hippurus*), grass emperor (*Lethrinus laticaudis*), frypan bream (*Argyrops spinifer*) and cobia (*Rachycentron canadum*) – are considered incidental species.

The Assessment and Monitoring Unit (AMU) began monitoring the catches of rocky reef species in 2006, after Allen *et al.* (2006) found that snapper was being harvested at or above sustainable levels. While this monitoring is concentrated on the three main target species, catch size structure information and biological material of these incidental species are also collected on an opportunistic basis.

Commercial fishers and charter operators accessing the RRFF are required to record catch data in the Queensland Line Fishery Logbook and the Queensland Commercial Fishing Tour Logbook, respectively, which are then maintained in the Commercial Fisheries Information System (CFISH) database. These data provide stock status information for use by fisheries managers, ensuring each species is being harvested at sustainable levels (e.g. Fisheries Queensland, 2011). These data are mostly daily catch records, with some bulk data (2+ days) also recorded.

P. auratus were historically the primary target of commercial fishers and charter operators, however declining catch rates and more stringent bag (≈in-possession) limits imposed on recreational anglers accessing the RRFF via fishing charters have seen the catch of the incidental species increasing as a proportion of total catch (see Appendix 3.10 for discussion). However, it is accepted that recreational anglers are responsible for the highest proportion of catch in the RRFF for most, if not all, species with recreational fishers responsible for 60% of the snapper catch (Campbell et al., 2009). Recreational catch is difficult to quantify with certainty (Campbell et al., 2009) given the number of participants and the diverse nature of the fishery. As such, species in the RRFF are predominantly managed using output controls – minimum legal sizes for all sectors and bag limits for recreational/charter fishers only. A summary of these output controls are given in Table 1. Commercial fishers are restricted to a maximum of six hooks and vessels less than 20m in length. Generally, in Queensland, MLSs are designed to allow fish species at least one spawning season, with MLS greater than the length at maturity (L_{50} – see Appendix 3.1).

Due to the fact that these species are considered incidental to snapper, pearl perch and teraglin, scant information is available in the literature regarding the age, growth and reproduction for most of these species in Queensland. However, the data generated by the opportunistic sampling undertaken by AMU is the most comprehensive dataset of rocky reef fish species' biological information available. The objective of this chapter is to collate the known biological information of the incidental species from the scientific and grey literature, the logbook (CFISH) data and the sampling undertaken by AMU since 2006.

Table 1 Minimum legal size (MLS) and bag limit restrictions of RRFF species for charter and recreational anglers in Queensland at June, 2012. Commercial fishers are regulated only by the MLS. *denotes that this is a combined limit for these two species so that recreational and charter fishers are allowed only 2 amberjack or 2 samsonfish or one of each species.

Species	MLS	Bag limit
Samsonfish	50cm	2*
Amberjack	50cm	2*
Yellowtail kingfish	60cm	2
Mahi mahi	50cm	5
Grass emperor	25cm	5
Frypan bream	n/a	n/a
Cobia	75cm	2

Commercial Logbook (CFISH) data

Figure 1 summarises the data from the Queensland Line Fishery Logbook (commercial) and the Queensland Commercial Fishing Tour Logbook (charter). Only data from post-2007 were used in analysing the commercial catch as Version 5 Queensland Line Fishery Logbook provided fields for most species, unlike previous versions which only had fields for snapper and pearl perch. The Queensland Commercial Fishing Tour Logbook provided for all species. However, only data from 2000 to 2011 were analysed due to a paucity of data for some species prior to this period.

In the commercial and charter sectors, cobia was an important secondary RRFF species. Since 2007, cobia has represented approximately 12% of landings from the RRFF, by weight, in the commercial sector (Figure 1a). In the charter sector, cobia catch increased from approximately 5% of total catch, by weight, in 2000 to 15% in 2006 (Figure 1b). Since 2009, cobia catch has increased to approximately 14% of total catch. The catch rate of cobia has declined slightly since 2007, from 28kg/boat/day to 20kg/boat/day in the commercial sector while, in the charter sector, catch rates have been relatively stable, with a slight increase evident since 2008.

The catch of grass emperor has increased significantly (Figure 1c) in the commercial sector and, in 2011, represented approximately 13% of total RRFF landings. Catch rate of grass emperor is relatively low in the charter sector (Figure 1c), corresponding to low catch, in weight, and high effort (Figure 1b) but has increased since 2000. The number of days where grass emperor were caught in the charter sector has increased significantly since 2009 (Figure 1b).

Amberjack catch has increased, as a proportion of total catch in both sectors, and represents the species with the highest catch rates at approximately 23kg/boat/day in both sectors (Figure 1c) in 2011. In the charter sector, amberjack catch rates increased significantly in the period 2002 – 2011 from 11kg/boat/day to 23kg/boat/day. Amberjack represent approximately 8% of total landings from the RRFF, by weight, in each sector.

Yellowtail kingfish represent less than 5% of total catch by weight in both sectors (Figure 1a) but catch rates are relatively high with 20kg/boat/day in the commercial sector in 2011 and 17kg/boat/day in the charter sector. Catch rates increased in the charter sector from less than 10kg/boat/day in 2000 to 23kg/boat/day in 2007. Yellowtail kingfish catch rates of have remained at approximately 20kg/boat/day in the commercial sector since 2007 (Figure 1c).

The catch rates of samsonfish exhibit annual variability in the commercial sector while, in the charter sector, catch rates increased significantly in the period 2005 – 2010 (Figure 1c). Samsonfish represent only a very small proportion of total RRFF landings in both sectors (Figure 1a), despite relatively high catch rates.

Both mahi mahi and frypan bream represent only a small proportion of RRFF total catch. Mahi mahi catch is approximately 2% of total landings from the RRFF in both sectors, while frypan bream catch is minimal (Figure 1a).

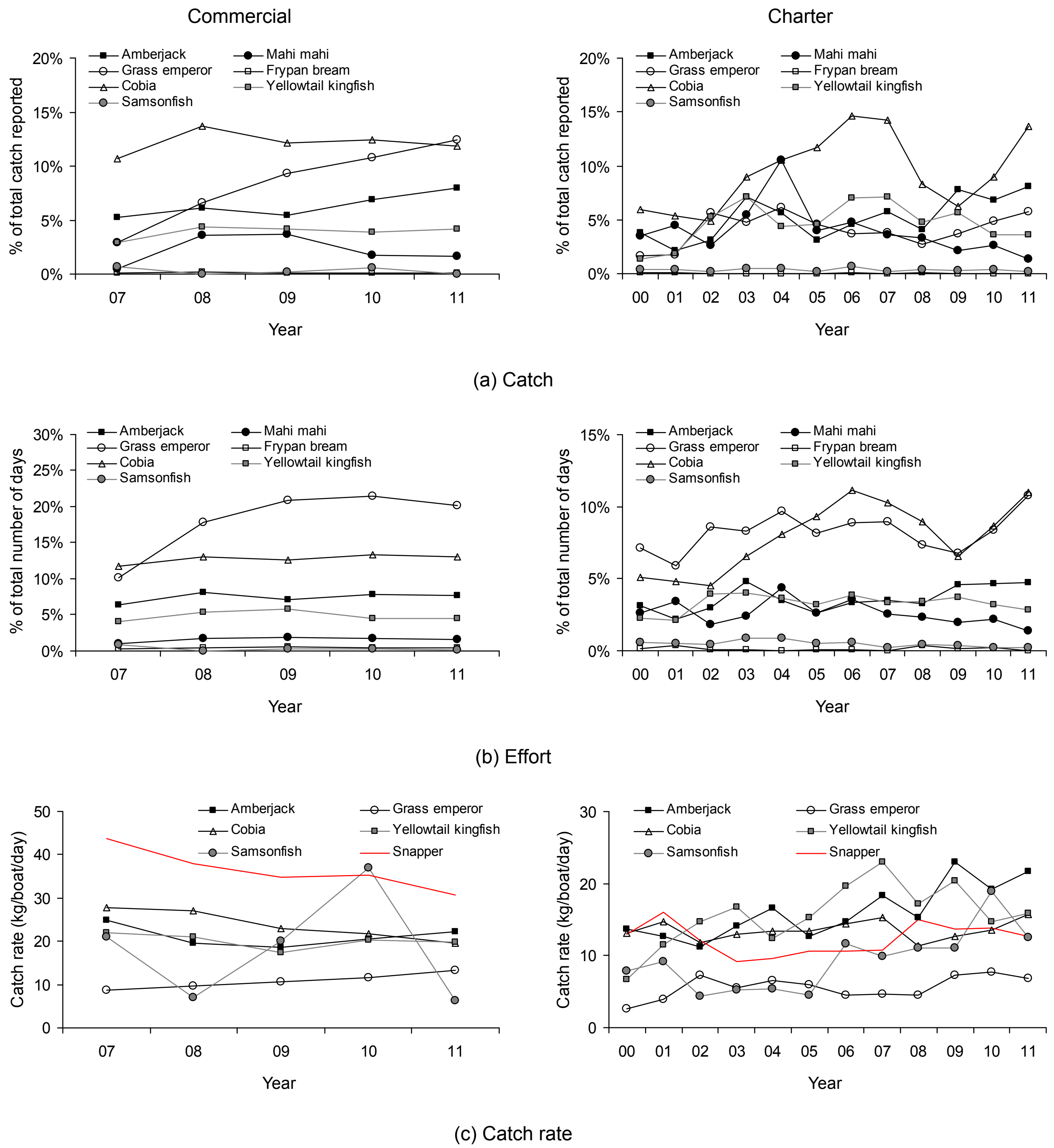

Figure 1 (a) Catch of the incidental RRFF species as a percentage of total catch by sector; (b) Number of catches reported of the incidental RRFF species as a percentage of total days reported by sector; and (c) catch rate, in kilograms per vessel per day, of the incidental RRFF species by sector.

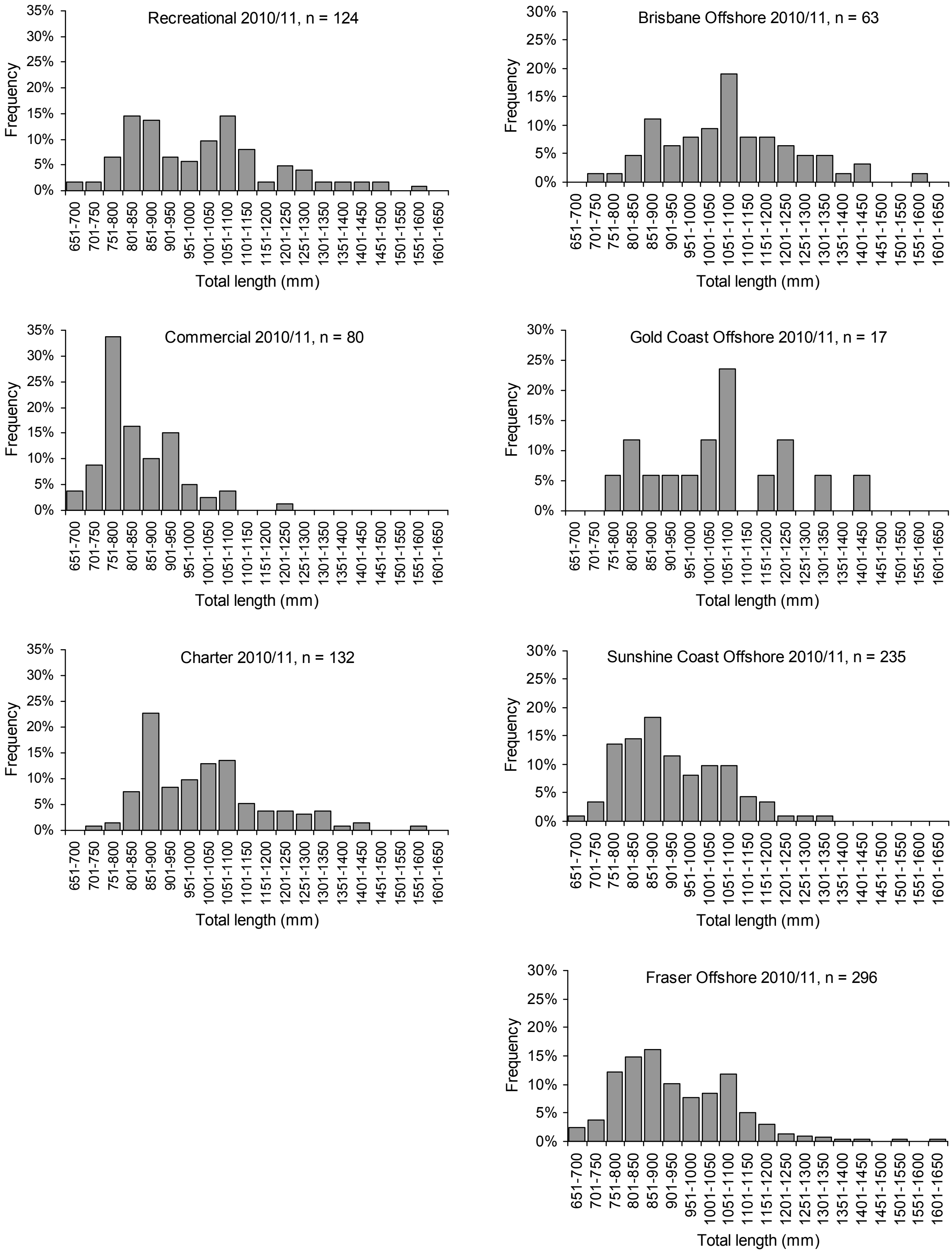

Figure 2 Length frequency histograms for cobia (*Rachycentron canadum*) measured by AMU during the period January 2010 to December 2011. Minimum legal size is 75cm TL.

Assessment and Monitoring Unit (AMU) Data

Length frequency data were recorded by AMU for amberjack, yellowtail kingfish and cobia during the period 2006 – 2012. There were only a few length measurements taken for samsonfish and no data were collected for frypan bream, mahi mahi and grass emperor.

Figures 2, 3 and 4 represent the data collected in 2010 and 2011 only. Prior to this period, MLS varied for some species (see Discussion).

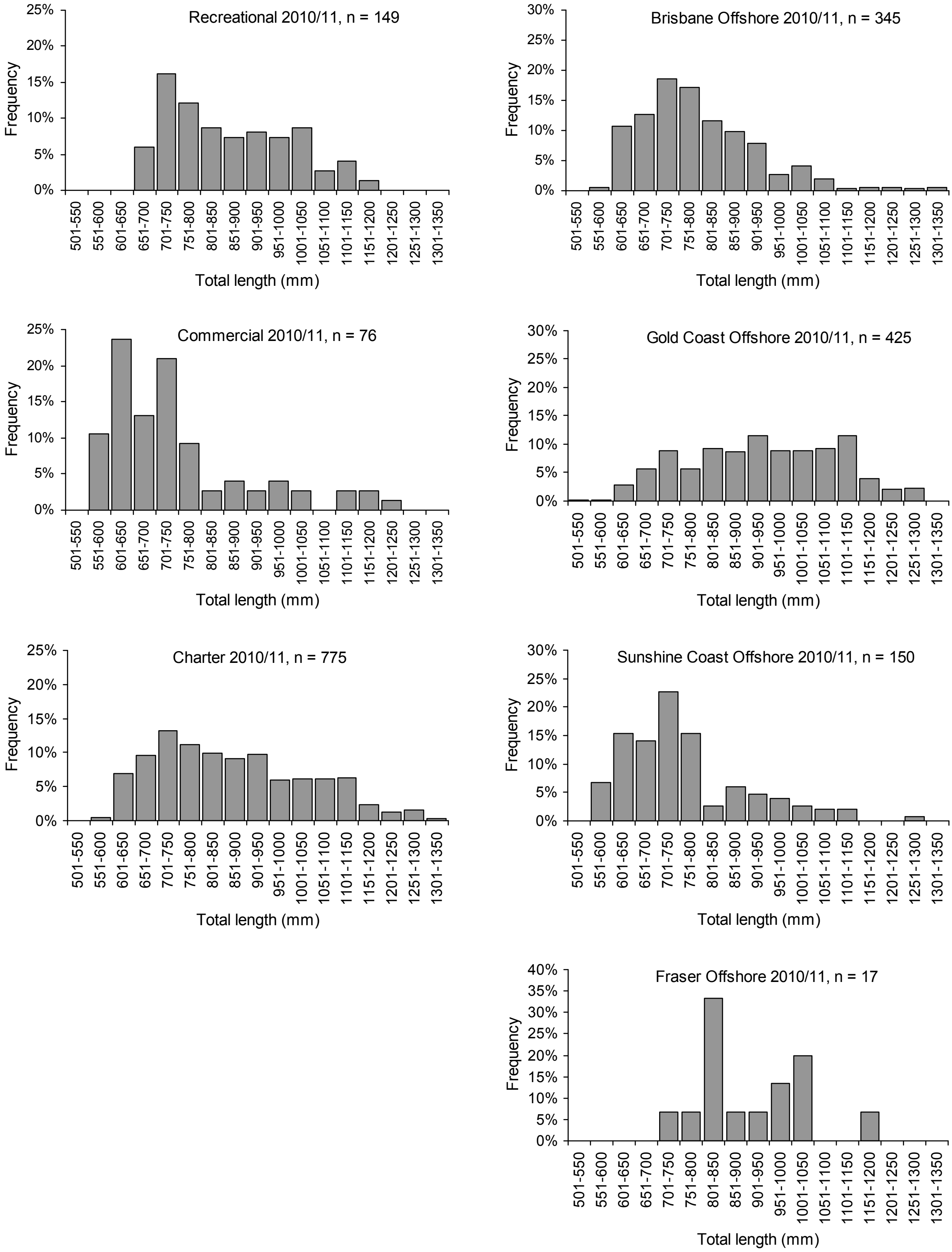

Figure 3 Length frequency histograms for yellowtail kingfish (*S. lalandi*) measured by AMU during the period January 2010 to December 2011. Minimum legal size is 50cm TL.

Figure 2 shows the length frequency distributions of cobia opportunistically sampled by AMU by sector and by sampling region. Commercial cobia catches were skewed toward the MLS, with 92.5% of cobia sampled below a metre in length, although these data were generated from a limited number of catches. In contrast, recreational and charter fishers caught cobia of varying sizes. Most cobia samples came from the Fraser Offshore and Sunshine Coast Offshore sampling regions.

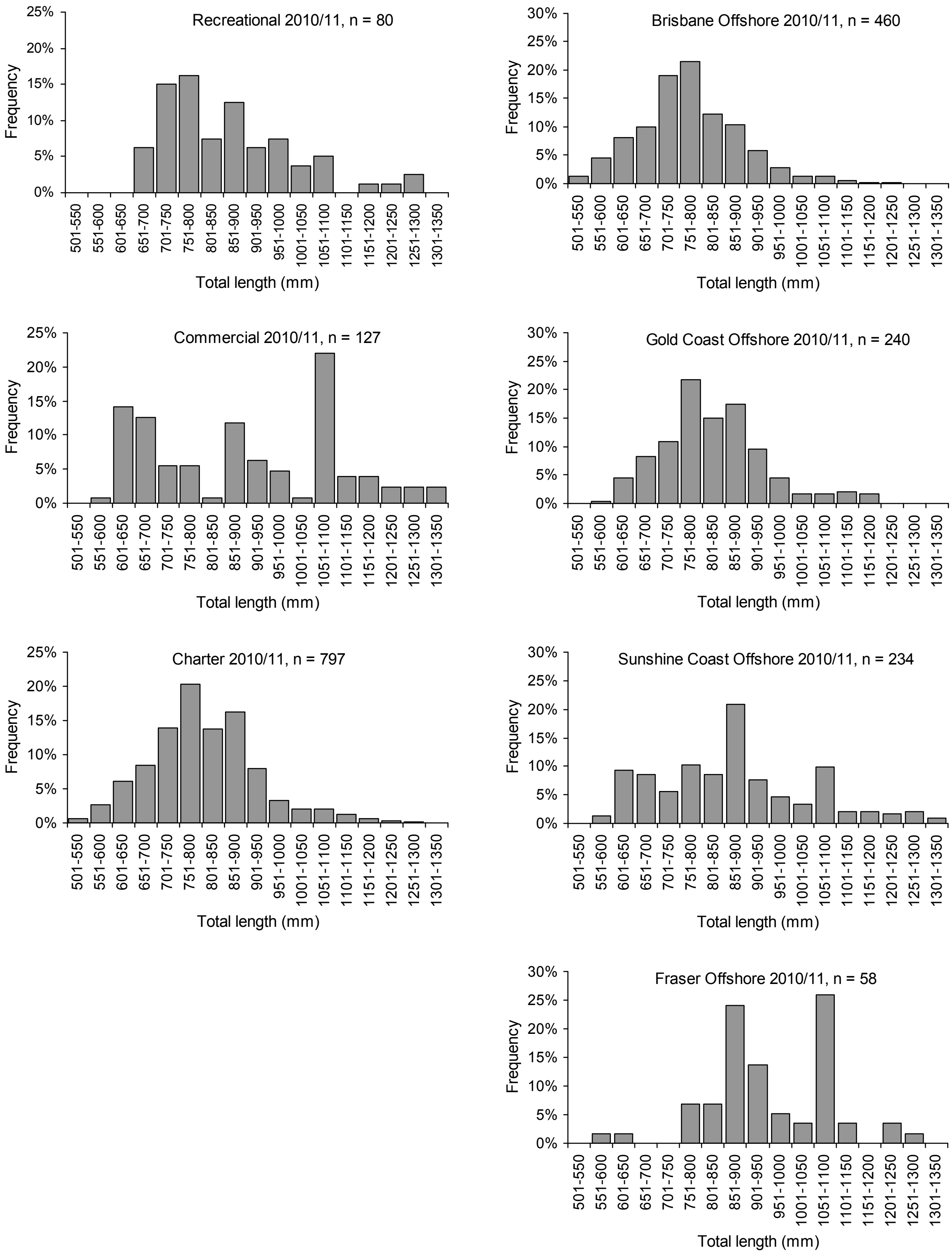

Figure 4 Length frequency histograms for amberjack (*S. dumerili*) measured by AMU during the period January 2010 to December 2011. Minimum legal size is 50cm TL.

The length frequency distributions of yellowtail kingfish sampled opportunistically by AMU were similar to those of cobia, with commercial fishers landing smaller and fewer yellowtail kingfish than both recreational and charter fishers (Figure 3). Charter fishers provided the most samples to AMU, with 775 lengths measured during 2010/11. Yellowtail kingfish sampled by AMU were most prevalent in the Gold Coast Offshore and Brisbane Offshore regions

Amberjack length frequency data were largely collected from the charter fishery (Figure 4), with 797 individuals measured in 2010/11. Of the amberjack sampled opportunistically by AMU, most were caught in the Brisbane, Gold Coast and Sunshine Coast regions (460, 240 and 234, respectively).

Literature Summary of Fisheries Information

Cobia (*Rachycentron canadum*)

Fry and Griffiths (2010) reported age, growth and mortality parameters from cobia caught in northern and eastern Queensland. The von Bertalanffy growth parameters derived during this study were L_∞ = 1,162mm and k = 0.53 for males (n = 92) and L_∞ = 1,243mm and k = 0.47 for females (n = 287), and were not significantly different. These authors reported fast growth rates, with fish reaching 623, 875 and 1005mm in their first, second and third year, respectively. Total instantaneous rate of mortality was estimated as $Z = 0.85yr^{-1}$, while the instantaneous rate of natural mortality was estimated to be $M = 0.35yr^{-1}$, (assuming a maximum age of 13 years). As such, fishing mortality was found to be high, close to the theoretical F_{max} level, coinciding with maximum sustainable yield.

Van der Velde, *et al*. (2010) described the reproductive biology of cobia in Queensland and found that the length-at-maturity (L_{50}) was 783mm FL. These authors found a 671mm TL female had mature gonads and was likely 1 year old. Female gonosomatic index (GSI – see Chapter 2 for derivation) was highest in October/November, with spawning occurring between September and June.

Samsonfish (*Seriola hippos*)

A comprehensive study on the Western Australian population of samsonfish was undertaken by Rowland (2009) who estimated the von Bertalanffy growth parameters as L_∞ = 1,139mm and k = 0.240 for males (n = 167) and L_∞ = 1,279mm and k = 0.188 for females (n = 207). Samsonfish grew rapidly in their first few years of life, reaching the MLS of 600mm TL after 2 years, with the oldest fish sampled at 29 years. Further, Rowland (2009) reported that the length-at-maturity (L_{50}) was 831mm FL (888mm TL), with Gonosomatic Index (GSI) of females, greater in size than L_{50}, highest in the period November to January. In this study, catch curve analysis (see Chapter 2 for details) were used to derive a total instantaneous rate of mortality $Z = 0.21yr^{-1}$, while the instantaneous rate of natural mortality was estimated to be $M = 0.16yr^{-1}$.

Amberjack (*Seriola dumerili*)

Amberjack are the largest member of the family Carangidae and are found throughout the world. Several articles report on aspects of the growth, mortality and reproduction of amberjack. Harris *et al*. (2007) reported the age, growth and reproduction of amberjack off the US east coast and derived the von Bertalanffy growth parameters as L_∞ = 1,105mm and k = 0.36 for males and L_∞ = 1,351mm and k = 0.22 for females. Harris *et al*. (2007) reported that GSI was highest in April and May, the spring months in the northern hemisphere.

Kožul *et al.* (2001) studied the age, growth and mortality of amberjack from Croatia. These authors reported that the von Bertalanffy growth parameters were L_∞ = 1,746mm and k = 0.19 for males and L_∞ = 1,3519mm and k = 0.22 for females. Further, the length-at-maturity (L_{50}) was found to occur between 750mm TL and 1071mm TL. The total instantaneous rate of mortality was reported by Kožul *et al.* (2001) as $Z = 0.41yr^{-1}$, with an instantaneous rate of natural mortality $M = 0.30yr^{-1}$.

A third study by Thompson et al. (1999) described the growth of amberjack from the Gulf of Mexico and found that the von Bertalanffy growth parameters were L_∞ = 1,389mm and k = 0.25. All fish older than 9 years were female.

<u>Yellowtail kingfish (*Seriola lalandi*)</u>

A study by Stewart *et al*. (2004) found that the von Bertalanffy growth parameters were L_∞ = 1,840mm FL and k = 0.054, with no significant difference between the growth of males and females, in the New South Wales population of yellowtail kingfish. The total instantaneous rate of mortality was reported as Z = 0.43yr^{-1} to Z =0.79yr^{-1} for 3-6 year olds and 3-14 year olds respectively. The instantaneous rate of natural mortality was estimated to be M = 0.12yr^{-1}.

Von Bertalanffy growth parameters were also derived by Gillanders *et al*. (1999a) who found L_∞ = 1,250mm FL and k = 0.189, using cohort analysis. Fish aged 1 year were found to be 350mm FL, and 828mm FL at age five. Further, Gillanders *et al*. (1999b) reported the length-at-maturity for yellowtail kingfish caught in New South Wales of L_{50} = 834mm.

<u>Grass emperor (*Lethrinus laticaudis*)</u>

Grass emperor were the subject of a study by Ayvazian *et al.* (2004) in Shark Bay, Western Australia. who found spatial variation in growth in the Shark Bay area, with the von Bertalanffy growth parameters for fish caught outside the bay found to be L_∞ = 592mm FL and k = 0.23. Parameters for fish caught inside the bay on the western side were L_∞ = 403mm FL and k = 0.27 and, for fish on the eastern side of the bay L_∞ = 469mm FL and k = 0.20.

These authors found that the length-at-maturity for female grass emperor was 226mm, with serial spawning during January and February, coinciding with maximum GSI.

<u>Mahi mahi (*Coryphaena hippurus*)</u>

Mahi mahi are a fast growing pelagic species found worldwide and have been the subject of many studies in the scientific literature. Rivera and Appeldoorn (2000) reported von Bertalanffy growth parameters of L_∞ = 1,457mm FL and k = 2.19. Growth was in excess of 3mm.day^{-1} in Florida, USA, Puerto Rico, Hawaii and the Gulf of Mexico.

Schwenke and Buckel (2008) reported von Bertalanffy growth parameters of L_∞ = 1,289mm FL and k = 1.27 for fish caught off North Carolina, USA. These authors also reported a length-at-maturity of L_{50} = 457mm for females and 476mm for males. Fish size adjusted GSI was highest in the northern spring and summer months of May, June and July.

<u>Frypan bream (*Argyrops spinifer*)</u>

Grandcourt *et al*. (2004) reported von Bertalanffy growth parameters of fish caught in the Southern Arabian Gulf were L_∞ = 524mm FL and k = 0.224. Total instantaneous rate of mortality was reported as Z = 0.967yr^{-1}, with the instantaneous rate of natural mortality estimated as M = 0.573 yr^{-1}.

Al Mamry *et al*. (2009) reported the von Bertalanffy growth parameters of fish caught in Oman were L_∞ = 645mm FL and k = 0.142. Length-at-maturity were found to be L_{50} = 372mm for females and 365mm for males. GSI increased in the spring, coinciding with the Monsoon period in the northern hemisphere, and reached a maximum in November.

Discussion

From studies in other regions, yellowtail kingfish appear to be the only incidental species likely to be prone to overfishing in Queensland. In a study conducted in New South Wales(Stewart et al., 2004), fishing mortality (F) was found to be 2.58 – 5.6 times the instantaneous rate of natural mortality (M). For all other incidental species, F has been found to be less than 1.5M, apart from the grass emperor which had a range of F/M of 0.95 – 1.71 (Ayvazian et al., 2004).

Table 2 Summary of von Bertalanffy growth parameters (L_∞ and k), length-at-maturity (L_{50}) and fishing mortality (F) as a proportion of the instantaneous rate of natural mortality (M) published in the scientific literature for the incidental RRFF species. Refer to text for source of data.

Species	L_∞ (mm) FL	k (yr^{-1})	L_{50} (mm) FL	F/M ratio
Samsonfish	♂ 1,139; ♀1,279	♂0.240; ♀0.188	831 FL; 888 TL	0.31
Amberjack	♂ 1,746; ♀1,351	♂ 0.19; ♀ 0.22	705 – 1071	0.37
Yellowtail kingfish	1,840	0.054	834	2.58 – 5.60
Mahi mahi	1,289	1.27	457	1.22
Grass emperor	592	0.23	226	0.95-1.71
Frypan bream	524	0.224	372	0.69
Cobia	♂ 1,162; ♀ 1,243	♂ 0.53; ♀ 0.47	783	1.43

Cobia are an important incidental species in the commercial and charter sectors and represented approximately 12% and 14%, respectively, of total RRFF landings in 2011. In recent years, cobia have become an emerging farmed species due to its fast growth rate and high economic value (Huang et al., 2011). As discussed in Appendix 3.10, the increased availability of advanced GPS and sonar technologies in the late 1990's and early 2000's has seen fishing vessels operating in the RRFF more efficiently, with increases in fishing power likely to have occurred. This, combined with the availability of powerful fishing rods, quality fishing reels and the use of braided fishing lines have led to increasing pressure on species like cobia. Cobia are known to aggregate in areas adjacent to reef and wrecks where they are particularly vulnerable to line capture. Cobia are a good target for charter vessels as they are a large species found relatively close to port, and are highly regarded as a table fish. As such charter vessels can provide clients with a satisfying experience whilst minimising costs. The addition of two artificial reefs just to the north of Moreton Island is likely to affect cobia catch in all three sectors in the short-term, with large catches taken in 2011 immediately after the artificial reefs were established.

Fry and Griffiths (2010) state that cobia have high productivity due to its fast growth and high fecundity, however, they also postulate that the populations in northern Australia are overfished. This is due to the fact that cobia are exposed to fishing mortality in their first year of life as, in Queensland, the MLS of 75cm is lower than the length-at-maturity (L_{50}) of 78.1cm FL. Fry and Griffiths (2010) suggest that an increase in MLS to 85cm TL would be useful in ensuring the sustainability of cobia as post-release survival is high in this species.

In 2011, grass emperor represented 12.4% of the total commercial RRFF catch, increasing from 3% in 2007 (Figure 1a). Given their relatively small size, this represents a significant number of individuals landed. Further, grass emperor were caught on 20% of all days reported by commercial fishers accessing the RRFF (Figure 1b). The current MLS for grass emperor of 25cm is higher than the length-at-maturity (L_{50}) of 22.6cm as reported by Ayvazian *et al.* (2004). These authors studied this species in Shark Bay, WA, which is on the same latitude as the Fraser Island to Sunshine Coast region. As such, it is reasonable to assume that grass emperor caught in Queensland are likely to have similar biological characteristics as those reported by Ayvazian *et al.* (2004), given that a significant proportion (≈20%) of the grass emperor catch is reported from the Fraser Island to Sunshine Coast area. Catch rates of grass emperor have increased in recent years in both the commercial and charter sectors and are likely the most commonly caught, by number, of the incidental RRFF species. It is, therefore, prudent to monitor catch rates to ensure the sustainability of grass emperor catch.

The current MLSs for samsonfish, amberjack and yellowtail kingfish are likely smaller than the length-at-maturity (L_{50}) of these species in Queensland, based on the results from other studies (i.e. Rowland, 2009, Kožul *et al.* 2001 and Gillanders *et al.*, 1999b, respectively). The MLS for these species was 75cm TL in March 2009, but was decreased in response to pressure from charter operators who felt that the 75cm MLS was detrimental to their businesses. Stewart *et al.*, (2004) stated that an increase in the MLS to 80cm TL from 60cm TL would provide better protection to immature yellowtail kingfish while substantially increasing yield. In New South Wales, small (≈50-60cm) yellowtail kingfish were the target of a trap fishery with catches of 500 t landed in the 1980's. However, in Queensland, the maximum commercial yellowtail kingfish catch since 1988 was approximately 11 t in 2008. As such, yellowtail kingfish in Queensland probably sustain significantly less fishing mortality than the NSW population.

The increased popularity of vertical jigging using sophisticated fishing tackle has facilitated a sportfishery targeting these large *Seriola* species (e.g. Rowland 2009) which are, for the most part, caught-and-released. The most recent Queensland recreational fishing survey (McInnes, 2008) reported that of the 41,000 samsonfish, amberjack and yellowtail kingfish caught in 2005, 18,000 (44%) were released by recreational anglers. Also, recreational and charter fishers are restricted to having only two individuals in possession. Given, the high estimates of post-release survival of yellowtail kingfish (Roberts et al., 2011) and samsonfish (Rowland, 2009), combined with the restrictive in-possession limits, it is unlikely that these species sustain high levels of fishing mortality from the charter and recreational sectors. However, Stephen and Harris (2010) reported a 93.62% discard mortality for amberjack based on a qualitative assessment of the condition of fish discarded in the south-eastern United States. As such, it would be prudent to assess the post-release survival of amberjack given the developing catch-and-release fishery in south-east Queensland.

In summary, the incidental species, combined, represent a significant proportion of the total RRFF landings. As a consequence of declining snapper catches and the availability of advanced fishing gear and fish-finding technologies, the catch of the traditionally incidental species have increased in the recreational, charter and commercial sectors. Apart from the fast-growing mahi mahi and the uncommon frypan bream, the catch of the incidental species requires continued monitoring, particularly the catch rate information from logbooks and the opportunistic catch length measurements undertaken by AMU. This is especially the case for yellowtail kingfish (shown to be overfished in New South Wales), amberjack, samsonfish and cobia which are currently managed with a MLS lower than the length-at-maturity. Conservative management measures, including stringent in-possession limits, reduce the risk of overfishing of the remaining incidental species. We recommend the following measures to reduce risks of overfishing of the respective species:

- Given their popularity as a catch-and-release sportfishery target and the stringent in-possession limit imposed on recreational and charter anglers, the post-release survival of amberjack should be assessed to ensure they do survive release.
- It would be prudent to conduct research on the biology of grass emperor to ensure the study by Ayvazian *et al*. (2004) is relevant to the Queensland population, especially regarding the length-at-maturity.

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APPENDIX 3.4 ESTIMATION OF LONG-TERM POST-RELEASE SURVIVAL, MOVEMENT AND GROWTH OF SNAPPER AND PEARL PERCH FROM RECREATIONAL TAGGING DATA.

Summary

The long-term effects of hook-and-line capture, tagging and release of two subtropical rocky-reef species (pink snapper *Pagrus auratus* and pearl perch *Glaucosoma scapulare*) in southern Queensland waters were examined by analysis of recreational tag release and recapture data. Body size (length) was found to have a significant influence on the survival of both species, with the survival rate of large fish being twice that of small fish. Capture depth was not a significant determinant of the survival of pearl perch, but it was for snapper, although there was no consistent trend. In both species the semi-quantitative release condition or (inverse) vitality index was a strong predictor of relative survival. The probability of a snapper exhibiting external signs of barotrauma increased with increasing capture depth and also with increasing size, indicating that the presence of barotrauma signs doesn't necessarily translate into higher mortality. However for pearl perch neither size nor capture depth appeared to affect the likelihood of externally-recognisable barotrauma. Both snapper and pearl perch are basically site-associated, with only a small fraction of the tagged population venturing far from their release locations. The von Bertalanffy growth parameters could not be estimated for snapper, probably because of data quality issues, but realistic estimates (L_∞ = 55.0cm and k = 0.29yr^{-1}),were obtained from a Fabens analysis of the pearl perch tag-recapture data.

Introduction

As a result of concern raised by stock assessment staff about the sustainability of pink snapper (*Pagrus auratus*) stocks in southern Queensland under current exploitation rates, a suite of management changes was proposed in 2010-11. However after considerable and frequently hostile public debate the recommendations were substantially watered down, to the extent that the only substantial change was the establishment of a 70cm. maximum legal size. For a 'slot' fishery with both maximum and minimum legal sizes to work effectively as a conservation measure it is assumed that the end result of releasing under-size and over-size fish (and of course any over the bag limit where this measure is also in place) will be able to contribute more recruits to the population. Just how effective this is will depend on the extent to which the released fish survive.

Several studies have investigated factors influencing the survival rates of pink snapper in Australian waters. Broadhurst *et al*. (2005) and Grixti *et al*. (2010) conducted cage and tank experiments with small snapper to investigate the short-term effects of recreational capture and handling, and found that the principal source of mortality was hooking location. The ingestion of hooks and their subsequent removal was found to cause bleeding and often resulted in the death of the fish.

In Western Australia, St John *et al*. (2009) carried out a structured experiment in which 604 snapper were caught by hook-and-line, treated for barotrauma, tagged and returned to the water. Rather than simply releasing the fish into the wild, the experimental procedure involved placing the fish in 75 cm diameter cages and submerging them back to approximately the depth from which they had been caught, then retrieving the cages after a period of up to 4 days. Survival was influenced primarily by capture depth. Among fish caught in shallow depths (<=30 m) survival rates were high (~97%), but this rapidly dropped to around 30% in fish taken from depth exceeding 40 m.

Stewart (2008) reports on a similar study in New South Wales, in which the snapper were captured off the northern NSW coast using commercial traps in depths to 56 m, then released in similar traps with closed entrance funnels to their capture depth. Again the results showed a significant depth effect, with high survival (~98%) among fish caught in the shallows but decreasing survival rates (to 45%) with increasing capture depth (to around 60 m). Stewart (2008) found that a lack of swimming equilibrium when the fish was returned to the water was not a good indicator of subsequent (short-term) survival. Experiments of this type, if correctly designed, can and have been used to estimate the effects of catching, handling, treating and releasing fish on their subsequent survival in the short term (days to perhaps weeks). However it is of great importance, but much more difficult, to estimate with any reliability what the ultimate survival/mortality outcomes may be in the long term (months to years). The two main issues associated with long-term survival estimation are identification and re-sampling. External tags of one sort or another have traditionally been the accepted way to mark fish in situations where the mark needs to be externally visible and easily recognisable even to anglers unfamiliar with the reason for the tag's existence. In situations where the tagging is carried out by recreational anglers the tags need to be inexpensive and easy (and relatively safe) to apply. Large-scale tagging programmes are often seen as being an ideal way to gain an understanding of post-release mortality, but simple recapture rates cannot provide that information. Tag loss, mortality due to the tagging process itself, non-uniform distribution of marked fish, non-uniform distribution of sampling effort and non-reporting of tags (Pollock *et al*. 1994) all conspire to bias the number of tagged fish that are recaptured. At best, the overall recapture rate derived from an uncontrolled tagging programme will merely provide an absolute minimum estimate of post-release survival, which is of very limited value to management. It is possible, however, to use the results of such a programme to examine the effects of various factors such as gear type, handling procedures, barotrauma signs, and pre-release barotrauma treatment on relative survival rates.

Perhaps the main reasons for recreational involvement in large-scale tagging programmes which don't have a specific research focus are to gain insights into the angled species' patterns of movement and rate of growth. Tag-and-release programmes also provide documentary evidence of an angler's commitment to the catch-and-release ideal where angling skill and expertise are more of a focus than taking home fish for consumption. This applies even more so for species with a very restricted bag-limit, so there's an incentive to keep fishing after the bag-limit is reached.

In this chapter we investigate the ability of a large tag-and-release dataset to shed light on factors influencing the relative survival of recreationally-caught pink snapper (*Pagrus auratus*) and pearl perch (*Glaucosoma scapulare*) in Queensland. We also examine whether the data accumulated over the last decade has significantly altered the conclusions of earlier work on the movement of snapper by Sumpton *et al*. (2003), and how closely estimates of growth derived from tag release and recapture align with those derived from analyses of the otoliths of Queensland snapper and pearl perch. We further use this information to verify conclusions drawn from the other chapters of this report that examine the post-release survival of both these species under more controlled experimental conditions.

Methods

Australian National Sportfishing Association Queensland (ANSAQ) anglers in Queensland have for a number of years contributed to research projects through their tag-release-recapture programme SunTag (Begg *et al*. 1997; McPhee *et al*. 1999, Sumpton *et al*. 2003). Since 1986 SunTag Queensland, a subgroup of ANSAQ, has accumulated a database of nearly 15,000 pink snapper (*P. auratus*) and 2,548 pearl perch (*Glaucosoma scapulare*) tag releases, and a significant number of subsequent recaptures with various pieces of related information about fish size and barotrauma symptoms, capture depth, hook type and lodgement location, and release and recapture dates and locations. The database is administered by InfoFish P/L, whose principal Mr W Sawynok has made the relevant data available to this Project in February 2012.

A mixed-model analysis was used to determine whether initial capture depth and/or body size had an appreciable effect on the probability of the fishes being recaptured. After selecting records which contained both depth and size data, the snapper dataset was reduced from 14,782 to 5,603 observations. As it is possible that angler behaviour and experience may influence the survival rate of the captured fish, we used a generalised linear mixed-model (GLMM) analysis (Schall 1991) in GenStat 14 (2011). Recapture was a binary score (recaptured or not recaptured), and length category and depth category the two predictor variates (factors). 'Angler' was included in the model as a random variate, because of the large number of anglers who contributed to the dataset, and (with a few outstanding exceptions) the relative sparseness of observations attributed to an individual angler. Prior to analysis the data were pooled into categories as follows:

LengthCat = INT(TL/50) and
DepthCat = INT(Water Depth/10)
where TL is total length in millimetres and Water Depth is in metres.

Because the numbers of observations for both fish size (length) and initial capture depth were highly variable across the range, classification of both variates and subsequent pooling of classes was essential prior to analysis. Classification was achieved simply by applying the formula:- Class = INT(X/ε). Where X is the recorded variable (depth in metres or length in millimetres), ε = 10 in the case of depth and 50 in the case of TL and INT is the rounded integer value.

A similar methodological approach was taken to investigating the effect of barotrauma on recapture rates. Both GLMM and GLM were used, with (initially) angler as the random variate and capture depth and fish size fixed effects, where appropriate, and barotrauma signs as the binary response variate. As the distance a fish moves between initial tagging and recapture is of great interest to anglers involved in the catch-tag-and-release programme, the database is well populated with location data, mostly based on a 2 x 2 km grid pattern. This grid pattern is overlaid on a number of printable charts covering most of the Queensland coastline and popular inland angling waters, available via the internet to anglers participating in the SunTag programme. The distance moved is computed by the SunTag system as the minimum straight-line distance in kilometres between the centroids of the release and recapture grids, and is registered on the database.

Using these data, the movement patterns of tagged snapper were summarised graphically with respect to time at large, to see whether fish that had been at large for a long time had also moved greater distances. In addition to movement, the catch-tag-and-release anglers are also interested in the amount of growth shown by the fish between release and recapture. Most recapture records included fish size (either as LCF or TL). Those given as LCF were converted to TL using regression parameters estimated from records where both measures were reported. The von Bertalanffy growth parameters were estimated using the Fabens (1965) method (Haddon, 2001) for comparison with those derived from otolith-based age readings.

Results

The SunTag dataset relating to the two species, extracted in February 2012, comprises 14,782 records of snapper tag releases and 2,550 pearl perch tag releases. 876 tagged snapper and 50 tagged pearl perch were recaptured, representing gross recapture rates of 5.9% and 2.2% respectively. Some snapper had been recaptured more than once (the maximum recapture number was 4), but in the following analyses, unless otherwise indicated, only the initial recapture is used because the system doesn't require subsequent releases of the same tagged fish to be logged separately. Only two pearl perch had been captured on more than one occasion.

Of the 14,782 tag-release records relating to pink snapper, 14,735 contained length measurements (either total length [TL] or caudal fork length [LCF] or both, in millimetres) greater than 100 mm, the lower limit for valid length records. As some lengths were recorded only as TL and some only as LCF, it was decided to convert LCF to TL, using parameters estimated from the straight-line regression of TL on LCF in the 9,601 instances where both were recorded, after removal of outliers. The resultant conversion formula was: TL = 9.442 + 1.10459 * LCF

Depth and length categories were derived by pooling adjacent classes by eye such that there were 5 or fewer categories and as even a distribution of sample sizes as possible. Because of the truncate configuration of the pearl perch's caudal fin, almost all body length measurements were reported as TL for this species. Therefore no conversions were necessary.

Generalised linear regression modelling (GLM) was used initially to investigate whether differences between anglers (in behaviour, skill etc.) were likely to have affected the survival and recapture probability of released tagged snapper. However the model failed to resolve with 'angler' as a fixed effect, so a generalised linear mixed model (GLMM) was then used with 'angler' as a random variate. The standard error of the estimated variance of the random term (angler) was 0.074, an order of magnitude greater than the variance estimate itself, indicating that this term was negligible. The Wald test indicated that the depth × size interaction was non-significant, and of the two fixed effects only fish size was significant ($P = 0.006$). Of interest is the fact that 'survival' (i.e. recapture) probability increased substantially with increasing body size, with recapture probabilities ranging from <1% for fish less than 25 cm to >5% for fish greater than 35 cm in length.

Table 1 Number of depth (m) records by class, and pooled categories for snapper.

Depth Class	Records	Pooled records	Mid-point of range (m)	Depth Category
0	1506	1506	5	0
1	545	797	20	1
2	252			
3	283	914	40	2
4	631			
5	2343	2418	60	3
6	75			

Table 2 Number of length (TL, mm) records by class, and pooled categories for snapper.

Length Class	Records	Pooled records	Mid-point of range (mm)	Length Category
0	18	920	100	0
1	0			
2	8			
3	894			
4	4534	4534	225	1
5	5692	5692	275	2
6	2987	2987	325	3
7	445	648	450+	4
8	96			
9	58			
10	49			

The angler term was therefore dropped from the model, which reverted to a standard GLM, simply testing the effects of depth and size and their interactions. This analysis showed again that the interaction term was non-significant ($P = 0.104$) but both main effects were, with $P = 0.003$ and 0.017 for fish length and capture depth respectively. A similar recapture trend with increasing body size was evident from this analysis (Figure. 1), with adjusted mean probabilities ranging from <2% among the smallest fish to around 5% among the largest.

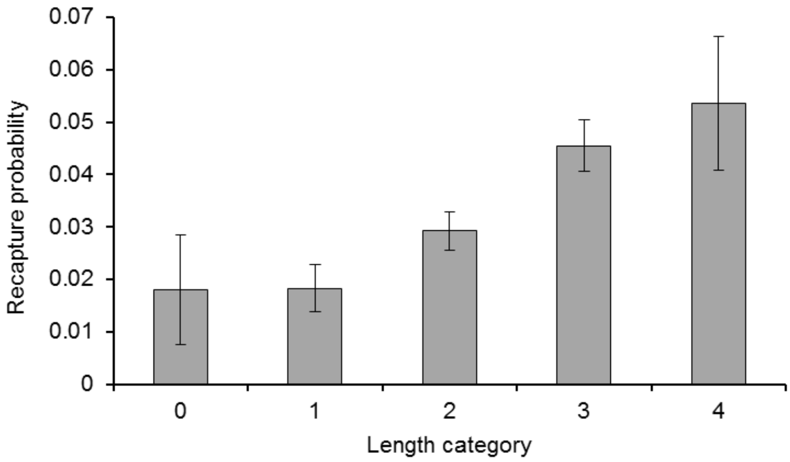

Figure. 1 Adjusted mean recapture probabilities (± s.e.) for snapper of increasing sizes. For details of the length categories refer to Table 2.

There were significant differences in the predicted recapture rate of snapper depending on the depth from which they were caught, although there was no convincing overall trend (Figure 2). Apart from fish caught in depth category 2 there was a slight reduction in adjusted survival rate from 4.5% to 3% as capture depth increased from shallow (<20 m) to deep (>50 m). However the trend was interrupted by the low survival (2%) of fish taken in 30-35 m depth.

Pearl perch recorded on the tagging database were caught from depths ranging from <10 m to 100 m, although the vast majority came from between 30 and 60 m. They were generally small fish, in the 20-40 cm range

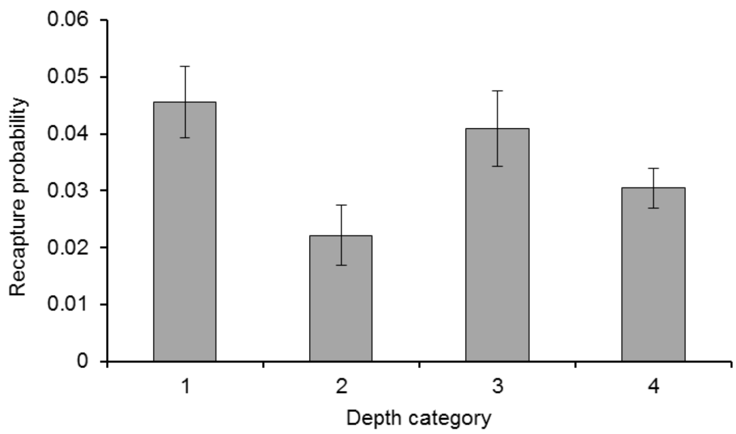

Figure 2 Adjusted mean recapture probabilities (±s.e.) for snapper taken from different (increasing) depths. For details of the depth categories refer to Table 1.

A GLM analysis of the categorical data showed that only body length was a statistically significant determinant of recapture or relative survival (P = 0.018). Neither capture depth nor the depth x size interaction term were significant. The adjusted mean recapture probabilities in Figure indicate that larger fish survive better than smaller fish. The very low estimates for sizes below length category 6 (i.e. <30 cm) and above category 8 (i.e. >45 cm) reflect the extremely low numbers of recaptures in these classes. In fact there were no recaptures at all of the smallest two length classes (3 and 4) despite 218 releases, and only 1 release in lengths above category 8, again not recaptured.

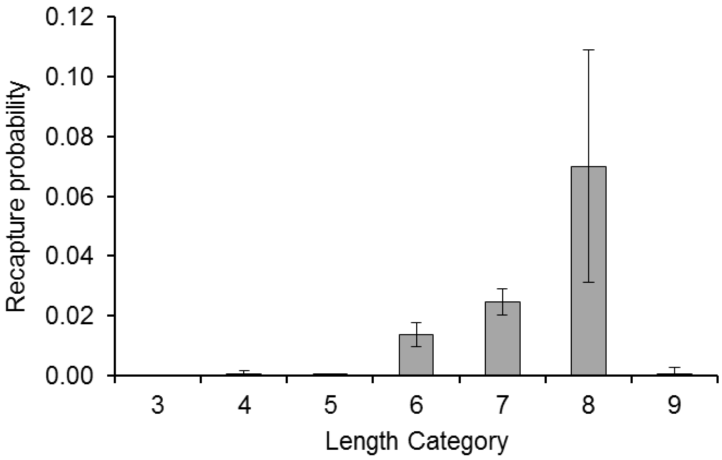

Figure 3 Effect of body size on the relative probability that a tagged pearl perch would be recaptured. Adjusted means and associated approximate standard errors are shown. See text for derivation of length classes.

To investigate whether this inconsistent recapture pattern (with depth) was the result of different barotrauma effects, we then tested whether capture depth and size were implicated in the severity of pressure-related signs as reported by the angler at initial release. Although there were several categories of barotrauma available to the angler, ranging from ‘nil’ through ‘swollen (abdomen)’ to ‘bulging eyes’ and ‘everted gut’, the frequency of the more severe forms was so low that informative analysis using all barotrauma sign categories was impossible, necessitating pooling the data into a simple binary variate indicating whether or not any signs at all were apparent.

An exploratory GLM analysis was carried out to see if there was an angler effect on barotrauma reporting. The dataset only included records where the angler had recorded a 'y' or 'n' against any form of barotrauma. In other words, a null field was not interpreted as an absence of barotrauma signs. This reduced the dataset to 3,874 records. With angler as fixed and barotrauma as the response (binary) variate, the main (angler) effect was highly significant ($P<0.001$), with adjusted means ranging from effectively zero to 0.75. This analysis was followed up with another GLM testing the effect of angler, capture depth and fish length on barotrauma. An initial trial indicated that the depth × length interaction was non-significant, so it was dropped from the model. With angler, depth category and length category as the main effects, all factors were significant (depth $P<0.001$, length $P<0.001$ and angler $P = 0.014$).

Figure 4 indicates that snapper taken from increasing depths are more likely to show signs of barotrauma, with the mean probabilities, after adjustment for angler effects, increasing from effectively zero in the shallowest depth range (<10 m) to about 16% in the deepest range (>50 m).

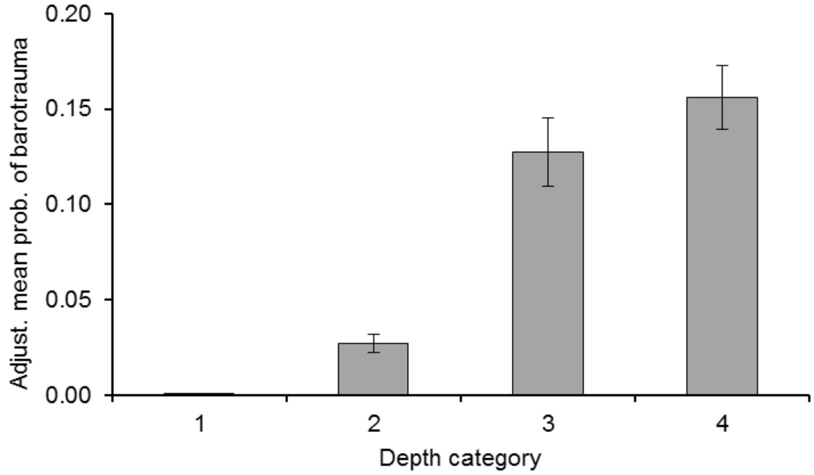

Figure 4 Adjusted mean probabilities (± s.e.) of snapper showing signs of barotrauma when captured from different depths. Depth categories were as shown in Table 1.

The influence of body size (length) on the likelihood of barotrauma signs, accounting for the effects of capture depth and random variation between anglers, is shown in Figure 5. As body size increased, the probability that a snapper would exhibit some degree of barotrauma also increased, from about 2% in the smallest fish to 13% in individuals more than 30 cm long (Figure 5).

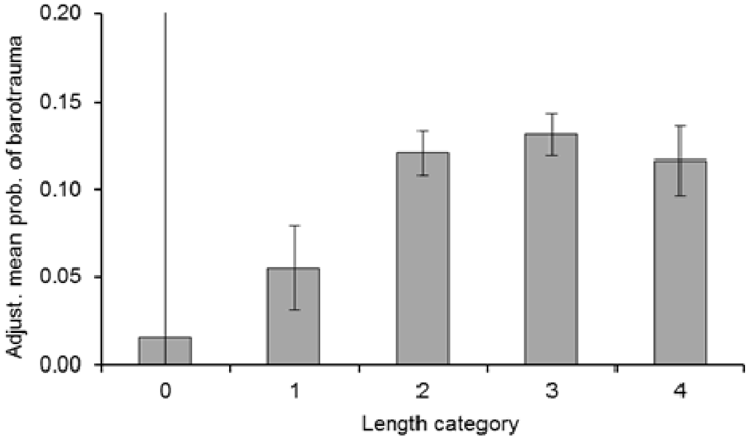

Figure 5 Austed mean probabilities (± s.e.) of snapper of differing lengths showing signs of barotrauma. Length categories were as shown in Table 2.

The effectiveness of venting and shotline releasing as barotrauma-relief treatments was tested (again with GLM) by estimating the recapture or relative survival rates of snapper that had been released either after having been vented, or released on a weighted shotline. Whether or not the fish showed signs of barotrauma was also included in the model, as the effectiveness of a treatment cannot be judged without knowledge of the symptoms. Again, because relatively few records indicated any barotrauma signs, and very few snapper had been shotline released, the number of observations in the various cells of the matrix was highly skewed. Nevertheless the model (barotrauma signs, treatment and interaction) was significant ($P<0.001$). The interaction term was highly significant ($P<0.001$), so the 2-way table of adjusted means was required. These indicated that among the individuals showing no signs of barotrauma, the best survival rates occurred when they were released either without any treatment (~4%) or by shotline (~5%), although the error bars around the latter estimate were very wide (Figure 6). Venting snapper which showed no sign of barotrauma seemed to be very ineffective.

Snapper exhibiting signs of body swelling (stage 1 barotrauma, *sensu* Brown *et al*. 2010) appeared to respond best to venting, with surprisingly low return rates resulting from release by shotline (~5%) and poor returns (~1%) among untreated fish (Figure 6). Perhaps the most surprising result was that fish with stage 2 barotrauma (Brown *et al*. 2010) – i.e. with part of the alimentary canal evaginated through the mouth as a result of a pressure-related increase in internal gas volume – appeared to fare best if released untreated (18% relative survival). Venting provided some benefit (~6%) but shotline releases were evidently totally ineffective.

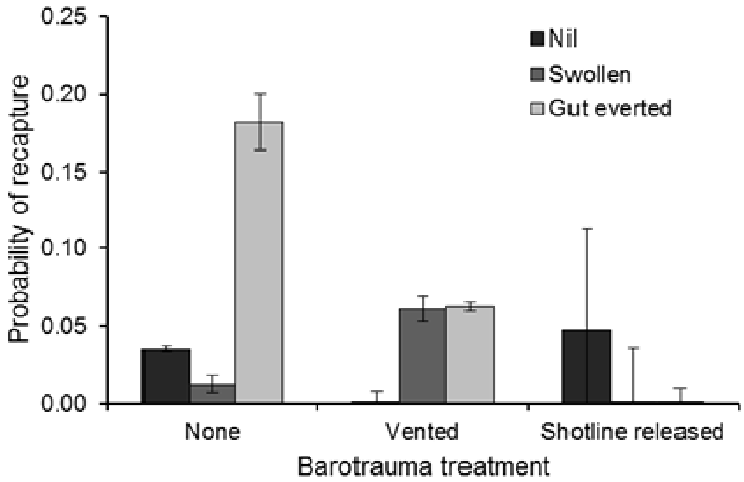

Figure 6 Effect of barotrauma signs and treatment of released snapper on the estimated probability of recapture (± s.e.).

The effects of barotrauma and treatment on the survival or recapture probability of pearl perch were investigated using generalized linear modelling, with both factors as binary variates because of data paucity. The interaction term could not be estimated, presumably because of aliasing in the model, and neither of the fixed effects was significant.

Previous research by Brown *et al.* (2008) and Benoît *et al.* (2010) has indicated that one of the most robust predictors of post-release survival is a (usually subjective) measure of the condition of the fish immediately after release. The release condition or vitality index is a score that describes the behaviour of the fish as it enters the water, and ranges (variously) from very active and suffering no apparent adverse effects of capture and handling through to moribund or effectively dead. To test the ability of release condition to predict the post-release survival of either pearl perch or snapper, separate GLMs were used, with release condition as a factor and recapture (a surrogate for survival) as the response variate. In both cases there was a significant release condition effect, and a clear trend towards greater mortality as the perceived vitality of the fish at release declined. Fish that appeared not to have suffered adverse effects of capture, handling and tagging showed the highest recapture rates (5.5% and 2% for snapper and pearl perch respectively), while the lowest recapture rates were estimated for snapper having the highest release condition (i.e. lowest vitality) scores of 4 and 5 (Figure 7). Few pearl perch were given a condition score of 3, and evidently none was in such poor condition at release to be given a 4 or 5.

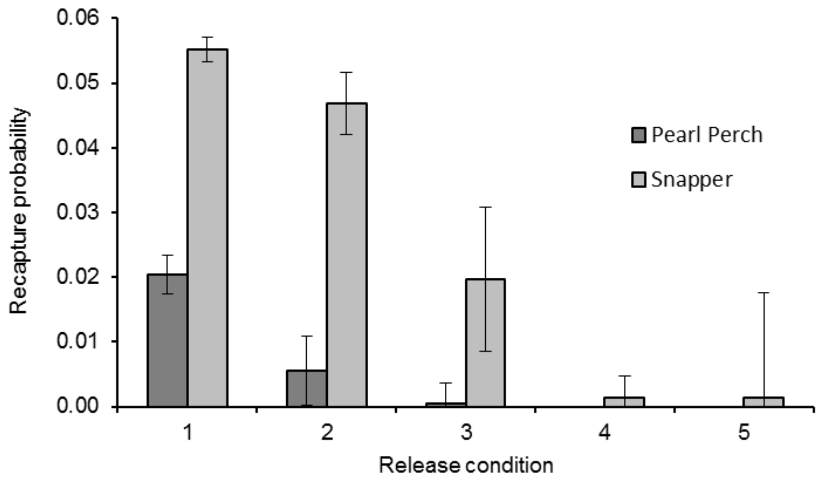

Figure 7 Effect of release condition on the recapture rate (relative survival) of tagged snapper and pearl perch, showing standard error of estimated means.

Of the initial dataset, 852 reported recaptures (including multiple recaptures) had usable records of time at large (days elapsed between release and recapture) and movement (minimum distance in km between the centroids of the grids in which the fish had been released and recaptured).

Most of the reported movement was highly localised, with 83.6% of the recaptures occurring within 1 km of the release point. Only 25 (2.9%) had moved 20 km or more, and four (0.5%) had moved 100 km or more.

The relationship between distance moved and time at large was quite variable, with some fish appearing to have moved considerable distances in a relatively short period of time, while several others that had been at large for more than three years were recaptured within a kilometre of their original point of release (Figure 8).

Despite this variability, the Pearson coefficient of correlation between the two variables was highly significant in a positive direction ($r = 0.158$ with 850 d.f.; $P < 0.01$), indicating that the longer the fish is at large, the more it will have moved. It seems logical that the 'population' of tagged animals would be expected to diminish with time as a result of natural mortality, tagging mortality, tag loss and (if the recaptures are not reported) fishing mortality. Thus the likelihood of a fish being recaptured would be greater for very short times-at-large, assuming some spatial uniformity in angler fishing pressure, than after lengthy periods. When the dataset was restricted to fish that had been at large for a minimum of 3 months the relationship was weaker but still just significant at the 0.01 level ($r = 0.127$ with 424 d.f.). This trend continued when only records with an elapsed time of 6 months or more were used. In this case $r = 0.114$, which, with 214 d.f., was not significant even at the 0.05 level.

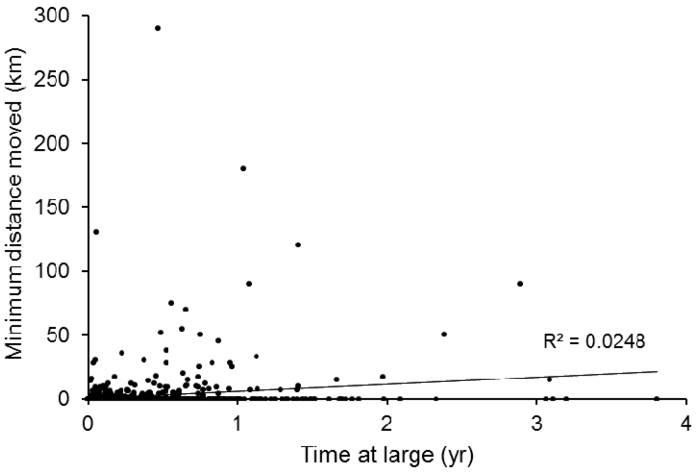

Figure 8 Relationship between distance moved by 852 tagged snapper and the time at large.

Of the 50 recapture records for pearl perch, 47 included movement data. As with snapper, there appears to be little consistent relationship between time at large and distance moved (Figure 9). By far the most fish were highly site-associated, having not moved more than about one kilometre, regardless of their time at large. However a few fish did move considerable distances in a relatively short time (up to 20 km in 6 months) but these were clearly a small minority.

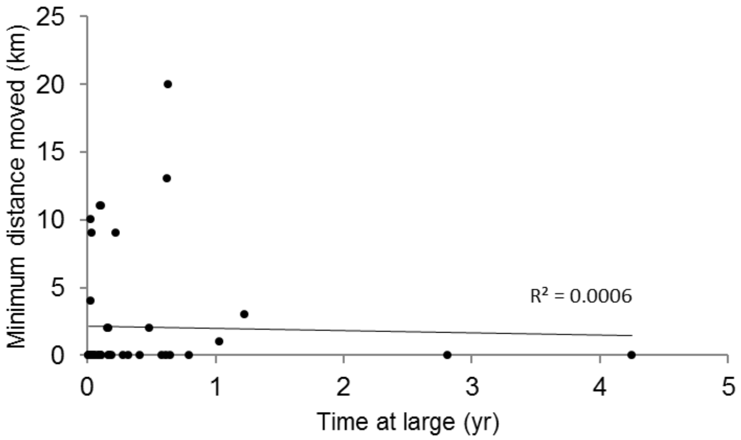

Figure 9 Relationship between the minimum straight-line distance moved by 47 tagged pearl perch and the elapsed time between release and recapture.

In the tagging database there were some 841 records with reported lengths (TL, mm) at release and recapture, as well as release and recapture dates. Initial trials with a Fabens model (Haddon 2001), based on least-squares minimisation, were unsuccessful as the model failed to converge.

While it is entirely possible that the length of a fish may not change, or may even be slightly diminished, in the event that it is recaptured soon after release, there were many records of zero or negative growth after considerable periods at large, which suggested some degree of measurement error on the part of either the tagger or the angler who recaptured the fish.

To examine whether this issue was causing the model to fail, all records showing negative or zero growth were removed, resulting in a set of 574 data points. This enabled the model to converge, but the use of many different combinations of seed values of L_∞ and k, the model failed to produce a sensible result, consistently converging on L_∞ = 33.7 and k= 1.2. This estimate of the average length at which snapper cease growing is clearly far from reality and can be discounted. The reason for this inconclusive result can probably be explained in reference to Figure which indicates a lack of a convincing relationship between the growth increment ΔL and the size at release L_t. One would normally expect the growth increment to diminish as the size at release increases, and trend towards L_∞ on the X-axis. The wide scatter of points in Figure 10 suggests a degree of imprecision or inaccuracy in the records which would be difficult to filter out objectively.

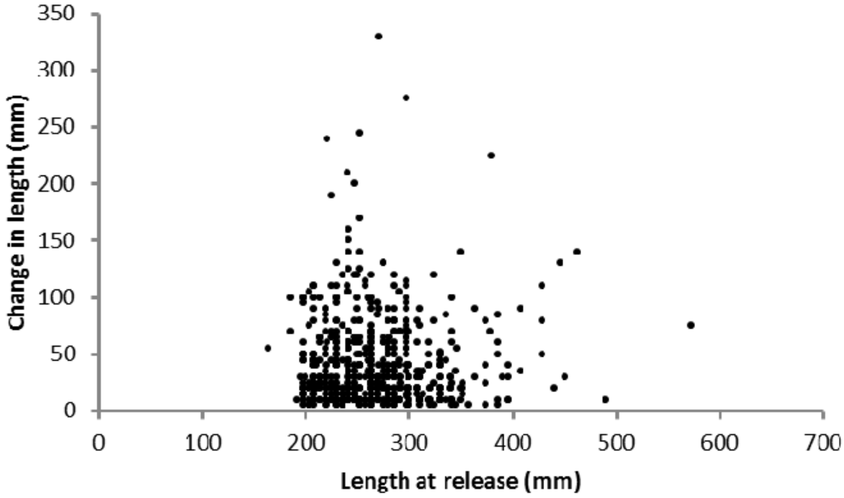

Figure 10 Relationship between growth increment and size at release of 575 tagged and recaptured snapper reported in the SunTag database. Records showing negative or zero growth have been excluded.

The 50 records of tagged and recaptured pearl perch all included total lengths at release and recapture, largely because this species' truncate tail does not lend itself to a fork-length measurement. All the released fish were small (<35 cm), and only 6 fish had been at large for more than 12 months. Despite the somewhat restricted distributions of L_t and ΔT, the Fabens model produced biologically-reasonable estimates of the von Bertalanffy growth parameters: L_∞ = 55.0 and k = 0.29, which yielded the growth curve shown in Figure 11.

Figure 11 Reconstructed von Bertalanffy growth curve for pearl perch based on Fabens parameter estimates from the SunTag release-recapture database.

Discussion

It is not possible to estimate post-release mortality or survival simply from the total numbers of releases and recaptures in an open, non-structured (i.e. non-experimental) tag and release programme, as there is no way of estimating the numbers of survivors that are *not* recaptured. All that can be said is that the overall annual survival rate is somewhere between an absolute minimum (about 6% for snapper and a little over 2% for pearl perch) and 100%. However, with the ancillary information provided in the SunTag database we were able to test some of the factors that might be expected to have an influence on long-term survival of snapper and pearl perch caught, tagged and released in a large recreational hook-and-line fishery. Some new and additional information on movement and growth was also obtained from the recapture data.

Uncertainty about the reliability of the data is always an issue when analysing data collected by a diverse and very large number of observers, particularly under circumstances that are often not conducive to accurate measurements. Measuring a live fish on a small boat in a choppy sea can be a difficult procedure, especially when the intention is to return the fish to the water as soon as possible and in the best physical state possible. When fish are 'on the bite' it can be tempting to continue fishing rather than pausing to record data about the fish that was just caught. This can result in estimates of size, barotrauma signs, and release condition being made after a batch of fish has been tagged and released. Despite the best of intentions, such 'recollected' measures may not be entirely accurate or precise. In the process of analysing the SunTag data in a number of ways, statistical problems were experienced that are almost certainly due to inaccurate or missing data. The results of the analyses may therefore not be as reliable as might be the case had the data been collected under a more structured, experimentally-controlled (and expensive!) programme.

The relative survival (as estimated by the proxy of recapture rate) of both snapper and pearl perch was significantly influenced by the size of the fish. Large fish survived the process of capture, tagging and release better than small fish, by a factor of about 2. This is in line with the findings of Broadhurst *et al*. (2005) and Grixti *et al*. (2010) who reported higher short-term mortalities among very small snapper as a result of hooking damage. By way of contrast, however, St John *et al*. (2009) found that body size had little effect on survival of snapper caught in depths less than 30 m, while among fish caught in deeper water mortality actually increased with increasing size, to the extent that not one of the largest fish (> 60 cm) survived the experimental procedure. We believe that size related mortalities may not necessarily be a result of different size effects of barotraumas, but to do more with general robustness of larger fish to capture and handling by recreational anglers.

Capture depth was a weak but statistically significant predictor of relative survival of snapper, but there was not a consistent trend across depths, with the lowest survival occurring among fish caught in depth-zone 2 (2%) compared with 4-5% in the adjacent zones 1 and 3. St John *et al*. (2009) reported quite high short-term survival at depths <30 m (similar to zone 2), but rapidly decreasing survival at greater depths. A similar trend was reported by Stewart *et al*. (2008) although the 'deep water' survival rates were much higher than those reported in the previous study. The reason for the lack of a consistent depth-related trend in the present study is not clear, the possibility of its being due to differences in skill or experience between anglers in different areas having been discounted by the results of the mixed model, which identified the angler effect as negligible. It may be, however, the result of variability between anglers being so great that real effects were obscured. Alternatively, differential depth related recreational effort can obviously affect some of these trends.

The depth and size-related effects on survival referred to above are probably mediated through physical or physiological processes revealed to a greater or lesser extent through signs of barotrauma and general vitality. An exploration of the relationship between capture depth and body size and angler on barotrauma signs of snapper revealed that the angler effect was significant. This was possibly because some anglers were more observant in detecting signs of barotrauma than others, or that there were major differences between anglers in their assessment of what the indicators of barotrauma actually are. As might be expected, the likelihood that a fish caught in the shallowest depth range would exhibit signs of barotrauma was low, but this increased rapidly with increasing depth. It is of interest that this trend was not reflected by an opposite trend in survival, suggesting that even though snapper caught in deep water are more likely to suffer from visible effects of barotrauma, that doesn't translate into higher mortality.

Body size was also a significant determinant of barotrauma, with larger fish being more likely to be affected than smaller fish. This is unlikely to be due to a confounding relationship between size and depth, as the model accounted for the depth effect when estimating the effect of size, and in any case there was not a significant interaction between the two variables. The fact that the recapture probability (i.e. relative survival) trended in the same direction as barotrauma probability is further evidence that visible barotrauma signs in snapper don't necessarily mean lower survival.

Linking barotrauma directly to mortality necessitated the involvement of another variable – barotrauma treatment. Unfortunately because so few records (relatively) contained both an indication of whether or not the fish showed any signs of barotrauma *and* evidence of treatment by venting or occasionally shotline releasing, the statistical models were unable to resolve the data. The fact that there was such a high adjusted recapture probability among fish that had everted stomachs but were released without any barotrauma treatment may have been due to a small number of research anglers being more attuned to identifying Stage 2 barotrauma, particularly when the fish's evaginated alimentary canal was not protruding beyond its mouth and was therefore much less noticeable that otherwise. However the fact that venting swollen fish appears to be advantageous in terms of reducing post-release mortality is more straightforward to explain. The whole point of venting is to allow the escape of gas that has expanded due to reducing ambient pressure on hauling the fish from depth. Deflating the swim bladder this way enables the fish to regain neutral buoyancy and therefore helps its submergence.

While the model output suggested that shotline releasing was the most effective way to maximise survival of fish showing no signs of barotrauma, the error surrounding this estimate was very high, indicating that it was probably not significantly different from venting or from no treatment at all.

Probably because of data inadequacies (mainly the lack of observations in certain combinations of factor levels) the effects of neither barotrauma nor treatment procedure for pearl perch were statistically significant.

As an alternative to assessing barotrauma, release condition or vitality index was found to be a stronger determinant of survival. It should be remembered that the higher values of 'release condition' actually represent lower vitality scores. Even though this is only a semi-quantitative statistic based on an assessment of the fish's behaviour as it is released, there was a very strong relationship between release condition and survival in both snapper and pearl perch, with survival decreasing markedly with increasing release condition scores. Although it doesn't provide any causal explanation *per se*, it is nevertheless a valuable pointer to potential survival rates and factors of influence (Benoit *et al*. 2010, Brown *et al*. 2010), particularly if circumstances do not allow for more detailed observations.

For reasons that could not be ascertained, it was not possible to derive biologically-reasonable growth parameter estimates for snapper from the tag-recapture data. It is possible that the very large number of short-term recaptures of small fish with highly variable length increments, due perhaps in part to the difficulty of measuring fish accurately at sea, biased the data and resulted in the least-squares model reaching an incorrect local parameter optimum. On the other hand, the data did allow the estimation of von Bertalanffy growth parameters for pearl perch, which (given the constraints of not having estimates of age) approximated those obtained from otolith analyses presented elsewhere in this report. Reconstructing the growth curve indicates that pearl perch reach minimum legal size (35 cm) at about 3-4 years of age, and effectively reach an average maximum asymptotic length of about 55 cm in approximately 10-12 years.

Both snapper and pearl perch appear to be predominantly site-attached, although a small number of snapper and a few small pearl perch moved substantial distances between release and recapture. The additional data accumulated since the study by Sumpton *et al*. (2003) confirm the authors' conclusions that snapper movement is rather localised, with only a small number of fish being caught more than a few kilometres distant from their release point. Pearl perch exhibited a similar pattern to snapper, although the available data were limited to 50 recapture observations. It appears that in both species the bulk of the population is site-associated, but, for reasons as yet unclear, a small proportion is prompted to move away to distant locations.

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APPENDIX 3.5 EXPERIMENTAL DETERMINATION OF THE SHORT-TERM POST-RELEASE SURVIVAL OF LINE CAUGHT PEARL PERCH (*Glaucosoma scapulare*)

Summary

Post-release survival of line-caught *G. scapulare* was assessed via field experiments where fish were angled using methods similar to those used by commercial, recreational and charter fishers. 186 *G. scapulare* were caught during 5 experiments, of which >90% were found to survive up to 3 days post-capture. Hook location was found to be the best predictor of survival, with the survival of throat- or gut-hooked *G. scapulare* being significantly ($P < 0.05$) lower than those hooked in either the mouth or lip. Post-release survival was similar for both legal (≥ 35cm) and sub-legal (<35cm) *G. scapulare*. Examination of the swim bladders in the laboratory, combined with observations in the field, revealed that swim bladders rupture during ascent from depth allowing swim bladder gases to escape into the gut cavity. As angled *G. scapulare* approach the surface, the alimentary tract ruptures near the anus allowing swim bladder gases to escape the gut. As a result, very few *G. scapulare* exhibit barotrauma symptoms and no barotrauma mitigation strategies were assessed. The results of this study show that *G. scapulare* are relatively resilient to catch-and-release suggesting that post-release mortality would not contribute significantly to total fishing mortality. We recommend the use of circle hooks, fished actively on tight lines, combined with minimal handling in order to maximise the post-release survival of *G. scapulare*.

Introduction

Pearl perch (*Glaucosoma scapulare*) are a schooling species found in schools (McKay, 1997) in depths to at least 200 metres in southern Queensland and northern New South Wales. In Queensland, *G. scapulare* are caught by fishers with hook-and-line, although juveniles are caught as bycatch in adjacent commercial prawn (*Melicertus plebejus*) trawl (Courtney *et al*., 2007) and sand crab (*Portunus pelagicus*) pot (Sumpton, unpublished data) fisheries.

The recreational harvest of *G. scapulare* is regulated by a minimum legal size (MLS) of 35cm total length (TL) combined with an in-possession bag limit of five individuals, while commercial fishers are regulated only by the MLS. These harvest regulations are designed to maintain effective spawning stock sizes (Brown *et al*., 2010) and lead to the mandatory discarding of individuals, termed regulatory discards by Kelleher (2005), the survival of which is unknown. The use of management regulations such as MLSs and bag limits achieve their specific purpose of conserving fish stocks only if regulatory discards survive (Broadhurst *et al*., 2006; Butcher *et al*., 2007; Butcher *et al*., 2008). The survival of discarded individuals is rarely estimated in specific fisheries and represents a large source of uncertainty in estimates of total fishing mortality (Davis, 2002).

A confounding factor to consider with regard to the post release survival of *G. scapulare* is the effect of catch-and-release angling. The increasing popularity of catch-and-release (see review by Arlinghaus *et al*., 2007) in recreational fisheries in Australia (McLeay *et al*., 2002; Henry and Lyle, 2003; St. John and Syers, 2005) promotes the voluntary discarding of catch. Fish species once targeted primarily for the table, including *P. auratus* and *G. scapulare*, are becoming increasingly popular with catch-and-release 'sportfishers' in Queensland. The increased popularity of this style of sportfishing has been due to technological improvements to fishing apparatus (Reynolds *et al*., 2009), from handlines and heavy monofilament to light, powerful fishing rods used in conjunction with braided and gelspun polyethylene fishing lines. Additionally, the increased trend in the use of specialised artificial lures has seen unprecedented numbers of sportfishing anglers targeting these rocky reef fish. These changes have occurred concurrently with an increase in the prevalence of recreational fishing magazine articles and televised fishing programs publicising innovative fishing techniques and promoting catch-and-release. To further illustrate this point, Henry and Lyle (2003) reported that ~50% of Queensland residents who responded to a national survey on recreational fishing stated that fishing for sport was a "very important" motivation to participate in recreational angling, while ~25% of respondents stated that fishing for food was a "not at all important" motivation to participate in recreational angling.

The survival of discarded line-caught fish is influenced by a variety of factors (see reviews by Arlinghaus *et al*., 2007, Bartholomew and Bohnsack, 2005 and Muoneke and Childress, 1994). These factors have been the subject of numerous studies in recent years and include hook type or size (Aalbers *et al*., 2004; Cooke *et al*., 2005; Grixti *et al*., 2007; Butcher *et al*., 2008; Graves and Horodysky, 2008; Mapleston *et al*., 2008), hooking location (Pope and Wilde, 2004; Butcher *et al*., 2007; Alós *et al*., 2008; McGrath *et al*., 2009), landing apparatus (Barthel *et al*., 2003; Danylchuk *et al*., 2008; De Lestang *et al*., 2008) and duration of exposure to air (Gingerich *et al*., 2007; Reynolds *et al*., 2009).

Although these factors are important in the post-release survival of *G. scapulare*, given this species' propensity to inhabit relatively deep water (McKay, 1997), bringing a fish to the surface can result in various pressure-related injuries referred to as barotrauma (Wilde, 2009). Typically, as line-caught fish are brought to the surface, gases within a fish's body expand according to Boyle's Law. As such, the volume of the gas within the swim bladder expands with decreasing pressure (i.e. depth), as do the dissolved gases found in the blood and tissue cells which leave solution and form bubbles (St. John and Syers, 2005). The expansion of gases results in symptoms of barotrauma such as the distension of the body cavity, gut eversion and exophthalmia (Brown *et al*., 2010). Prior to rupture, the expanding swim bladder may cause injuries to the adjacent organs as described by Wilde (2009) and Rummer and Bennett (2005). Barotrauma has been reported as having a significant effect on the post-release survival of line-caught demersal reef species in Australia including West Australian dhufish *G. hebraicum* (St. John and Syers, 2005), snapper *P. auratus* (Stewart, 2008), coral trout *Plectropomus leopardus* (Brown *et al*., 2008) and saddle-tail sea perch *Lutjanus malabaricus* (Sumpton *et al*., 2008).

McInnes (2008) estimated that of the 356 000 *G. scapulare* caught by recreational anglers in 2005, 208,000 (~58.4%) were discarded either due to management regulations or voluntarily. Given the magnitude of discards, it is prudent to quantify the fate of these discarded animals in order to ensure the efficacy of the management strategies used in the Queensland rocky reef fishery to regulate the catch of *G. scapulare*. The objective of this study was to quantify the short-term (3 day) survival of *G. scapulare* using the vertical enclosures described by Brown *et al*. (2010). Preliminary field trials showed that *G. scapulare* exhibited no barotrauma symptoms at a macroscopic level and, as such, the efficacy of barotrauma mitigation strategies was not assessed.

Methods

The post-release survival field experiments were conducted in an area adjacent to Double Island Point at the southern end of Fraser Island and in the waters off Cape Moreton (Figure 1), in south east Queensland, Australia. These areas were chosen as they are known to support large populations of *G. scapulare* and allow for experiments to be conducted in both shallow and deep water.

Double Island Point – Shallow (<80m)

G. scapulare habitat in the Double Island Point (Area A in Figure 1) experimental area consists of rocky reef, particularly surrounding the Wolf Rock Exclusion Zone, and flat, broken gravel substrates. Water depths in these areas range between 30m and 50m.

Post-release survival was assessed using the vertical enclosures described by Brown *et al*. (2010), similar to those described by Render and Wilson (1996). Three cylindrical enclosures, or socks, were constructed of #36 ply, 4-inch (101mm) trawl mesh sewn into a cylinder 1.9m in diameter and 15m deep (Figure). Seven galvanized steel (12mm rod) hoops, 1.9m in diameter, were used to maintain the cylindrical shape of the socks and were separated by 27.5 meshes (~2.5m). The upper-most hoop, positioned at the sea surface, was welded to an eighth hoop via four lengths of galvanized steel rod (12mm diameter by 50cm in length). This upper section was enclosed by mesh in order to prevent floating animals escaping and provide protection from predation by birds and sharks. Four large (50cm diameter) polyethylene floats were attached to the inside of the upper enclosure to provide positive buoyancy, whilst three 13kg weights were shackled to the lower-most hoop to ensure the enclosure remained vertical throughout the experiments.

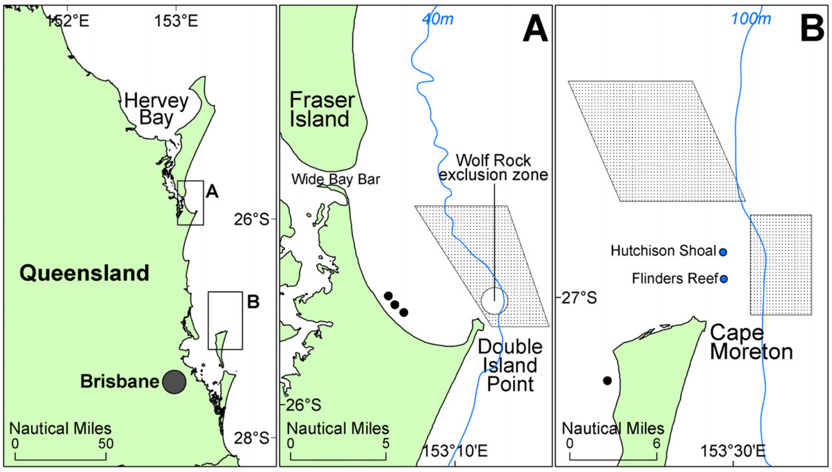

Figure 1 Location of post-release survival experiments. (A) The Double Island point area was the location for the shallow (<80m) experiments; (B) The Moreton Island area was the location of the deep (>80m) experiments. The black circles represent the location of the cages when used and the shaded areas represent the fishing grounds.

To facilitate retrieval, four lengths of 4mm stainless steel chain, each approximately 1.2m, were shackled to the second-to-lowest hoop and then attached to a 20m x 12mm polyethylene retrieval rope. A dan-buoy with a radar reflector was attached to the upper end of the retrieval rope. The portion of the mesh below the lower-most hoop was gathered together and a drawstring attached in the manner of a trawl-net codend. The 'floor' of the socks were lined with shade cloth, similar to the product used by Fokeera-Wahedally and Bhikajee (2005), which provided the captive animals with some protection from current and also prevented the escape of smaller individuals.

Each sock was anchored to the seafloor via, respectively, 60m of 12mm polyethylene rope, 10m of 12mm galvanized steel chain and a 16kg fluke-style anchor. The anchor line was then attached to a sock via three bridles of 12mm polyethylene rope and a quick-release clip. The socks were deployed close to the shore in approximately 20m water depth at the start of each experiment as protection from the south-east winds and northerly current predominant in the area.

G. scapulare were angled from the Fisheries Research Vessel (FRV) *Tom Marshall*, a 14.5m aluminium diesel-powered catamaran, and a 5.8m aluminium centre cab, MV *Makaira*, with two anglers allocated randomly to each vessel. Individual fish were angled using conventional rod-and-reel, employing 1 to 3 hooks attached to a 20-30kg breaking strain monofilament mainline via 15cm of 15-20kg breaking strain monofilament branch lines above a lead sinker, the weight of which ranged between 200g and 750g depending on such factors as depth and current. The hooks used were J-style Mustad "Big Red" in size 5/0, baited with pilchards *Sardinops neopilchardus*, squid (Family *Loliginidae*) or mullet *Mugil cephalus*.

Once caught, relevant data were recorded by the angler, including time of day, hook location, hooking-related injuries, capture depth and external signs of barotrauma. Each fish was then tagged using a numbered Hallprint™ T-bar tag and placed in a holding container supplied with flow-through seawater. Two 1.4 t polyethylene holding tanks were located on the stern deck of the *Tom Marshall*, while a modified and plumbed 110-litre insulated fish box acted as the holding tank on the *Makaira*. Approximately 45 minutes after the first fish had been placed in a holding tank, the fish caught on the *Tom Marshall* were transferred to the holding tank aboard the *Makaira* before all fish were transported to a pre-determined sock for release. Once at the sock, tag number, the time since capture (i.e. surface interval) and the release condition of each fish were recorded. This procedure was repeated until fishing ceased for the day and repeated on subsequent days. Fishing was carried out over three days, with each sock containing the catch from separate days.

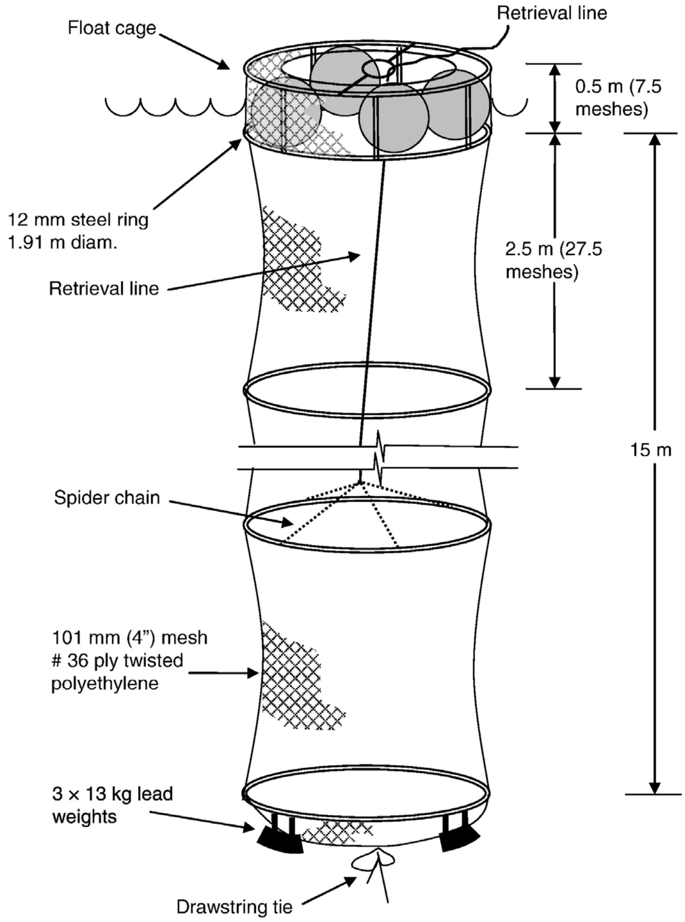

Figure 2 The vertical enclosure or "sock" used to quantify the post-release survival of *G. scapulare* at the Double Island Point site (see Figure 1).

On the fourth day of each experiment, the first sock, containing the catch from the first day of fishing, was retrieved. The socks were designed to be retrieved by the retrieval rope so that the hoops came together in concertina-fashion, apart from the lower-most hoop, which formed a codend-like compartment at the base of each sock. Once the anchor line had been removed from the sock, via the quick-release clip, the dan-buoy was recovered and the retrieval rope was passed through a small snatch block at the end of a 2-tonne hydraulic crane, mounted on the stern of the *Tom Marshall*, before being attached to a capstan. Once the sock was aboard, the drawstring was released and the fish removed to one of the 1.4 t holding tanks at which time, all fish were assessed for vitality and tag numbers recorded.

Cape Moreton – Deep (>80m)

Given the distances of the fishing grounds from the sheltered waters required to deploy the socks, two methods were employed to hold captured fish from the Cape Moreton area. Depending on prevailing weather and fishing location, captured fish were either left in the holding tanks for a period of 2-3 days or transferred to a modified sock on the western side of Moreton Island (see Figure 1). For the purposes of the deep water experiments, one sock was modified by removing the middle section so that the sock was five metres deep.

All fishing took place aboard the *Tom Marshall* using methods described above. Once again, captured fish were tagged before removal to the flow-through holding tanks to identify individuals, after relevant data were recorded by the angler. Once fishing was complete each day, the fish were either left in the holding tanks or removed to the modified sock, depending on the weather conditions and the distance to the sock. At the completion of the experiment, all fish were retrieved from the modified sock and placed in the holding tanks, at which time the tag number of each fish was recorded and its vitality assessed.

In both shallow and deep experiments, all *G. scapulare* were euthanised and stored in the vessel's on-board freezer. Once back at the laboratory, all fish were dissected in order to determine the extent of barotrauma-related injuries. Before dissection, each fish was immersed in water and air was injected into the gut cavity, via a small-bore hypodermic needle, to provide information regarding the likely escape route of swim bladder gases during capture.

Fish were then eviscerated carefully, in order to ensure the swim bladder remained intact. The swim bladder was examined and the presence/absence of a perforation was recorded, as was the size, shape, any signs of healing and the location of the perforation, as a distance from the anterior edge of the swim bladder as a percentage of its length. If no perforations were located, the swim bladder was injected with air, via the small-bored hypodermic needle to assess whether the swim bladder had healed and to detect the location of any perforation not located by the first inspection.

In accord with methods described by Campbell *et al*. (2011), post-release survival was assessed using generalised linear modelling (GLM) via a binomial distribution with a logit link function, where vitality – a binomial variable with 0 = dead and 1 = alive – was the response variable. Water depth and fish length were transformed from continuous variables into categorical variables, with depths transformed into either Shallow (< 80m) or Deep (≥ 80m) and fish length transformed into either Sub-legal (<35cm TL) or Legal (≥ 35cm TL). The effects of several qualitative factors on survival were also tested including: signs of barotrauma present (none, exophthalmia, swollen gut cavity, everted stomach); the presence of bleeding (none, light, heavy); hook location (lip, mouth, throat, gut, outside mouth); holding facility (sock, modified sock, holding tank); and the presence of any injuries (none, eye, gill, jaw, moderate scale loss and heavy scale loss). Experiment number (1–6) was also added to the model in order to assess the spatial and temporal variability in post-release survival across all experiments. The final model was determined using the "rsearch" function in Genstat (2011), whereby the initial model contained all factors, some of which were removed via backwards elimination until an appropriate model is found based on the adjusted correlation coefficient (adjusted R^2). The final model, therefore, consisted of depth, size and any other factor found to have had a significant effect on post-release survival.

Three further GLMs were used to determine the effects of the aforementioned factors on the size of swim bladder perforations, signs of healing of these perforations and the presence of barotrauma symptoms. The first GLM tested the effects of relevant factors on perforation size in millimetres via a normal distribution with an identity link function while the second GLM tested the effects of relevant factors on the presence of healing of swim bladder perforations – a binomial variable with 0 = no healing present and 1 = healing present – via a binomial distribution with a logit link function. The third GLM tested the effect of relevant factors on the presence of barotrauma symptoms – a binomial variable with 0 = no barotrauma symptoms and 1 = barotrauma symptoms present – via a binomial distribution with a logit link function. Again, the "rsearch" function in Genstat (2011) and backwards elimination were used to identify the most appropriate model.

Results

A total of 186 individuals were used to assess the post-release survival of pearl perch caught during 5 experiments, ranging in size from 19cm TL to 61cm TL. Of these, 43 were over the MLS of 35cm TL, while 122 were caught in depths less than 80m. 174 pearl perch exhibited no barotrauma symptoms, while 173 pearl perch were hooked in either the mouth of lip. Table 1 provides the numbers of pearl perch in each level of each factor used in the GLM analysis of post-release survival. 96 of the 186 (~52%) pearl perch used in the analysis were caught in water less than 80m deep and were less than the MLS. Most (93.5%) showed no signs of barotrauma and most (93%) were hooked either in the mouth or lip.

The GLM indicated that depth (shallow or deep; $P = 0.035$), the location of the hook upon capture ($P < 0.001$) and observed barotrauma symptoms ($P = 0.036$) significantly affected the post-release survival of pearl perch (Table 2). Size was found not to have significantly ($P > 0.05$) affected post-release survival, although this factor was left in the model in order to determine the survival of legal and sub-legal fish. The final model is shown in Table 2.

Table 1 Number of pearl perch as a function of depth, size, depth x size, barotrauma signs and location of hook upon capture.

Factor	Level	Number of observations
Depth	Shallow (< 80m)	122
	Deep (≥ 80m)	64
Size	Legal (≥ 35cm TL)	143
	Sub-legal (< 35cm TL)	33
Depth x Size	≥ 80m x ≥ 35cm	17
	≥ 80m x < 35cm	47
	< 80m x ≥ 35cm	26
	< 80m x < 35cm	96
Barotrauma symptoms	None	174
	Swollen gut cavity	5
	Gut everted	7
Hook location	Lip	53
	Mouth	120
	Throat	7
	Gut	2
	Outside mouth	4

The GLM indicated that overall survival was 93.6%. Survival was 93.11% for legal fish and 93.74% for sub-legal fish, with no significant ($P > 0.05$) difference between the two (Figure 3). Using the "SBNTEST" command in Genstat (2011), the sample size required to detect a difference in survival between legal and sub-legal fish would be approximately 24,300 for each category, assuming a 95% confidence level and power of the test set at 0.8 (Figure 4).

Table 2 Accumulated analysis of deviance from the GLM of post-release survival of pearl perch. Depth is a categorical variable where recorded depths were transformed into either shallow (< 80m) or deep (≥ 80m) and size is a categorical variable where individual total lengths were transformed into either legal size (≥ 35cm) or sub-legal.

Factor	d.f.	Deviance	Mean deviance	Deviance ratio	Approx. chi prob.
Depth	1	4.460	4.460	4.46	$P = 0.035$
Size	1	1.998	1.998	2.00	$P = 0.157$
Barotrauma symptoms	2	6.642	3.321	3.32	$P = 0.036$
Hook location	4	27.166	6.792	6.79	$P < 0.001$
Residual	177	64.022	0.362		
Total	185	104.287	0.564		

The GLM indicated that pearl perch caught in deeper (≥ 80m) water had lower survival (91.16%) than those caught from shallower water (94.87%), although this difference was not statistically significant (i.e. $P > 0.05$). Using the "SBNTEST" command in Genstat (2011), the sample size required to detect a difference in survival between pearl perch caught in deep (≥ 80m) and shallow (< 80m) water would be approximately 740 for each category, assuming a 95% confidence level and power of the test set at 0.8 (Figure 4).

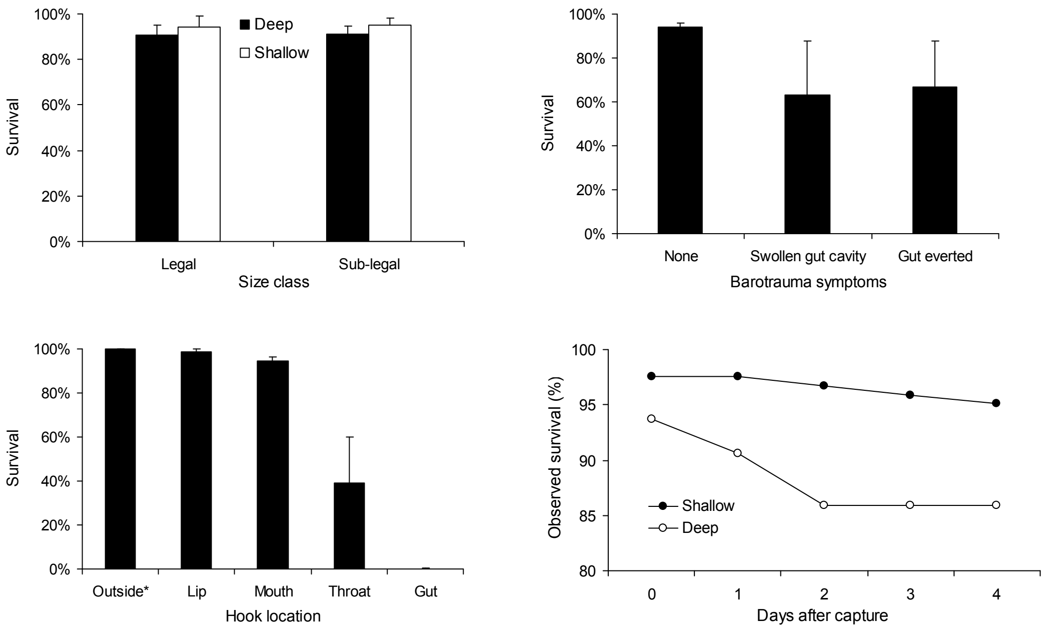

Figure 3 Post-release survival of pearl perch as a function of depth, size, hook location upon capture, observed barotrauma symptoms and days after capture. *Outside represents hooks located outside the mouth upon capture.

Observed barotrauma symptoms were found to have significantly (*P* = 0.036) affected the post-release survival of pearl perch at the 95% confidence level. Post-release survival was highest (94.28%) for those pearl perch which exhibited no signs of barotrauma (*n* = 174). 76.53% of pearl perch observed with an everted gut (*n* = 7) survived, while 63.21% of pearl perch observed with a swollen gut cavity (*n* = 5) survived. These reductions in survival, compared to those pearl perch without any barotrauma symptoms, were significant only at the at the 90% level of confidence (*P* = 0.053 and *P* = 0.065, respectively).

Hook location was also found to have significantly (*P* < 0.001) affected post-release survival. No gut-hooked fish (*n* = 2) and only 38.93% of throat-hooked fish (*n* = 7) survived. Pearl perch hooked in the lip, mouth or outside the mouth had survival rates of 98.66%, 94.44% and 99.99%, respectively. The survival of throat-hooked fish was found to be significantly lower than both lip-hooked and mouth-hooked fish (*P* < 0.01). The low number of gut-hooked fish made statistical comparison to other categories problematic, with Genstat (2011) suggesting there was no significant difference between the survival of gut-hooked fish and fish hooked in other locations, despite the fact that no gut-hooked fish survived.

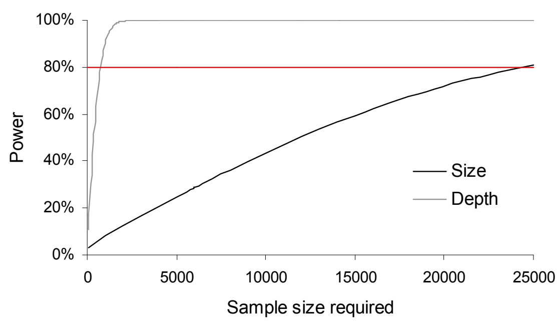

Figure 4 Sample size required to detect a difference in pearl perch post-release survival as a function of size (legal: ≥ 35cm TL and sub-legal: <35cm TL) and depth of capture (deep: ≥ 80m and shallow: < 80m), given the results from the GLM analysis in Figure, at the 95% confidence level. The red line represents power of 80%.

Fish size, water depth and the time held after capture significantly (*P* < 0.05) affected the incidence of the healing of swim bladder perforations (Table 3) acquired during capture. The incidence of healing was significantly higher in fish caught in deeper water ($P = 0.010$) and for sub-legal ($P = 0.014$) pearl perch (see Figure 5a), while the incidence of healing was higher in animals kept for longer periods.

Table 3 Accumulated analysis of deviance from the GLM analysis of the healing of swim bladder perforations in pearl perch caught during the survival experiments. Depth is a categorical variable where recorded depths were transformed into either shallow (< 80m) or deep (≥ 80m) and size is a categorical variable where individual total lengths were transformed into either legal size (≥ 35cm) or sub-legal.

Factor	d.f.	Deviance	Mean deviance	Deviance ratio	Approx. chi prob.
Depth	1	5.875	5.875	5.87	$P = 0.015$
Size	1	6.338	6.338	6.34	$P = 0.012$
Time held	1	4.729	4.729	4.73	$P = 0.030$
Residual	178	235.275	1.322		
Total	181	252.218	1.393		

No other factor was found to have significantly affected the incidence of swim bladder healing in captured pearl perch. Neither fish length nor water depth was found to have had a significant effect on the size of swim bladder perforations in line-caught pearl perch during the experiments.

Depth category was found to have had a marginally significant ($P = 0.08$) effect on the presence of barotrauma symptoms in pearl perch, with individuals caught in deeper (≥ 80m) water more likely to exhibit barotrauma symptoms than those caught from shallower (< 80m) water (Figure 5b). Using the "SBNTEST" command in Genstat (2011), the sample size required to detect a difference in the presence of barotrauma symptoms in pearl perch caught from deep (≥ 80m) or shallow (< 80m) water is 232 for each category, assuming a 95% confidence level and power of the test set at 0.8

Discussion

The overall pearl perch post-release survival of 93.6% is at the higher bounds of reported post-release survival of discarded fish. Bartholomew and Bohnsack (2005) reported that catch-and-release discard survival averaged 82% (range 5 to 100%) in a meta-analysis of 274 studies of post-release mortality of freshwater and saltwater species, with 46% of survival estimates reported to be above 90%. This estimate included data from a previous study (Muoneke and Childress, 1994), which reported an average post-release survival of approximately 81.5% from a meta-analysis of 132 separate studies of freshwater and saltwater species. As such, the survival rates generated in the current study suggest pearl perch are less susceptible to post-release mortality than other species studied.

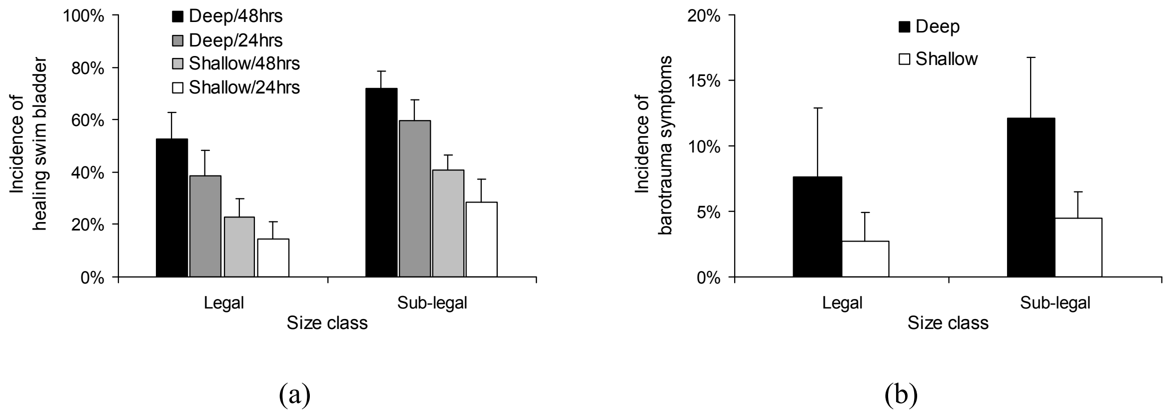

Figure 5 Incidence of (a) healed swim bladders in line-caught *G. scapulare* as a function of size (legal: ≥ 35cm TL and sub-legal: <35cm TL), depth of capture (deep: ≥ 80m and shallow: < 80m) and time held after capture (24 hours or 48 hours) and (b) barotrauma symptoms in line-caught *G. scapulare* as a function of size and depth of capture.

The high survival rates in the current study are in contrast to results reported by St. John and Syers (2005) for the West Australian dhufish *G. hebraicum*, a congeneric species found in similar latitudes and depths as *G. scapulare*. These authors reported 49% survival for *G. hebraicum* caught at depths up to 59 metres, with survival as low as 14% for fish caught between 45 and 59 metres. However, these authors used small, circular (75cm diameter) cages to determine post-release survival rather than the socks used in the current study. Brown *et al*. (2010) compared the post-release survival of red emperor (*Lutjanus sebae*) using cages like those used by St. John and Syers (2005), to that from the socks used in the current study and found that the survival of *L. sebae* was significantly reduced in fish housed in the smaller cages during survival experiments. It is likely, therefore, that the results reported by St. John and Syers (2005) underestimate the survival of *G. hebraicum*. This is based on the fact that these authors reported that duration of caging affected the mortality of *G. hebraicum*, while this factor was found not to have significantly affected the survival of *G. scapulare* in the current study. Those *G. scapulare* that were caught in deeper water that died, did so within 2 days of capture, with 4 dying immediately upon capture (Figure 3), whereas the cumulative mortality of *G. hebraicum* increased with days after capture in all but one depth range (St. John and Syers, 2005).

Only 12 of the 186 (6.45%) *G. scapulare* caught during the survival experiments exhibited barotrauma symptoms. St. John and Syers (2005) reported that exophthalmia and enlarged stomachs occurred in a high proportion (~45% and ~58%) of captured *G. hebraicum* caught in depths between 45 and 59 metres, respectively. These symptoms were also present in *G. hebraicum* caught in shallower water (15-29 metres and 30-44 metres) although at lower incidences. In contrast, the incidence of barotrauma symptoms was significantly lower in *G. scapulare* caught during the current study with only 10% and 4% of fish caught in deep water (≥ 80m) and shallow water (< 80m), respectively, exhibiting barotrauma symptoms. There was no incidence of exophthalmia in *G. scapulare*, even from 130 metres water depth. The everted stomachs observed in *G. scapulare* were confined to the buccal cavity, unlike those observed in snapper caught incidentally during the field experiments which often had stomachs that protruded well beyond the buccal cavity. Survival was lower for those *G. scapulare* exhibiting barotrauma symptoms, although not significantly so at the 95% confidence level.

St. John and Syers (2005) attributed the very low post-release survival rates of *G. hebraicum* to their susceptibility to barotrauma, highlighting several contributing factors including habitat and relative volume of the swim bladder. Contrasting post-release survival rates in congeneric species was also reported by Brown *et al*. (2010), who highlighted that two Lutjanids, *L. sebae* and *L. campechanus*, had post-release survival rates of 1.6% and 80% (as reported by Rummer and Bennett, 2005), respectively. However, these authors offer no explanation as to the cause of the difference in mortality rates. Although speculative, one cause may be the respective habitats favoured by the respective glaucosomatids, with *G. hebraicum* most often associated with hard reef (McKay, 1997; Hesp *et al*., 2002), whilst McKay (1997) state that *G. scapulare* are a "midwater feeder moving well up off the bottom". As such, *G. scapulare* may be better able to adapt to changes in ambient pressure compared to *G. hebraicum*, resulting in milder and lower incidences of barotrauma symptoms in the former.

Of the 141 *G. scapulare* that had air injected into the gut cavity in the laboratory, air was found to escape the gut cavity through the vent in 124 (~88%) individuals. This suggests that, for the most part, as *G. scapulare* are caught and brought toward the surface, the air within the swim bladder expands until the swim bladder bursts (see Figure 6). At this point, air escapes into the gut cavity and continues to expand as the fish is brought closer to the surface. At some point, the alimentary canal perforates, allowing the air to escape the gut cavity. These stages of barotrauma are consistent with those reported by Brown *et al*. (2010) for *L. sebae*. Bubbles were often observed rising to the surface when *G. scapulare* were being angled as a result of the perforation of the alimentary tract and the gases escaping the gut cavity, with larger bubbles observed in deeper water depths suggesting that the rupture of the alimentary tract occurred at greater depths.

In shallower water, the pressure changes are much more rapid than those for fish caught in deeper water. That is, according to Boyle's Law, the volume of gas within the gut cavity of *G. scapulare* would double between 10 metres water depth (i.e. 1 atmosphere of pressure) and the surface, whereas the volume would increase only by approximately 10% between 80 and 90 metres water depth. In shallow water, the increase in volume of swim bladder gases would be rapid, with a likely significant expulsion of gases through the perforated alimentary tract. In contrast, a relatively protracted increase in volume would occur from depths greater than 80 metres, resulting in a burst swim bladder and perforation of the alimentary tract occurring at greater depth, with residual swim bladder gases expanding in the gut cavity throughout the remainder of the ascent, particularly in the last 20 metres, resulting in the mild barotrauma symptoms observed in some of the fish caught at depths greater than 80 metres.

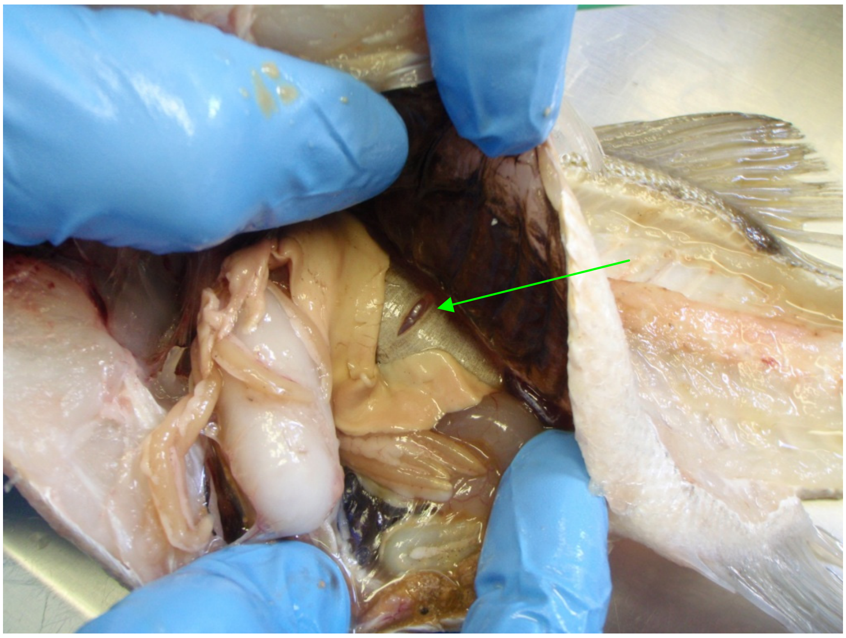

Figure 6 The swim bladder of a *G. scapulare* caught at Double Island Point. Note the mesenteric tissue forming a barrier over the rupture resulting in a partially-inflated swim bladder. Such a swim bladder was classified as healed.

We assumed that all *G. scapulare* caught as part of the experiments suffered barotrauma and were likely to have had the swim bladder burst at some point during capture. Injection of air into the swim bladder of *G. scapulare* in the laboratory revealed that, in a significant number of individuals, the swim bladder showed signs of healing (Figure 5a). Healing was most likely in sub-legal fish caught from deep water and kept for 48 hours. Very few articles appear in the literature detailing the healing of burst swim bladders, however, Bruesewitz *et al*. (1993) indicated that the swim bladders of burbot *Lota lota* healed within a week of being pierced by a hypodermic needle in an experiment conducted in Lake Michigan. Further, Bellgraph *et al*. (2008) reported that the ruptured swim bladders of rainbow trout *Oncorhynchus mykiss* began healing within seven days and were completely healed after 14 days.

The speed at which the swim bladder heals may be important in the survival of *G. scapulare* in the longer-term. A ruptured swim bladder will result in an inability to maintain position at a given depth without significant finning due to negative buoyancy (Render and Wilson, 1994). *G. scapulare* were observed finning whilst held in holding tanks aboard the *Tom Marshall*, with the caudal fin making S-shaped movements while the pectoral fins moved in a figure-eight pattern in order to maintain position within the tank due to the slight current generated by the seawater in-flow. This may lead to exhaustion and a resultant decrease in survival due to predation in the wild (Render and Wilson, 1996). The fact that most perforations were present in the ventral surface of the swim bladder may allow swim bladder gases to be formed and locate on the dorsal surface and provide buoyancy despite the perforation being present. Further, Render and Wilson (1994) observed that the partially inflated swim bladder in the red snapper *L. campechanus* allowed the individual to find neutral buoyancy at some depth. Given that a high proportion of the *G. scapulare* examined in the laboratory in the current study had a partially inflated swim bladder, we assume that a released individual would be able to find a depth at which it could maintain position until the swim bladder healed. Of course, this would likely increase the risk of predation, particularly if the fish were released in deeper water. Due to the mild barotrauma symptoms observed in *G. scapulare*, all but one fish were able to submerge without assistance.

In accord with Muoneke and Childress (1994) and Bartholomew and Bohnsack (2005), hook location was found to have been the best predictor of the post-release survival of line-caught *G. scapulare* (Figure 3, Table 2). Survival was lower in throat-hooked or gut-hooked fish, with no gut-hooked fish surviving capture (*n* = 2). The location of the hook upon capture (or hooking location) has been found to be a significant factor affecting the post-release survival of several species in Australia including *G. hebraicum* (St. John and Syers, 2005), Australian bass *Macquaria novemaculeata* (Hall *et al*., 2009a), mulloway *Argyrosomus japonicus* (Butcher *et al*., 2007), yellowfin bream *Acanthopagrus australis* (Broadhurst *et al*., 2005; Broadhurst *et al*., 2007; Butcher *et al*., 2007), black bream *Acanthopagrus butcheri* (Grixti *et al*., 2008), sand whiting *Sillago ciliata* (McGrath *et al*., 2009), sand flathead *Platycephalus bassensis* (Lyle *et al*., 2007) and yellow stripey *Lutjanus carponotatus* (Diggles and Ernst, 1997). As such, in order to ensure the post-release survival of line-caught *G. scapulare*, it is prudent to employ methods that reduce the incidence of deep-hooking during capture.

Firstly, several authors suggest the use of circle or re-curved hooks (see Figure 7), where the point of the hook is perpendicular to the hook shank, in order to prevent the ingestion of hooks by demersal reef species. For example, Bacheler and Buckel (2004) reported that the use of circle hooks reduced the incidence of gut hooking of cod *Epinephelus* spp. to 0.8% compared to 15% for J-style hooks. Further, Aalbers *et al*. (2004) reported the incidence of deeply-hooked juvenile white sea bass *Atractoscion nobilis*, a similar species to teraglin, decreased from 24% using J-style hooks to 14% using circle hooks. Butcher *et al*. (2008) also found that the circle hooks reduced the ingestion of hooks by 33% compared to J-style hooks in line-caught yellowfin bream *A. australis*. Additionally, Cooke and Suski (2004) stated that mortality rates were reduced by 50% when circle hooks were used, as opposed to using J-style hooks, in a meta-analysis of 43 studies comparing the effects of circle and J-style hooks on post-release mortality. These authors report that the incidence of lip-hooking is significantly greater for circle hooks compared to J-style hooks.

Figure 7 Sub-legal *G. scapulare* caught using a circle hook. Note the hook point is perpendicular to the shank. *G. scapulare* have a relatively large mouth enabling the use of large hooks, which minimise the incidence of throat- or gut-hooking. Note also the hook is located in the jaw hinge, enabling easy removal.

Apart from the use of circle hooks to minimise deep-hooking of line caught fish, further hook modifications have been used to achieve this goal. Willis and Millar (2001) attached small pieces (either 20mm or 40mm) of wire to the eyes of hooks at an angle of approximately 60° to the hook shank. These authors suggested that the use of these modified hooks could significantly reduce the likelihood of catching sub-legal *P. auratus* in a commercial longline fishery in New Zealand. A similar modification was tested by Butcher *et al*. (2008) who reported significant decreases in the deep-hooking of yellowfin bream *A. australis* compared to both J-style and circle hooks. Although this strategy to reduce deep-hooking of *G. scapulare* may be effective, given the size of the mouth, it would be prudent to test the size of the piece of wire for this species. However, fishers are likely to reject the idea based on the perception that catch rates will be reduced significantly using these modified hooks and, as such, some education would be required to alleviate these concerns.

Thirdly, hook size has also been shown to decrease the incidence of deep-hooked fish. For example, Cooke *et al*. (2005), found that they hooked larger fish and had a lower incidence of gut-hooked bluegill *Lepomis macrochirus* using larger circle hooks with a caveat that large circle hooks can and do hook small fish and can cause significant injuries (e.g. eye hooking). Further, Grixti *et al*. (2007) reported that deep hooking could be reduced in black bream *Acanthopagrus butcheri* by using larger hooks, without affecting catch rates. As with the Cooke *et al*. (2005) study, Grixti *et al*. (2007) suggested that larger hooks may contribute to decreases in post-release survival by increasing the severity of injury. Alós *et al*. (2008) observed that the survival of derbio *Trachynotus ovatus* decreased using small hooks, with the incidence of deep-hooking higher when smaller hooks were used. *G. scapulare* have a relatively large mouth and, as such, relatively large hooks can be used without affecting catch rates. Circle hooks of size 5/0 – 8/0 are appropriate.

Although there has been an increase in the use of artificial lures when targeting rocky reef fish, the majority of anglers and commercial fishers use natural bait. Most often, anglers fish actively using either paternoster-style rigs (one to six hooks attached to a mainline via snoods above a weight) or floatlines (baits drifted through the water column with small weights attached) resulting in the absence of slack line, a factor known to increase the incidence of gut-hooking (Grixti *et al*., 2007). The fact that we used fishing gear and practices representative of the recreational fishery and caught only two (~1%) gut-hooked fish is evidence that these fishing practices result in few gut-hooked fish. However, the use of natural baits has been shown to increase the risk of deeply-hooked fish (Bartholomew and Bohnsack, 2005), with resultant decreases in post-release survival (Diggles and Ernst, 1997). The use of relatively large circle hooks used in conjunction with natural bait would significantly reduce the risk of gut-hooked fish, increasing post-release survival in *G. scapulare*. Cooke and Suski (2004), however, made the point that large circle hooks can reduce catch rates as circle hooks need to be of a size that allows the hook to move freely in the mouth so that it is able to orientate correctly allowing the hook point to penetrate the jaw hinge.

The use of artificial lures has increased in the rocky reef fishery in south-east Queensland in recent years, particularly in the recreational sector. Soft plastic artificial baits, attached to lead-head jigs, and heavy knife-jig lures, employing single large hooks, common among recreational fishers are both conducive to low incidences of gut-hooking, particularly when used in conjunction with low-stretch braided and gelspun polyethylene fishing lines. Artificial lures have been shown to increase post-release survival in several species in Australia. For example, Diggles and Ernst (1997) found that the post-release of the yellow stripey *L. carponotatus* and wire-netting cod *E. quoyanus* was highest using artificial lures compared to natural baits. Also, Hall *et al*. (2009b) stated that Australian bass *M. novemaculeata* caught using natural baits were more likely to die than those caught on lures. Several overseas studies have also detected differences in survival as a function of terminal tackle. Nelson (1998) reported that 14% of striped bass *Morone saxatilis* caught using bait were deeply-hooked, compared to only 3% for lure-caught fish. Arlinghaus *et al*. (2008) found that northern pike *Esox lucius* were more likely to swallow natural baits than artificial lures. These authors also stated that soft plastic lures are more likely to be swallowed than hard baits, made from metal or hard plastic, due to the fact that they resemble food items more closely but also because they are fished passively and are thus more likely to be swallowed.

Recreational anglers using artificial lures are more likely to have superior handling practices to those fishers targeting rocky reef fish for food. Lure-fishers are generally better-equipped to return fish and use knotless landing nets, gloves, lip-grip devices, hook removal devices or combinations of these items. De Lestang *et al*. (2008) reported that knotless landing nets resulted in fewer and less severe injuries in landed barramundi *Lates calcarifer*. Further, Barthel *et al*. (2003) found that knotless landing nets resulted in fewer fin abrasions in landed bluegill *Lepomis macrochirus*, with mortality rates of 6% for knotless landing nets compared to 14% for fish landed with fine-knotted landing nets.

The removal of hooks has been shown to significantly affect the post-release survival of line-caught fish. Wilde and Sawynok (2009) examined the recapture rate (a proxy for post-release survival) of 27

Australian fish species tagged-and-released fish as part of a co-operative tagging program. These authors suggest that fish with the hooks left *in situ* are 18% more likely to be recaptured than those where hooks are removed. Similarly, Fobert *et al*. (2009) found that cutting the line is a more effective release method for deeply-hooked *L. macrochirus*. Butcher *et al*. (2007) studied the post-release survival of two species, *A. australis* and *A. japonicus*, and found that fish that had ingested hooks on capture experienced high mortalities (87.5% and 72.7%, respectively) when the hooks were removed compared to 1.7% and 16%, respectively, when the line was cut. The removal of hooks from deeply-hooked fish intended for release provides a confounding interaction of three important factors when considering post-release survival – hooking location, trauma associated with hook removal and air exposure or handling time. That is, the retrieval of hooks located in the gut is likely to require increased handling time and subject the fish to excessive trauma during hook removal. In the current study, only two fish were gut-hooked, of which one had the hook removed. Both gut-hooked fish died. Further, of the seven fish that were throat-hooked, five died, two of which had the hooks removed. Obviously, there is insufficient information to make recommendations regarding the removal of hooks from deeply-hooked *G. scapulare*; however, given the significant increases in survival reported by Butcher *et al*. (2007) it would be beneficial to avoid hook removal in deeply-hooked fish.

In conclusion, *G. scapulare* appears to be a resilient species with regard to catch-and-release, with our experiments indicating that more than 90% survive capture. *G. scapulare* swim bladders rupture during ascent from depth, with swim bladder gas escaping into the gut cavity. As angled *G. scapulare* approach the surface, the alimentary tract ruptures allowing swim bladder gases to escape the gut. This was confirmed during field work, with air bubbles observed exiting the anus close to the surface. Hook location was found to be the best predictor of post-release survival, with the survival of gut- and throat-hooked *G. scapulare* significantly lower than those hooked in the mouth or lip. Using traditional fishing methods – baited J-style hooks on paternoster rigs - very few fish were gut-hooked resulting in low post-release mortality. The use of circle hooks, fished actively on tight lines, combined with minimal handling will maximise the post-release survival of *G. scapulare*.

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APPENDIX 3.6 EXPERIMENTAL DETERMINATION OF THE SHORT-TERM POST-RELEASE SURVIVAL OF LINE CAUGHT TERAGLIN (*Atractoscion aequidens*)

Summary

Both controlled experimental studies and observer trips on recreational and charter vessels showed that post-release survival of teraglin was higher than previously acknowledged, providing air was vented from the body of fish that displayed barotrauma symptoms or they were released by a “capsule”. Short-term post-release survival of teraglin decreased with increasing depth with virtually 100% mortality when fish were caught in water exceeding 70m depth. A discard mortality of 60% was determined as the experimental discard mortality rate for undersized fish of this species but it is recognised that this rate could be significantly higher depending on the actual handling practices employed by individual fishers. This was confirmed by the variation in the ability of teraglin to recover from line capture across the various observer trips where post-release survival was assessed. Like snapper and pearl perch, many teraglin are able to recover from swimbladder damage caused by barotrauma, particularly if caught in water less than 50m in depth. One of the features of teraglin biology which reduces the susceptibility of the population as a whole to barotrauma effects is the tendency for smaller undersized teraglin to be more abundant in shallower water (<50m) (at least on the Gold Coast) where they are less susceptible to post-release mortality, and the effects of barotrauma are not as severe. Larger individuals are more commonly caught in deeper water (>60m) where post-release survival is not as great, but as most of these fish are retained by anglers because they are above the MLS, the issue of poor post-release survival is not as significant. When damage to swimbladders of dissected teraglin was noted the damage was fairly consistent across the depth range from which fish were sampled (30 to 110m). The size of the split in the swimbladder rarely exceeded 30mm and in some individuals there was evidence of fairly rapid resealing and possible healing of the swimbladder as mesenteric tissue initially formed a weak seal across the damaged bladder. We have also provided evidence that indicates male teraglin were less susceptible to barotrauma than females which we postulate as being due to the possession of sonific muscles which are absent in the female. These muscles may allow males to better control the volume of their swimbladders thus mitigating barotraumas effects. All fishers should be encouraged to use barotrauma relief measures such as venting and capsule release on this species.

Introduction

In recent years increases in minimum legal size and reduced recreational bag limits have been applied to a range of species caught in the Queensland rocky reef fishery, largely to reduce fishing mortality and ensure the protection of an adequate spawning population to reduce risk of overfishing. Any such increase in MLS and decrease in bag limit will result in the return of an increasing number of fish to the water subsequent to their initial capture. For many rocky reef species the effects of these regulatory changes have not been evaluated, largely because of the paucity of available information on the numbers of line-caught fish that survive after being released and this is one of the objectives that the present research was designed to address. In order for these management measures to be effective a significant proportion of fish that are released must survive the catch and release process.

The situation for teraglin differs somewhat from the other species of rocky reef fish in that, contrary to the recent trend of increasing minimum legal size, the teraglin fishery had a reduction in the MLS from 45cm to 38cm in December 2002. This decision was based on anecdotal evidence and data from the Gold Coast charter fishery which suggested that discard mortality of teraglin was extremely high (>90%) and the vast majority of the catch was made up of fish between 38 and 45cm, most of which were subsequently released and suffered unacceptable levels of mortality. In the absence of other sustainability indicators for teraglin the decision was made to reduce the MLS, and at the same time lower the bag limit in order to reduce the overall mortality of teraglin. This lowering brought the management of teraglin in line with NSW which already had an MLS of 38cm but there was still uncertainty about the levels of post-release survival experienced by teraglin, as the evidence of excessively high post-release mortality was not universally acknowledged by fishers.

Despite the lack of scientific data on the survival of teraglin there have been several studies that have examined post-release survival issues of other species of Sciaenidae and these have often shown a high degree of susceptibility to barotrauma-related mortality, in particular. Black jewfish (*Protonibea diacanthus*), for example, have very high post-release mortality even when taken in comparatively shallow depths. Phelan (2008) estimated almost half of the fish landed in water 10-15m deep would not survive due to barotrauma-related injuries. In that study, all fish caught from depths greater than 15m were assessed as being unlikely to survive. In contrast mulloway (*Argyrosomus japonicus*) are known to be fairly resilient to line capture particularly those caught in shallower estuarine conditions.

This chapter reports on a series of experiments designed to estimate the short-term survival rates of teraglin, and the benefits associated with two barotrauma-relief treatments (venting and capsule release). Venting involves piercing the side of the fish with a hollow needle to allow the gas in the expanded swim-bladder (or gut cavity if the swim bladder has burst) to be released. This method is now widely used in Australia (e.g. the *Gently Does It* programme) and is a well accepted practice although there is still some debate about its efficacy for some species and whether it is a technique that should be widely encouraged. Capsule release has not had widespread adoption in Queensland to date. Brown *et al.* (2008) highlighted the potential benefits of this method for a number of coral reef species and it is reasonable to assume that benefits will also translate to rocky reef species, many of which belong to the same families as the coral reef species already studied. We also examine the internal physical effects of capture and barotrauma and attempt to assess the capacity of this species to recover in the long term from the effects of barotrauma when released after line capture.

Methods

Two sets of experimental techniques were used to examine the effects of fishing on post-release survival of teraglin. The first involved dedicated research excursions designed to catch teraglin from a range of depths and evaluate their short-term (3 days) post-release survival (hereafter referred to as "Controlled Experiments". The second set of experiments were conducted on board recreational and charter vessels and involved a qualitative assessment of handling techniques and the effect of various relief treatments on more subjective indices of survival. Often this was simply whether the fish swam from the surface out of view or whether it survived for several hours in on-board holding tanks. These latter experiments are hereafter referred to as "Fishery Observations".

For both these sets of experiments, and whenever it was possible to collect samples of fish caught from a known depth, fish were examined in the laboratory and dissected to investigate their anatomical response to barotrauma. In the case of the controlled experiments on board the research vessel, all fish were dissected in the laboratory but the majority of fish examined anatomically from the charter and recreational catches were less than 38cm as fish greater than this were usually retained by anglers.

Experiment 1 (Controlled experiments)

Three broad areas (chosen after consultation with experienced recreational and commercial line-fishers) were selected as study locations as they were popular teraglin fishing grounds and fulfilled the requirements of different depth strata. These sites were Square Patch (depth range 75 to 85m) the Cathedrals (depth range 40 to 60m) and reefs off the Gold Coast (depth range 20 to 110m).

The experiment was set up to test the relative effectiveness of the most common barotrauma-relief releasing method (venting) on the short-term survival of teraglin A detailed description of the experimental apparatus (holding socks) and onboard holding techniques can be found in Appendix 3.5. The experiments were conducted on board the FRV *Tom Marshall*, a 14m catamaran, over the period March 2010 – June 2012.

Fish were captured using standard rod and line techniques and the following data were recorded : date and time of capture, capture depth (m), total length (mm), hook location (lip, mouth, throat, gut, or foul/other), barotrauma signs (nil, swollen, gut protruding, eyes bulging [exophthalmia]), bleeding (nil, light or heavy), injury (nil, jaw, eye, gills, scale loss). After the application of a uniquely-numbered HallPrint™ dart tag into the dorsal musculature, the fish was placed into 1.4t holding tanks filled with clean flow through seawater and held on board for up to 3 days where they were routinely observed and subsequent mortalities recorded. Immediately prior to release into a holding tank the treatment (venting) was administered to all fish as initial trials showed that some fish that displayed barotrauma symptoms still attempted to swim down but became exhausted. Fish which could not immediately swim down from the surface were termed 'floaters', and were most often (but not always) associated with the nil-treatment or control fish. Time of release, release condition (a subjective classification of the status of the fish on release into the holding tank or holding sock following treatment, ranging from 1 = excellent condition to 5 = moribund) were recorded when fish were added to the tank. As barotrauma symptoms were always evident for teraglin all fish were included in the analysis. Additional data in the form of comments were taken in situations where something unusual was observed such as the production of sound on capture (croaking). Over the three days of the experimental period the condition of each fish was periodically noted (together with its tag number) as were any unusual behaviours. At the completion of the experiment all surviving fish were killed by placing in chilled seawater (Rowland *et al*., 2006) for later dissection and examination in the laboratory along with those that had died during the experiment.

Experiment 2 – Fishery observations

Fish examined in these trials were predominantly sampled in offshore waters adjacent to the Gold Coast and Stradbroke Island. All fish were caught from line fishing vessels (5 -14m in length) including recreational and charter vessels using rod and reel and a range of different gear types in terms of line thickness, hook and sinker sizes. There was no experimental control over the gear type used by these fishers and the skill level of anglers varied dramatically, particularly those fishing on board charter vessels. Depth of capture ranged from 20m to 100m but most fishing was restricted to reefs corresponding to areas known commonly as 24 fathom, 36 fathom and 42 fathom reefs. For analyses, depths have been grouped into three depth ranges: 30 to 49m (shallow) 50 to 79m (medium) and 80 to 109m (deep) corresponding to the commonly known depth stratified fishing areas recognised by fishers. When teraglin were caught they were released using one of a number of techniques. They were either released without further treatment, laterally vented using a hypodermic syringe, released with the aid of a release capsule, had their abdomens massaged to presumably burst the swimbladder and release gases or they were launched head first into the water to force them from the surface.

(a) (b)

Figure 1 (a) Photo of the release capsule used to release teraglin (snapper in the photo) and other rocky reef in field trials conducted in southern Queensland. (b) Undersize snapper swimming out of capsule at depth.

When accompanying recreational and charter fishers, all fish caught were broadly assessed for barotrauma symptoms using the same system as used in the controlled experiments. The total length of each fish was measured to the nearest cm and fish studied were within the size range of 33 to 79cm although the majority observed and/or dissected were undersized (33 – 38cm).

The apparatus used for "capsule release" was a bell-shaped device made from soft nylon trawl-mesh, formed around an upper (30cm in diameter) and a lower steel hoop (45 cm square hoop) (see Figure 1). When a fish was released and was seen to float on the surface the device was placed over the fish which was then lowered to an appropriate depth with an attached line, whereupon the fish - with its swim bladder re-compressed – was presumably able to swim free. This sort of device has been described in the literature (e.g. see Bruesewitz *et al*. 1993), but there is little evidence of its having been used directly for barotrauma relief (except in Western Australia) rather than as a control against which the effectiveness of other methods such as venting could be assessed.

Laboratory techniques

In the laboratory, fish were dissected and examined to investigate organ damage as a result of capture and barotrauma. Fish were firstly assessed in terms of the firmness of their gut as either "soft", "medium" or "hard". The former was recorded when the stomach area was flaccid and this condition was always associated with a ruptured swimbladder and a lack of air in the gut cavity. A "hard" stomach was recorded when the gut was well distended from its normal position and a force of approximately 1 kg applied to it failed to the distort the gut more than 1 cm. "Medium" was anything between these two extremes. Upon dissection the sex, gonad stage and a subjective gut fullness index (empty to full) were recorded. Internal organs, particularly the liver, pancreas, gut and swimbladder were then examined and any abnormality recorded. In the case of swimbladder this involved measuring the maximum size (±2 mm) of the rupture(s) using vernier callipers. The position of the rupture(s) was recorded in terms of relative position along the length of the swimbladder. Haemorrhaging was also recorded.

Male teraglin are known to "croak" with the aid of sonific muscles and this characteristic was used in the field to discern males from females (and non-croaking males). Upon dissection of fish in the laboratory and relating the sex of fish back to field observations of noise production it was observed that a significant proportion of males also did not make any sound on being landed and thus sex discrimination in the field was incompletely determined.

Statistical analysis

The data from the controlled experiments were analysed by multi-factor binomial generalised linear regression models (GLMs) in GenStat v. 11.1 (GenStat, 2011) with a logit link function using survival (dead or alive) as the response variate. For the purpose of analysis the continuous variable of water depth was converted to a categorical factor - either shallow (40 to 50m) or deep (75m to 85m). There were no fish taken in intermediate depths during the controlled experiments. Likewise, size was categorised into either sublegal (<38cm) or legal (≥ 38cm). Other factors that were recorded including hook location, bleeding and injuries were not included in the analysis due to lack of data coverage.

Initial GLMs were conducted to determine the extent to which release condition was a good predictor of the ultimate fate of the fish, taking into account the other factors mentioned above. It was considered that 'release condition' was heavily confounded with many of the other factors under consideration, and in fact would represent the combined effects of depth, barotrauma, length, and other effects of capture and release. A second level of GLM analysis was therefore performed to investigate the individual effects of these factors, excluding 'release condition'.

Results

Experiment 1 (Controlled experiments)

All teraglin caught during the controlled experiments showed signs of barotrauma (Table 1) regardless of depth of capture and only one individual was observed to have self "buccal vented" – that is, had released swimbladder gases by puncturing their everted gut with their teeth. It was possible that larger numbers had self buccal vented but this seems unlikely as all teraglin caught were assessed as having a swollen gut indicating that they had not vented (completely) all of their swimbladder gases. One fish caught in 80m was observed with their gut everted from their mouth on initial capture but 1 hour later was observed to have recovered from this condition in the holding tank.

Table 1 Raw unmodelled data showing the number of teraglin in each class of factor that survived line capture and release during experimental trials

Factor	Class	Survived	Died	Total
Depth	40m to 50m	24	12	36
	75m to 85m	1	10	11
Size	<38cm	17	7	24
	≥38cm	8	15	23
Depth x size	40m to 50m, <38cm	17	6	23
	40m to 50m, ≥38cm	7	6	13
	75m to 85m, <38cm	0	1	1
	75m to 85m, ≥38cm	1	9	10
Barotrauma symptoms	None			0
	Swollen gut	22	17	24
	Gut everted	3	4	7
Release condition	1	7	8	7
	2	11	8	19
	3	6	4	10
	4	1	19	11

A range of exploratory models were initially run to assess dominant factors and interactions, with the factors used in the final model being length, depth, sex and barotraumas symptoms. None of the two-way interaction terms were significant and the presumed main interaction term of depth x size was also not significant ($P=0.596$) and was dropped from the final model, which resulted in only two factors (length and depth) having a significant effect ($P < 0.05$) on short-term survival (Table 2). We chose to include barotrauma symptoms in the final model as it was considered important to investigate the possible differential effects of these symptoms because it was hypothesised that a fish with its gut everted may have been suffering the effects of barotrauma more than a fish whose gut was swollen.

The effects of various factors on the survival of teraglin are shown in Figure 2. Over 60% of teraglin that were released and vented in depths of 40 to 50m survived capture and release (at least in the short-term) but only 10% survived when caught in depths greater than 75m. Survival of sub-legal (<38cm) teraglin was also significantly greater than larger fish (approximately 60% survival compared with 40% survival of larger fish). While sex was not a significant effect there was a trend towards a lower survival of females in comparison to males. Despite these results we still have concerns about the depth x size interaction as aliasing caused by the higher proportion of larger animals caught in the deeper waters were influencing the results and the insignificant interaction was probably more a result of small sample size.

Table 2 Accumulated analysis of deviance table from the binomial GLM assessing various factors affecting short-term (3 days) post-release survival of teraglin. (Significant factors are shown in bold).

Factor	d.f.	Deviance	Mean deviance	Deviance ratio	Approx chi prob
Depth	1	6.678	6.678	6.68	**0.010**
Length	1	6.315	6.315	6.31	**0.012**
Sex	1	0.629	0.629	0.63	0.428
Barotrauma symptoms	2	0.599	0.299	0.30	0.741
Residual	41	50.914	1.242		
Total	46	65.135	1.416		

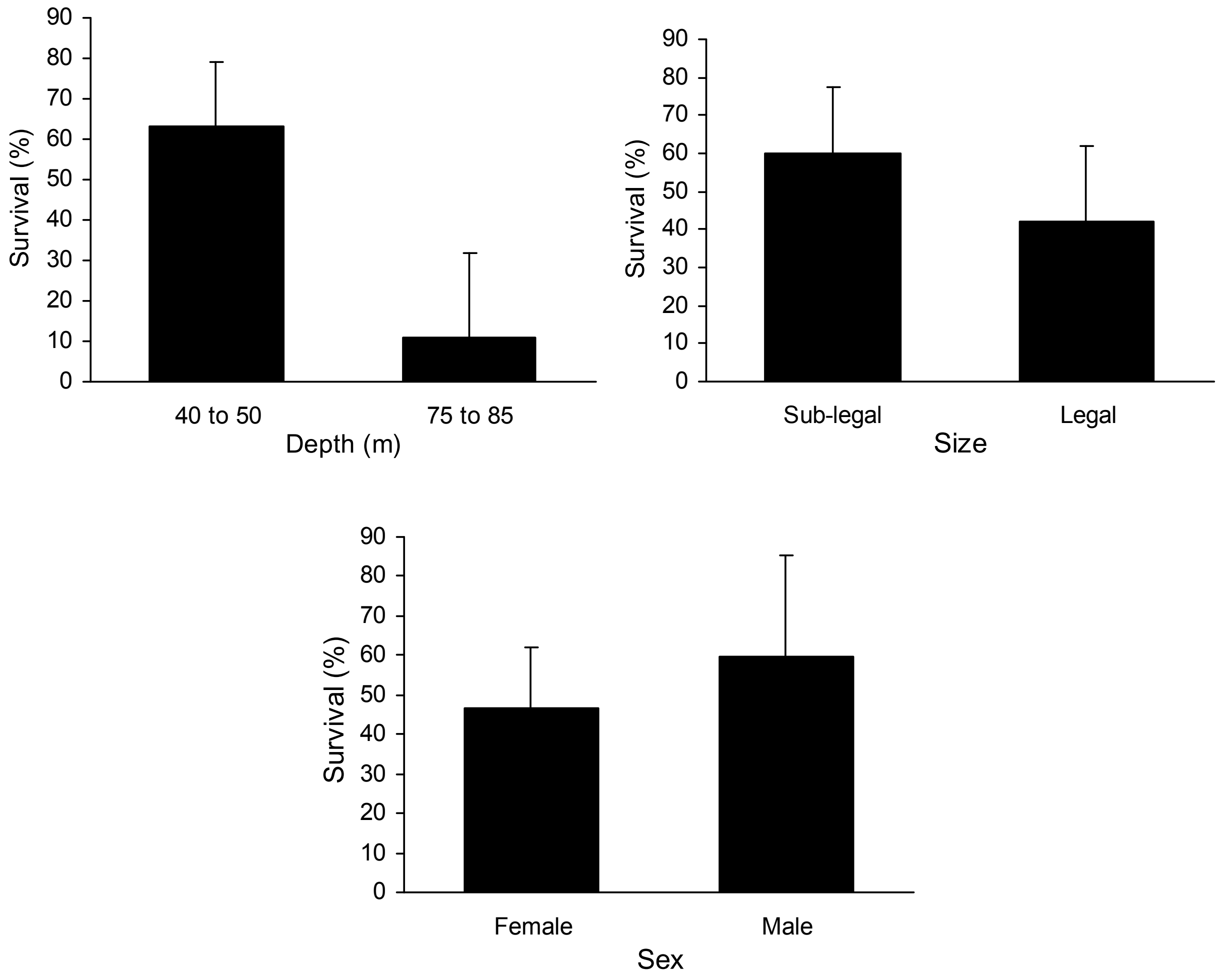

Figure 2 Model predictions of post-release survival of teraglin caught in two depth and size categories. Vertical bars are 95% confidence intervals.

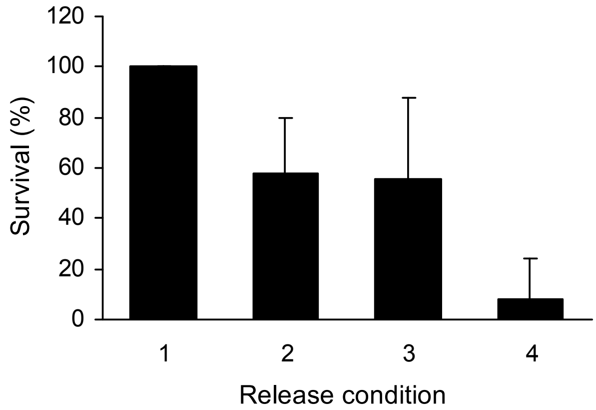

Figure 3 Model predictions of post-release survival of teraglin assessed in various release condition categories.

The survival of fish assessed as having the highest category of release condition (category 1) was 100% with survival declining dramatically with poorer release condition. Less than 10% of category 4 fish (those that initially floated upon release) survived, regardless of treatment (Figure 3).

Only 4 of the 7 fish (57%) that were observed croaking on capture survived and these fish were caught in both deep and shallow areas. Subsequent dissection indicated that they were all males, of which all but one had a ruptured swimbladder. While there were too few croaking males caught to statistically test the effect of "croaking" the size of the holes in the swim bladders of these fish were quite small being between 1mm and 15mm in maximum dimension.

Experiment 2 – Fishery observations

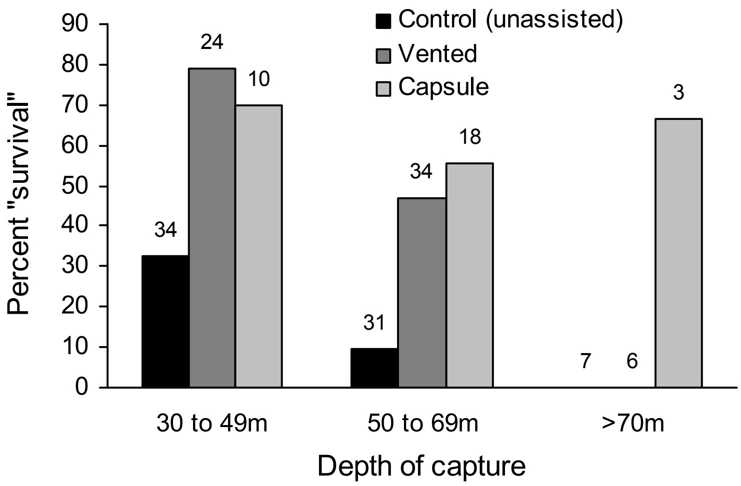

Figure 4 Effect of two barotrauma relief techniques on the percentage of teraglin that were able to swim away out of sight after capture and release from various depth ranges. Sample sizes are shown above each bar. For capsule release percentages are those fish that did not float back to the surface after release.

While we had originally hoped to identify the sex of teraglin on the basis of their croaking this was quickly proven to be inconsistently determined in the field as not all males made a croaking sound on capture. Despite a wide variation in the release mechanisms used by line fishers there was clearly a strong depth related effect on the "survival potential" depending on treatment and depth of capture (Figure 4). Only 16 fish were released in water exceeding 70m in depth but none of the vented or control fish "survived". One of the three capsule-released fish was also not seen to resurface following release by capsule suggesting that it may have survived and been able to swim away. Other techniques used by charter boat operators to enable teraglin to swim away included massaging the stomach (presumably to vent gases from a ruptured alimentary canal) and launching the fish head first into the water so that it was forced well below the surface, but none had enough replication or experimental control to allow the statistical analysis of their individual effects. However, at times it was noted that fish treated in these ways were at least able to swim out of sight. On some vessels these methods were very effective with success rates over 60% on some trips and depths.

A qualitative observation that was consistent across all observer trips was that the majority of "croaking" teraglin (presumably males) were able to be returned to water unassisted when they were caught in water less than 50m deep. We initially presumed these were males that had their swimbladders intact; however, as noted earlier 6 of 7 fish that were observed croaking in our controlled experiments had ruptured swimbladders.

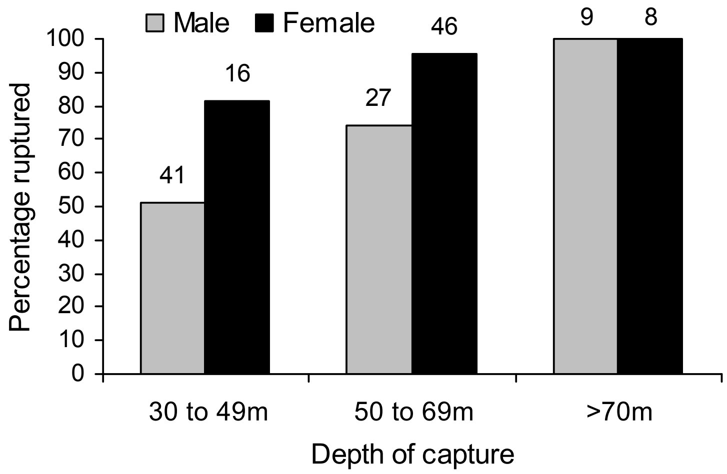

Figure 5 Percentage of undersized male and female teraglin caught in three depth ranges in offshore waters of southern Queensland that had ruptured swim bladders. Sample sizes are shown above each bar.

All fish (both male and female) caught in water greater than 70m had ruptured swimbladders (Figure 5) whereas a proportion of fish caught in shallow (30 to 49m) and moderate (50 to 59m) depths had swimbladders that remained intact when they were examined in the laboratory with males less likely to have ruptured swimbladders compared to females in both shallow and medium depths.

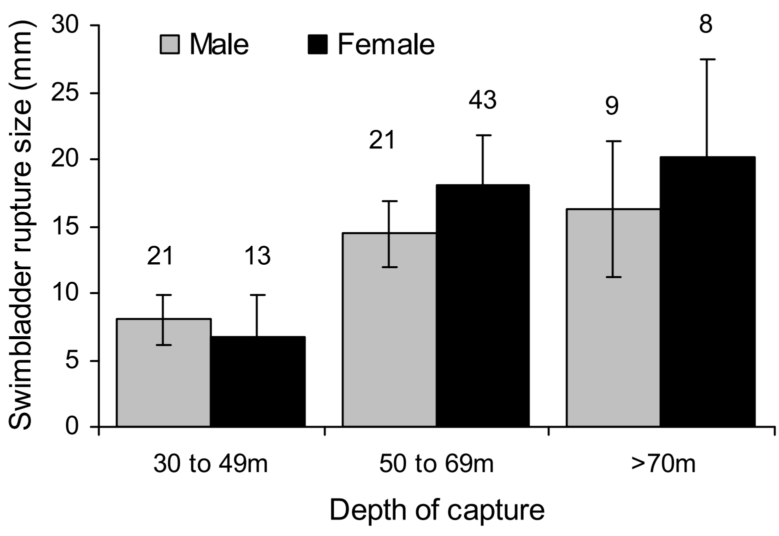

Figure 6 The mean size (± 95% confidence intervals) of swim bladder ruptures in male and female teraglin caught in three depth ranges in offshore waters of southern Queensland based on charter and recreational samples. Samples sizes are shown above each bar.

Swimbladders typically ruptured on the ventral side at a point 30% to 90% along the length of the organ from the posterior end (average = 70%). The average size of the ruptures (when standardised for fish size) increased with depth but there were no significant differences in the size of the ruptures between males and females ($P>0.05$) at any depth (Figure 6). Rarely (1% of fish) were there more than one rupture present along the swimbladder.

There was a range of physiological effects of barotrauma other than just a ruptured swimbladder and everted gut in this species. Corneal bleeding was present in 13% of fish. Another significant physiological effect of barotrauma was the rupturing of veins in the liver which was noted in 4% of fish. We also qualitatively assessed the level of bleeding and found that while few fish (6.3%) showed no signs of internal bleeding the remainder were categorised as having only slight bleeding apart from the fish that suffered haemorrhaging in the liver. Total voiding of the stomach was observed in 77% of fish and none of the fish caught in the controlled experiments were able to have air expelled from their bodies when pressure was exerted along their gut indicating that there had been no (major) rupturing around the anus or other area from which air could escape. Dissections of fish that had suffered barotrauma but had survived the short-term experiment showed that some had partially sealed the ruptures, and in other cases immediately after capture mesenteric tissue had covered the hole enabling a partial seal to form allowing the swimbladder to still retain some gases (Figure 7). Some evidence of this "healing" was observed in 25% of cases.

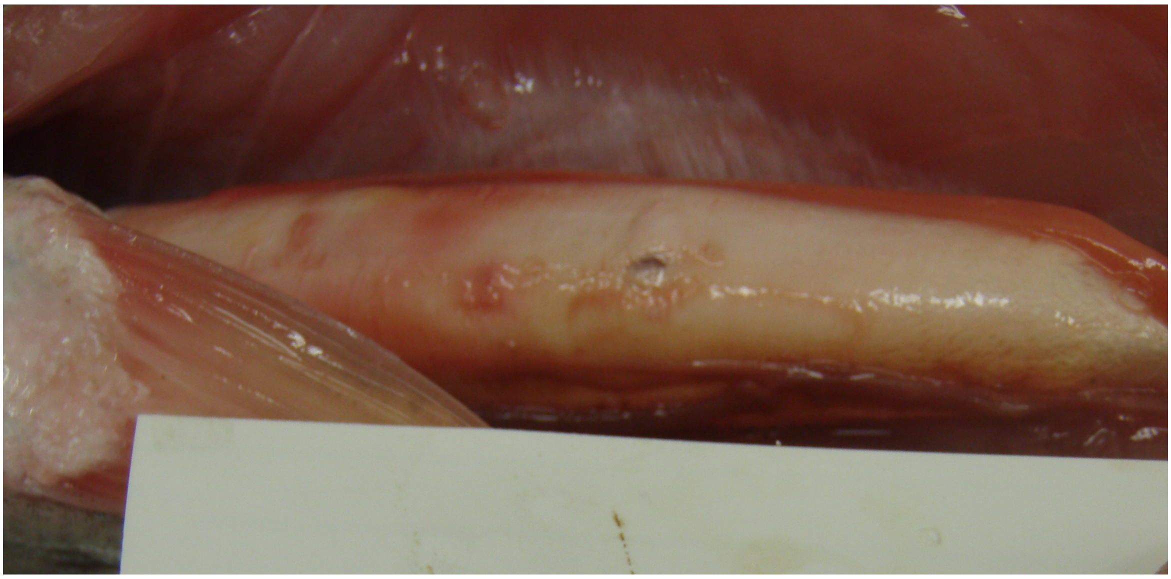

Figure 7 Partially deflated ruptured swimbladder of a male teraglin caught in 47m showing mesenteric tissue creating a partial seal of the rupture. Some air remained in the swimbladder and this fish was held in a tank one day prior to dissection.

Figure 8 Inflated swimbladder of a 33cm female teraglin caught in 45metres. Note the flattened surface of the gonad caused by the pressure of the swimbladder.

We also collected information on gonad stage but results were too variable to draw any conclusions regarding the impact of gonad size on barotrauma-related injuries but it was clear that females in particular with more advanced stages of gonad development had gonads that had been distorted by the pressure exerted by the expanding swimbladder (Figure 8).

Discussion

The post-release survival rates of teraglin determined in this study puts it at the "moderate level" of survival compared with other species of fish. In the most recent assessment of post-release survival, Bartholomew and Bohnsack (2005) collated 274 studies that examined catch and release survival and found that on average 82% of fish survived catch and release.

The original design of the controlled experiment involved the use of our modified "sock" that allowed released fish to return to depth but conditions in the open ocean where teraglin could be fished were such that it was not safe to deploy the sock due to strong current and adverse sea conditions in the fishing area. In our preliminary trials, fish were observed attempting to swim from the water surface when placed in on-board holding tank but as they were unable to descend more than 1.5m they quickly became exhausted after repeated attempts to descend and quickly floated back to the surface. While we acknowledge that a proportion of these fish would have survived without treatment (an observation confirmed and quantified by our fishery observations) we believed that a compromise was necessary that would enable the evaluation of the effects of venting on survival without proper experimental controls as we were getting independent data on non-treated (control) fish using our direct fishery observations. Preliminary trials also showed that holding teraglin for even a short amount of time (<30 seconds) without venting or enabling them to swim down to a depth that would enable repressurisation severely reduced their ability to survive.

Aalbers *et al.* 2004 noted that eighty percent of white seabass mortalities occurred within 24 hours and 91% within 3 days with no mortalities occurring after 5 days of a 90 day experimental period. Although the fish in that study did not suffer exclusively from barotrauma, mortalities were more related to hooking damage. Nonetheless we contend that there is enough evidence in the literature to confirm that the vast majority of line fishery related post-release mortalities occur in the first couple of days (McCleay *et al*. 2002, Brown, *et al*. 2008).

The majority of teraglin caught suffered some swimbladder damage and all fish caught in the controlled experiments displayed symptoms of barotrauma regardless of the depth of capture. There was, however, no depth related increase in the severity of external symptoms as gut everted fish were caught in all depths and corneal bleeding and other internal pathology was evident across the depth range covered.

Despite this, there was a wide variation in the response of teraglin to barotrauma when fish were observed on charter vessels, but this was not consistent across vessels. On some occasions when fishing in the same depths none of the fish were capable of descending without venting and yet at other times when fishing the same depth all fish descended without any further intervention. It is a well known observation that fish can be induced to suffer barotrauma more readily by a rapid retrieval, particularly over the last 10m as the fish nears the surface. We speculate that these variations are largely due to the effects of retrieval time and other fishing gear related issues as there are considerable differences in the gear and skill level of anglers, particularly on charter vessels. Retrieval time was quantified on occasions during observer trips and it was noted that the severity of barotraumas symptoms could be influenced by the retrieval pattern as the fish neared the surface. Some fishers were effectively able to induce fish to evert their gut by quickly winding in the fish, particularly over the last 10 metres below the surface.

It has previously been demonstrated that hooking location was a very important determinant of fish survival (Brown *et al.* 2008, and Appendix 3.5 and Appendix 3.7). Deep-hooked fish (i.e. where the hook was lodged in the throat, gullet or gut) were not removed from the analysis of barotrauma even though a poorer survival rate was evident for these fish compared with lip or mouth hooked fish. This is consistent with many other studies examining the effects of hooking damage (Muoneke and Childress 1994, Cooke and Suski 2004). In our controlled experiments we were more interested in determining overall survival and depth related effects rather than testing the effects of treatment. Even if we had included this as a randomised effect, it would ultimately have suffered from lack of contrast in the data, since very few teraglin had been hooked in the throat or gut during our trials.

The presence or otherwise of externally visible signs of barotrauma is of obvious significance to short-term survival (Brown *et al.* 2008). We were unable to test differences in survival between fish with no visible barotrauma signs and those with serious symptoms (extruded gut or exophthalmia) in our controlled experiments as all fish displayed barotraumas symptoms. We do note however that this species may not always display easily recognised external symptoms as fish caught on observer trips (particularly from water >70m) sometimes had a flaccid gut where swimbladder gases had been "self vented" most likely as a result of the gut being perforated on ascent to the surface. Body size was also a significant predictor of short-term survival, with large fish not surviving as well as the smaller sublegal fish. While this was significant in the model it was not significant when the interaction of depth and size was included even though that interaction was non-significant. Brown *et al.* (2008) likewise found greater survival of larger fish for some coral reef species speculating that this was due to the development of gonads limiting the expansion of the swim bladder within the body cavity of large, more mature fish. More research is required to ultimately determine the interaction of depth of capture and size on release survival of teraglin in order to get a more balanced design in the analysis of the depth-size interaction.

Also, it is possible that regardless of the amount of care taken in venting a fish there is always a possibility that enough excess gas remains in the fish to affect its ability to submerge immediately without assistance. Sciaenids have been characterised by having a membranous swim bladder which ruptures easily, the released gas becoming trapped within the abdominal mesenteries. We saw little evidence of this trapping in the mesenteries for teraglin despite observing a high prevalence of ruptured swimbladders. Re-pressurisation by releasing the fish with a shotline or release capsule (see Bruesewitz *et al*. 1993), will (unlike venting) overcome the buoyancy problem and improve the individual's survival chances.

When a hooked fish is being brought to the surface from depth the time is usually much longer than when fishing in shallower water and fish may not have the capacity to maintain its abdominal tension, particularly if it has become exhausted as a result of struggling. On some occasions project staff observed fish bloat a short time after they had been placed in the holding tank and likewise saw one fish that had previously had their gut everted recover from this without venting (other than "self venting"). This may have been caused by relaxation of the abdominal wall, which allowed the swimbladder to expand (causing bloating) or even swimbladder rupturing post capture. After decompression of largemouth bass *Micropterus salmoides* as a result of having been brought to the surface, Feathers and Knable (1983) observed that bloating occurred on average 5 minutes after capture. Lee (1992) found the same species to be better able to re-submerge if returned to the water very soon after capture, presumably because this enabled repressurisation of the swimbladder before weakened muscles caused bloating to occur. These observations are consistent with the hypothesis of muscular control and would indicate that the time between capture and subsequent release should be as short as possible. This is particularly relevant to teraglin as they quickly became exhausted after release into holding tanks and lost the ability to swim down from the surface. Rapid release of captured fish is traditionally recommended for obvious reasons, principally to reduce physiological stress and damage caused by prolonged time out of water and to reduce potential UV damage to the fish's eyes (Brown *et al.* 2008). While rapid release may be achievable in a basic catch and release fishery where de-hooking devices are used, there could be issues in tag-and-release operations, where the time taken to measure and tag the fish increases the likelihood of delayed bloating occurring. This needs to be considered in any future tagging work on this species. The term 'release condition' was tested to represent the combined effects of all the factors that might have influenced the survival rates of the fish during their capture, handling, and treatment. Release condition was clearly a dominant factor, even though the condition index was a relatively qualitative measure (on a 1-5 scale) and subject to inter-angler variability. During our controlled experiments it was obviously more consistently applied as the same anglers, WS, MC and MMc caught and treated all fish.

There is little doubt that venting and capsule release (as well as other methods), help overcome the buoyancy problems associated with barotrauma (Brown *et al*. 2008). Our experiments provided estimates of short-term (3 days) survival of teraglin. There is a strong likelihood that some effects of capture, handling and release may not become evident for weeks after release (McLeay *et al*. 2002). For example, the stomach and urinary organs are important in maintaining blood osmolarity in teleosts (Forgan and Forster, 2007) and in addition perforation of the stomach may also allow acid, and bacteria to enter the abdominal cavity possibly causing peritonitis and subsequent mortality. We found little evidence of significant damage to the gut in teraglin. While most fish had stomachs that were empty when they were examined, few were seen to have guts that had been ruptured either by self venting or by the pressure of escaped swim bladder gases. Self-venting or buccal venting was regularly seen for snapper but this was not a common observation in teraglin. The short-term experiments also protected the fish from surface predation, which is a well recognised additional cause of mortality amongst fish unable to swim from the surface (Bruesewitz *et al*. 1993). Teraglin are particularly vulnerable to this, since unlike snapper and pearl perch, they seem less capable of "self venting" when their swim bladder ruptures and a high proportion of untreated teraglin were seen floating on the surface when released from fishing vessels. When a fish is released and floats on the surface a release capsule is useful, particularly during drift fishing because it can be readily placed over a fish and lowered to a depth that would allow pressure equalisation.

Our results indicate that swim bladder damage increases with depth and in fact all teraglin that were caught in depths greater than 75m had ruptured swimbladders. This, and the observation that there was little short-term survival in experiments for fish caught at these depths, as well as few fish successfully swimming away from the surface without venting at moderate depths (50 to 69m) suggests that mortality is very high in deeper parts of the fishery. It appears that few teraglin captured and released in depths greater than 75m would survive.

The difference found in the occurrence of swim bladder ruptures and survival between males and females also has fisheries and ecological implications. Differential sexual mortality could lead to a gradual change in the sex ratio and a possible impact on recruitment. Sex ratios of individual catches that were examined as part of other research conducted during the present project were seen to vary dramatically being strongly dominated by either sex at times (In some cases over 90% of samples of over 30 fish were one sex). Some fishers believe that this is due to schooling by sex and there is currently no evidence to suggest a consistent dominance of males in catches. In fact, samples we collected as part of our controlled experiments had a 2 to 1 ratio of females to males and we believe that there is currently no evidence that there has been an ecological shift in sex composition in the teraglin population.

In a previous unpublished report Merwe (unpublished 2000) investigated the swim bladders of undersized teraglin, caught off the Gold Coast in depths of 24 and 36 fathoms, to determine the extent of the swimbladder damage and found that 64 percent experienced ruptured or distended swim bladders, with a significantly higher proportion of females (97%) compared to males (45%) having ruptured / distended swim bladders. We found similar results although the extent of the sexual difference was not as great. After finding no significant difference in wall thickness or swim bladder weight between sexes Merwe

(2000) speculated that male teraglin's superior resistance to barotraumas could result from more efficient gas secretion and resorption mechanisms. We are unsure of the mechanism that may enhance the survival of male teraglin. However, males of the Sciaenidae family are known to make croaking sounds during feeding and breeding periods, which are believed to be generated through the use of specialised sonific muscles on the inner wall of the body cavity that are used in conjunction with air movements controlled by the swim bladder. While the importance of sound production has been well documented during periods of reproductive activity the role of sonic musculature in ameliorating the effects of barotrauma is less well researched. We have provided some evidence that males are less susceptible to barotrauma than females but we are not aware of the mechanism that provides protection for the males. It could be argued that these muscles and other physiological adaptations (better gas movement mechanisms) could enable males to better control swim bladder volume. What is certainly established is that males retain the ability to "croak" even with a ruptured swimbladder.

For many species spawning behaviour comprises a series of 'spawning rushes' during which a male and female fish have been observed swimming rapidly toward the surface in close proximity, releasing gametes, then immediately returning back down to their original depth (Samoilys and Squire 1994). In the case of coral trout these 'rushes' could be over a 12 m depth range. Brown *et al.* (2008) suggested that these fish may have tensed the abdominal musculature hindering the swimbladder from expanding to the point of rupture. Because the rushes are so rapid, this muscular control may only have to be maintained for a few seconds. It is also possible that the increasing swimbladder volume associated with the reduction in ambient pressure may aid the extrusion of gametes. In other words, the swimbladder may be an integral component of the mechanics of spawning for some species. It is still uncertain whether this is the case for teraglin. Establishing the reasons for these sexual and behavioural differences in effects of pressure change on fish was beyond the scope of this research but is an important area for further research. Particularly establishing the reason why male teraglin seem to be more tolerant to the effect of barotrauma.

The most common approach of mitigating the effect of barotrauma has been to deflate swim bladders using a hypodermic needle, a process known as venting. In Queensland, this has traditionally been done laterally by venting an area behind the pectoral fin with a hollow needle. This process of releasing the expanded swimbladder gases and thus reducing positive buoyancy allows the fish to descend to deeper water. It is a technique widely used by anglers around the world, although its effectiveness is not universally acknowledged (Wilde 2009). A study by Keniry *et al*. (1996), on yellow perch caught within five to eight fathoms found that venting the swim bladders increased survival and allowed fish to recover neutral buoyancy more effectively than unpunctured individuals. Similar results were found in deflation of the black sea bass, with increased benefits in deflation found with increasing depth of capture (Collins *et al*. 1999). However the latter authors also noted that deflating the swim bladders of vermilion snapper under exactly the same circumstances had a lesser degree of benefit to their survival. Factors such as predation, solar radiation and handling are also difficult to quantify. These differences in results between species indicate that the impacts of depressurisation affect different species to varying extents and each species requires independent consideration when investigating and implementing management strategies. This is clearly the case among the three species investigated in this report where barotrauma symptom severity and recommended treatments varied among species. Teraglin is clearly a species where some type of intervention is recommended and we would advocate either lateral venting or capsule release. Shotlining, as carried out predominantly is Western Australia would also be beneficial but in the past we have encountered resistance to this technique in Queensland (Brown *et al*. 2008).

Dissection of the teraglin sampled that were above the MLS also revealed that some of the severely bloated individuals possessed ruptured swim bladders causing their body cavity to be filled with the escaped swimbladder gases. This was more commonly observed in individuals caught in greater than 50m. In shallower depths, teraglin often had highly distended swim bladders, which had expanded to totally fill the body cavity, putting great pressure on internal organs and the body wall. This varied impact of fishing depressurisation on the swim bladders of teraglin has significant implications for the successful management of the fishery. Any treatment that allows teraglin to return safely to depths from which it was caught may have different survival implications depending on whether the fish have a distended or ruptured swim bladder. The use of a hypodermic needle to release the air from a bloated teraglin may be beneficial if the swim bladder is actually distended, but will likely have reduced effectiveness if the process simply releases the expanded air from the body cavity of an individual with a ruptured swim bladder. Although individuals with ruptured swim bladders could descend from the surface after artificial deflation, their ability to attain neutral buoyancy could be reduced due to the swim bladder damage.

The extent of swim bladder damage in terms of the size of the rupture has also been found to affect recovery time and post-release survival. Largemouth bass vented with a hypodermic needle rapidly attained neutral buoyancy (Shasteen and Sheehan 1997), however when the rupture exceeded five millimetres the time of recovery increased to over 31 hours. The majority of teraglin that were sampled possessed ruptures that exceeded five millimetres in diameter, typically 20 to 30mm. Therefore the teraglin that experienced significant swim bladder ruptures would be expected to expend more energy and take longer to heal than those fish not suffering from the effects of barotraumas.

The fact that we have established that the post-release survival of teraglin is potentially greater than first thought reduces the risk of unsustainable fishing of this species, although it is still a significant source of mortality in this fishery. While we are still uncertain about the precise degree to which fish size effects the ultimate survival of teraglin, the fact that small fish do not suffer higher mortality than larger fish is reassuring given the high number of smaller fish released due to minimum legal size restrictions. The MLS was originally reduced from 45 to 38cm in an effort to minimise this mortality and it seems that this has been an effective management response as charter catch rates have been maintained and the biology of the species indicated that the risk of overfishing is lowered given early sexual maturity and high fecundity.

Running counter to this is the evidence presented in Appendix 3.11 which indicates that the current bag limit of 5 would be quickly reached more often than for either pearl perch or snapper. This results in larger fish also being released, probably more commonly in deeper water where mortality is higher. At present there is no evidence to suggest that this fishery would benefit from a maximum legal size and on the basis of the size/depth stratification, as well as the higher mortality of larger fish, such a measure would not be recommended on the basis of post-release mortality.

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APPENDIX 3.7 EXPERIMENTAL DETERMINATION OF THE SHORT-TERM POST-RELEASE SURVIVAL OF LINE CAUGHT SNAPPER (*Pagrus auratus*)

Summary

Snapper (*Pagrus auratus*) is a popular recreational and commercial species caught on rocky reef habitat in offshore waters of South-East Queensland. Size limits and other restrictions result in the release of a large number of snapper. We quantified the short-term (1 ≈ 3 days) post-release survival of snapper and trialled a new venting technique. Snapper were found to have an overall short-term survival of 88%. There was no significant difference in survival across the 3 depth ranges studied (37-50m, 51-100m, 100-180m). Survival of legal vs. sub-legal (MLS 35cm) snapper was not significantly different, however there was a trend for sub-legal fish to have better survival in the shallower depth class and a marginally significant interaction between depth and size at the 90% confidence level. Gut hooking and presence of bleeding were found to be significant factors affecting survival. Traditional lateral venting techniques were shown to cause no harm and allowed fish to return to depth. We trialled a venting technique based on observations of snapper inadvertently piercing their everted stomach with their teeth and releasing trapped swim bladder gasses. This technique was called "buccal venting" and involved piercing the stomach protruding into the buccal cavity or out of the mouth with a 16 gauge hypodermic needle (a practice previously not encouraged). Short-term survival in buccal vented fish was not significantly different from fish vented in the traditional manner. All fish were dissected upon completion of experimental trials to ascertain rates of healing for swim bladders and stomachs. Healing of swim bladders was evident in 27% of snapper dissected after 1-3 days in captivity. Healing of stomachs was observed in 61% of fish that had been buccal vented.

Introduction

The importance of accurate estimates of discard mortality rates for stock assessments and fisheries management has been highlighted globally (Alverson *et al.*, 1994). Considerable research has focused on the rates of discard mortality for line caught fishes in recreational and commercial fisheries with some estimates of discard mortality equal to the reported catch (Broadhurst *et al.*, 2005; Butcher *et al.*, 2008; Campana *et al.*, 2009; Brown *et al.*, 2010). High discard rates and low survival of released fish have the potential to reduce the effectiveness of conservation measures such as bag limits and minimum legal sizes.

In Queensland the snapper fishery is predominantly an offshore hook and line fishery with most of the catch taken in waters >30m (Sumpton *et al.*, 2003). Estimates of catch and release rates for the recreational sector since 1997 have shown discard rates between 57% and 76% (Higgs, 1999; 2001; McInnes, 2006; 2008). Snapper stocks in South East Queensland (SEQ) have been identified as overfished based on recent stock assessments (Allen *et al.*, 2006; Campbell *et al.*, 2009) and catch age frequencies. These stock assessments used estimates of discard mortality ranging from 40% to 70% based on previous studies for discarded snapper (Stewart, 2008; St John *et al.*, 2009) which suggests considerable impact of discarding on snapper stocks. The introduction of a new limit for recreational anglers of only one fish over 70cm total length with a reduction in the bag limit from 5 to 4 has the potential to increase the already high discard rate. Mortality rates for released snapper have been shown to vary amongst studies but increase dramatically with increased depth. Stewart (2008) found no mortalities for snapper taken in shallow waters to 21m with the mortality rate rising to 55% for snapper captured from depths between 45 and 59m. Whilst St. John *et al.* (2009) showed a mortality rate of 69% for fish taken from depths between 45 and 65m. In contrast tagging studies have had reasonable returns of between 5.9% and 62% suggesting that post-release survival may be higher then previously thought (Appendix 3.4; Gauldie, 2000; Moran *et al.*, 2003; Sumpton *et al.*, 2003). Given that the fishery in Queensland is predominantly a deep water fishery this study looked at developing a more precise estimate of discard mortality for snapper taken in depths greater then 50m.

In addition to acquiring more accurate and precise estimates of survival for assessment purposes, there is generally the desire to improve the survival of those fish that are subsequently returned to the water, particularly when fish are taken in relatively deep water and suffer the effects of barotrauma.

Many studies have looked at various ways of increasing the post-release survival of target species. While mortality in line caught fish has been attributed to a wide range of factors including hook size, type and hooking locations (Arms *et al.*, 1994; Cooke *et al.*, 2003; Butcher *et al.*, 2007; Wilde and Sawynok, 2009); handling; surface interval, depth of capture and subsequent barotrauma (McLeay *et al.*, 2002; Bartholomew and Bohnsack, 2005; Brown *et al.*, 2010), the effects of barotrauma can sometimes be ameliorated by appropriate handling and treatment. Barotrauma relief measures such as using a heavy weight to return fish to depth (St. John and Syers, 2005) and venting have been investigated for a wide range of species with mixed results (Wilde, 2009; Brown *et al.*, 2010). Wilde in his 2009 review postulated that venting may in fact reduce the survival of fish, particularly those taken in deeper waters. However other studies have shown benefits from venting to be species specific. One study found an increase in the survival of vented red snapper (*L. campechanus*) but venting red grouper (*Epinephelus morio*) was of no benefit (Burns and Restrepo, 2002). Similarly Brown *et al.* (2008) showed venting to increase survival for only one (*L. malabaricus*) of a suite of six coral reef fish studied. In cage experiments venting has been shown to cause no harm to snapper with no difference in survival between vented and unvented fish (St John *et al.*, 2009).

The present study examines the effect of depth of capture, size, and barotrauma treatment on the short-term survival of snapper. In addition, a new venting technique was trialled. This was based on observations of snapper with severe barotrauma symptoms inadvertently biting into their protruding stomach and releasing the swim bladder gasses trapped within the body cavity. We called this "Buccal" venting as it occurred in the buccal cavity. The ability of a fish to survive the effects of barotrauma depends on the physical damage caused by the trauma and by its capacity to heal subsequent damage to internal organs. Laboratory studies have shown healing of swim bladders can occur within very short time frames (Shasteen and Sheehan, 1997; Burns and Restrepo, 2002; Bellgraph *et al.*, 2008). Given that the stomachs of snapper were being pierced we examined the stomachs and swim bladders of all fish held for 1 – 3 days for signs of infection and to ascertain if healing had occurred.

Methods

Experimental site selection

Fish were captured from a range of sites for these experiments. Areas offshore from Double Island Point, and Moreton Island were targeted based on depths and catch likelihood. Capture sites at Double Island Point ranged in depth from 37 – 50 metres whilst depths at the other sites ranged from 51 – 180 metres (Appendix 3.5, Figure 1).

The experiments carried out at Double Island point utilised the apparatus described in Appendix 3.5. Fish were caught by hook and line using standard recreational fishing tackle of rod and reel or deck winch, all with braided lines except for one angler who used monofilament. Upon capture all snapper were tagged with a uniquely numbered HallPrint™ tag. All snapper over 20cm total length were kept and those showing symptoms of barotrauma were included in the experiment and treated (or not depending on experimental protocol). All snapper were placed in one of two 1.4 tonne flow through holding tanks on board the Fisheries Research Vessel the "*Tom Marshall*" a 14m catamaran before transport to the floating socks via the Fisheries Research Vessel "*Makaira*" a 5.8m Centre Cab powerboat. Details recorded included: angler; time of capture; fork length (FL); barotrauma symptoms (none, bloating, gut extrusion, exophthalmia); bleeding (none, slight, severe), injury (no damage, hooked in eye, gill damage, jaw damage, moderate scale loss, heavy scale loss), hook location (lip, mouth, gut, outside), treatment (none, lateral vent, buccal, self buccal) sock identification, release condition (1 – 5 as per Appendix 3.5) and release time into sock. Surface interval, that time between capture and release into the floating socks, was kept to a minimum where possible and socks were lifted after 3 nights.

Fish were laterally vented in the recommended manner (Florida Sea Grant 2005, Brown *et al*. 2010). Where the stomach was protruding (Figure 1) buccal venting was done with the same size hypodermic needle (38mm x 16 gauge) and syringe (3ml) (Figure 2) used in the traditional venting treatment. In some instances the stomach was accidently pierced with the hook point before the needle could be used or snapper would bite down piercing the everted stomach and release the trapped swim bladder gasses. Observations of the hook point piercing the stomach were recorded as buccal vented with any observations of the fish biting down and piercing the stomach being recorded as “self” buccal vented. Fish that displayed barotrauma symptoms were assigned a treatment in the order they came on board.

(a) (b)

Figure 1 (a) Snapper caught in 40 metres with stomach protruding through mouth (b) Snapper caught in 60 metres with stomach in buccal cavity

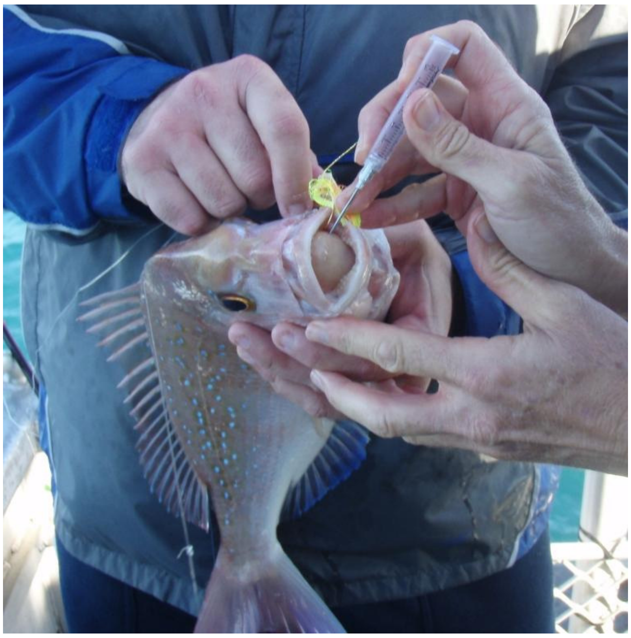

Figure 2 Snapper caught in 60 metres being buccal vented

Due to logistical considerations such as wind, swell, current and shipping traffic the standard socks were unable to be used for the deeper catch sites offshore from Moreton Island. For these trips experimental protocols remained the same except that snapper were kept on board in the flow through tanks mentioned above instead of release into the socks. Additionally, one sock was modified and reduced to a hang depth of 5m for one trip (as per Appendix 3.5). Fish were kept on board through the day and transferred into the sock at the end of each day at the cessation of fishing. At the end of each experiment fish were recovered and their tag number, condition and vitality (dead or alive) recorded. Fish were then euthanized and frozen for subsequent dissection of the stomachs and swim bladders in the laboratory.

Dissections were carried out on all fish recovered. Decomposition of a small number of fish that died in the socks shortly after capture meant that no meaningful examination could be made of the swim bladder or stomach. The size and position of all holes in the swim bladder were recorded as were signs of healing. Swim bladders that appeared to be healed were injected with water and pressurised to test if healing had occurred. The stomachs were examined for holes, any signs of healing or infection and if they had returned to a normal position. If the stomach appeared to be healed it was dissected out and pressurised with a syringe to test if healing had occurred.

Statistical analysis was carried out using multi – factor generalised linear modelling (GLM) in GenSat v. 11.1 (GenStat, 2008) with a binomial distribution and logit function using vitality (0 = dead, 1 = alive) as the response variable. The continuous variables, depth and fish length, were transformed into categorical variables. Depth was converted into shallow (≤50m), moderate (51-100m) and deep (>100m) whilst fish length was converted into sub-legal (<35cm) or legal (≥35cm). The other factors included in the model were: signs of barotrauma (none, exophthalmia, stomach protruding into the buccal cavity or out of the mouth, swollen abdomen); bleeding (yes, no); hook location (lip, mouth, throat, mouth, gut, outside or foul hooked); injury (none, eye, gill damage, jaw damage, moderate scale loss, heavy scale loss). Also included in the model was experiment number (1 – 6), sock identifier, surface interval and time in captivity to assess any spatial and temporal variability. The rsearch function in Genstat (2008) was used to determine the final model by eliminating factors that were not significant. In the initial analysis the complete data set was used to determine if any factors significantly affected survival. Snapper that did not present with barotrauma symptoms upon capture were removed from the data set and another GLM was carried out to determine if any differences existed between treatments. A third model used these same factors with the addition of factors from the dissection results. These included presence/absence of: a perforated swim bladder with number, size and position of any perforations; healing of swim bladder; partial inflation of swim bladder; air from anus; stomach in normal position; perforation of stomach and healing of any perforations. Response variates used were vitality, swim bladder healed; size of hole in swim bladder and if the stomach had returned to a normal position.

Results

Table 1 Raw data for numbers of snapper in each factor and level and the resultant survival during experimental trials

Factor	Level	Survived	Died	Total	% Survival
Treatment	Buccal	77	4	81	95%
	Vent	57	12	69	83%
	None	46	7	53	87%
	No Symptom*	55	8	63	87%
* Fish not included in the analysis of treatment as they showed no barotrauma symptoms					
Depth Class	Shallow (37-50m)	122	13	135	90%
	Moderate (51-100m)	36	6	42	86%
	Deep (>100m)	22	4	26	85%
Size	Legal (≥35cm)	42	9	51	82%
	Sub-legal (<35cm)	138	14	152	91%
Depth x Size	Shallow x Legal	10	4	14	71%
	Moderate x Legal	20	2	22	91%
	Deep x Legal	12	3	15	80%
	Shallow x Sub-legal	112	9	121	93%
	Moderate x Sub-legal	16	4	20	80%
	Deep x Sub-legal	10	1	11	91%
Bleeding	Yes	9	6	15	60%
	No	230	24	254	91%

Overall post-release survival for snapper caught in this study was 88%. Not all snapper caught showed signs of barotrauma (23%). In some instances anglers observed bubbles rising with the fish from depth and the captured fish would then present with no barotrauma symptoms. All fish were used in the model to ascertain overall survival. However, due to the uncertainty of how and where swim bladder gas was escaping, snapper that exhibited no symptoms of barotrauma were excluded from the analysis of treatment. Of note is that there was no observed difference in survival between untreated fish that showed barotrauma symptoms included in the analysis of treatment compared to those that did not show barotrauma symptoms and were therefore excluded from the analysis (Table 1). The proportion of fish (23%) that did not display any barotrauma symptoms was the same across all depth classes. Size of fish and depth of capture did not significantly affect survival (Figure 3a).

Bleeding at time of capture was significant (P<0.05) with a predicted survival of 66% for fish that were bleeding compared to 88% for those that were not (Table 2). Likewise hooking location was a significant factor (P<0.05) with 4 of the 5 gut hooked fish dying (2% of catch) (Figure 3b). Where gut hooking occurred the line was cut and the hook left in. No significant differences in catch rates or hooking locations between anglers were found.

In the analysis to test if treatment was significant no difference in survival for buccal vented fish (93%) versus self buccal vented (96%) was found (P > 0.05). Subsequent analysis combined these two levels as buccal vented. While treatment was found to be a significant factor affecting survival (Table 2) pairwise t tests showed no significant (P>0.05) differences (Table 3). However, a possible trend towards lower survival for vented fish was observed (Figure 4a). A power analysis showed that 189 observations for each treatment would be needed to detect a difference assuming a 95% confidence level and power of the test set at 0.8. Survival was not affected by time in captivity (Figure 4b).

Table 2 Accumulated analysis of deviance table with no symptom, no treatment fish removed from data set. The binomial GLM assessed various factors affecting short-term (1 – 3 days) post-release survival of snapper (Significant factors are shown in bold).

Factor	d.f.	deviance	Mean deviance	Deviance ratio	Approx chi pr
Bleeding	1	7.3068	7.3068	7.31	**0.007**
Hook Location	3	10.7012	3.5671	3.57	**0.013**
Treatment	2	6.8358	3.4179	3.42	**0.033**
Size	1	3.6420	3.6420	3.64	0.056
Depth Class	2	0.4069	0.2034	0.20	0.816
Residual	196	127.3068	0.6495		
Total	205	156.1995	0.7619		

Table 3 Pairwise 't' probabilities of the effects of different barotrauma treatments on snapper

t probabilities of pairwise differences			
Buccal	*		
None	0.209	*	
Vent	**0.095**	0.669	*
	Buccal	None	Vent

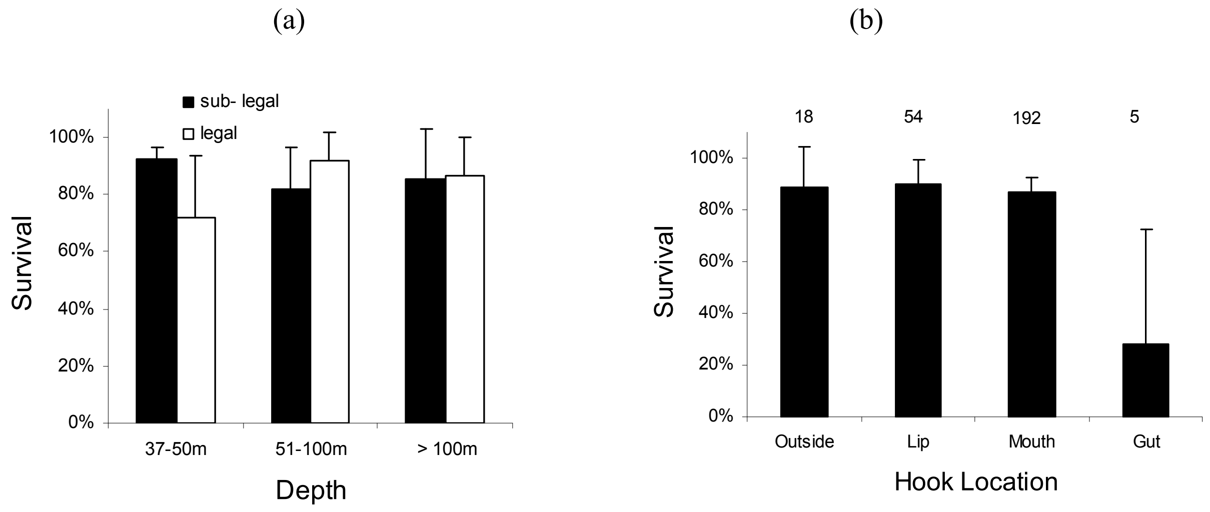

Figure 3 Predicted survival of snapper for: (a) sub-legal and legal snapper in 3 depth classes and (b) hook location. Error bars are 95% confidence intervals.

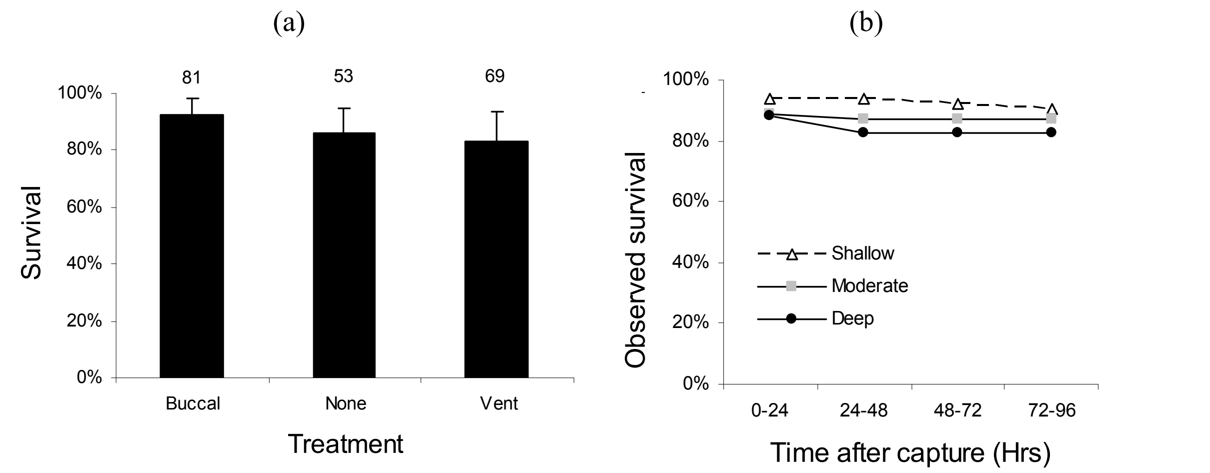

Figure 4 Predicted survival for: (a) each treatment (Error bars are 95% confidence intervals) and (b) observed survival accumulated by day.

No factors from the dissections were found to have affected survival. The swim bladder was healed in up to 61% of the snapper dissected. However, rates of healing varied as their was no way of ascertaining if snapper recovered from the socks (15m deep) after 3 nights had healed and then ruptured again or had not healed at all (Figure 5). Rupturing of the swimbladder occurred at the rete mirabile in 46% of the snapper examined. The size of the rupture was significantly larger for fish taken in the deeper depth class and larger ruptures were less likely to have healed (Figure 6). Only 3% (n=7) of snapper dissected showed no signs of a rupture in the swim bladder.

Figure 5 Swim bladder showing site of healing with a secondary rupture. This probably occurred when the fish was recovered from the 15m deep sock.

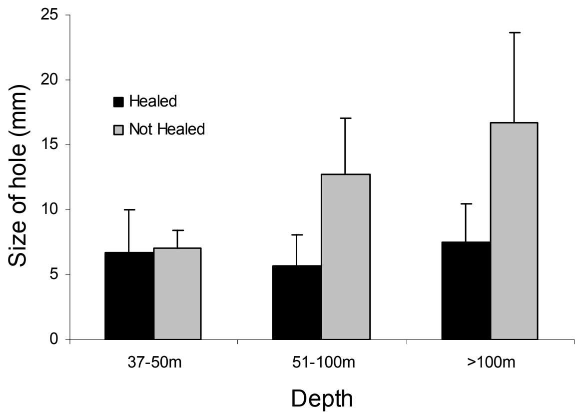

Figure 6 The average size of perforation in healed and unhealed swim bladders for each depth class. Error bars are 95% confidence intervals

For snapper that exhibited stomach prolapse the dissections revealed that the stomach had returned to a normal position within the gut cavity for 64% of fish with a higher proportion of 73% for vented fish. For snapper that were not vented (buccal, self and no treatment) the stomach was often slightly inverted, and clenched around the site of any wound in the stomach. The stomachs of snapper that were buccal vented (including those that "self" buccal vented) were found to have healed in 61% of cases (Figure 7). Two fish that had not been buccal vented had stomachs that displayed healed wounds the same as those displayed by buccal vented fish. Signs of infection were found in only 4% (n = 3) of the buccal vented fish when dissected.

During experimental trials swim bladder gas was observed bubbling from the anal vent of snapper floating in the on board tanks. Of the fish dissected 19%showed air bubbles from the anal vent when pressurised and placed under water.

(a) (b)

Figure 7 (a) Stomach *in situ* showing healed wound from buccal venting. (b) Stomach from buccal vented fish dissected out and pressurised to test if healed.

Discussion

The overall rate of post-release survival for snapper determined in this study was 88% with no difference in survival associated with increased depth or size of fish. This is in marked contrast to results from previous studies where survival rates were estimated to be as low as 31% for snapper taken from depths shallower than those fished in this study (St John *et al.*, 2009). It also contrasts with the review of recreational tagging data (Appendix 3.4) where the survival rate for larger fish was found to be higher. In a review of 274 studies assessing catch and release angling mortality Bartholomew and Bohnsack (2005) found the average post-release survival was 82% across all studies.

The 2009 stock assessment of the Queensland snapper fishery identified snapper as overfished (Campbell *et al.*, 2009). Similar concerns have been identified by fisheries managers for some snapper stocks in other states where snapper are found. Post-release survival estimates used in the Queensland stock assessment model ranged from 30 – 60%. These figures are much lower than the 88% ± 2% s.e. post-release survival found in this study. Additionally, this study estimated survival across a much broader depth range than in previous studies reflecting the areas targeted by snapper fishermen in SEQ. In the past the offshore snapper fishery in SEQ has occurred for the most part in depths between 50 – 100m. However, a burgeoning population, localised stock depletion along with technological increases in marine electronics and a subsequent increase in fishing pressure has meant that snapper are being targeted more often in depths >100m.

Previous studies into the post-release survival of snapper have shown higher mortality rates associated with increased depths. Mortality rates have been high with post-release survival estimates ranging from 31% to 45% in depths ranging from 45 – 65m (Stewart, 2008; St John *et al.*, 2009). Given that the fishery in South East Queensland commonly targets waters deeper then this and the concomitant increase in mortality that has been attributed to depth, more precise post-release survival estimates for these deeper waters are important. This study looked at the post-release survival for fish captured in depths ranging from 37 – 180m across three depth classes (37-50m; 51-100m; >100m) and showed the same high levels of survival across all depth classes. Unlike previous studies no decrease in post-release survival was found with increased depth. In addition, the proportion of snapper that presented at the surface with no symptoms of barotrauma was identical across all depth classes with no difference in survival for these fish. Due to logistical considerations the snapper captured from the deeper depth classes were kept in flow through tanks on board the research vessel for much longer periods then those caught from the shallower depth class which were transferred to the sea socks within an hour. Survival was no different for these fish even though it was a less then ideal environment in comparison to the socks as use of the tanks did not allow fish to repressurise by returning to any sort of depth as was possible with the 15m deep socks. In this study the minimum depth snapper were taken from was 37m which may mean that any differences in survival with depth are only seen when comparing depths < 30m with those >30m as per the various studies reporting high survival for these shallower depths (Stewart, 2008; St John *et al.*, 2009; Grixti *et al.*, 2010). Although keeping fish in cages as a way to test short-term survival rates has been used in a wide range of studies it seems that keeping snapper caught from deeper waters in cages may be a flawed methodology given the results of this study. Brown *et al*. (2010) found that cages of a similar size to those used by St. John *et al.* (2009) were unsuitable due to the subsequent cage related high mortality of *Lutjanus sebae*. In this study no decrease in post-release survival was found for snapper taken from deeper waters even though they were kept in flow-through tanks on board with no opportunity to repressurise compared to snapper taken in the shallower depth classes and kept in the socks. The two previous studies conducted over similar time frames reported decreasing survival with depth for snapper attributing these results to barotrauma and depth related mortality though it may in fact be more to do with logistical considerations and cage size (Stewart, 2008; St John *et al.*, 2009).

Many studies have identified deep hooking as an important factor affecting survival across a wide range of species (Bartholomew and Bohnsack, 2005; Alós *et al.*, 2008; Mapleston *et al.*, 2008; St John *et al.*, 2009). Rates of gut hooking in snapper were very low (<2%, n = 5) but the associated mortality was high (80%). However, in contrast to Grixti *et al*. (2010) there was no relationship between hooking location and bleeding with only one gut hooked fish displaying signs of bleeding. Bleeding in snapper was rare with only 5.6% (n = 15) of the catch recording any signs of bleeding. However it was a significant factor in reduced survival with bleeding fish only having a survival rate of 66%. Whilst gut hooking and bleeding were significant causes of mortality, occurrence was rare and post-release survival for snapper was high.

The perceived benefit from venting fish is to facilitate a quick return to capture depth by allowing the expanded swim bladder gas to escape. The assumption is that fish floating on the surface are more susceptible to mortality from predation and exposure such as damage from sunlight (Florida Sea Grant, 1999). This technique has become widely accepted and is recommended to recreational anglers by Recfishing Australia as well as U.S. National Marine Fisheries Service. In contrast a review of a range of studies assessing the benefits of this technique concluded that the practice should be banned (Wilde, 2009). Benefits of venting have been shown to be species specific with fish taken in the same locations and depth exhibiting very different barotrauma symptoms and responses to venting (Collins *et al.*, 1999; Burns and Restrepo, 2002; Brown *et al.*, 2008). A short-term (3 day) survival study that included two closely related species *Lutjanus malabaricus* and *Lutjanus erythropterus* found an increase in survival for *L. malabaricus* but not *L. erythropterus* when vented. These two species were captured from the same depth at the same site in mixed schools but exhibited substantial differences in both barotrauma symptom and survival (Brown *et al.*, 2008). *L. malabaricus* had a significantly higher survival when vented but still had a much lower survival then its congener *L. erythropterus*. It appears that treatment for barotrauma was only significant for the species that suffered lower survival and more severe barotrauma symptoms.

As all snapper were kept in enclosures no estimate of the impact of predation and exposure upon survival was made in this study. Whilst venting did not significantly increase survival it did allow snapper to return to depth in the sock or equalise and swim upright in the flow through tanks. Lateral venting of snapper would allow them to return to depth and avoid exposure and predation at the surface in comparison to snapper that have barotrauma symptoms and are unable to submerge. Analysis of recreational tagging data (Appendix 3.4) showed lateral venting of snapper with barotrauma symptoms to increase survival. However its efficacy on snapper that exhibited a prolapsed stomach was questioned with untreated fish having a higher survival. Given the number of snapper that were observed in this study “self buccal venting” and the higher survival for these fish it may well be that the untreated fish in the tagging data set consisted of a fair proportion of fish that had self buccal vented.

For snapper that exhibited the barotrauma symptom of having their stomach forced out of their mouth buccal venting appears to be a useful tool, at least for short-term survival. Buccal venting allowed swim bladder gasses to escape and appeared to offer better survival then venting whilst allowing fish to return to depth. It seems counterintuitive to pierce the stomach as a way of increasing survival but the fact that it mimics what occurred when snapper inadvertently bit down on their protruding stomach (“self” buccal venting) may explain its success. The paradigm for an expected outcome of such a procedure would be a high incidence of mortality due to infection, loss of osmolarity control and bleeding. However this was not reflected in the short-term survival experiments or the subsequent analysis of the dissection results where the majority of buccal vented fish had stomach wounds that had healed. Additionally, two fish that had not been buccal vented displayed scars on their stomachs of the same size and shape that were exhibited by buccal and self buccal vented fish, possible evidence of self buccal venting from a previous capture.

Movement of snapper through the water column to feed is well established with spawning aggregations observed occasionally in surface waters (Kailola *et al.*, 1993). Given that snapper are known to feed on crustaceans, molluscs and fish (Kailola *et al.*, 1993) perhaps it is not unusual to find evidence that the stomachs of snapper have been pierced. The high incidence of healing (61%) and the low rates of infection (4%) observed in the stomachs in comparatively short time periods (~ 3 days) along with reasonable tag returns (Appendix 3.4) suggest that the negative impacts of buccal venting on snapper are few. Benefits of using this method are that it may be very close to what happens naturally where snapper have been observed biting down on the protruding stomach (this study), it is very easy to do and there is no need for special tools or training as the point of a clean sharp hook would suffice. Problems with this method are that there is no estimate of survival over the long term and it is only applicable to snapper that have their stomach protruding through the buccal cavity. Results for the standard venting procedure have been shown to be species-specific even for congeners such as *L. malabaricus* and *L. erythropterus* (Brown *et al*., 2008). Use of buccal venting on other species could have deleterious effects far outweighing those associated with the traditional venting method. Damage to the stomach and a failure to return to a normal position within the body cavity have been listed as effects of barotrauma (Phelan, 2008; Wilde, 2009). However Burns (2009) in a laboratory experiment reported that both *Epinephelus morio* and *Lutjanus campechanus* fed within 1-2 hours of stomach prolapse and that dissections of wild caught fish showed that whilst there was evidence of stomach prolapse these fish were feeding normally and appeared healthy. The rate of healing observed in snapper over a short time period suggests that negative impacts upon the survival of snapper using buccal venting are minimal.

Rapid healing of swim bladders has been reported in a number of studies (Shasteen and Sheehan, 1997; Nichol and Chilton, 2006; Burns, 2009). Healing of swim bladders in snapper appears to occur within 24 hours with no increase in the observations of healing for fish held in captivity for longer times. The unexpectedly high rates of healing associated with increased depth may possibly be linked to the way in which the rupture occurs. Fish taken from deep waters would have initially been subjected to a much lower pressure differential than fish taken from the shallower waters. In fish that have a smaller perforation in the swim bladder gasses may be escaping sooner leading to a less catastrophic burst. Perhaps this more gradual change in pressure more closely mimics vertical movement through the water column of snapper.

While we have shown that buccal venting does not reduce short-term survival rates for snapper, long term impacts are unknown. Given the mixed results for lateral venting studies (Wilde, 2009) we would not recommend buccal venting for any other species. However, we would recommend some type of treatment for snapper that display symptoms of barotrauma and are unable to return to depth as floating at surface level exposes snapper to increased risk of predation and damage from sunlight. Whilst this study only quantitatively investigated the use of lateral venting and buccal venting techniques, we see no harm in using either release weights or release cages as techniques for relieving barotrauma symptoms and improving post-release survival. While we did not specifically test release weights we did use release cages to successfully release snapper and teraglin.

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APPENDIX 3.8 DISTRIBUTION OF JUVENILE PEARL PERCH IN SOUTH-EAST QUEENSLAND FROM TRAWL SURVEYS

Introduction

The eastern king prawn fishery is part of the larger East Coast Otter Trawl Fishery (ECOTF) and targets eastern king prawns, as well squid, bugs (*Thenus* and *Ibacus* species) and scallops (*Amusium balloti*). In 2010, 26,012 t of eastern king prawns (EKP) were landed in the fishery (Fisheries Queensland, in press), valued at approximately $39million. The bycatch from this fishery is substantial, with Courtney *et al*. (2007) – hereafter referred to as "the bycatch project" – estimating that it likely exceeds 12,000 t annually. During the late 1990's there was considerable pressure placed on trawl fishery managers to reduce bycatch as it often contained species of conservation interest such as turtles. As such, three separate trawl surveys were undertaken in order to provide information on the bycatch associated with the EKP fishery in south-east Queensland.

The first two surveys were completed as part of the FRDC-funded project *Bycatch weight, composition and preliminary estimates of the impact of bycatch reduction devices in Queensland's trawl fishery* (Courtney *et al.*, 2007). These authors completed two surveys in south-east Queensland, with aims of testing the effects of bycatch reduction devices (BRDs) on the catch of eastern king prawns (*Melicertus plebejus*), as well as the associated incidental catch of non-targeted species. These surveys were supplemented by information gathered by observers that opportunistically sampled catches from commercial vessels. The third survey (Dodt, 2005) was designed to improve the understanding of the distribution and abundance of Sygnathids (seahorses, seadragons, pipefish and pipehorses) – hereafter referred to as "the Sygnathid project" – in south-east Queensland and their interaction with trawlers operating in the shallow water EKP fishery.

Although these surveys were not designed to measure the abundance of pearl perch, they provide valuable information regarding the distribution of juvenile pearl perch in south-east Queensland. From these data, it was then possible to design the protocols for the baited remote underwater remote video (BRUV) sampling detailed in Chapter 10.

Methods

Shallow water EKP Survey

The following methods are summarised from Courtney *et al*. (2006) and the reader is directed to consult this report for detailed descriptions of the methods used.

In summary, the first survey conducted was designed to test the effects of a radial escape section BRD (RES) and a turtle excluder device (TED) in the shallow water EKP fishery. A commercial trawl vessel was chartered for 10 nights in October 2001, which towed triple-gear (three nets), commonly used in the fishery. Only catches from the two outside nets were analysed. The nets had headline lengths of 12.8m (7 fathoms) and a mesh size of 50.8 mm (2 inch). Mesh size in the codends was 45mm.

59 trawl shots were undertaken resulting in samples being obtained from 118 individual net trawls. Trawl length was approximately 53 minutes, at 2.4knots. Logbook data were used to ensure the sampling was representative of the areas fished by commercial trawl operators in October, so that the number of experimental trawls allocated to each CFISH Grid (see Appendix 3.10) was proportional to the average trawl effort in that grid from the previous 5 years.

Four codend types were compared: (1) standard codend only (considered as an experimental "control" net), (2) standard codend with TED only, (3) standard codend with radial escape section BRD only, and (4) standard codend with both TED and radial escape section BRD. The standard codend was 75 meshes long and 100 meshes in circumference and constructed from 48-ply polyethylene trawl mesh, with a mesh size of 45 mm. The TED used throughout the charter was a modified Wicks TED and was sewn into a codend extension at 42˚ from the horizontal, in top-shooter mode (i.e. large bycatch expelled upwards towards the surface).

On completion of each trawl shot, the bycatch from each net was placed into baskets and weighed, before being placed into storage boxes in the vessel's freezer. If required, a 10kg sub-sample of bycatch was taken. In the laboratory, bycatch species were identified to species level, counted and weighed. The length of a maximum of 20 randomly-selected individuals of each species was also recorded. Catch of each species was converted to weight (g) per trawled area (ha). When sub samples were taken, the weight of those species in the sub-samples was adjusted according to the total weight of the bycatch on the back deck from the corresponding net trawl to estimate the total weight of the species from each net trawl.

Deep water EKP Survey

Sample collection and laboratory protocols for the deepwater survey were similar to those for the shallow water survey described above. However, this survey tested the effects of a square mesh codend in the deepwater EKP fishery in July 2002. As is standard in the deepwater trawl fishery, larger nets were used in the survey (22m headline length as opposed to the 12.8m headline length used in the shallow water survey). Again, three nets were used, with catches from the outside nets analysed. Mesh size was 50.8mm in the body of the net and 47mm in the codend. This survey resulted in 65 shots and 130 samples of bycatch.

Observer data

Data gathered as part of the shallow water EKP and deep water EKP surveys were supplemented by data recorded by observers boarding commercial vessels opportunistically. The observers recorded similar information to that recorded during the dedicated research surveys to establish the effects of the BRDs and TEDs used by fishers operating in the fishery. Bycatch samples were retained for later processing in the laboratory. This provided useful information on bycatch assemblages caught during commercial fishing operations and were, therefore, representative of the fishery.

Sygnathid survey

The methods used in the Sygnathid survey were similar to those used in the shallow water EKP survey. This survey was conducted in 2005 using standard commercial trawling gear (Dodt, 2005). Trawl shots were only one nautical mile in length and approximately 27 minutes duration. Net configuration was the same as that used in the shallow water EKP survey. As both outside nets were identical, catches were pooled and overall catch rate per shot were analysed. Bycatch catches were converted to catch rates using the methods described above.

Results

Shallow water EKP

Pearl perch were present in 47 of the 204 (23%) net trawls sampled in the shallow water EKP fishery during the bycatch project. Average pearl perch catch per hectare was 0.876 individuals and 13.87 grams. Pearl perch were distributed across the sampled area from the Southport Seaway, north to Noosa. Depth ranged from approximately 25m (14 fathoms) to 91m (50 fathoms). The pearl perch caught during the bycatch project were small, averaging 6.2cm FL. The largest concentrations of pearl perch in the shallow water EKP fishery were located in approximately 70m (35 - 40 fathoms) in areas adjacent to North Stradbroke and Moreton Island (Figure).

Snapper *Pagrus auratus* were the only other RRFF species caught in the shallow water EKP fishery. Snapper were caught in approximately 1% of net trawls with an average length of 11.8cm FL. Snapper catch rates in the shallow water EKP fishery were 0.424 $g.ha^{-1}$ and 0.006 $individuals.ha^{-1}$.

Deep water EKP

Pearl perch were present in only 24 of the 201 (12%) net trawls sampled in the deep water EKP fishery (Figure). Average pearl perch catch rate was 0.023 $individuals.ha^{-1}$ and 5.929 $g.ha^{-1}$. Depth ranged from approximately 91m (50 fathoms) to 190m (104 fathoms). The pearl perch caught in the deepwater were larger, averaging 18.7cm FL.

Snapper were the only other RRFF species caught in the deep water EKP fishery. Snapper were caught in approximately 0.5% of net trawls with an average length of 180mm FL. Snapper catch rates in the shallow water EKP fishery were 0.205 $g.ha^{-1}$ and 0.001 $individuals.ha^{-1}$.

Sygnathid survey

Pearl perch were present in only 11 of the 87 (12%) trawls sampled during the Sygnathid survey (Figure). Average pearl perch catch rate was $0.02g.ha^{-1}$ and 0.08 $individuals.ha^{-1}$. The pearl perch caught during the survey had a mean fork length of 6.8cm. Only one snapper was caught during the survey.

Discussion

Prawn trawling is associated with relatively soft substrates of sand and/or mud. As such, the results of the trawl samples detailed in this chapter indicate that the only rocky reef species associated with such substrates outside of Moreton Bay are pearl perch and, to a much lesser extent, snapper. Sumpton and Jackson (2005) reported that significant numbers of juvenile snapper are caught by trawlers in Moreton Bay, yet very few are caught in the adjacent offshore king prawn fisheries. This suggests that once snapper leave Moreton Bay, proportionally more inhabit hard ground, not accessible to prawn trawlers.

Further, no teraglin were caught in 600+ net trawls analysed as part of the current study. This indicates that juvenile teraglin do not inhabit the soft, trawled substrates in the sampling area. Teraglin either settle on hard substrates as fry or recruit from areas south of the sampling area.

In contrast, pearl perch appear to be a relatively common species on trawl grounds between Noosa and Southport in depths of around 60 metres. The highest concentrations occur around Cape Moreton and Point Lookout (Figure 1 and Figure 2). Pearl perch use these shallower habitats as juveniles approximately 60mm in length. This was confirmed by a blue swimmer crab (*Portunus pelagicus*) fisher, who reported he had caught a large number of juvenile pearl perch in crab pots. Courtney *et al.* (2007) report that the most common species in the shallow water EKP fishery include the crab *Portunus rubromarginatus*, the gurnard *Lepidotrigla argus*, the lizardfish *Saurida grandisquamis* and the pinky *Nemipterus theodorei* which occurred in 84.3%, 76%, 77% and 70% of trawl samples from the shallow water EKP fishery, respectively. Pearl perch were encountered in 23% of samples, the 41st most frequently encountered species in the shallow water EKP fishery.

However, pearl perch are less frequently encountered in the deep water EKP fishery. Courtney *et al.* (2007) report that the most common species in the shallow water EKP fishery include the gurnard *Lepidotrigla argus*, the flathead *Ratabulus diversidens*, the crab *Charybdis bimaculata* and the stinkfish *Callionymus moretonensis* which occurred in 90.5%, 87.0%, 75.5% and 64.5% of trawl samples from the deep water EKP fishery, respectively. Pearl perch were encountered in only 12% of trawl samples, the 70th most commonly encountered species.

Larger pearl perch are present in trawl samples from soft substrates in deeper water. It is difficult to ascertain if the larger fish are present in the deeper areas year-round or if the fish caught during the July 2002 deep water EKP survey are the same cohort as those caught in the October 2001 shallow water EKP survey. However, the growth curves presented in Appendix 3.1 suggest that this may be the case.

The maximum size of pearl perch caught during the trawl sampling is approximately 25cm. Fish larger than this are likely able to avoid capture by the trawl gear. As such, larger fish may also be present on the deep water trawl grounds but are not selected by the sampling gear.

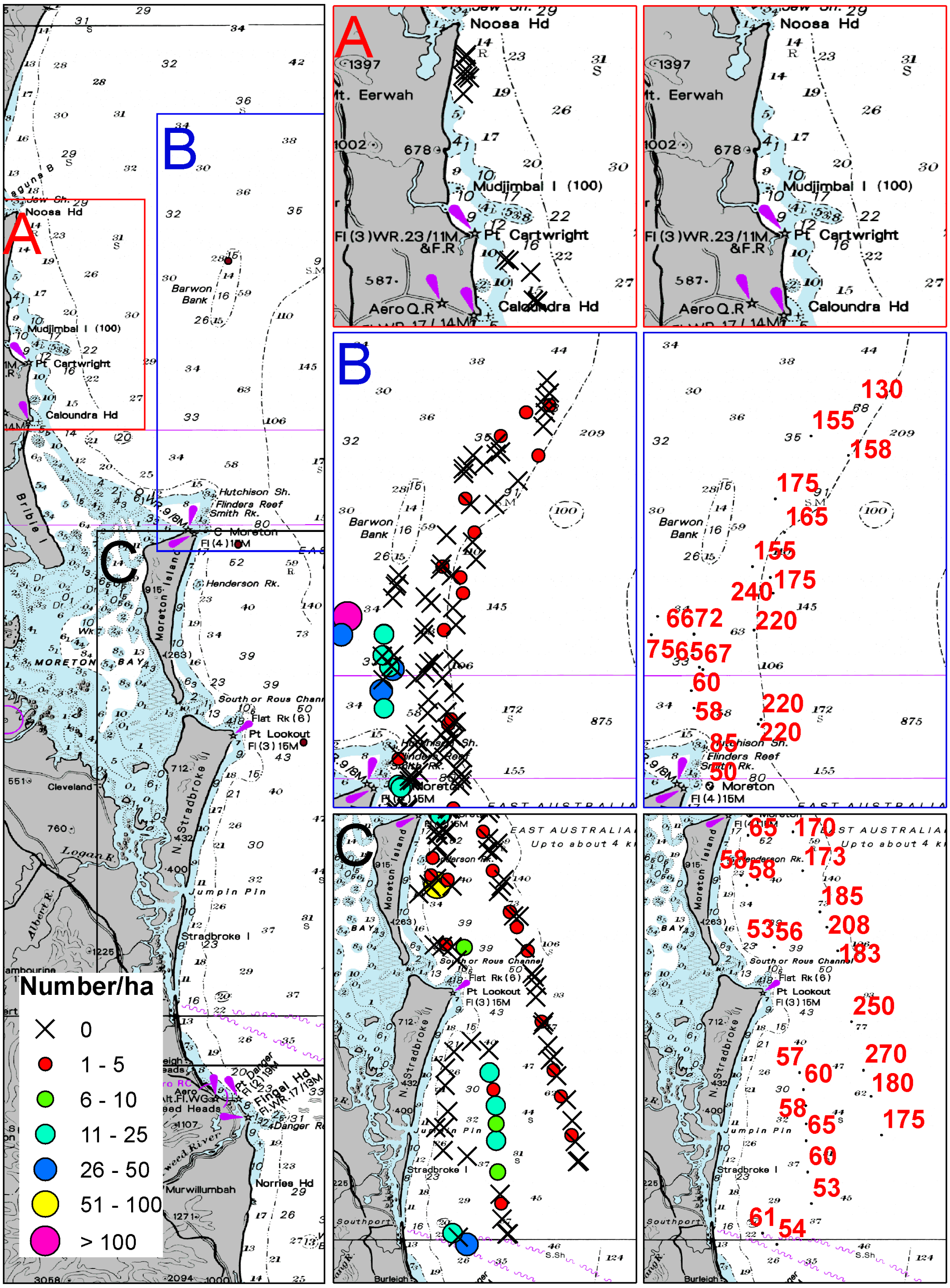

Figure 1 Catch rate of pearl perch, caught by commercial trawlers throughout a project assessing the bycatch composition in Queensland's east coast otter trawl fishery (Courtney *et al.*, 2007). Average catch rates of pearl perch in the shallow water EKP fishery (<91m) were 13.8g.ha^{-1} and 0.876 individuals.ha^{-1} and 5.9g.ha^{-1} and 0.023 individuals.ha^{-1} in the deep water EKP fishery (>91m).

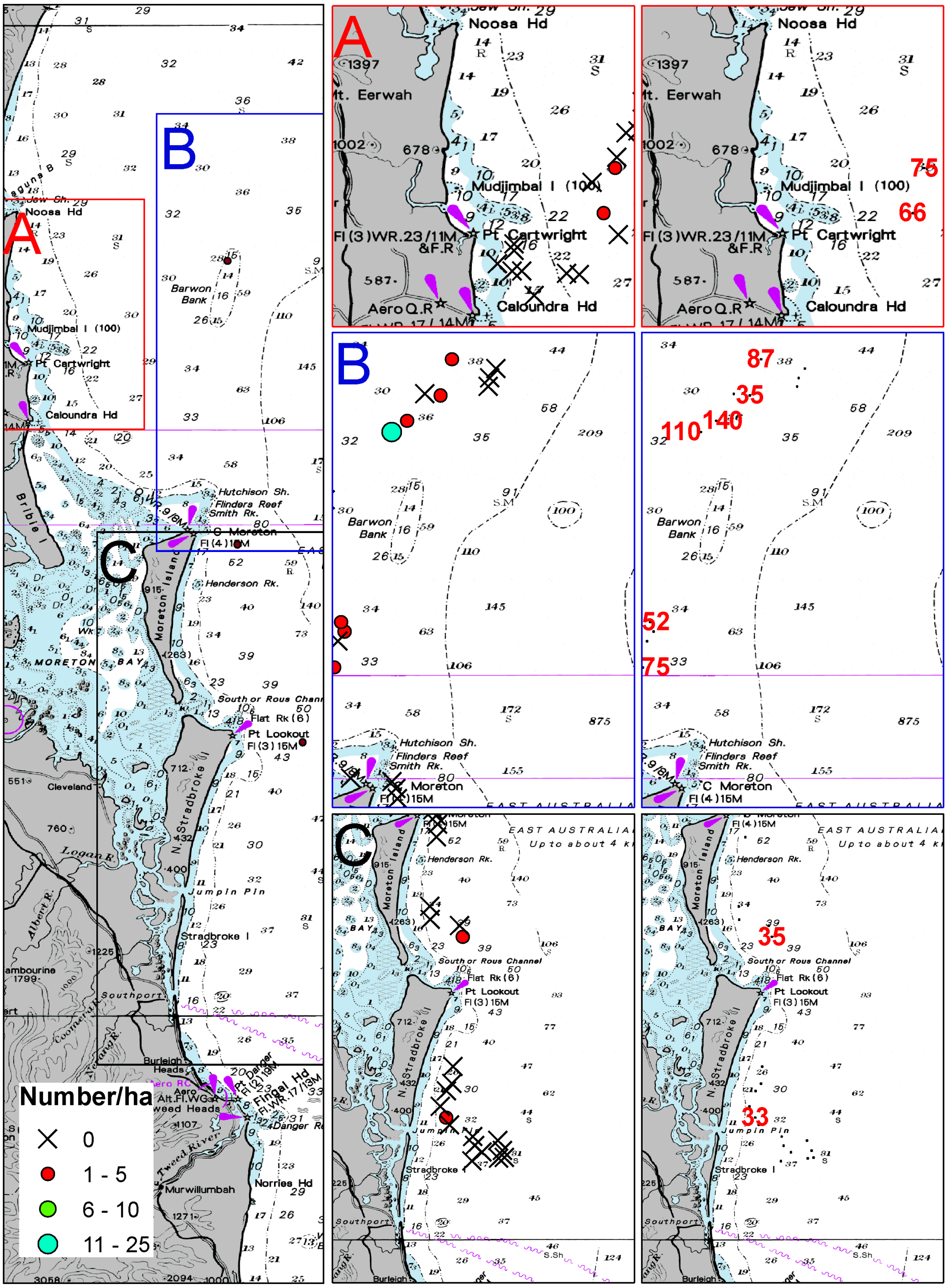

Figure 2 Catch rate of pearl perch, caught by a trawler during a survey assessing the Sygnathid bycatch in Queensland's shallow water eastern king prawn (Dodt, 2005). Average catch rate of pearl perch was 0.08 individuals.ha^{-1}.

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APPENDIX 3.9 USING BAITED CAMERAS TO DETERMINE HABITAT ASSOCIATIONS OF KEY ROCKY REEF FISH SPECIES AND FISH ASSEMBLAGES IN OFFSHORE WATERS OF SOUTHERN QUEENSLAND

Summary

Despite their economic importance for fisheries, and their conservation significance, very little is known of the fish assemblages present on the continental shelf of southern Queensland with most research work on reef assemblages focussing on coral rather than rocky reefs. In addition there is only limited information about the specific habitat requirements of juveniles and adults of two of the highly targeted demersal rocky reef species (pearl perch (*Glaucosoma scapulare*) and teraglin (*Atractoscion aequidens*)) despite an extensive understanding of the preferred habitats of the main target rocky reef species, snapper (*Pagrus auratus*). To address this information deficit, fish-habitat relationships on the continental shelf adjacent to the Sunshine Coast, Queensland were investigated in the austral winter of 2011. Baited Remote Underwater Video Stations (BRUVS) were used to survey demersal fish assemblages over three broad benthic habitat types (sand, gravel and rocky reef) at two depth ranges (29 – 51 m and 52 – 75 m). A total of 125 species of fish from 44 families were recorded in 187 BRUVS samples analysed. Six fish assemblages were identified based on depth and habitat type. A significant interaction between depth and habitat type implied that the differences between habitats were not consistent between the two depth ranges. As expected, fish species richness increased with the structural complexity of habitat. A broader investigation of sandy/gravel habitats from Stradbroke Island to Moreton Island was also undertaken using still camera techniques. Juveniles and adults of the three main target species were rarely seen on sandy habitats despite juvenile pearl perch being sampled in the same areas with alternative sampling gears (trawls and traps). Only one teraglin was seen in the BRUVS but pearl perch were found predominantly in the deeper habitats with a higher relative abundance on more structured habitat. Few pearl perch were found on the more open sandy habitats where they have previously been taken in traps and in prawn trawls. Adult snapper were seen at all depths and all habitat types but again were more abundant on the more structured habitats. We hypothesise that the lack of juveniles of pearl perch in samples is related to their seasonal utilisation of these habitats and to their nocturnal feeding activity. The pattern of differential seasonal use of open sandy habitats is consistent with the behaviour of snapper whose juveniles are seasonally vulnerable to capture on open, less-structured habitat. In contrast to snapper whose juveniles are abundant on inshore estuarine habitat, pearl perch are restricted to oceanic areas. A more extensive temporal coverage that sampled at night would be needed to more precisely delineate habitat utilisation patterns. Current marine park zoning arrangements for the Moreton Bay Marine Park offer a level of protection for snapper but are less likely to protect pearl perch and teraglin.

Introduction

Existing knowledge of demersal fish-habitat associations is dominated by information derived from intertidal habitats and those shallow coastal and coral reef habitats that can be visually sampled through SCUBA-based census methods (Roberts and Ormond 1987; Robertson and Duke 1987; Laegdsgaard and Johnson 1995; Mumby *et al.* 2004; Manson *et al*. 2005a; Manson *et al*. 2005b; Emslie *et al.* 2010; Malcolm *et al.* 2010). Deeper continental shelf habitats have been less intensively studied world-wide due to technological constraints. However, rapid progress in digital video and acoustic seabed mapping technologies has enabled many seabed habitat mapping projects Australia-wide and globally. The use of Baited Remote Underwater Video Stations (BRUVS) is a relatively recent technological development that enables non-extractive, non-destructive fish-habitat surveys to be conducted in areas of continental shelf that are beyond accessible depths of SCUBA-based sampling (Harvey *et al.* 2007). Unlike traditional extractive sampling tools (such as trawls, seine nets, traps), BRUVS can be used in a wide range of habitats, including areas of complex rocky relief where trawl and seine nets are ineffective (Pitcher 2007). Consequently, BRUVS can provide data that have considerably less habitat-related bias than traditional extractive sampling methods (Stoner *et al*. 2008), and allow access to deeper habitats than SCUBA-based methods. Data collected in this way are biased towards scavenging piscivorous species that may be attracted to the bait. However, many non-piscivorous fish species have been recorded in BRUVS studies. For example, in a comparison of the ability of baited and unbaited remote underwater video stations to discriminate among demersal fish assemblages, Harvey *et al.* (2007) found bait attracted more predatory and scavenging species than unbaited stations without altering the abundances of herbivorous and omnivorous species. Therefore, despite its biases, the use of bait can still facilitate collection of adequate data for comparing fish assemblages. While this is an issue if the aims of the research are to establish community associations it is less of an issue when distributions of individual carnivorous species are of interest (such as in the current investigation).

Due to the shallow water focus in the field of demersal marine ecology, our knowledge of important interactions and processes has been largely informed by studies conducted in habitats of less than 30 m depth (Brokovich *et al.* 2008), despite extensive fisheries and other exploitation in deeper areas. For example, commercial and recreational line fisheries in south-east Queensland target economically important deep-water continental shelf carnivorous fishes such as *Pagrus auratus* (snapper), *Glaucosoma scapulare* (pearl perch) and *Atractoscion aequidens* (teraglin). Interactions and processes in deeper waters may differ from those that occur in shallow waters due to a range of factors associated with increased depth; including decreases in wave action and irradiance, tidal and current influences and changes in sources of benthic production (Waddington *et al.* 2010). Those factors and others are likely to affect the assemblages of fish species, and their interactions with available habitats (Wernberg 2008). Thus, it is uncertain whether relationships between fish assemblages and structural habitat types observed in shallow waters are representative of those that occur at greater depths.

A number of recent studies have investigated relationships between habitat type and demersal fish assemblages (Francis *et al*. 2002; Anderson and Millar 2004; Bouchon-Navaro *et al*. 2005; Toller *et al*. 2010; Yahya *et al.* 2011). Research has been conducted world-wide across a variety of scales, both spatial and temporal, and a paradigm has emerged that composition of demersal fish assemblages is strongly influenced by the type of associated benthic habitat. For instance, Toller *et al.* (2010) identified significantly different fish assemblages associated with five habitat types in the Caribbean Sea: fore reef, outer reef, inner reef flat, soft-bottom lagoon and hard-bottom lagoon. Studies have quantified the structural complexity of sampled habitats and found significant positive correlations between habitat complexity and parameters such as species richness, total fish abundance and abundance of fish species (Chittaro 2004; Gratwicke and Speight 2005; Hunter and Sayer 2009). Structural complexity is often associated with abundance of resources such as shelter for prey species of fish and invertebrates, increased surface area, availability of microhabitats and variety of substrata to support epibenthic life (Garcia-Sais 2010; Gratwicke and Speight 2005; Ross *et al.* 2007).

In addition to the physical structure of benthic habitats, significant relationships have been described between depth and fish assemblages (Brokovich *et al*. 2008; Cappo *et al*. 2011; Chouinard and Dutil 2011; Francis *et al.* 2002; Malcolm *et al*. 2010). For instance, Francis *et al*. (2002) sampled fish over a broad spatial and temporal range in New Zealand (latitude 34 – 54°S; depth 4 – 1500 m; 37 years) and identified distinct species assemblages at each of four broad habitat types based on depth: The inner continental shelf, mid to outer continental shelf and shelf edge, upper continental slope and mid continental slope. Similarly, both Brokovich *et al*. (2008) and Chouinard and Dutil (2011) described significantly different demersal fish assemblages at sites of different depth ranges. While these studies described the influence of depth independent to that of habitat type, Malcolm *et al.* (2010) identified significantly different fish assemblages among sites within a category of physical habitat type yet at different depths. This suggests both physical habitat type and depth play important roles in determining fish assemblages; and potential interactions between depth and habitat type must be considered when investigating factors determining fish assemblages.

The identification of fish species assemblages and their relationships with habitat type and depth ranges has implications for marine zoning for conservation and fisheries management. The description of species assemblages has potential as a tool for understanding the relationships between species and their environment and may provide a useful parameter to monitor biodiversity and the quality of particular habitats (Brown 2000). If strong and predictable relationships can be detected between fish assemblages and benthic habitats, there is potential for habitat to be used as a predictor of species distribution and abundance patterns (Anderson *et al.* 2009). Thus habitat may be a useful proxy for particular species or assemblages, and may contribute to the development of marine zoning plans (Brown 2000; Anderson *et al*. 2009). For example, if commercially or recreationally important fish species are associated with particular habitat types and/or depth ranges then those habitats or depths may provide proxies to enable fisheries managers to determine marine zoning plans to best ensure future fisheries production. Similarly, if species of conservation significance are associated with particular habitat types, those habitats may be useful proxies in marine zoning for conservation purposes.

To address the paucity of knowledge about fish-habitat relations on continental shelves at depths beyond the reach of standard SCUBA diving and to understand the importance of these habitats to important line caught rocky reef species, this study investigated fish assemblages in an area of southeast Queensland's continental shelf, focusing on the effects of depth and habitat type. The aims of the study focused at both the individual species level for pearl perch, teraglin and snapper and also at the community level. Specifically we attempt to define the important habitats/depths for juveniles of our key rocky reef species and at a broader level to determine whether there were significant differences in the demersal fish assemblages amongst three different benthic habitat types, at two different depth ranges. Habitats sampled represented different levels of structural complexity, ranging from sand to rocky reef, with gravel as an intermediate habitat. Shallow samples were taken from 29.5 – 51.5 m depth and deep samples were taken from 51.5 – 73.6 m depth. We also analysed still images collected over a broader spatial scale from a related project that investigated crab relative abundance in marine protected areas and open areas. These sampling locations were limited to soft habitats in water from 10 to 80m but still covered areas where trawl samples had previously found juveniles of all three species of interest.

Methods

The two surveys used to assess habitat utilization of the rocky reef species will be hereafter referred to as the BRUVS survey and the BRUCS survey. The former used baited underwater video cameras facing across the sea floor and is the main source of the data discussed in this chapter. The BRUCS survey used multiple still images collected using vertically facing cameras.

BRUVS Survey – Sunshine Coast

Baited Remote Underwater Video Stations (BRUVS) were used to investigate demersal fish-habitat relations on an area of continental shelf adjacent to the Sunshine Coast, Queensland, between 29.5 and 73.6 m depth (Figure 1). This study area was selected because it supports populations of commercially and recreationally important line fishing species and previous trawl surveys have sampled juvenile pearl perch and teraglin in these areas. In addition samples of juvenile pearl perch have regularly been reported in the traps of commercial blue swimmer crab fishers working in the open sandy habitat chosen in the area.

Sampling was conducted from a 14.5 m Fisheries Research Vessel *Tom Marshall*. Video sampling was conducted in late autumn/early winter (May – July 2011) to take advantage of high underwater visibility that was a result of the typically low levels of phytoplankton at that time of year (Connell and Gillanders 2007). In addition blue swimmer crab fishers had noted juvenile pearl perch in their pots during the period February to May and it was believed that these fish should still be on the habitat during the period chosen.

Sampling was based on a two-way factorial design, with the factors being habitat type and depth. Three habitat types were sampled, categorized broadly as sand, gravel, rocky reef (Figure 2) with an additional "kelp" habitat defined after analysis of the videos. This particular area of Queensland's continental shelf supports many types of vegetated and biogenic benthic habitat, however the choice of these three broad habitat types enabled the representation of a rough gradient of complexity with sand being the simplest habitat, followed by gravel and finally rocky reef as the most structurally complex habitat. Sand habitats were defined as being of 100% sandy substratum with no obvious epibenthic plants or invertebrates creating any relief (Figure 2). Rocky reef habitats were defined as having at least 80% rocky substratum (estimated from a single frame of video footage) with relief greater than approximately 40 cm. Gravel habitats were an intermediate habitat type with a hard or rubble substratum of relief less than 20 cm, and the presence of limited biogenic structure such as algae or gorgonians (Figure 2). Kelp habitats (consisting of low *Ecklonia radiate* meadows were also sampled and these comprised hard substratum with some *Ecklonia radiate* present. These were only categorized after viewing the BRUVS footage and they were excluded from the analysis because they were considered to be a unique habitat not really representative of the less vegetated rocky reef habitat. Shallow samples were those taken from 29 – 51 m depth, and deep samples were from 52 – 75 m depth.

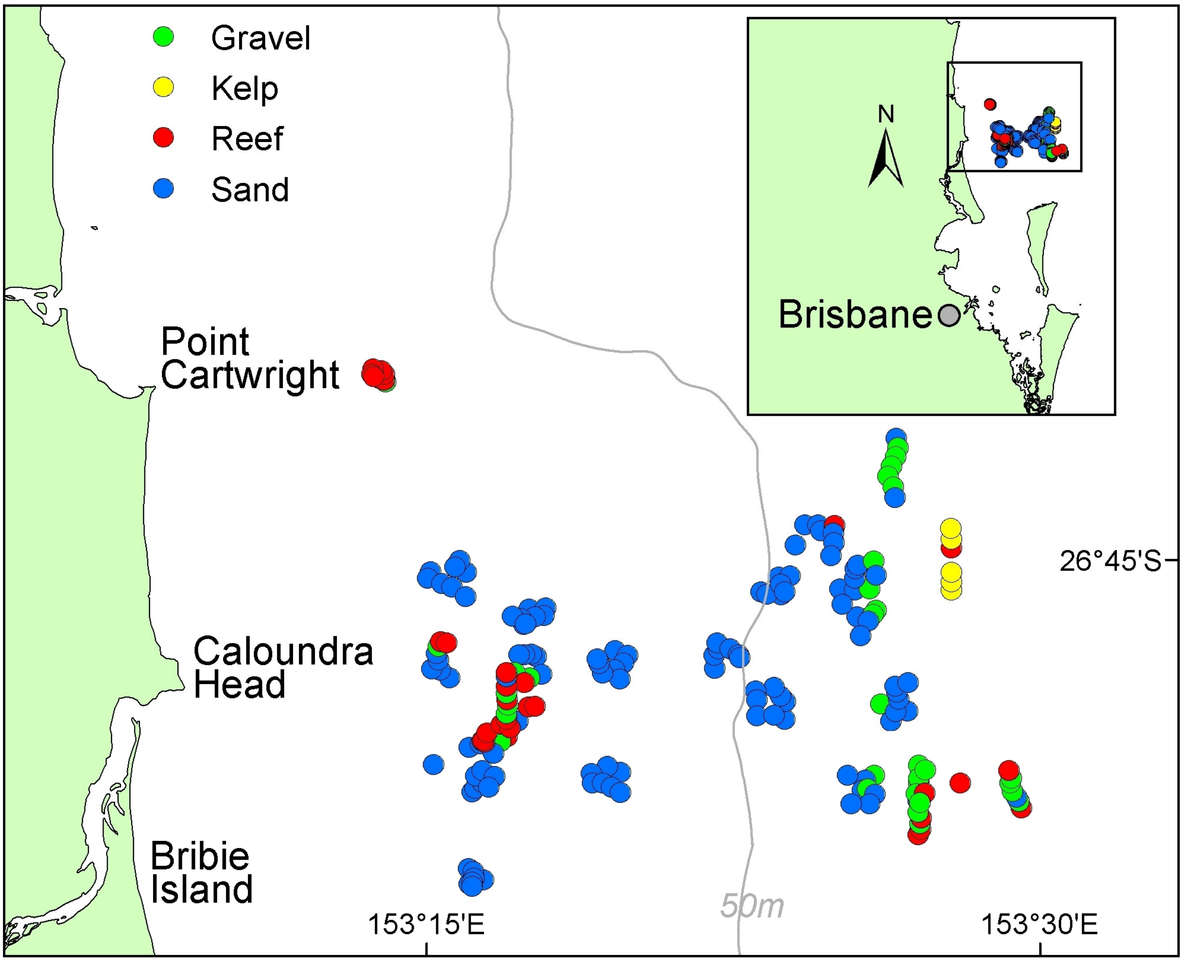
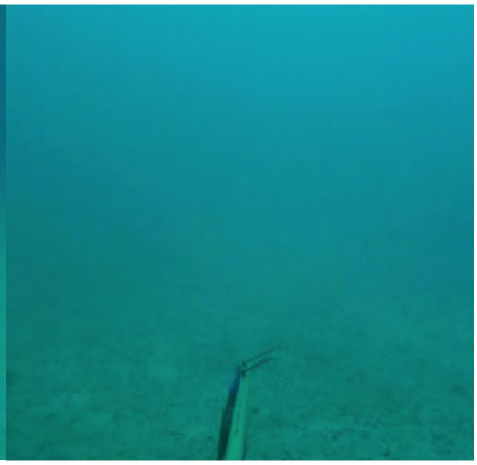


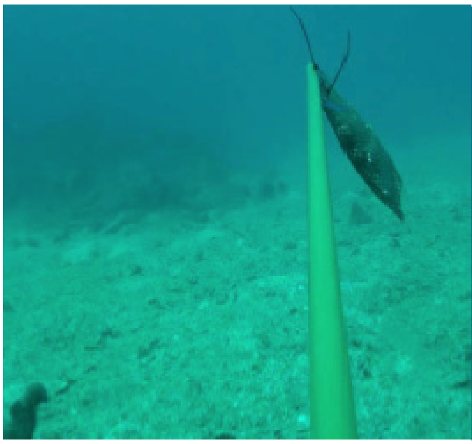
Figure 1 The location of the 185 BRUVS deployments. The 50 m depth contour is shown offshore from the coast. Deep samples were taken offshore from this contour and shallow samples taken closer to the coast. Colours represent the different habitat types.

Topographic maps of the study area provided information about depth and the approximate location of rocky reef and sand habitat (Department of Natural Resources and Water 2008). Earlier surveys of the region and information from fishers also assisted with the location of habitat that was thought to contain juveniles of the three main target species. From this information blocks of 1 square nautical mile were chosen, containing at least 80% of a particular habitat type within either the deep or shallow depth range. Within each block eight sites were randomly selected for BRUVS deployment. Sites were at least 100 m apart so each BRUVS acted independently, minimizing the possibility of attracting individual fish from one BRUVS to another (Cappo 2007; Harvey *et al*. 2007). When at sea, onboard GPS equipment was used to locate sites. Due to inaccuracies in the topographic maps and habitat patchiness within each block, habitat was further categorized for each site using an onboard seabed classification system and color sounder. This ensured sampling was conducted on areas of habitat at least 400 m^2, which minimized the edge effects of attracting fish from a different habitat type. Analysis of video footage confirmed habitat classification. The order in which blocks were sampled was randomly allocated to minimize small scale temporal and spatial biases.

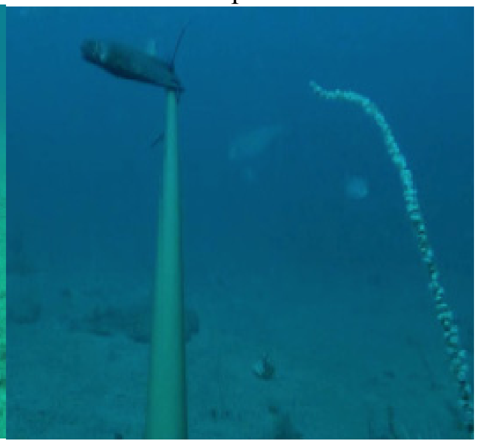
Shallow sand



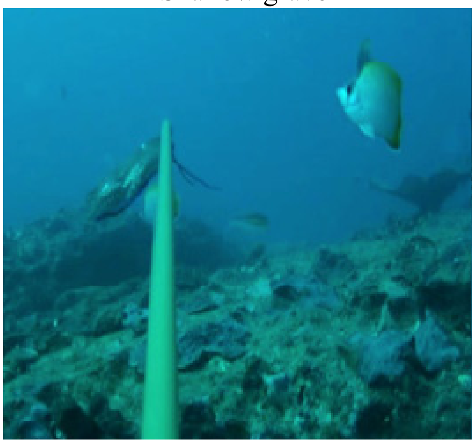
Deep sand



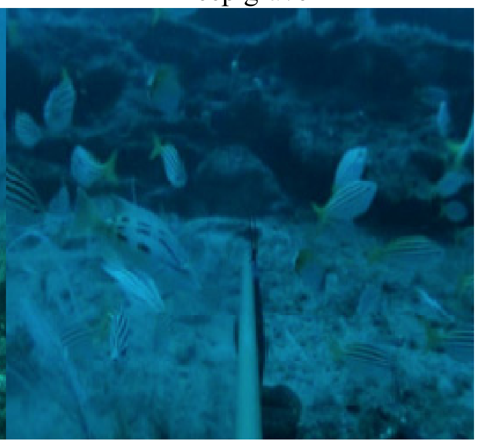
Shallow gravel



Deep gravel



Shallow rocky reef



Deep rocky reef

Figure 2 Representative photographs of the seven different depth/habitat sample groups. (Still shots extracted from videos using Event Measure^{TM}. NB quality of image was far higher in videos).

Deep kelp

At each deployment, a 60 minute video sample was recorded on to a 16 GB SD card. Since deploying and retrieving BRUVS can influence fish assemblages for up to four minutes in some habitats (Harvey *et al*. 2007), the first five minutes of each recording was discounted during analysis. Sampling was conducted between 08:30 and 16:30 h to ensure adequate ambient light availability and to avoid crepuscular changes in fish behaviour (Harvey *et al.* 2007).

The BRUVS System

Eight BRUVS were used in the study, each comprised of a single Sony HDR-CX100E digital video camera with (x0.6) wide-angle lens in a custom built PVC underwater housing, attached to a trestle-shaped frame that rested on the substrate when deployed (Figure 3). The camera model chosen is highly sensitive to light and therefore ideally suited to sampling in low light conditions at depths of up to and exceeding 100 m. Each BRUVS was fitted with lead ballast bars prior to deployment to ensure stability, with the total weight of each BRUVS being 28 kg. A semi-rigid bait arm of electrical conduit held a plastic mesh bag containing approximately 1 kg of crushed pilchards (*Sardinops neopilchardus*) 1.5 m in front of the camera lens (Cappo 2004). Pilchards are readily available, inexpensive bait that have a demonstrated ability to attract fish (Cappo 2004). The camera was manually focused to 3 m to enable a standardized field of view to approximately 1.5 m behind the bait and to facilitate compensation for variable levels of visibility (Malcolm 2007). Site information was filmed on a white board prior to each deployment, to ensure tapes were not mislabelled. Each BRUVS was deployed and retrieved by means of an onboard winch and a rope and polystyrene float system. Rope length was approximately twice the water depth to prevent the BRUVS becoming unstable in swell or currents, or the float sinking.

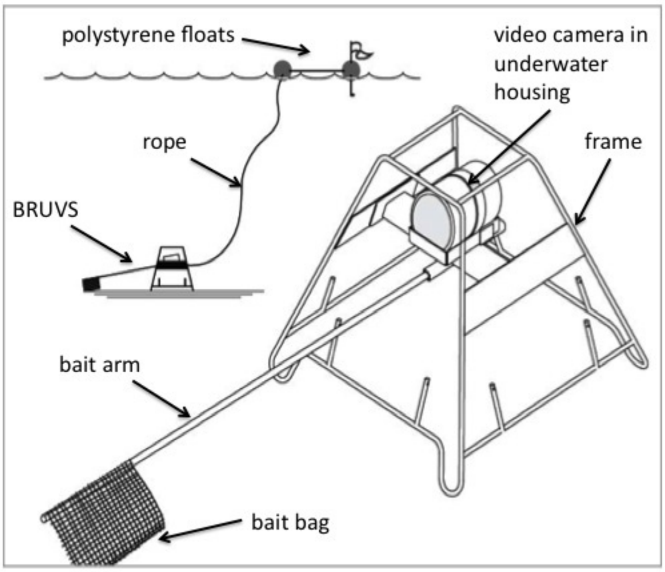


Figure 3 Baited Remote Underwater Video Station (BRUVS) (modified after Stowar *et al*., 2008), showing position on the sea floor and details of the bait arm and bag, camera housing and frame.

Analysis of Videos

Videos were analysed using Event Measure ™ software. Due to inaccuracies in topographic maps and the inability of the seabed classification system to determine exact habitat type, some habitat types were under-represented and a balanced experimental design was not achieved. Of 187 video samples used in the final analysis: 69 were shallow sand, 8 shallow gravel, 24 shallow rocky reef, 47 deep sand, 25 deep gravel, 9 deep rocky reef and 5 deep kelp. Videos were played back in normal time for the majority of samples. Samples with an average of ≥ 1 min between fish sightings were analysed at double speed.

Where possible, individual fish were identified to species level using Allen (2005) and Hutchins and Swainston (1986). Individuals that were too cryptic to be identified to species were identified to genus level; those that were beyond approximately 2 m from the bait bag were too far from the camera for identification and were omitted from the data. The relative abundance of fish species in a single sample (1 h video) was estimated by MaxN, the maximum number of individuals of that species seen together in any one frame on the entire tape (Cappo 2007; Harvey *et al.* 2007; Malcolm 2007). MaxN is a useful and conservative index of relative abundance, as it removes the possibility of repeatedly counting individuals that leave and re-enter the field of view (Harvey *et al*. 2007).

Data Analysis

Multivariate data analysis was conducted using PRIMER™ ver. 6 software (Clarke and Gorley 2006). Prior to analysis, species MaxN data for each sample were log (x+1) transformed to balance the contributions of both abundant and rare species (Clarke and Gorley 2006). Transformed data were compiled into a matrix (species MaxN by sample) and used to calculate a Bray-Curtis similarity matrix. Multi-dimensional scaling (MDS) was conducted on the Bray-Curtis similarity matrix. Samples were represented as points in 2-dimensional space such that the relative distance between points indicated relative dissimilarity of samples in terms of fish assemblage.

Permutational analysis of variance (PERMANOVA) was used to test the response of fish assemblage to the factors depth and habitat (using PERMANOVA+ for PRIMER ™ ver. 6 software). PERMANOVA has superseded the standard ANOSIM (analysis of similarity) test because of its ability to analyse more complex experimental designs, and to allow interaction terms to be explicitly tested (Anderson *et al*. 2008). A PERMANOVA analysis was run using Type III sums of squares. Due to a significant interaction between depth and habitat ($P < 0.001$), pair-wise PERMANOVA analyses were run among all levels of habitat within each level of depth. A similarity of percentages (SIMPER) routine was conducted on the original log (x + 1) transformed data to identify:- (1) The extent to which each species contributed to similarities within each distinct fish assemblage, and (2) The extent to which each species contributed to distinguishing different fish assemblages.

Raw abundance data for each habitat and depth range were plotted for six fish species. Analysis of these data using a non-parametric 2-way ANOVA (Friedman test) was not possible due to the unbalanced design, therefore relative abundance could only be interpreted graphically (Venables and Smith 2010). Habitat effects on the relative abundance of six individual species (*Pagrus auratus, Glaucosoma scapulare, Choerodon venustus*, *Saurida undosquamis, Atractoscion aequidens, Pentapodus paradiseus* and *Nemipterus theodorei*) were analysed using binomial and gamma mixed model generalized linear models with logit of MaxN as the dependent variable and depth and habitat type as factors.

BRUCS Survey – Moreton Island and Stradbroke Island

Readers are referred to Brown (2012) for a detailed description of methods used in this survey but some key features of the survey are presented below.

The two 'areas of interest' chosen were located in two broad near-shore oceanic areas outside Moreton Bay (i) east of South Passage and (ii) east of Jumpinpin (Figure 4). These were selected because of reasonably closely situated Marine National Park, Conservation Park, Habitat Protection and General Use zones, and un-zoned areas, which overlapped to some extent and also the areas represented habitat that supported crab populations. No rocky reef habitats were sampled as the main focus of the research was sampling of sand habitats that were likely to contain crabs. In addition, the use of gear set on a bottom trotline would have snagged on any bottom structures. Despite this both sand and gravel areas were sampled as were a range of different vegetation types.

Sites were chosen by overlaying the Moreton Bay Marine Park (MBMP) zones on 6 x 6 minute fishery sub-grids each of which is divided into 100 equally-spaced sites. All sites within the selected area were assigned to their respective zonal category, and a random sample of sites within zones selected such that the total number in each area of interest was 60 (potentially 12 per zone). The number of sites per zone is roughly proportional to the size of the zone.

The cameras used in these surveys were still image cameras facing vertically downwards and mounted on a frame 1.6m above the seafloor. Crushed pilchards (*Sardinops neopilchardus*) were also used as bait (usually 3 pilchards per bait bag) but their utility was limited by the fact that the images were "still" images collected using a vertically facing still camera. Such a system made the accurate identification of some fish species difficult due to both the movement of the fish causing blurred images, as well as the inherent difficulty in identifying fish from a dorsal rather than lateral aspect. Sampling at each survey site consisted of deploying 10 pieces of apparatus (typically 4 pots, 4 dillies and 2 camera frames (BRUCS) clipped in random order onto a trotline at 50 m intervals. The BRUCS were programmed to shoot one frame each minute, with a total set time of an hour (typically 60 frames).

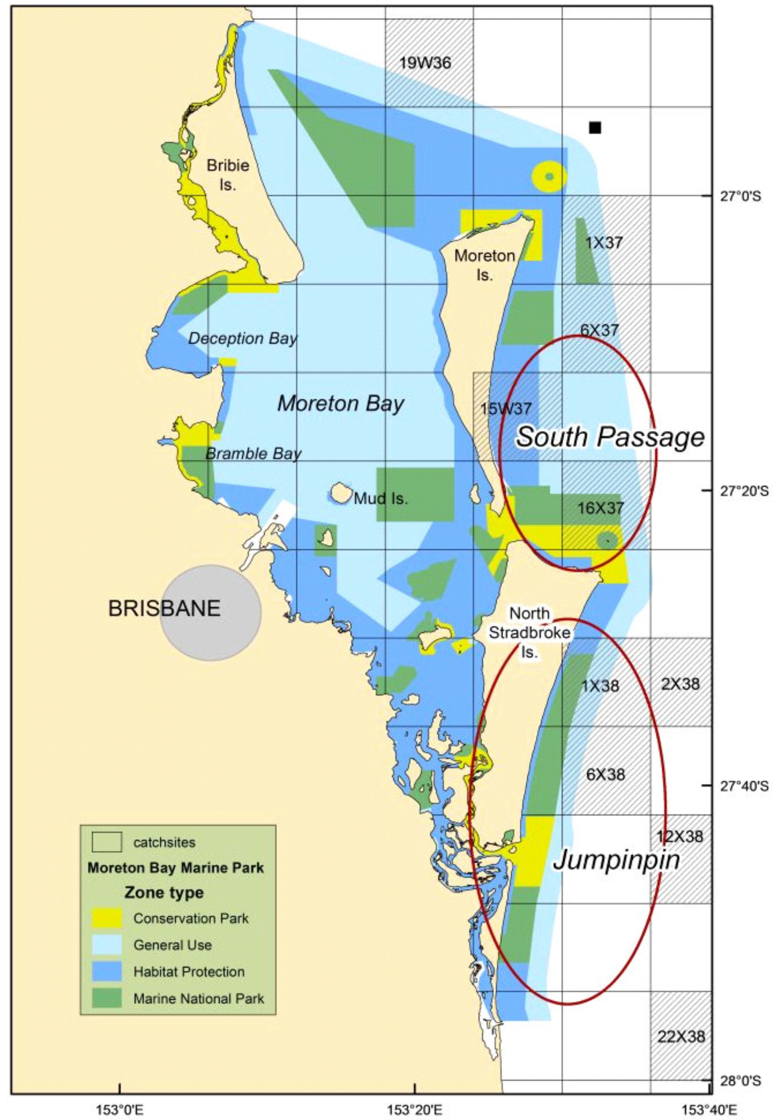


Figure 4 The two sampling areas (South Passage and Jumpinpin), showing the new MBMP zoning and AMU spanner crab survey 6x6 min sub-grids (labelled squares). Green zones are closed to all forms of fishing. Yellow zones are recreational line fishing zones, while light green and blue zones are open to line fishing.

While it was generally more difficult to identify fish from still images, pearl perch and snapper were relatively easy to discern in images taken from an overhead aspect. The dark patch at the base of the dorsal fin and large eyes of pearl perch were readily discernable in still images, while the lighter colour of the pelvic and pectoral fins of snapper as well as the blue dots on the body assisted with the snapper identification (see Figure 5). We were unable to consistently distinguish teraglin in the BRUCS samples due to their lack of distinguishing features and similarity in form to several other species in the areas. All snapper and pearl perch were measured but only categorized into two size classes (small and large) based on those that were less than and greater than the current minimum legal size (currently 35cm for both species).

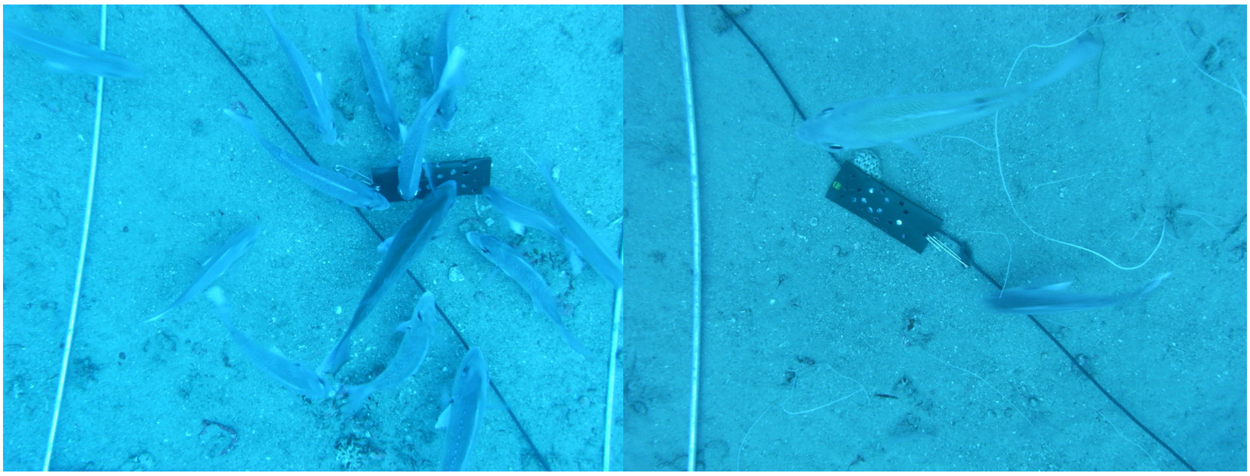


Figure 5 Photos taken using BRUCS showing the distinguishing features of both snapper and pearl perch in images. Small school of snapper on the left, and a single pearl perch and snapper on the right.

Results

BRUV Survey – Sunshine Coast

A total of 125 species of demersal fish from 44 families were recorded in the 187 BRUVS samples collected on the Sunshine Coast continental shelf (Table 6). Most species were recorded infrequently, with only five species recorded in more than 20% of samples, while 53 species were recorded only once (Figure 6). Bony fishes were represented by five orders, and dominated by Perciformes (perch-like fishes; 90 species), while cartilaginous fishes were represented by 8 species from five orders. Carnivores were the primary functional group present across all samples, including scavengers, benthic feeders and mobile predators; herbivores were present but rare.

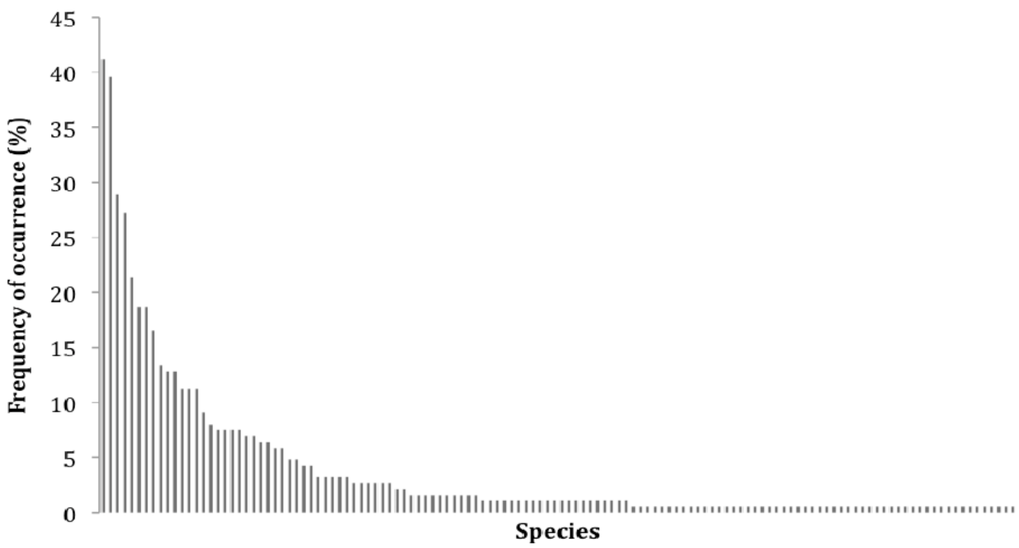


Figure 6 Frequency of occurrence of the 125 fish species observed in 187 video samples across three habitat types and two depth ranges.

The MDS 2-dimensional ordination with the lowest stress value of 0.15 indicated clusters of samples based on both benthic habitat type and depth (Figure 7). To the left of the plot black symbols represent samples taken from sandy substrata; while to the right open symbols represent those taken from rocky reef. Grey symbols represent samples taken from areas of gravel substrata, and the position of these relatively midway between sand and rocky reef indicates an intermediate fish assemblage. Clusters of samples distinguished by depth were also distinct. Samples taken from kelp habitat, were also relatively closely clustered.

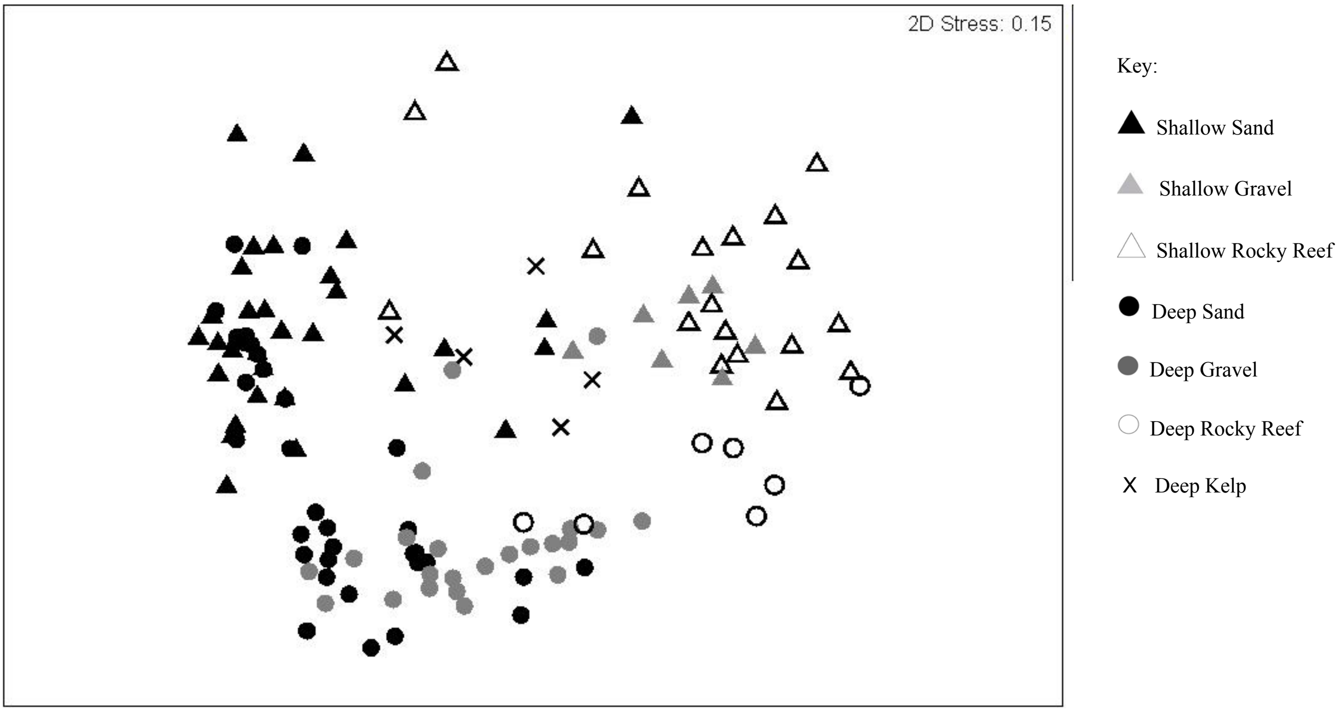


Figure 7 Multi-dimensional scaling (MDS) 2-dimensional ordination of the 187 samples based on fish species MaxN (measured by Bray-Curtis similarity coefficient): relative proximity of points represents relative similarity of samples in terms of fish assemblage.

There was a significant interaction between habitat and depth (PERMANOVA Pseudo-F = 9.1599, $P < 0.001$) indicating that the relationship among habitats was not consistent across depth (Table 1). A pair-wise comparison of habitat types within each level of depth revealed significant differences ($P < 0.05$) in fish assemblage between habitat pairs at each depth, with the exception of shallow rocky reef and gravel (Tables 2 and 3).

Table 1 PERMANOVA results indicating significant effects of depth and habitat on fish assemblage as well as a significant interaction between these factors.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Depth	1	25729	25729	16.637	0.001	997
Habitat	3	1.10E+05	36746	23.76	0.001	999
Depth x Habitat**	2	16790	8395.2	5.4284	0.001	998
Residuals	180	2.78E+05	1546.5			
Total	186	4.52E+05				

Table 2 Post hoc pair-wise comparison (Tukey's HSD test) of fish assemblage data between habitats within shallow samples (S: Sand; G: Gravel; R: Rocky Reef).

Groups	t	P(perm)	Unique perms
R, S	6.8111	0.001	998
R, G	1.144	0.198	999
S, G	5.0189	0.001	996

Table 3 Post hoc pair-wise comparison (Tukey's HSD test) of fish assemblage data between habitats within deep samples (S: Sand; G: Gravel; R: Rocky Reef; K: Kelp).

Groups	t	P(perm)	Unique perms
R, S	4.0412	0.001	998
R, G	2.7445	0.001	999
R, K	1.5998	0.002	772
S, G	3.6048	0.001	999
S, K	2.567	0.001	997
G, K	2.3659	0.002	997

Fish assemblages

Results from the SIMPER analysis indicated which species contributed to each distinct fish assemblage, and the percentage contribution of each (Table 10.4). SIMPER also identified species responsible for distinguishing fish assemblage pairs associated with habitat type at each depth level (Table 5).

Shallow sand assemblages were dominated by *Saurida undosquamis*, which contributed 92.48% of the similarity amongst these samples (Table 4). Species contribution to amongst-habitat similarity in shallow gravel sites was more even, with *Pentapodus paradiseus* having the highest contribution (28.57% contribution) and two other species contributing >10% (Table 4). Shallow rocky reef assemblages were most diverse, with more species contributing to the similarity amongst samples. Principle contributing species were *Pentapodus paradiseus* (15.35% contribution) and *Choerodon venustus* (11.1% contribution).

Saurida undosquamis was the dominant species (53.28% contribution) in fish assemblages associated with deep sand habitats (Table 4). As for shallow habitats, species contributions to amongst-habitat similarity in deep gravel sites were more even than deep sand sites, with *Nemipterus theodorei* (54.95% contribution) and *Choerodon venustus* (18.63%) having >10% contribution. Rocky reef was the most diverse deep assemblage with *Choerodon venustus* (20.32% contribution), *Pagrus auratus* (20.13% contribution), *Chaetodon guentheri* (15.8% contribution) and *Glaucosoma scapulare* (10.43% contribution) all having >10% contribution. Deep kelp was less diverse, the similarity amongst kelp associated assemblages driven by *Pagrus auratus* (45.42% contribution) and *Choerodon venustus* (28.97% contribution) (Table 4).

The SIMPER analysis indicated that shallow and deep sand associated assemblages were dominated by the same species, *Saurida undosquamis* and this was reflected in the MDS ordination where considerable overlap was apparent between the two assemblages. Depth was more important in defining the assemblages associated with gravel and rocky reef habitat. Depth was irrelevant in the analysis of samples taken from kelp as only deep sites were sample. Species contributions to amongst-habitat similarity were more even in shallow gravel than deep gravel samples. *Choerodon venustus* was an important contributor to similarities amongst both deep and shallow gravel assemblages; yet no other main contributing species were the same in both. Three species (*Choerodon venustus, Pagrus auratus* and *Parupeneus spilurus*) contributed to similarities amongst samples in both deep and shallow rocky reef; yet additional contributing species were distinct with depth.

Table 4 Species causing intra-group dissimilarities (80% cumulative) based on Log (x+1) transformed data and Bray-Curtis dissimilarity. Species are in decreasing % contribution.

Species	**Contribution %**	**Cumulative %**
Shallow Sand Average similarity = 27.93		
Saurida undosquamis	92.48	92.48
Shallow Gravel Average similarity = 43.66		
Pentapodus paradiseus	28.57	28.57
Choerodon venustus	22.18	50.75
Parupeneus spilurus	14.08	64.82
Pagrus auratus	6.67	71.49
Chaetodontoplus meredithi	6.51	78
Gymnocranius audleyi	5.52	83.51
Shallow Rocky Reef Average similarity = 27.25		
Pentapodus paradiseus	15.35	15.35
Choerodon venustus	11.1	26.44
Parupeneus spilurus	9.88	36.32
Chaetodontoplus meredithi	9.78	46.1
Pagrus auratus	8.44	54.54
Chaetodon guentheri	8.3	62.84
Siganus nebulosus	6.85	69.69
Prionurus microlepidotus	5.08	74.77
Pterocaesio diagramma	4.92	79.68
Parapercis sp.	3.73	83.42
Deep Sand Average similarity = 27.42		
Saurida undosquamis	53.28	53.28
Nemipterus theodorei	39.61	92.89
Deep Gravel Average similarity = 39.97		
Nempiterus theodorei	54.95	54.95
Choerodon venustus	18.63	73.58
Coris picta	6.46	80.04
Deep Rocky Reef Average similarity = 32.20		
Choerodon venustus	20.32	20.32
Pagrus auratus	20.13	40.46
Chaetodon guentheri	15.8	56.25
Glaucosoma scapulare	10.43	66.68
Parupeneus spilurus	8.12	74.8
Gymnothorax sp.	4.79	79.58
Lutjanus russellii	4.57	84.16
Deep Kelp Average similarity 28.24		
Pagrus auratus	45.42	45.42
Choerodon venustus	28.97	74.39
Gymnocranius audleyi	8.17	82.56

Table 5 Species causing inter-group dissimilarities (50% cumulative) within each depth level based on Log (x+1) transformed data and Bray-Curtis dissimilarity.

Species	Contrib. %	Cum. %	Species	Contrib. %	Cum. %
Shallow Sand & Shallow Rocky Reef Average dissimilarity = 97.79			Deep Sand & Deep Rocky Reef Average dissimilarity = 95.52		
Pentapodus paradiseus	8.21	8.21	*Pagrus auratus*	8.2	8.2
Siganus nebulosus	6.79	15	*Nemipterus theodorei*	8.2	16.4
Pterocaesio diagramma	6.74	21.75	*Glaucosoma scapulare*	6.76	23.16
Saurida undosquamis	6	27.75	*Chaetodon guentheri*	6.54	29.7
Prionurus microlepidotus	5.43	33.18	*Choerodon venustus*	6.17	35.87
Parupeneus spilurus	4.72	37.89	*Atypichthys strigatus*	5	40.87
Choerodon venustus	4.49	42.38	*Parupeneus spilurus*	4.63	45.49
Chaetodon guentheri	4.34	46.72	*Saurida undosquamis*	4.23	49.73
Chaetodontoplus meredithi	4.13	50.85	*Pterocaesio diagramma*	3.34	53.07
Shallow Sand & Shallow Gravel Average dissimilarity = 96.06			Deep Sand & Deep Gravel Average dissimilarity = 86.48		
Pentapodus paradiseus	12.77	12.77	*Choerodon venustus*	12.43	12.43
Choerodon venustus	9.52	22.29	*Saurida undosquamis*	10.70	23.13
Parupeneus spilurus	8.4	30.69	*Nemipterus theodorei*	8.12	31.24
Pagrus auratus	7.2	37.88	*Lethrinus genivittatus*	7.06	38.30
Pseudocaranx dentex	6.43	44.31	*Coris picta*	6.37	44.68
Saurida undosquamis	6.08	50.39	*Abalistes stellatus*	5.68	50.36
Shallow Rocky Reef & Shallow Gravel Average dissimilarity = 66.92			Deep Rocky Reef & Deep Gravel Average dissimilarity = 72.02		
Siganus nebulosus	7.32	7.32	*Nemipterus theodorei*	10.37	10.37
Pterocaesio diagramma	6.28	13.6	*Pagrus auratus*	7.6	17.97
Pentapodus paradiseus	5.13	18.73	*Glaucosoma scapulare*	6.28	24.25
Prionurus microlepidotus	5.12	23.86	*Chaetodon guentheri*	5.53	29.78
Parupeneus spilurus	4.74	28.59	*Atypichthys strigatus*	5.21	34.99
Chaetodon guentheri	4.67	33.27	*Parupeneus spilurus*	4.17	39.16
Pagrus auratus	4.6	37.87	*Coris picta*	3.96	43.12
Pseudocaranx dentex	4.51	42.38	*Lethrinus genivittatus*	3.71	46.83
Gymnocranius audleyi	4.01	46.39	*Pterocaesio diagramma*	3.43	50.25
Choerodon venustus	3.77	50.16			

Individual fishery target species

Of the three main fishery target species, *Pagrus auratus, Glaucosoma scapulare* and *Atractoscion aequidens*, only *P. auratus* was present on all habitat types in both deep and shallow water (Figure 8). The frequency of occurrence of *P. auratus* was significantly different between all habitat/depth groups, and this species was most abundant in deep rocky reef habitats. No small juvenile snapper <20cm were seen in any of the BRUVS samples.

There were also no juvenile *Glaucosoma scapulare* (<20cm) seen on any of the BRUVS with the majorityof fish exceeding 25cm in length. *G. scapulare* were most abundant in deep rocky reef habitat and were absent over shallow sand and gravel, with significantly different frequency of occurrence between all habitat/depth groups. The relatively high standard error for this species reflects both the small sample size but also the relatively wide range in MaxN seen for this species. *Atractoscion aequidens* was recorded in only one of the 187 samples, a deep gravel site.

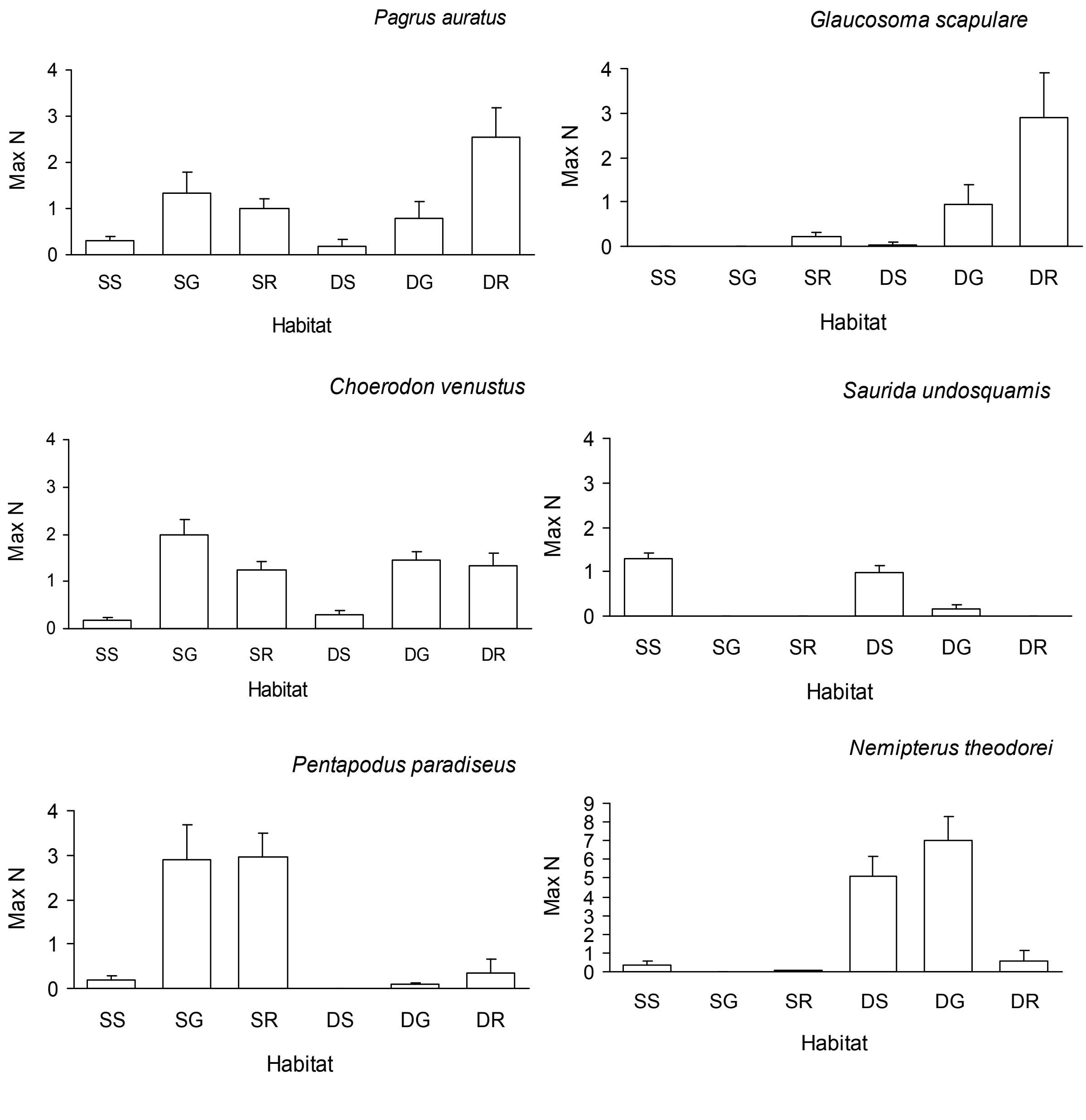


Figure 8 Relative abundance distribution of six relatively common species (mean and standard error) in BRUVS samples off the Sunshine Coast, Southern Queensland.

Species important in defining or separating assemblages

Choerodon venustus and *Saurida undosquamis* were the two most frequently occurring species in the study, occurring in 76 and 74 of the 187 samples respectively (Table 6). *Choerodon venustus* which is also an important fishery species was recorded in all habitat types in both deep and shallow water (Figure 7) but was more common on the more structured habitat types of reef and gravel. *S. undosquamis* was recorded only over shallow sand, deep sand and deep gravel habitats. Most footage viewed on sand habitat had a MaxN of either one or two for this species, reflecting a fairly ubiquitous and consistent distribution across these habitats. *Pentapodus paradiseus* occurred in 35 of the 187 samples and over all habitats with the exception of deep sand (Figure 7). Relative abundance of *P. paradiseus* was similarly high over shallow gravel and shallow rocky reef, and lower over shallow sand, deep gravel and deep rocky reef. *Nemipterus theodorei* was recorded in 54 of the 187 video samples over all habitats except shallow gravel (Figure 7) was highest in deep samples (both sand and gravel) where it was the dominant species.

BRUCS Survey – Moreton Island and Stradbroke Island

The analysis of the BRUCS was limited to determining MaxN for only two species of fish – snapper and pearl perch. From a general qualitative perspective there were clearly both spatial and temporal relationships among the crab assemblages and these are described by Brown (2012). It was rare to see either snapper or pearl perch in the same images as crab species although there were apparently no visible differences in the habitat types in the images. Both species were more frequently associated with a coarser sediment sometimes with associated sparse macroalgae and other organisms. The highest MaxN for snapper was 16 while for pearl perch it was only 4. Figure 9a and 9b shows the relative abundance of both species in the sampled areas over the two years of sampling. These results are broadly similar to those identified from the BRUVS samples taken on similar habitat further north off the Sunshine Coast which shows some fish on the sandy less structured habitats but more commonly on the more structured rocky reef habitats.

None of the fish sampled were classified as juveniles and in fact over 70% of pearl perch observed were above the current MLS. The opposite was the case for snapper with the majority being less than 35cm although two large individuals (>50cm) were observed on sandy habitat that had a very patchy cover of macroalgae.

Despite the fact that teraglin are a common reef fish in the area of Jumpinpin we were unable to consistently identify this species in images. Snapper and pearl perch were not observed in either year of the BRUCS surveys in the Jumpinpin area as well despite the fact that reefs are located in similar close proximity to those off southern Moreton Island. Characterization of the bottom types indicated that the sediment types where both pearl perch and snapper were recorded were gravel sites rather than sand. It was interesting that many of the areas sampled were characterized on maps as being areas of reef yet they had little complexity and on numerous occasions BRUCS landed on sand and gravel substrates in a similar result to the BRUVS analysis conducted further north off the Sunshine Coast.

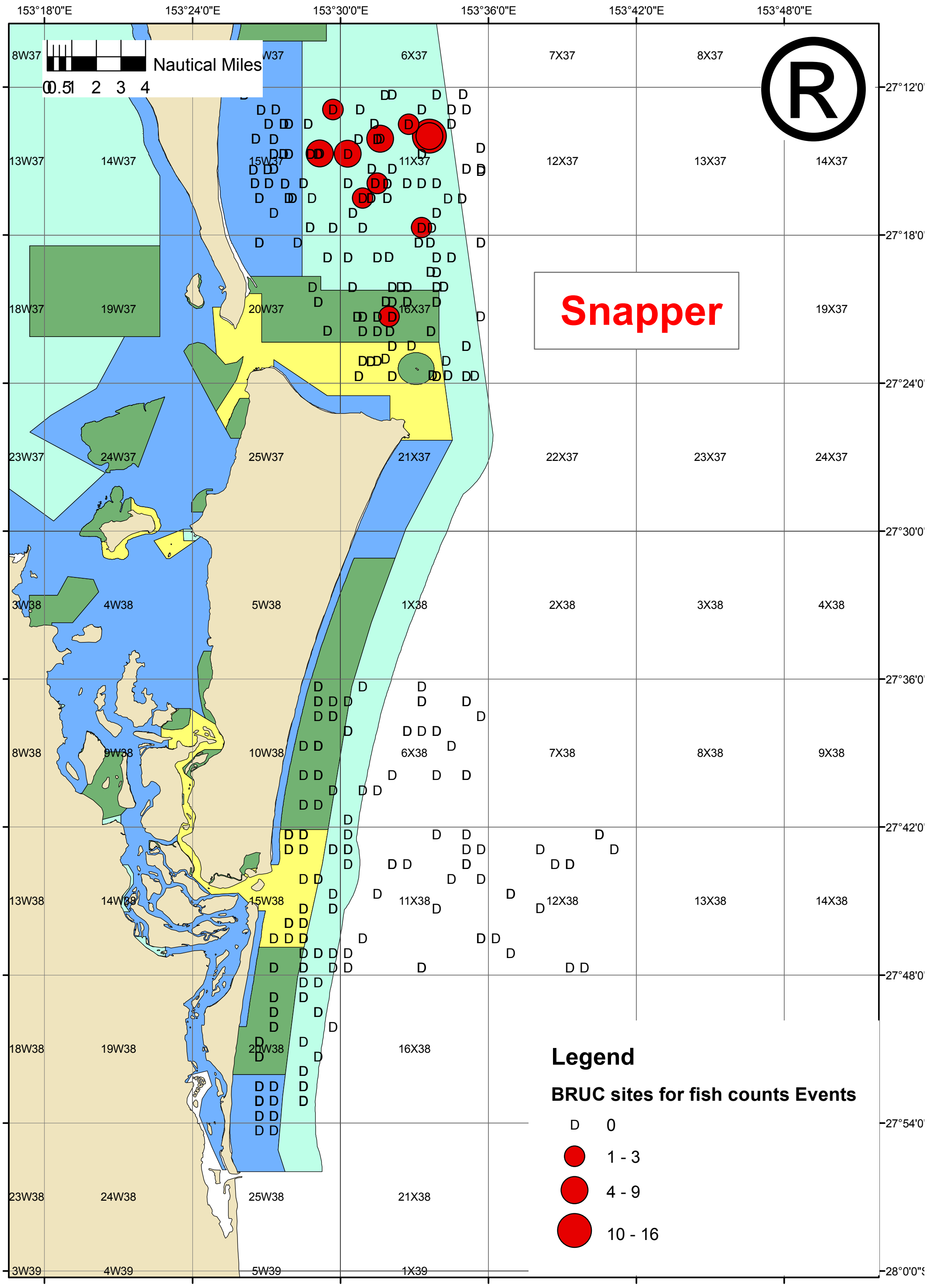


Figure 9a Relative abundance (MaxN) of snapper (*Pagrus auratus*) on BRUCS conducted during October to December in 2009 and 2011.

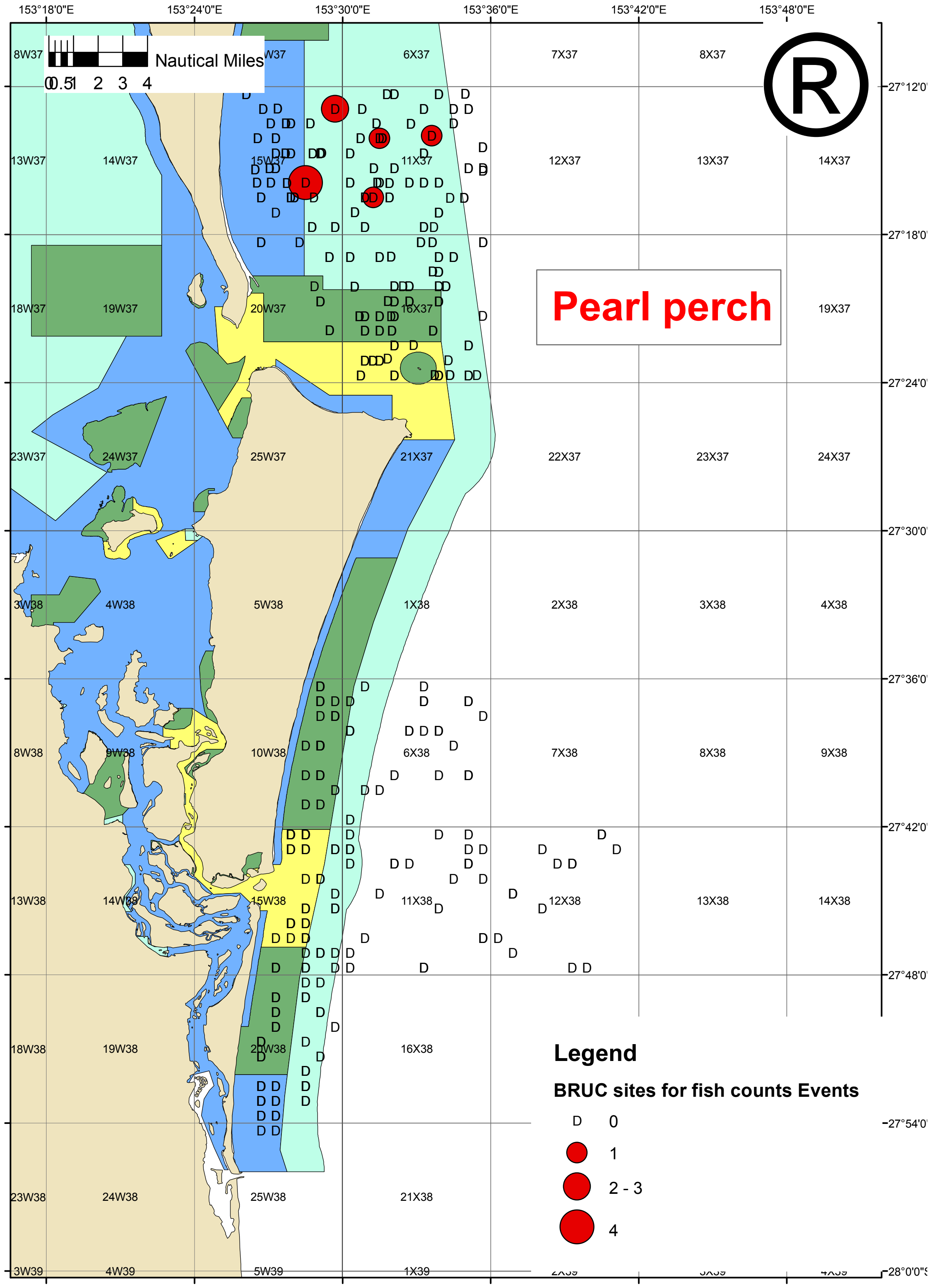


Figure 9b Relative abundance (MaxN) of pearl perch (*Glaucosoma scapulare*) on BRUCS conducted during October to December in 2009 and 2011.

Discussion

This BRUVS study has identified and described demersal fish assemblages associated with particular benthic habitat types at two different depth ranges on the continental shelf adjacent to the Sunshine Coast, Queensland and investigated soft substrate habitats across a wide range of areas extending to the Gold Coast. As expected we found that both depth and physical structure of benthic habitat significantly affected the composition of demersal fish assemblages. Despite this we were unable to find significant numbers of juveniles of any of the three main species of fisheries interest despite the relatively extensive sampling of habitat thought to be suitable for juveniles of these species and where they had previously been sampled in trawls and incidentally caught in crab pots. The following discussion will therefore focus firstly on the findings at the individual species level for the main fisheries target species (in particular snapper, pearl perch and teraglin). Secondly we discuss our results at the fish community level as this is important for a more global understanding of the overall ecology of the area necessary for any ecologically based management. At this community level, information may inform our understanding of the possible implications of climate change and other environment perturbations that may operate at altering fish communities on longitudinal (depth scales) as well as latitudinal scales.

Juvenile fish of individual rocky reef species

Juveniles of the most important species fished in the area were rarely seen in either the BRUVS or BRUCS samples despite adults of those species being represented in samples. This could be due to the seasonal availability of some of the species. Juvenile snapper for example, are known to be strongly seasonal in Moreton Bay when using trawl sampling due partially to gear selectivity as well as related to purely the seasonal abundance of 0+ year old snapper which tend to be more abundant during the austral spring and summer (Sumpton and Jackson 2005). It was surprising that juvenile pearl perch were not seen in any BRUVS samples taken off the Sunshine Coast. The area chosen represented an area where juveniles had previously been identified in crab pots as well as otter trawl samples. Research in Western Australia on the closely related *Glaucosoma hebraicum* has likewise failed to sample many small juveniles in trawl, trap or BRUVS surveys despite considerably more sampling effort than was undertaken by the present study. Juvenile *G. hebraicum* have only recently been seen by divers in relatively shallow water in WA.

Larger pearl perch were more abundant in the deeper areas and were absent from the sand habitat, a result conflicting with expectations of the previous trawl surveys where juveniles were trawled in the same areas sampled by the BRUVS. This could be due to their generally more cryptic nature, as noted earlier, the seasonal nature of their abundance on different habitats or even small scale diurnal behaviours. Trawl samples were taken during the evenings and it is possible that juveniles of this species may move off reef areas to forage in sandy habitat at night where they may also enter the pots of commercial blue swimmer crab fishers. Their large eye suggests that they may be more of a nocturnal predator, an observation further supported by fishers who often report elevated catch rates when fishing for this species at night.

Snapper were also found at both depth ranges and in all habitats although more were seen on the more complex gravel and reef habitats compared with the sand. Snapper are more ubiquitous across the region and have a higher relative abundance than all other species of fisheries importance (apart from venus tuskfish). This feature of their ecology confirms that their catch rates are more likely to reflect the relative abundance of the species, more so than species that have a highly patch distribution such as pearl perch and teraglin. The lack of juvenile teraglin was expected given the relative paucity of these fish in previous trawl samples conducted in the region and lack of reports of their capture by fishers in all sectors. We still cannot be certain about the habitat relationships of this species as we were unable to accurately identify teraglin in the still camera BRUCS used in the southern part for the survey area where the relative abundance of this species is known to be greatest.

Ichthyofauna community across all habitats and depths

Like demersal fishes described in previous studies (Cappo *et al*. 2011; Magurran and Henderson 2003), the ichthyofauna recorded here comprised prevalent species that were ubiquitous throughout the study area, abundant species that were distinctly associated with particular habitats and rare species that occurred infrequently in particular habitats. *Choerodon venustus* (venus tuskfish) and *Saurida undosquamis* (large-scale grinner) were the two species most important in distinguishing between fish assemblages associated with different habitat types. *Choerodon venustus* was a prevalent species, ubiquitous across all habitat types and was the most frequently occurring species in the study. This is an endemic species to the tropical and sub-tropical waters of Australia's east coast and while it is a reef-associated species is also common over gravel and sand, as exemplified by the present study. *Saurida undosquamis* is commonly associated with sand and mud substrata (Allen *et al.* 2005; Golani 1993) and is a common trawl bycatch species in the shallow water eastern King prawn fishery operating in southern Queensland (Courtney *et al*. 2007). In this study it was the predominant species in all samples taken from sand habitats off the Sunshine Coast, contributing to 92.48% of the similarity amongst fish assemblages found at shallow sand habitats and 53.28% of the similarity amongst those found at deep sand habitats. The pattern of high numbers of rare species (those occurring in only one sample) is not unexpected considering that ecological communities tend to comprise few prevalent or abundant species, whereas the majority of species are rare (Brown 2000; Magurran and Henderson 2003; Preston 1948). Species rarity may be explained by one of three theories: (1) rarity may be an artifact of the sampling methodology (e.g. the species was transient or the sampling method was inefficient for the species' behaviour or ecology) (Novotny and Basset 2000); (2) 'suffusive rarity' (the species was rare in this particular locality, sampling period); (3) 'diffusive rarity' (the species was rare throughout its entire geographic range) (Schoener 1987). In this study, each of these mechanisms is probably operating as many of the "rare" species is certainly relatively abundant throughout the region and some are species of minor fisheries importance.

Structural complexity and species diversity

Of the three habitat types sampled, rocky reef habitats had the highest fish diversity, represented by abundance of species contributing to the similarity amongst samples. Gravel habitats supported an assemblage with intermediate diversity and sandy habitats had the lowest diversity of species. These three habitats represent a gradient in structural complexity, which is clearly driving this gradient in species diversity. Structural complexity has been shown to be important in determining fish assemblages present in shallow waters, with a number of previous studies showing significant positive correlations between the structural complexity of benthic habitat and parameters such as species diversity, total abundance of species and species richness (Chittaro 2004; Gratwicke and Speight 2005; Hunter and Sayer 2009). Gratwicke and Speight (2005), for example, identified two components of habitat complexity, rugosity and the variety of benthic life forms, as important predictors of species richness in associated demersal fish assemblages, and vertical relief of substratum as the most important predictor of total fish abundance. In summary, this study demonstrated that more complex habitat was associated with higher species richness and fish abundance than less complex habitat. Similarly, Hunter and Sayer (2009) found positive relationships between increasing structural complexity of benthic habitat and total abundance of fish, species richness and species diversity. Such positive associations between these parameters of fish assemblages and the structural complexity of associated benthic habitat types may be explained by the abundance of resources at more complex habitats. Firstly, structurally complex habitats afford shelter and consequently reduce the risk of predation; consequently the abundance of prey species may be higher in more complex habitat types (Laegdsgaard and Johnson 1995; Ross *et al*. 2007). In addition, habitats of higher complexity would have greater surface areas with higher levels of substratum related productivity, availability of microhabitats and variety of substrata and may therefore support more fishes due to an increased availability of epibenthic food resources (Gratwicke and Speight 2005; Garcia-Sais 2010). The fact that results presented here are similar to those reported from studies conducted in shallow coastal and coral reef habitats suggests that the interactions and processes driving fish-habitat relationships in shallow water systems may also be important in these relatively deeper water habitats, and that the relationships between fish assemblages and structural complexity of habitat types may be similar in both deeper and shallow shelf areas.

Composition of fish assemblages by habitat type and depth

The composition of different fish assemblages off the Sunshine Coast reflected the known habitat and depth associations as well as the functional group of the species. While some information is available regarding the habitat and depth preferences as well the trophic group of fish families, there is limited knowledge about the ecology of most species important in defining these assemblages. Small, reef associated fishes from families such as Nemipteridae, Pomacanthidae, Labridae, Chaetodontidae and Mullidae dominated shallow rocky reef habitats. These families include benthic feeding invertivores, omnivores and herbivores (Moyle and Cech 2004). Deeper rocky reef assemblages comprised species of similar reef associated families, but also showed a prevalence of both *Pagrus auratus* and *Glaucosoma scapulare*, larger piscivores that are commonly associated with deeper water rocky reefs (Hutchins and Swainston 1986) and are important commercial and recreational species. In contrast, both deep and shallow sandy habitats were dominated solely by the synodontid *Saurida undosquamis*, a common demersal piscivore that is known to inhabit trawling grounds and sandy areas (Allen *et al.* 2005; Golani 1993). Gravel associated assemblages comprised species from similar families to those found over rocky reef habitat, including species from families such as Labridae, Pomacanthidae, Nemipteridae and Mullidae. These species are primarily demersal carnivores that feed on benthic invertebrates and occasional small fish (Moyle and Cech 2004). While functional groups and families were similar in the assemblages associated with both shallow and deep gravel habitats, the individual species differed, reflecting depth preferences. *Nemipterus theodorei* (Theodore's threadfin bream), for instance, has been described as more prevalent in deeper habitats (Cappo 2007), and here this species contributed to 54.95% of the similarity amongst assemblages found at deep gravel sites, whereas it made no notable contribution to the assemblages associated with shallow gravel.

Applied significance

The identification of distinct fish assemblages associated with benthic habitat type and depth has potential implications for ecological fisheries management of rocky reef stocks. If fish-habitat and depth associations can be determined as strong and predictable, these habitat types and depth ranges may be useful as predictors of the likely occurrence of fish assemblages or of particular species. In light of recent progress in digital video and acoustic seabed mapping technologies, mapping seabed habitats is often more efficient than sampling patterns of species abundances (Pitcher 2007). In the present study significantly different assemblages of demersal fishes were found in association with different habitat types in both deep and shallow water, and certain species were found to be important in defining assemblages associated with only one particular habitat type and depth range. These patterns were operating at relatively fine spatial scales at both the community and individual species levels. This is of course well known to experienced fishers who are aware of these differences and who target particular reefs or fine scale fishing locations (GPS marks) because they are known to be preferred sites for individual species. These "hot spots" are known to vary dramatically over the scale of less than 100m even on the presumed same habitat and these observations suggest that while habitat complexity may be a broad surrogate, patterns at the individual species level may be more complex.

Glaucosoma scapulare (pearl perch), for example, was found in shallow rocky reef, deep rocky reef, deep gravel and deep sand habitats, however it was only found to be an important species causing similarities between the assemblages found at deep rocky reef sites. Thus deep rocky reef areas may potentially be used as predictors of the likely occurrence of *G. scapulare*, which may enable fisheries managers to determine zoning plans to best ensure future fisheries production of this species. If habitat is to be accurately used as a surrogate for ichthyofauna, the precision and spatial resolution of topographic maps, the fine scale composition and configuration of habitat types relative to each other and taxa-specific biological information must all be considered (Anderson *et al.* 2009). We note that variations in relative abundance of species at all spatial scales on essentially the same habitat can result in "habitat" based surrogates offering differential protection for individual species. The current Moreton Bay Zoning plan clearly has significantly different impacts on the three target species investigated here, having the greatest protective benefit on snapper whose juveniles are abundant in Moreton Bay.

Limitations of methodology

Like all sampling techniques used to survey fish communities there are inherent biases associated with BRUVS and BRUCS. Firstly, bait tends to attract scavenging and predatory species and as such data collected using these techniques may be biased towards these species (Cappo *et al*. 2007a; Cappo *et a*l., 2007b; Stowar 2008). The use of baited video stations has been demonstrated, however, to increase the capability of data to discriminate between fish assemblages associated with distinct habitat types when compared with data collected using unbaited video stations (Cappo *et al*. 2007; Harvey *et al.* 2007)(Cappo *et al*., 2007b) and as the main focus of this present study was to investigate the relative abundance of carnivores of fisheries importance this is less of an issue. In a comparison of the utility of baited and unbaited remote underwater video stations, Harvey *et al*. (2007) found that while baited stations attracted more carnivores than unbaited stations, the abundances of herbivorous and omnivorous species did not decrease. Baited video stations have also been shown to record greater overall fish abundance and a higher diversity of herbivorous fishes and benthic feeders than unbaited video stations (Cappo *et al*. 2007)(Cappo *et al*., 2007b). Whilst the data collected in the present study showed a prevalence of piscivorous species (e.g. *Saurida undosquamis, Choerodon venustus, Pagrus auratus, Glaucosoma scapulare, Pentapodus paradiseus, Nemipterus theodorei*), the species contributing to dissimilarities between assemblages also included benthic invertivores (e.g. *Heniochus monoceros, Parapercis* sp*., Chaetodontoplus meredithi*) benthic omnivores (e.g. *Chaetodon guentheri*) and herbivores (e.g. *Pomacentrus australis*) (Allen *et al*. 2005). This suggests that while bait-related biases were present, the data reflected those of previous studies in which a range of functional groups were represented and so community analysis we believe is representative of real community differences.

The present study was limited by its unbalanced sampling of habitat types, and while the multivariate techniques utilised were sufficiently robust to enable analysis of the unbalanced design, the sampling technique itself may have impacted the reliability of the data. It was not always possible to accurately select habitat types from the deck of the research vessel and as a result all depth and habitat combinations were not equally represented. While this would be problematic if data were analysed using parametric univariate analysis, it is less of a problem for non-parametric multivariate analysis, unless a particular habitat type is so rare in the data that the samples may not be representative of that habitat type. Some treatment groups had considerably lower replication than others. Given that BRUVS are a sampling technique that relies on the behaviour of fishes in response to the bait (Stowar 2008), this may not have been sufficient replication to represent the diversity of fish assemblages associated with that habitat type. It may also have contributed to the rarity of some species, for instance *Atractoscion aequidens* (teraglin) is an important fisheries target species in the study area yet it was recorded in only one sample in the entire BRUVS study. This study also had the prime objective of investigating species of particular fisheries importance and whose juveniles were hypothesized (based on specific fisheries information) to be found on less complex habitats, so the under-sampling of structured habitat is less relevant in this case as at the level of individual species there was a focus on less structured habitat due to the possible effects of trawling and other fisheries in the area, thus effectively biasing some BRUVS sets.

The small scale spatial differences in species assemblages and fine scale differences in individual species distributions were analytical issues in this study. The “patchy” nature of much of the rocky reef habitat meant that many of the BRUVS which were supposed to set on rocky reef habitat deployed on a different habitat than expected due to the effects of currents and depth. Fish on more complex habitats, possibly only a few metres away from where the BRUVS deployed, but out of sight of the camera, would clearly be able to move to the field of view of the camera. Temporal changes in assemblages are also a feature of many fish communities and these are often influenced by the seasonal abundance of juveniles which may enter and leave particular habitats over quite well defined periods (as previously discussed for snapper). The BRUCS were not as simple to interpret as the BRUVS but it was still possible to identify pearl perch and snapper consistently and we feel that at least for these two species our results provide a reasonable estimate of relative abundance of these two species over the area covered by the sampling.

Future research

While the present study looked at habitat types independently, habitat connectivity and habitat mosaics and the migration of fishes between habitats may contribute significantly to the composition of demersal fish assemblages. It is also essential to analyse BRUVS/BRUCS samples collected across a range of seasons and years to investigate the influence of seasonal and inter-annual changes on fish assemblages. We believe that this is vitally important in the case of determining significant, yet hard to define small scale utilisation of habitats by juvenile fish in particular. As there is a deficit of ecological knowledge about many of the species in the present dataset there is scope for species-specific ecological studies, prioritising the species identified here as important for distinguishing habitat associated fish assemblages.

Individual species also showed strong depth related differences in relative abundance of their adults even over the relatively small difference in depth range (30m) investigated by the present study off the Sunshine Coast. While the effects of climate change will act latitudinally to shift species distributions either north or south, differences in temperature and current conditions with depth also suggests that there may be depth related (or latitudinal) shifts as well. The fact that there are bands of reefs off the southern Queensland coast where species assemblages differ dramatically suggests that ecological effects could be dramatic and difficult to predict given the vastly different assemblages evident in this study at even small spatial scales. The capacity of species to adapt to changes may see strong competitors replacing other species and altering community composition as we transition bands of rocky reef across the continental shelf. Under these scenarios it would be possible for species to maintain their existing latitudinal range by extending (or contracting) their depth distribution, and this is an area that requires research attention. Our ability to delineate such changes will be limited by the very fine scale differences that occur spatially (as shown by this study) and also most likely over finer temporal scales.

Table 6 Mean MaxN of species in BRUVS samples from the continental shelf adjacent to the Sunshine Coast, Queensland, ranked in order of frequency of occurrence in 187 samples.

Family	Species	Mean MaxN	Frequency of occurrence
Labridae	*Choerodon venustus*	0.66	76
Synodontidae	*Saurida undosquamis*	0.74	74
Nemipteridae	*Nemipterus theodorei*	2.36	54
Sparidae	*Pagrus auratus*	0.60	51
Mullidae	*Parupeneus spilurus*	0.46	40
Nemipteridae	*Pentapodus paradiseus*	0.61	35
Chaetodontidae	*Chaetodon guentheri*	0.45	35
Pomacanthidae	*Chaetodontoplus meredithi*	0.25	31
Balistidae	*Abalistes stellatus*	0.15	25
Lethrinidae	*Gymnocranius audleyi*	0.24	24
Lethrinidae	*Lethrinus genivittatus*	0.29	24
Glaucosomatidae	*Glaucosoma scapulare*	0.32	21
Carangidae	*Pseudocaranx dentex*	0.71	21
Labridae	*Coris picta*	0.26	21
Pinguipedidae	*Parapercis* sp.	0.14	17
Acanthuridae	*Prionurus microlepidotus*	0.48	15
Lutjanidae	*Lutjanus russellii*	0.07	14
Pomacentridae	*Pomacentrus australis*	0.15	14
Caesionidae	*Pterocaesio digramma*	1.34	14
Siganidae	*Siganus nebulosus*	1.05	14
Nemipteridae	*Nemipterus hexodon*	0.09	14
Muraenidae	*Gymnothorax undulatus*	0.07	13
Carangidae	*Trachurus novaezelandiae*	0.76	12
Muraenidae	*Gymnothorax* sp.	0.06	11
Chaetodontidae	*Heniochus monoceros*	0.09	11
Acanthuridae	*Acanthurus dussumieri*	0.11	11
Echeneidae	*Echeneis naucrates*	0.07	10
Pomacentridae	*Chromis nitida*	0.19	9
Cheilodactylidae	*Cheilodactylus vestitus*	0.06	8
Labridae	*Pseudolabrus guentheri*	0.06	8
Kyphosidae	*Atypichthys strigatus*	0.30	8
Chaetodontidae	*Chelmon rostratus*	0.06	7
Rhinobatidae	*Trygonorrhina fasciata*	0.03	6
Aulopidae	*Aulopus purpurissatus*	0.03	6
Serranidae	*Epinephelus undulatostriatus*	0.03	6
Nemipteridae	*Scolopsis monogramma*	0.03	5
Grammistidae	*Diploprion bifasciatum*	0.03	5
Labridae	*Bodianus frenchii*	0.04	5
Pomacanthidae	*Centropyge tibicen*	0.04	5
Rhinidae	*Rhynchobatus australiae*	0.03	5
Labridae	*Bodianus perditio*	0.03	5
Mullidae	*Parupeneus pleurostigma*	0.04	4
Echeneidae	*Remora remora*	0.02	4
Pomacanthidae	*Centropyge flavicauda*	0.03	4
Acanthuridae	*Naso annulatus*	0.06	3
Chaetodontidae	*Chaetodon rainfordi*	0.03	3
Mullidae	*Mulloidichthys vanicolensis*	0.02	3
Pomacentridae	*Pomacentrus coelestis*	0.04	3

Carangidae	*Gnathanodon speciosus*	0.06	3
Orectolobidae	*Orectolobus ornatus*	0.02	3
Monacanthidae	*Paramonacanthus choirocephalus*	0.02	3
Ostraciidae	*Anoplocapros inermis*	0.02	3
Carangidae	*Seriola hippos*	0.02	3
Kyphosidae	*Microcanthus strigatus*	0.04	2
Labridae	*Cheilinus fasciatus*	0.01	2
Labridae	*Choerodon fasciatus*	0.02	2
Labridae	*Choerodon graphicus*	0.02	2
Lethrinidae	*Gnathodentex aureolineatus*	0.04	2
Lutjanidae	*Lutjanus fulviflamma*	0.01	2
Lutjanidae	*Paracaesio xanthura*	0.02	2
Mullidae	*Parupeneus barberinoides*	0.02	2
Scombridae	*Sarda orientalis*	0.01	2
Siganidae	*Siganus punctatissimus*	0.02	2
Chaetodontidae	*Chelmonops truncatus*	0.01	2
Labridae	*Bodianus unimaculatus*	0.02	2
Lutjanidae	*Lutjanus adetii*	0.03	2
Lutjanidae	*Lutjanus sebae*	0.02	2
Lutjanidae	*Lutjanus vitta*	0.04	2
Lethrinidae	*Lethrinus lentjan*	0.01	2
Orectolobidae	*Orectolobus maculatus*	0.01	2
Rhinobatidae	*Aptychotrema rostrata*	0.01	2
Mullidae	*Parupeneus chrysopleuron*	0.02	2
Tetraodontidae	*Canthigaster callisterna*	0.01	2
Muraenidae	*Gymnothorax eurostus*	0.005	1
Muraenidae	*Gymnothorax thrysoideus*	0.005	1
Apogonidae	*Apogon* sp.	0.005	1
Balistidae	*Sufflamen chrysopterum*	0.005	1
Carangidae	*Carangoides ferdau*	0.04	1
Carangidae	*Carangoides gymnostethus*	0.05	1
Carangidae	*Caranx* sp.	0.005	1
Carangidae	*Trachurus mccullochi*	0.01	1
Carcharhinidae	*Carcharhinus* sp.	0.005	1
Chaetodontidae	*Chaetodon flavirostris*	0.01	1
Chaetodontidae	*Chaetodon kleinii*	0.01	1
Chaetodontidae	*Chaetodon plebeius*	0.01	1
Chaetodontidae	*Chelmon muelleri*	0.005	1
Chaetodontidae	*Coradion altivelis*	0.005	1
Cirrhitidae	*Cirrhitichthys aprinus*	0.01	1
Fistulariidae	*Fistularia commersonii*	0.005	1
Fistulariidae	*Fistularia petimba*	0.01	1
Hexanchidae	*Hexanchus griseus*	0.005	1
Labridae	*Achoerodus viridis*	0.005	1
Labridae	*Bodianus diana*	0.005	1
Labridae	*Cirrhilabrus punctatus*	0.005	1
Labridae	*Hemigymnus melapterus*	0.005	1
Lethrinidae	*Lethrinus laticaudis*	0.005	1
Lethrinidae	*Lethrinus nebulosus*	0.005	1
Lethrinidae	*Lethrinus* sp.	0.04	1
Lutjanidae	*Lutjanus* sp.	0.005	1
Monacanthidae	*Cantherhines dumerilii*	0.005	1
Monacanthidae	*Cantheschenia grandisquamis*	0.005	1
Monacanthidae	*Meuschenia flavolineata*	0.005	1
Monacanthidae	*Meuschenia trachylepis*	0.005	1
Mullidae	*Upeneichthys lineatus*	0.005	1
Muraenidae	*Enchelycore ramosa*	0.005	1
Muraenidae	*Gymnothorax meleagris*	0.005	1
Nemipteridae	*Nemipterus* sp.	0.005	1
Nemipteridae	*Pentapodus aureofasciatus*	0.01	1
Nemipteridae	*Pentapodus* sp.	0.01	1
Nemipteridae	*Scolopsis bilineata*	0.005	1
Pempherididae	*Pempheris affinis*	0.01	1

Pomacentridae	*Chromis margaritifer*	0.01	1
Pomacentridae	*Dascyllus melanurus*	0.005	1
Pomacentridae	*Dascyllus trimaculatus*	0.01	1
Rachycentridae	*Rachycentron canadum*	0.02	1
Sciaenidae	*Atractoscion aequidens*	0.02	1
Serranidae	*Epinephelus malabaricus*	0.005	1
Serranidae	*Epinephelus fuscoguttatus*	0.005	1
Serranidae	*Epinephelus quoyanus*	0.005	1
Serranidae	*Epinephelus* sp.	0.005	1
Siganidae	*Siganus fuscescens*	0.06	1
Sphyrnidae	*Sphyrna mokarran*	0.005	1
Sphyrnidae	*Sphyrna* sp.	0.005	1
Apistidae	*Apistus carinatus*	0.005	1

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APPENDIX 3.10 CATCH RATES OF PEARL PERCH AND TERAGLIN FROM THE COMMERCIAL AND CHARTER SECTORS IN QUEENSLAND

Summary

Historically, pearl perch *Glaucosoma scapulare* and teraglin *Atractoscion aequidens* were secondary targets for commercial fishers and charter fishers in south-east Queensland, with snapper *Pagrus auratus* the most commonly caught reef-associated species. However, a decline in catch rates of snapper, combined with decreasing bag limits for charter fishers, has seen pearl perch and teraglin catches increasing in the last decade. As an index of abundance, catch rates of these species, based on logbook data, were standardised via generalised linear mixed models using both random and fixed terms. The catch rate standardisation quantified variation in catch rates according to a number of spatial and temporal terms. Catch rates for both pearl perch and teraglin increased throughout the early 2000's in both the commercial and charter sectors with year, month and catch location found to have significantly ($P < 0.01$) affected catch rates and were highest in the commercial sector. Lunar phase had no significant effect ($P > 0.05$) on the catch rates of pearl perch or teraglin in either sector. Pearl perch catch rates reached 36kg/boat/day in 2006 in the commercial sector and 13kg/boat/day in the charter sector in 2005. Teraglin catch rates in the commercial sector reached 58kg/boat/day in 2005 and 17kg/boat/day in 2010 in the charter sector. The prevalence of advanced Global Position System (GPS) and sonar technology has likely increased the efficiency of vessels accessing the Rocky Reef Finfish Fishery (RRFF), leading to increases in fishing power. We recommend that the effect of the introduction of GPS and sonar technologies be quantified and incorporated into catch rate standardisation models to ensure more precise indices of abundance in stock assessment models.

Introduction

The RRFF is an important multi-species line fishery, with a commercial gross value of production (GVP) of $1.3million (Fisheries Queensland, 2011). For the purposes of managing the RRFF, the following species are classified as rocky reef fish: snapper (*Pagrus auratus*), pearl perch (*Glaucosoma scapulare*), teraglin (*Atractoscion aequidens*), samsonfish (*Seriola hippos*), amberjack (*Seriola dumerili*), yellowtail kingfish (*Seriola lalandi*), mahi mahi (*Coryphaena hippurus*), grass emperor (*Lethrinus laticaudis*), frypan bream (*Argyrops spinifer*) and cobia (*Rachycentron canadum*). Fishers primarily target snapper, pearl perch and teraglin in areas on, or adjacent to, hard reef in shelf waters south of Bundaberg. The total harvest from the RRFF is approximately 1,291 t with the commercial and charter sector accounting for 215 t and 120 t, respectively (Fisheries Queensland, 2011).

Since 1988, the Queensland Government has maintained a compulsory logbook system for Queensland's commercial fishers. Similarly, logbooks have been compulsory in the charter sector since 1996, following a two year trial period. Commercial and charter operators accessing the RRFF are required to report daily catch in logbooks that are submitted to the Assessment and Monitoring Unit (AMU) of Fisheries Queensland. Primarily, the data are used to provide Fisheries Queensland with information regarding catch and effort which are then reported in various publications including Annual Status Reports (e.g. Fisheries Queensland, 2011). Similarly, catch and effort data are used by stock assessment scientists as an index of abundance in Stochastic Stock Reduction Analysis (SSRA) and/or Sex, Age and Length Stock Analysis (SALSA) modelling frameworks.

Historically, fishers operating in the RRFF were restricted to fishing grounds close to land due to 1) the range of their relatively small vessels, powered by carburettor-fuelled two-stroke outboard engines and 2) landmarks were required to return to productive fishing grounds. Technological advancements in 4-stroke and fuel-injected 2-stroke outboard engines, sonar and Global Positioning Systems (GPS) have seen fishers operating further offshore, accessing more productive fishing grounds. This expansion of the fishery, with access to highly productive unfished reefs increasing through the 1990's and into the early 2000's, has led to a situation where catch rates of pearl perch and teraglin remained stable or increased over this time, despite a reduction in abundance.

Commercial fishers and charter operators traditionally targeted snapper due to its availability and high consumer demand, with other rocky reef fish landed incidentally (Sumpton *et al.*, 1998). However, snapper catch rates declined throughout the 1990's and early 2000's (Allen *et al.*, 2006; Fisheries Queensland, 2011), forcing commercial fishers and charter operators to diversify and target other rocky reef fish. The combination of the expansion of the RRFF and the change in targeting behaviour have seen observed catch rates of pearl perch and teraglin increasing since the early 2000's and, specifically, since 2003 when management strategies were altered to ensure the long-term sustainability of these species. At this time the minimum legal size (MLS) for pearl perch was increased from 30cm (TL) to 35cm in order to maintain an effective spawning stock, while the MLS was decreased from 45cm to 38cm for teraglin due, partly, to high mortality in discarded individuals (Sumpton *et al.*, 1998).

Throughout the period in which the logbook system has been in operation, the nominal effort unit used in the RRFF is a boat-day. However, changes in fishing technology and practices have seen an increase in the efficiency of a boat-day, with resultant changes in catchability and the divergence from correlation between the observed catch rates (i.e. catch in kilograms per boat per day) and abundance. The SSRA and SALSA modelling frameworks require the standardisation of catch rates which removes any variation in catch rate not attributable to changes in abundance (Maunder and Punt, 2004). This essentially ensures that catch rates are correlated with abundance over time by removing biases in catch rate data due to changes in the efficiency of fishing effort (O'Neill and Leigh, 2007) as well as natural variation due to factors such as lunar phase (Courtney *et al.*, 1996). As such, statistical models are used to quantify and remove the variation in catch rates according to a set of identified explanatory variables. Factors associated with fishing gear and changes in fishing practices have been shown to have significantly affected the catch rate of some target species, with, for example, factors such as vessel size (Battaile and Quinn, 2004), engine size (Marchal *et al.*, 2002) and the use of GPS/plotters (Robins *et al.*, 1998) reported as having a significant effect on the catch rates of trawl-caught species.

Although fishery-independent data sources are the ideal when deriving indices of abundance, for the most part their cost and availability prohibit their use (Maunder and Punt, 2004). As such, the standardisation of catch rates from fishery-dependent catch data is the subject of numerous journal articles in the scientific literature. The authors of these articles suggest a variety of methods with which to standardise catch rates, with generalised linear models (GLMs) and their extensions, generalised additive models (GAMs) for exploratory analyses (Cardinale *et al.*, 2009) and generalised linear mixed models (GLMMs), being the most common. GLMs model the non-linear relationship between the dependent variable and a linear combination of explanatory variables (Maunder and Punt, 2004), allowing for regression analyses to be performed on dependent variables with non-normal error distributions (Venables and Dichmont, 2004).

Several authors have used GLMs to standardise catch rates using data reported by commercial fishers (e.g. Robins *et al.*, 1998; Bishop *et al.*, 2004; Xiao, 2004; Ye *et al.*, 2005). However, the use of GLMs for the standardisation of catch rate data can be problematic when factors with many levels, such as vessel identifiers or spatial strata, are used to quantify variation in catch. This is due to the fact that the GLM estimates parameters for each level of all factors in the regression equation which makes adjusting catch rates for these factors computationally complex (Michael O'Neill, personal communication, 2011). To remedy this, factors with many levels can be incorporated into a generalised linear mixed model (GLMM), via a Restricted (or Residual) Maximum Likelihood (REML) analysis, as a random term. GLMMs allow for the use of both fixed and random terms and are useful in longitudinal studies where correlated, multiple measurements are recorded for a single individual (Chen *et al.*, 2003; Bolker *et al.*, 2009). In a REML analysis, the variation in catch rate attributable to individual fishers is quantified via the addition of the random term "licence number". Rather than estimating parameters for each licence number, as would be the case for the fixed effects GLM procedure, the REML focuses on the variance of the distribution from which the random parameters, in this case licence number, are assumed to have come (Venables and Dichmont, 2004). This method has been used by several authors to standardise catch rates for commercial species in Queensland including O'Neill and Leigh (2007) and Campbell *et al.* (2010), while Marriott *et al.* (2011) used mixed models to quantify the effects of changes in technology on the catch rates of the West Australian dhufish (*Glaucosoma hebraicum*). O'Neill and Leigh (2007) reported that the inclusion of the vessel identifiers as a random term in a REML analysis may be able to quantify the effects of unknown factors such as fisher knowledge on catch rates.

In this chapter, linear mixed models will be applied using the REML procedure in Genstat (2011) to standardise pearl perch and teraglin catch rates from the commercial and charter sectors for a range of factors. This will provide accurate information regarding relative abundance of these species for use in the modelling frameworks mentioned, as well as Annual Status Reports published by Fisheries Queensland.

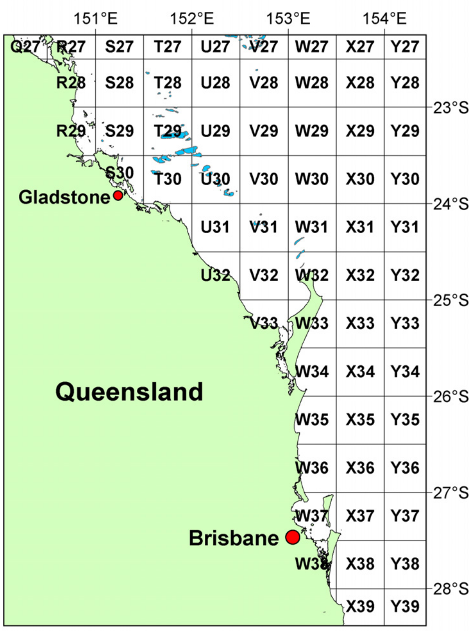

Figure 1 30 minute x 30 minute CFISH grids used by commercial fishers and charter operators when reporting catch location in the RRFF.

Methods

Daily commercial and charter catch data were supplied by the Assessment and Monitoring Unit of Fisheries Queensland for all RRFF species. The database received from Fisheries Queensland contained daily catch records with associated Authority Chain (licence) Number, CFISH (30 minute by 30 minute) Grid (see Figure 1), year, month and the catch of each RRFF species in kilograms. Single catches reported for periods greater than 5 days (i.e. bulk data) were excluded from the analyses as per Brown (2010). Only data for catches from the line fishery were analysed, with any catch from the inshore net fishery excluded. Teraglin catches prior to January 1997 were excluded from the catch rate standardisation analyses due to a paucity of data prior to this date. These data were also used to summarise pearl perch and teraglin catch in the RRFF.

Four linear mixed models were used to adjust the catch rates of pearl perch and teraglin from the commercial and charter sectors, each containing both random and fixed terms. In each model, the response variable was the pearl perch or teraglin catch per vessel in kilograms per day in the log scale. The fixed terms included year, month and the spatial component, CFISH Grid. In order to minimise variation in catch rates according to CFISH Grid, those grids with less than 20 days of effort over the period where logbooks were in operation were excluded from the analysis.

In accordance with methods described by O'Neill and Leigh (2007), quantifying the influence of lunar phase on catch rates was achieved via the addition of a measure of luminance corresponding to a sinusoidal pattern between 0 for the new moon and 1 for the full moon. A second covariate was added whereby the luminance measure was advanced 7 days (~¼ lunar period) in order to detect a lag in the response of catch rates to lunar phase. Further, as described by O'Neill and Leigh (2007) and Su *et al.* (2008), the associated catch of other species was used to adjust for the targeting behaviour of fishers via the addition of the associated snapper catch in kilograms on the log scale. The only random term added to the models was licence number, a unique identifier for each licence holder.

REML analyses were performed using Genstat (2011) statistical software. Year and Month were included in all models, as adjusted means were required for these factors, while CFISH grid was also included in each model. Individual terms were included according to their effect on the deviance term generated by the REML procedure in Genstat (2011), an approximation of the Akaike Information Criteria (AIC). Corresponding snapper catch was omitted from the model if the REML calculated a positive parameter estimate for this term (David Mayer, personal communication). The lunar covariates were omitted if their effect on catch rates were not statistically significant (i.e. $P > 0.1$).

The adjusted means from the GLMMs were back-transformed according to methods described by Zhou and Gao (1997) and, using these methods, bias-corrected estimates of the mean catch rate in kilograms per boat per day were calculated as:

$$\theta_y = e^{\left(\mu_y + \frac{s^2}{2}\right)}$$

where θ_y is the bias–corrected back-transformed mean catch rate in year y, μ_y is the adjusted mean catch rate in the natural log scale in year y and s^2 is the residual mean square from the REML. Further, according to Zhou and Gao (1997), the 95% confidence intervals for θ_y are given by:

$$e^{\left[\left(\mu_y + \frac{s^2}{2}\right) - 1.96\sqrt{\frac{s^2}{n_y} + \frac{s^4}{2(n_y - 1)}}\right]} < \theta_y < e^{\left[\left(\mu_y + \frac{s^2}{2}\right) + 1.96\sqrt{\frac{s^2}{n_y} + \frac{s^4}{2(n_y - 1)}}\right]}$$

where n_y is the number of observations in year y and 1.96 is the critical value for the 95% Confidence Limit. The same methods were used to calculate catch rates as a function of month.

Results

A total of 289,759 daily catch records were reported throughout the period that logbooks have been mandatory in the commercial and charter sectors of the RRFF, with landings of ~5,979 t (Table 1). The charter sector expended approximately 52% of the total effort in the RRFF, yet contributed only 23% of the total catch. Snapper dominated total catch in both the commercial and charter sectors, with catches of 2,793 t and 622 t, respectively.

Table 1 Number of days that catch was reported and total catch in tonnes by species and sector in the RRFF. The commercial logbook data represents catches from January 1988 to June 2011, while the charter sector data represents catches from December 1993 to June 2011. Data are from the line fishery only, with catch from the inshore net fishery ignored.

Species	Number of daily catches		Catch (tonnes)	
	Charter	Commercial	Charter	Commercial
Amberjack	4,089	5,389	60.5	131.0
Cobia	8,937	12,802	116.9	320.6
Frypan Bream	160	209	0.6	1.3
Grass emperor	13,061	8,373	53.5	88.2
Mahi mahi	3,606	1,449	59.3	65.4
Pearl perch	32,719	29,951	264.1	829.3
Samsonfish	794	4,075	6.7	86.3
Snapper	65,548	66,906	622.0	2,793.1
Teraglin	18,885	4,515	161.6	166.0
Yellowtail kingfish	4,193	4,098	56.8	95.3
Total	151,992	137,767	1,402.1	4,576.9

Total snapper catch averaged approximately 104 t until 2002, before significant increases in catch occurred in 2003, 2004 and 2005 (Figure 2). Catch has decreased annually since 2005. Effort increased from 1,869 boat days in 1990 to 4,023 boat days in 1998. Effort then averaged more than 3,300 boat days until 2009 and 2010, when effort decreased.

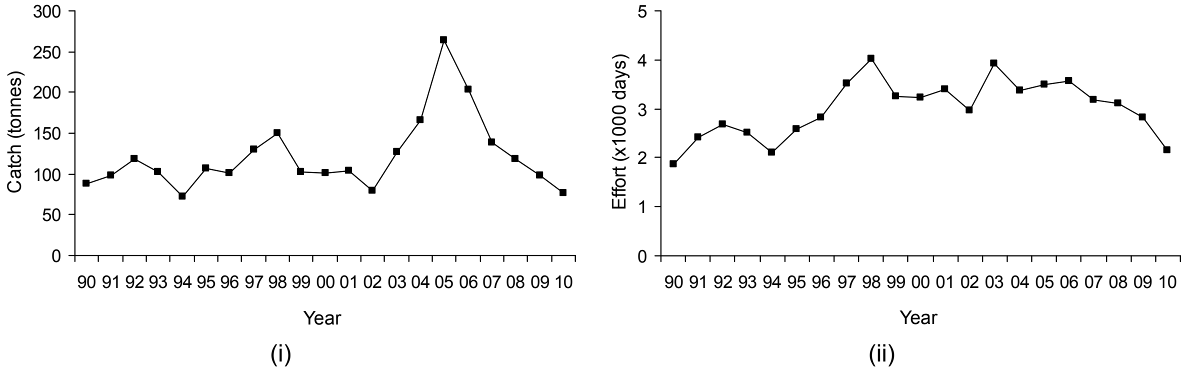

Figure 2 Catch (i), in tonnes, and effort (ii), in 1000's of days, for snapper in the RRFF from logbook data.

Pearl perch were the next most commonly reported species in both sectors, whilst teraglin and cobia were also important for the charter and commercial sectors, respectively. Although snapper accounted for the highest proportion of catch by commercial and charter operators in the RRFF, the snapper catch has decreased as a percentage of total catch (Figure 3) in recent years. Snapper catch in both sectors was approximately 40% of total catch in the RRFF in 2010, down from in excess of 80% at the start of the respective logbook periods. The commercial sector was more reliant on snapper, even after 2000, with snapper contributing around 55% of total catch until 2007, compared to less than 40% in the charter sector. Presently, the snapper catch represents around 40% of the total catch in both sectors.

The catches of teraglin and pearl perch, as a percentage of total catch, have remained relatively stable in both sectors (Figure 3). Since 2000, pearl perch have comprised approximately 20% of the catch in both sectors, while teraglin are of less importance to the commercial sector (<5% of total catch since 2000) compared to the charter sector (~10%). The catch of the traditionally incidental RRFF species has increased over time in both sectors (Figure). Cobia have become an increasingly important target species in both the commercial and charter sectors in recent years, while the catch of both grass emperor and amberjack has also increased since 2000. Frypan bream, samsonfish and mahi mahi remain only a small proportion of the total RRFF catch (Table 1).

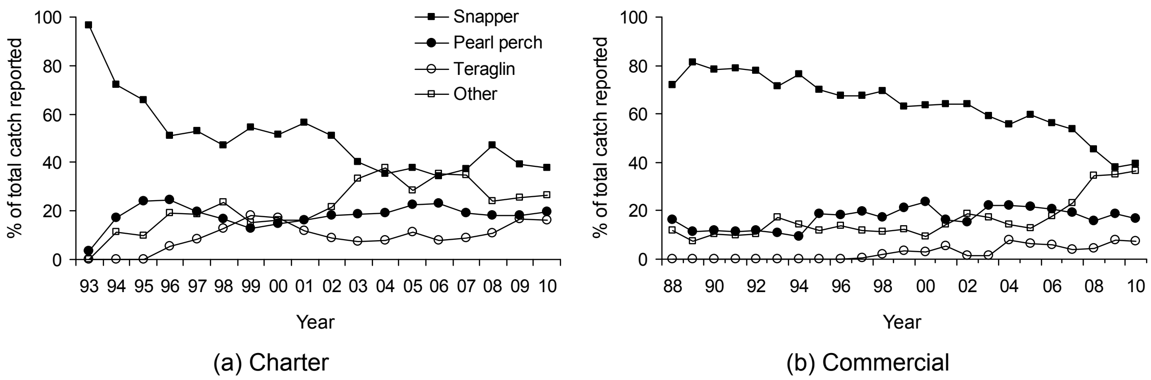

Figure 3 Percentage of total catch landed by line in the charter and commercial sectors by species from logbook data.

Catch and effort have increased for pearl perch and teraglin in both the commercial and charter sectors since the start of the respective logbook periods (Figure 5), with catch and effort being correlated. In 2005, significant increases were observed in catch and effort for pearl perch and teraglin in both the commercial and charter sectors. Similar peaks were also observed in 2009 and also around 1997-1999.

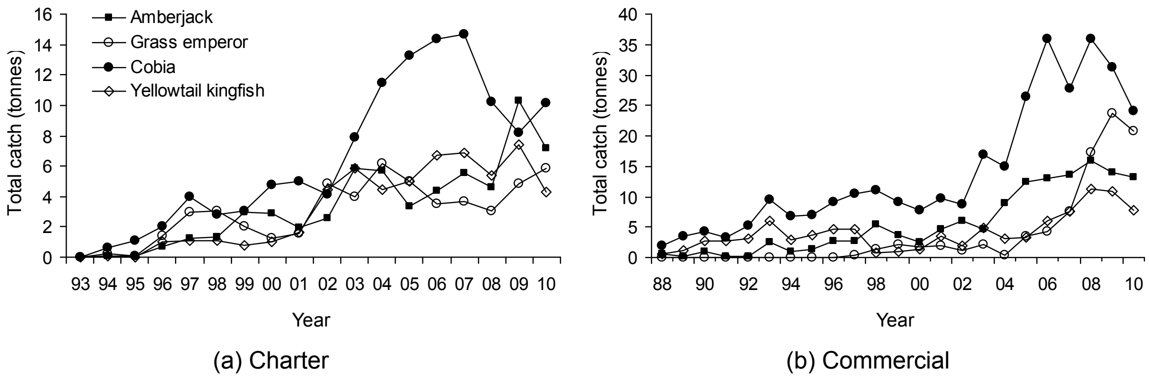

Figure 4 Total catch (in tonnes) of traditionally incidental species ("Other" species in Figure 3)Figure 3 Percentage of total catch landed by line in the charter and commercial sectors by species from logbook data.

For both pearl perch and teraglin, the distributions of catch (in kg/boat/day) are heavily skewed, with small catches predominating in both sectors (Figure 6). Approximately 92% of catches of both pearl perch and teraglin in the charter sector are less than 30 kg/boat/day, while 75% and 66.6% of pearl perch and teraglin catches, respectively, are less than 30 kg/boat/day in the commercial sector. 4% and 6.8% of pearl perch and teraglin catches, respectively, are greater than 100kg/boat/day in the commercial sector.

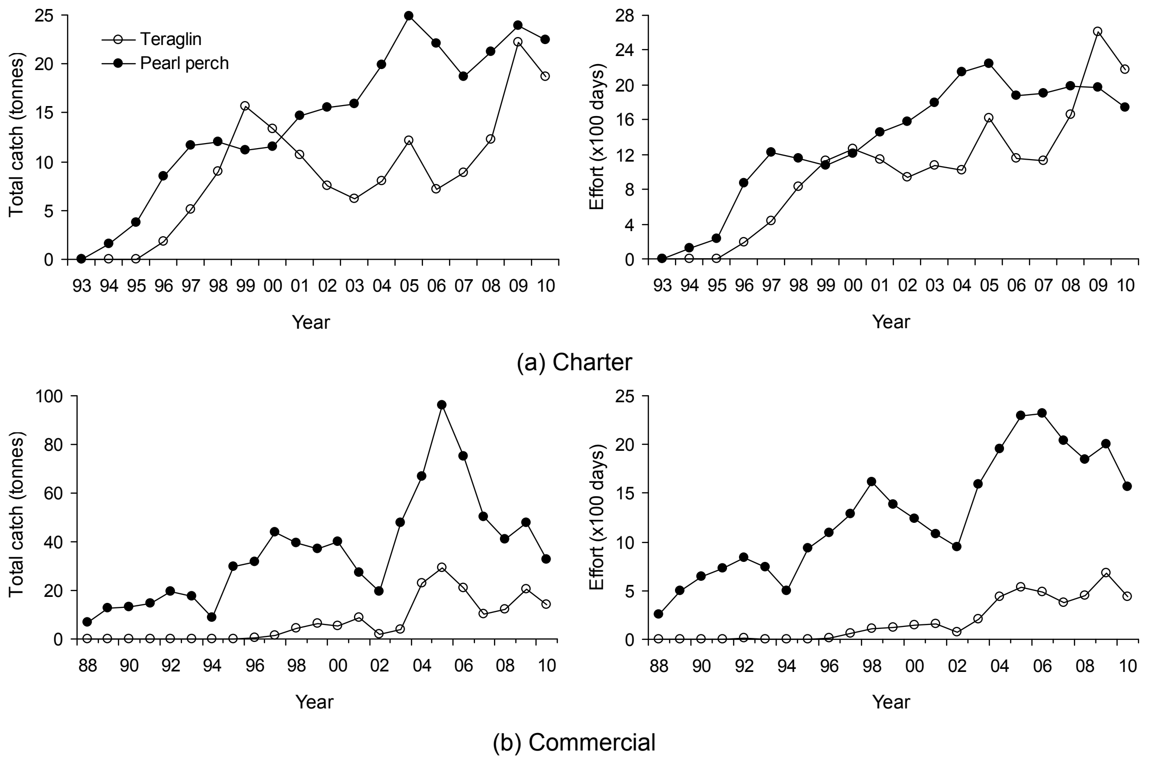

Figure 5 Total catch (in tonnes) and effort (x100 days) in the charter and commercial sectors of the RRFF from logbook data.

Teraglin are targeted primarily in the area adjacent to, and to the south of, Moreton Bay (Figure 7), largely in inshore areas. Approximately 31% of teraglin landed by the commercial sector since 1993 have come from the area offshore of Moreton Island, the South Passage Bar and the northern end of North Stradbroke Island (CFISH grid X37 from Figure1). This area is also frequented by charter operators, accounting for approximately 16.5% of teraglin landed by charter fishers. However, 53.4% of all teraglin landed by the charter sector have been caught in the area between the Southport Seaway and the northern end of North Stradbroke Island (X38).

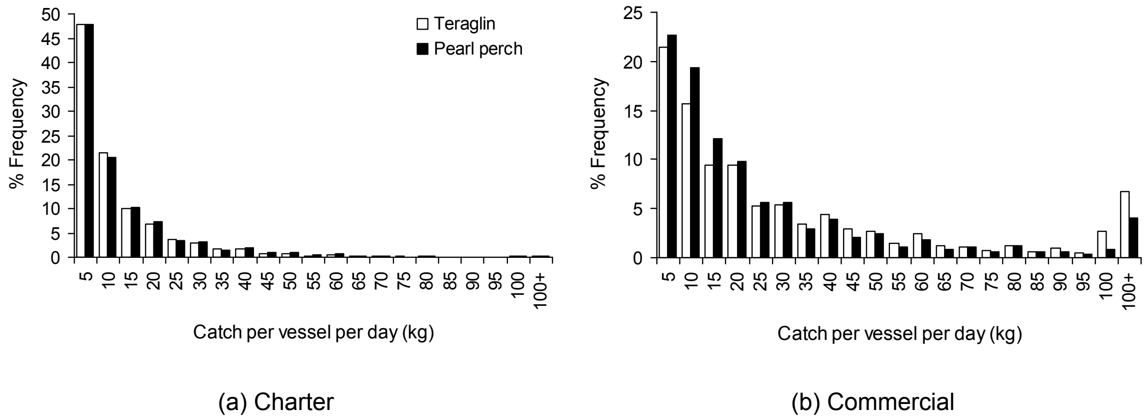

Figure 6 Frequency histograms of daily line catch in kilograms from the charter and commercial sectors for teraglin and pearl perch from logbook data.

Pearl perch are more widespread in their range, with the highest proportion of commercial catch coming from grounds adjacent to Fraser Island, Double Island Point, Moreton Bay and North Stradbroke Island. Charter operators tend to fish closer to shore, in similar areas to those fished by commercial operators.

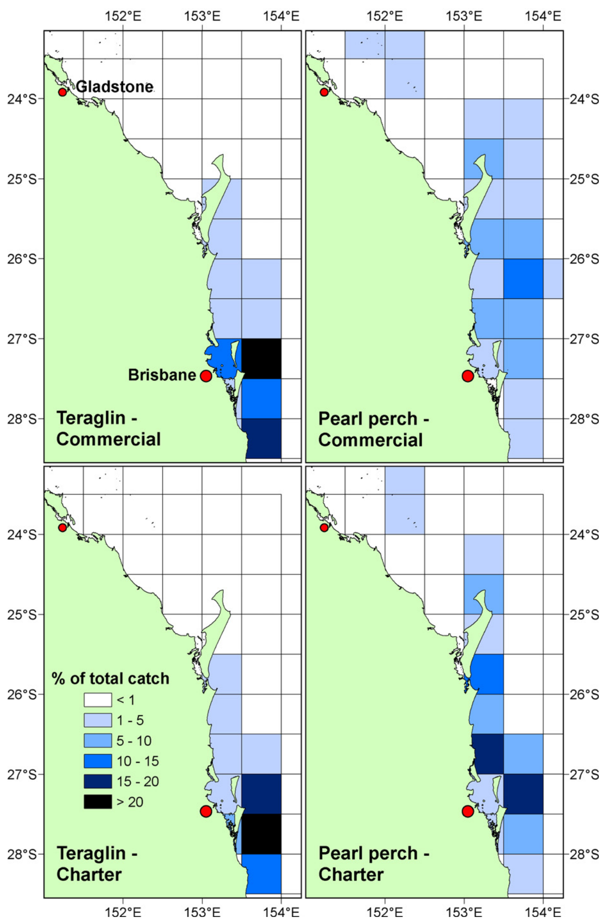

Figure 7 Distribution of catch of pearl perch and teraglin from the commercial and charter sectors of the RRFF, as a percentage of the total catch of each species in each sector, from logbook data.

Mean standardised catch rate of pearl perch from the commercial sector was 27.7 kg/boat/day compared to 10.4 kg/boat/day from the charter sector. Further, the mean standardised catch rate of teraglin from the commercial sector was 44.5 kg/boat/day compared to 11.3 kg/boat/day from the charter sector. Since 2000, the catch rates of pearl perch and teraglin, in both sectors, have increased (Figure 8).

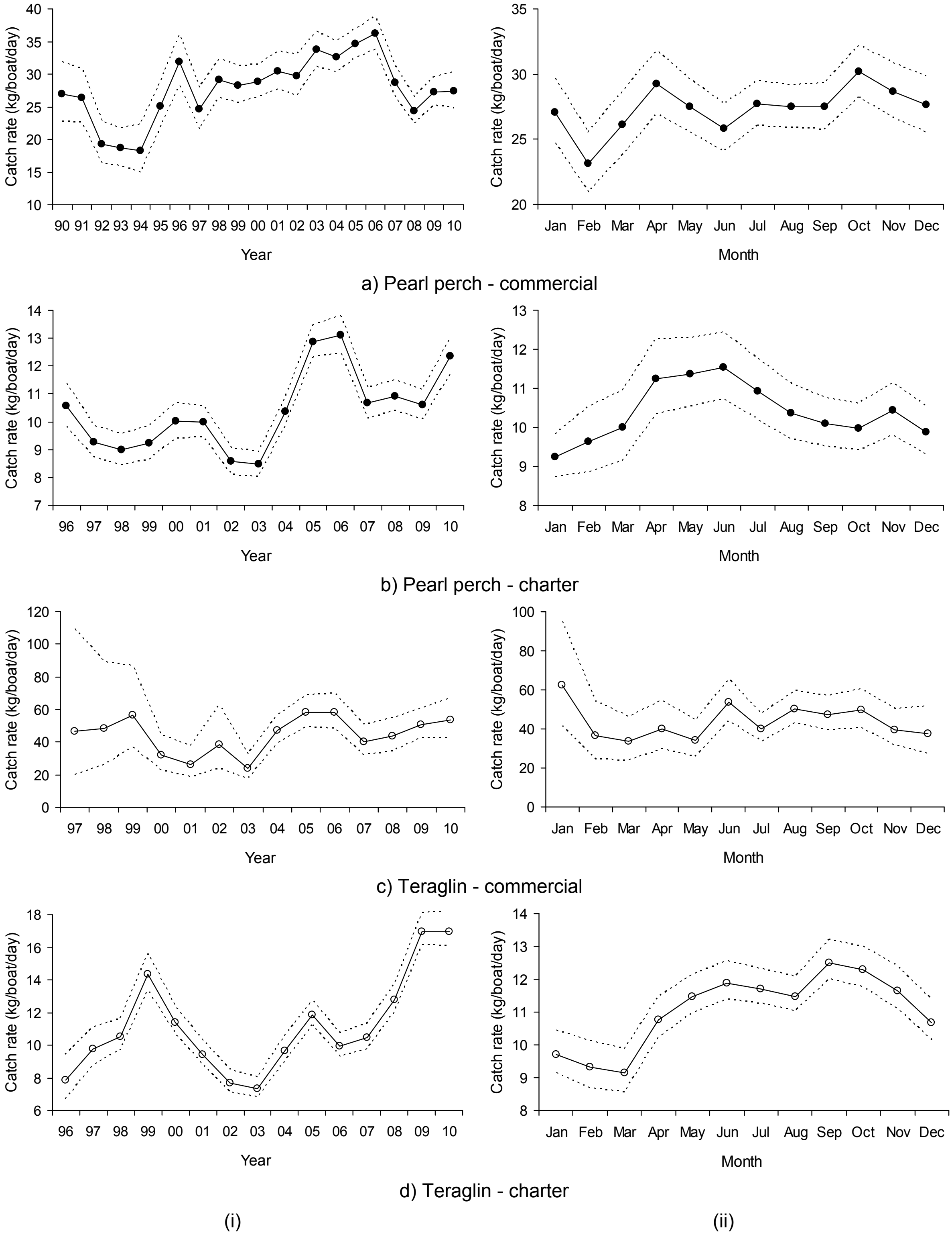

Figure 8 Bias-corrected back-transformed mean pearl perch and teraglin catch rates (in kg/boat/day) as a function of (i) year and (ii) month from the charter and commercial sectors of the RRFF. Dotted lines represent 95% confidence intervals.

The REML analyses indicates that the catch rates of pearl perch and teraglin from the RRFF were found to be significantly affected by temporal and spatial factors (see Table 2). The temporal factors, year and month, and the spatial factor, CFISH grid, were all found to significantly affect the catch rates of pearl perch and teraglin from the charter sector. In the commercial sector, the temporal factors had a significant effect on the catch rates of pearl perch and teraglin, while the spatial component had no significant effect (P = 0.67). Lunar phase was found not to have had any significant effect on the catch rates of pearl perch and teraglin in either sector. Further, there was a positive correlation between daily catches of pearl perch and teraglin and their associated snapper catches (Figure 9) and, as such, this variable was excluded from all analyses. From this point on, catch rate refers to the standardised catch rates from the REML analyses.

Pearl perch catch rates from the commercial sector increased from 18.2 kg/boat/day in 1994 to 36.2 kg/boat/day in 2006, before decreasing to approximately 27kg/boat/day during the period 2007-2010 (Figure 8a). Catch rates were highest in April and October and lowest during February.

Pearl perch catch rates from the charter sector remained at 9-10 kg/boat/day until 2001, before decreasing to 8.5 kg/boat/day (Figure 8b). Catch rates then increased to 13.1 kg/boat/day in 2006, followed by a decrease to 10.7 kg/boat/day during 2007-2009. In 2010, the catch rate of pearl perch from the charter sector increased to 12.3 kg/boat/day. Catch rates were higher from April, May and June.

Teraglin catch rates from the commercial sector decreased from 56.3 kg/boat/day in 1999 to 23.8 kg/boat/day in 2003 (Figure 8c). Since 2003, however, catch rates have increased with 53.4 kg/boat/day being caught in 2010. Teraglin catch rates were highest in 2006, with a standardised catch rate of 58 kg/boat/day being landed by commercial fishers. Catch rates of teraglin from the commercial sector increased from March (33.5 kg/boat/day) through to October (49.6 kg/boat/day), before a decrease was evident during the summer months, with a peak of 53.8 kg/boat/day occurring in June.

Teraglin catch rates from the charter sector decreased from 14.4 kg/boat/day in 1999 to 7.4 kg/boat/day in 2003 (Figure 8d). As with the commercial catch rates, teraglin catch rates from the charter sector have increased since 2003, reaching 17 kg/boat/day being caught in 2009. Catch rates of teraglin from the charter sector increase from 9.1 kg/boat/day in March to 12.5 kg/boat/day in September, before decreasing through the summer months.

Discussion

In accord with results reported by Campbell *et al*. (2009), anecdotal evidence supplied by commercial fishers suggest that snapper catch rates have declined significantly in recent years, forcing rocky reef fishers to target other species (J. Schiffiliti, B. Sutton, S. Butterworth; personal communications). Campbell *et al*. (2009) analysed snapper catch rates as part of a stock assessment, finding that snapper are either fully-fished or overfished. These authors found that the commercial catch rates were hyperstable, where catch rates remained relatively constant, or increased, despite increasing levels of fishing effort. Since 2007, catch rates of snapper have declined in the commercial sector. The decrease in snapper catch was evident in both the commercial and charter sectors from logbook data, with snapper catch decreasing as a proportion of total catch (Figure 3).

In the commercial sector, reductions in snapper catch rates have occurred concurrently with significant increases in fuel price and, despite the use of increasingly efficient outboard engines, this has led to fishers accessing fishing grounds closer to their home base. This is evident from logbook data, with inshore CFISH grids receiving increasing levels of fishing effort since 2000. In these grids, fishers can target wrecks, pinnacles and other favourable habitat known to hold large populations of cobia, yellowtail kingfish and pearl perch, traditionally considered as incidental catch by fishers targeting snapper. Further, some fishers target grass emperor on gravel and low relief reef areas, close to shore off the Sunshine Coast. These behaviours allow fishers to maximise profit by minimising fuel and other costs. This behaviour is evident from the logbook data, with the catch of these species increasing in recent years (see Figure 4).

Additionally, commercial rocky reef fishers have diversified into adjacent fisheries, particularly the deepwater line fishery targeting bar cod *Epinephelus ergastularius*, blue-eye trevalla *Hyperoglyphe antarctica*, hapuka *Polyprion oxygeneios* and bass grouper *Polyprion americanus* (Sumpton *et al.*, in press). Many commercial fishers also now target large red emperor *Lutjanus sebae* and other coral reef fish, in waters off Double Island Point and Fraser Island. Specialised techniques have been developed by rocky reef fishers to target these high value species, with some fishers using bottom discrimination software on computers to identify likely habitat.

Commercial rocky reef fishers are accessing these fisheries due to the high likelihood of large catches of species with high market value. However, as Sumpton *et al*. (in press) highlight, the effect of this increase in effort on the sustainability of the deepwater fishery is unknown. Similarly, the increasing catch of large red emperor at the southern end of their distribution may also be having an affect on the stock, particularly if spawning is occurring in this location. The inshore areas around Double Island Point are known to produce large catches of undersize (< 55cm TL) red emperor (Brown *et al.*, 2010) which suggests that the large red emperor may be spawning offshore and, hence, the effect of increasing catch and effort in these areas may be impacting red emperor stocks.

Increasing observed catches of the traditionally incidental species can also be explained by changes in the reporting behaviour of commercial fishers, as a consequence of changes to the Queensland Line Fishery Logbook, over time. Successive versions of the commercial Queensland Line Fishery Logbook have made provision for the reporting of more species. All versions of the Queensland Line Fishery Logbook up to July 2004 had snapper as the only rocky reef fish, with fields for coral reef fish and mackerel (see Figure 11), with three "Other" fields. In 2004, the fourth version of the Queensland Line Fishery Logbook (LF04, see Figure 12) had provision for the reporting of both snapper and pearl perch and two other rocky reef fish. The fifth version (LF05, see Figure 13), in operation since 2007, had provision for the reporting of all rocky reef fish. Figure 3b shows that the catch of species other than snapper, pearl perch and teraglin increased as a proportion of total catch from 2005, averaging 12.75% of total catch up to and including 2005 before increasing annually in the period 2006-2010, with 36.3% of RRFF landings being species other than snapper, pearl perch and teraglin in 2010.

Although the catch of species such as yellowtail kingfish, grass emperor and amberjack have increased since 2000, the annual catch of pearl perch and teraglin, as a proportion of total catch, have remained relatively stable in both the commercial and charter sectors (see Figure 3). Despite this, observed pearl perch and teraglin catch and effort have increased in both the commercial and charter sectors (Figure 5), as discussed below.

Sumpton *et al*. (1998) suggested that the increase in commercial pearl perch catch in 1995 (see Figure 5a) were not a result of the introduction of a MLS in 1993 but were likely a result of targeted fishing and expansion of effort into lightly-exploited fishing areas. Standardised catch rates of pearl perch (Figure 8a) reveal that 1994 was a particularly poor year for pearl perch in the commercial sector, as expected after the imposition of a MLS in the preceding year, before significant increases in catch rates during subsequent years. Although Sumpton *et al.* (1998) stated that the introduction of the MLS was unlikely to have caused the increasing catch rates in 1995/6, they also reported that average weight of commercially-caught pearl perch increased by 50% in 1994. This suggests that, prior to the introduction of the MLS, commercial fishers targeted smaller pearl perch. Given this, it is likely that the introduction of the MLS forced fishers to target slightly larger pearl perch and the increases in catch rates in 1995 and 1996 may have been a result in the increase of the average weight of individuals caught, rather than an increase in the number of fish caught.

The observed pearl perch catch rates reported by Sumpton *et al.* (1998) were similar to the standardised catch rates from the current study. The REML analysis implies that commercial pearl perch catch rates increased after 1994 through until 2006, most likely as a result of several factors. Firstly, as was the case for the snapper fishery, commercial fishers utilised highly efficient four-stroke and fuel-injected two-stroke outboard engines, allowing fishers to increase their range and access offshore reefs that were previously only lightly-fished. This, combined with the increased use of affordable, highly-sophisticated GPS and sonar equipment allowing fishers to accurately identify likely fish-holding habitat, improved the commercial fishers' ability to locate and exploit aggregations of pearl perch well offshore.

Further, during the 1990's and early 2000's, the use of mechanised fishing equipment, in the form of hydraulic and electric fishing reels, increased. This equipment allows fishers to target aggregations of pearl perch efficiently utilising up to six hooks on heavy mainlines. Also during this time, quality packaged bait became increasingly more available and less expensive. The bait – squid, cuttlefish, octopus, pilchards, scad, etc – are sourced from both domestic and overseas suppliers after being packaged fresh and frozen at sea. The advancements in fishing equipment, combined with quality bait used specifically to target pearl perch and the use of sophisticated GPS and sonar equipment, resulted in an increase in the efficiency of a unit of effort and has contributed to the increases in commercial pearl perch catch rates in Figure 8a.

Secondly, the shift away from targeting snapper, as a result of decreasing catch rates, saw fishers targeting pearl perch and resultant increases in catch rates. Although pearl perch were considered as bycatch during the early years of the logbook programme, commercial fishers realised the marketability of pearl perch given the species' status as a highly-prized table fish (McKay, 1997) and began expanding into locations known to produce quantities of pearl perch. Although caught over rocky reef with snapper, pearl perch are also known to inhabit areas adjacent to rocky reef, specifically in areas supporting wire weed (Gorgonid soft corals) and similar organisms. Such areas are now targeted by all sectors, with one such area near Hutchison's Shoal (see Appendix 3.5) referred to as Pearl Perch Alley. Further, wrecks and pinnacles, known to hold large populations of pearl perch, are easily targeted using the GPS and sonar equipment discussed above. The expansion into such areas and the deep waters referred to earlier has contributed to the increases in commercial pearl perch catch rates presented in Figure 8a.

Marriott *et al*. (2011) reported similar catch rate trends for commercially-caught West Australian dhufish (*Glaucosoma hebraicum*) from southern Western Australia, to those from the current study. However, these authors reported that the addition of factors relating to the uptake of colour sounders, GPS and electric reels significantly affected dhufish catch rates after using a mixed model analysis. Marriott *et al*. (2011) suggest that the adoption of these new technologies over time resulted in a divergence between the observed commercial dhufish catch rate and abundance. In an attempt to quantify the effects of the adoption colour sounders and GPS on pearl perch catch rates in the current study, a preliminary analyses was undertaken using data collected by Sumpton *et al.* (in press). These data quantified the proportion of fishing effort where colour sounders and/or GPS units were used by recreational anglers and were collected as part of a survey of recreational anglers accessing the rocky reef fishery in southern Queensland. The addition of an index of the use of technological advancements in the REML analysis revealed that the pearl perch catch rate data from the current study would be significantly lower than those presented in Figure 8a, with similar trends produced to those for the Marriott *et al*. (2011) study. The collection of information regarding the adoption of fishing-related technology by commercial fishers will be undertaken prior to the next snapper stock assessment scheduled for 2014 to ensure these data can be used to produce more accurate standardised catch rates.

Further, Jones and Luscombe (1993) reported on the effect of the adoption of fish-finding technology on the catch rates of snapper in the South Australian Scalefish fishery. These authors attributed a 5-50% increase in snapper catch rates caught over natural reefs to the installation of colour sounders.

Commercial catch rates of pearl perch were highest in April and October (Figure 8a), coinciding with relatively high mean gonosomatic index (see Appendix 3.1). Although it is difficult to substantiate, it is likely that the increased catch rates in April and October evident from the REML analysis are a result of commercial fishers exploiting aggregations of pearl perch that are either spawning or gathering to spawn. Sumpton *et al.* (1998) found that catch rates were not significantly different throughout the year, although decreases were apparent in March and October, contrasting with results in the current study. Further, Sumpton *et al.* (1998) reported that commercial pearl perch catch rates were highest in January and December. However, the data used to generate these results were submitted by commercial fishers up until 1996 and, as such, the catches were taken prior to the expansion of the pearl perch fishery discussed above. Prior to this, snapper were caught primarily over rocky reef, with pearl perch landed as bycatch in these areas. However, during the spawning months, pearl perch likely vacated the rocky reef areas and aggregated elsewhere, resulting in lower catch rates during these months for fishers primarily targeting snapper over rocky reef areas. The diversification of the RRFF during the late 1990's and through the 2000's has seen these aggregations targeted, resulting in the high catch rates during April and October in Figure 8a.

Teraglin were of much less importance to commercial fishers compared to pearl perch with teraglin accounting for only approximately 3% of total landings during the Queensland Line Fishery Logbook period, while pearl perch accounted for 18% (Figure 5a and Figure 5b). In accord with Sumpton *et al.* (1998), the reporting of commercial teraglin catch was minimal prior to 2000, with less than 150 boat-days of reported effort per year. Since 2003, effort has increased and reached a maximum of 683 boat-days in 2009, while commercial catch rates also increased post–2003 (Figure 8c). Although less teraglin are caught by commercial fishers compared to pearl perch, individual daily catches are significantly higher, with 9.5% of all catches being 100 kg or more. The lack of catch prior to 2004 may be a result of the format of the Queensland Line Fishery Logbook, with only two fields available for rocky reef fish, as discussed above.

The REML analysis revealed that, since 2003, commercial teraglin catch rates have averaged 50 kg/boat/day, with a maximum of 58 kg/boat/day reached in 2005 (Figure 11.5b). As with the snapper catch rates reported by Campbell *et al*. (2009), teraglin catch rates increased in the period 2004-2006, coinciding with the investment warning as discussed previously, after a period of declining catch rates (Figure 8c). The commercial catch rates of teraglin are highly correlated to the catch rates of snapper reported by Campbell *et al*. (2009) up until 2007, with teraglin catch rates increasing annually since this time. This suggests that, unlike pearl perch, teraglin have remained an incidental catch of fishers targeting snapper in rocky reef areas where significant populations of teraglin are located. Areas such as Square Patch, off the South Passage Bar, and the reefs south of Point Lookout, off Stradbroke Island, are examples of locations regularly fished by all sectors, targeting snapper and teraglin.

Recent increases in commercial teraglin catch rates (Figure 8c), during a time when snapper catch rates are decreasing, suggest that some commercial fishers have targeted teraglin. Teraglin are relatively easy to target given their propensity to form dense schools over rocky reef (Sumpton *et al.*, 1998). Once aggregations are located, large catches are possible, with 6.7% of all teraglin catches being greater than 100kg. As with pearl perch, advances in fish-finding technologies, along with the increased availability of high quality bait, have contributed to increases in catch rates. Similar trends were observed in the Kwazulu-Natal line fishery in South Africa, where slinger *Chrysoblephus puniceus*, a Sparid similar to snapper, were heavily exploited by commercial and recreational fishers, resulting in a reduction in the size of slinger caught (Penney *et al.*, 1999). The reduction in size of slinger led to an increase in the targeting of teraglin (called geelbek in South Africa) and other Sciaenids, the catch of which increased from <10% of landings historically, to one-third of total catch in 1997.

As with the commercial sector, charter operators appear to have diversified away from targeting snapper. Charter operators are now preferring to concentrate effort on aggregating species likely to return higher catches for their clients, rather than accessing fishing areas that yield high numbers of snapper (e.g. travelling 55kms to the Barwon Banks off Mooloolaba). Charter operators are likely to access areas close to shore due to restrictive fishing hours, with the number of relatively low-cost, half-day charters increasing in recent years (Ray Joyce, personal communication). On the Gold Coast, the charter sector accesses inshore reefs or wrecks, which yield good numbers of teraglin and tailor (*Pomatomus saltatrix*) and minimise the cost of fuel. Similarly, Brisbane-based charter operators target areas that are known to yield high catch rates of teraglin, pearl perch, yellowtail kingfish and cobia, including Square Patch and Caloundra Wide, thereby providing a satisfying experience for clients and minimising fuel costs.

The analysis of snapper catch rates from the charter sector by Campbell *et al*. (2009) revealed that catch rates declined from 1999 to 2007, while increases in catch rates of pearl perch and teraglin were evident over this period (Figure 8). Further, the catch of amberjack, grass emperor, cobia and yellowtail kingfish have increased since the introduction of the Queensland Commercial Fishing Tour Logbook, with cobia catch increasing almost exponentially in the period 2001-2005 (Figure 4).

The catch rates of pearl perch and teraglin caught by the charter sector were significantly lower than those from the commercial sector (Figure 8). This is due to at least three factors. Firstly, charter operators provide a base from which recreational anglers are able to access the RRFF and, as such, the recreational anglers are bound by bag limits. Current bag limits restrict charter anglers to 5 of each species per angler per day, resulting in lower catch rates than the commercial sector. Secondly, the hours-fished-per-day by commercial fishers is significantly higher than that from charter sector. As stated previously, many charters are now only around half a day. As such, in order to compare catch rates between the commercial and charters sectors, hours-fished-per-day should be reported in logbooks. Further, the reporting of hours-fished-per-day would also be beneficial in order to quantify the effect of, and remove variation attributable to, this factor. It is likely that hours fished would significantly affect the catch rates of all species in both sectors, yet very few logbook records contain this information. Lastly, commercial operators are superior fish-catchers to those accessing the RRFF aboard charter vessels. Although very good recreational anglers employ the services of charter vessels on occasion, the overwhelming majority of charter fishers targeting snapper, pearl perch and teraglin are relatively inexperienced – most experienced recreational anglers have their own vessels and, as such, do not require the services of charter operators.

Pearl perch and teraglin catch rates increased from the charter sector after the management changes in 2003. As with the commercial fishery, the introduction of more sophisticated GPS and sonar technology, combined with the shift away from targeting snapper, has contributed to these increases. The inclusion of covariates describing the uptake of GPS and colour sounders, as discussed above and by Marriott *et al*. (2011), would likely result in decreasing catch rates of both species in the charter sector.

Although the catch rates of pearl perch and teraglin are likely to have been affected by the fish finding technologies discussed earlier, the fishing gear used by anglers accessing the RRFF via charter operations has also likely affected catch rates. In recent years, the availability of high-quality fishing equipment, combined with the increased used of braided fishing lines and purpose-designed artificial lures, has increased the efficiency of charter-based fishing effort. Traditionally, charter fishers used monofilament fishing lines, baited with pilchards or squid, on paternoster rigs. Although these methods are in use today, undoubtedly a higher proportion of charter anglers are employing braided fishing lines, chemically-sharpened hooks, quality carbon-fibre fishing rods and fishing reels capable of landing very large fish due to improving drag systems. It is, therefore, prudent to quantify the effects of these advancements in gear-related technology in order to provide better estimates of fishing power associated with these factors.

Further, the prevalence of fishing-related internet sites has seen an unprecedented amount of information available to recreational anglers accessing the RRFF via charter vessels. Internet forums enable recreational fishers to gather information regarding fishing gear and techniques which would have taken much longer prior to the popularity of such forums. Such information is also used by charter operators and commercial fishers, who are able to access internet forums to assess likely fishing spots and target species based on fishing reports posted on such sites by recreational anglers. The internet also provides anglers access to overseas retail outlets specialising in fishing equipment such as braided fishing line, along with internet-based auction sites. Throughout the period where the Australian dollar was weak against the American dollar, high-quality fishing tackle was available at reduced prices given the lack of sales tax on some imported equipment (<$1000). The weakening of the American dollar against the Australian dollar recently has increased the popularity of overseas purchasing because of the decrease in cost of high-quality fishing tackle to Australian anglers. Although difficult to quantify, these factors have certainly affected fishing power in the charter sector.

The pearl perch and teraglin catch rates in Figure 8b and Figure 8d show that 2003 was a poor year for both these species in the charter sector. However, during the subsequent 2-3 years, catch rates increased significantly. This also occurred in the recreational and charter snapper fishery as reported by Campbell *et al*. (2009). The fact that the catch rates of these rocky reef species increased in the years immediately after the management changes described earlier were introduced suggests that the changes contributed to the increase in catch rates for these years.

In the case of teraglin, the decrease in the MLS from 45cm to 38cm would have resulted in an increase in the number of individuals caught, particularly in the commercial fishery where fishers are not restricted by bag limits. This is obvious in the catch rate data, with teraglin catch rates increasing from ≈24 kg/boat/day in 2003 to ≈49 kg/boat/day in 2004. However, the teraglin catch rate in the charter sector increased only by approximately 30%, most likely as a consequence of the existing bag limit of 5 per angler per day and the decrease in the average weight of the smaller fish targeted after the decrease in minimum legal size. Increases in the teraglin catch rates from the charter sector since 2007 are likely due to charter operators concentrating effort on inshore reefs where smaller teraglin are caught in large numbers. Although these fish are smaller, charter anglers are able to catch their bag limits easily once a school is found.

Similar to teraglin, pearl perch catch rates increased significantly in 2004 and 2005 in the charter sector. This is difficult to justify given that the imposition of a higher MLS would have likely resulted in a reduction in catch immediately after the management changes. However, the management changes were brought into effect during September 2003 and, given a 30cm pearl perch would take approximately 9-10 months to reach 35cm (see Appendix 3.1 for growth curves), these fish would have been available for capture from around May/June, 2004. At this time, therefore, a large pulse of 35cm fish would have recruited to the exploited portion of the fishery, given that post-release survival is high (see Appendix 3.5). This would have contributed to the increased catch rates throughout late 2004 and 2005 (Figure 8d) along with the adoption of fish finding technologies discussed earlier. The fact that the pearl perch catch rates decreased from the commercial fishery (Figure 8a) suggests that commercial operators target slightly larger pearl perch as discussed in Appendix 3.1, reducing the impact of the increase of MLS introduced in 2003.

Pearl perch and teraglin catch rates were highest during the winter/spring period in the charter sector. During the summer months, many charter operators target pelagic species, corresponding to a decrease in the catch of rocky reef fish. This is particularly the case in recent years, with many charter operators catering for anglers wishing to catch spotted mackerel *Scomberomorus munroi*, Spanish mackerel *Scomberomorus commerson* and marlin *Makaira indica* during the summer months. Penney *et al*. (1999) reported a similar phenomenon in the KwaZulu-Natal line fishery where line fishers targeted king mackerel (Spanish mackerel) during summer months. Further, charter operators have diversified into catch-and-release angling targeting amberjack, yellowtail kingfish and samsonfish with highly-sophisticated tackle developed by Japanese anglers, specifically for these schooling, hard-fighting species. Light, powerful graphite fishing rods combined with robust, well-made fishing reels and braided polyethylene fishing lines have allowed anglers to target these large predatory rocky reef fish, resulting in less effort being applied to bait-fishing for traditional rocky reef fish.

Further, weather conditions during the summer months in south-east Queensland are influenced by large high pressure systems in the Great Australian Bight which result in strong south-easterly winds. As such, charter operators are constrained by weather during summer, resulting in low catches of rocky reef fish. In recent years, south-east Queensland has experienced dramatic flooding events which have also reduced access to the RRFF by charter operators during January, February and March. In contrast, late autumn and spring are characterised by periods of relatively calm conditions typified by lighter south-westerly winds during the morning and light onshore seabreezes in the afternoon.

From the REML analyses, CFISH grid, Year and Month significantly affected catch rates in all models, apart from CFISH grid in the commercial teraglin analysis due to the low number of grids in which commercial fishers landed teraglin. Ideally, the spatial resolution of logbook data should be enhanced, with only a small percentage of current logbook records containing site (6 x 6 nautical miles) information. This could be achieved using GPS technologies interfaced with electronic logbooks like those used in Salmonid fisheries in Canada. In this fishery, commercial fishers use electronic tablets interfaced with a GPS receiver to record catch and location information before reporting the information via email to the management agency (Ron Goruk, Fisheries and Oceans Canada, personal communication). Such information in RRFF would provide important information regarding locations, depths and time fished during a fishing day. At present, the location information is at a resolution of 30 x 30 nautical miles which, in south-east Queensland, may incorporate catches landed in depths ranging from 20m to 150m. The imposition of such management measures, however, is unpopular with fishers. As such, it is important to extend the benefits of such systems to fishers including the ease in recording information using drop-down menus, etc, decreasing times to fill-out logbooks, reports of catch information for use by the fisher (fishing diary) and sending the logbook information via email negating the need to send paper-based information.

In conclusion, pearl perch and teraglin catch rates have increased in both the charter and commercial sectors. This was driven by a reduction in the catch rates of snapper, a consequent redirection of fishing effort onto these two species and increases in fishing power attributable to advancements in fish-finding and fish-catching technologies. Further research should focus on quantifying the effects of these advancements on catch rates. Logbook information has shown that snapper catch has decreased in the last 10-12 years in both the commercial and charter sectors, with the landings of amberjack, cobia, yellowtail kingfish and grass emperor increasing during this time. The targeting of pearl perch and, to a lesser extent, teraglin will have ramifications for the populations of these species.

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Supplementary Information

Table 2 Tests for fixed effects from REML analyses after dropping individual terms from the full fixed model. Licence number was added to each model as a random term. Lunar phase, lunar phase offset by 7 days and associated snapper catches were added to each model but were excluded if there was no significant effect.

Species – Sector	Fixed term	Wald statistic	d.f.	*F*-statistic	*P*
Teraglin – Charter	Year	614.64	15	40.98	$P < 0.001$
	Month	125.43	11	11.40	$P < 0.001$
	Grid	54.50	15	3.63	$P < 0.001$
Teraglin – Commercial	Year	77.15	13	5.93	$P < 0.001$
	Month	37.21	11	3.38	$P < 0.001$
	Grid	6.79	9	0.74	$P = 0.670$
Pearl perch – Charter	Year	310.31	15	20.69	$P < 0.001$
	Month	387.13	29	13.35	$P < 0.001$
	Grid	100.74	11	9.16	$P < 0.001$
Pearl perch – Commercial	Grid	628.67	21	29.94	$P < 0.001$
	Year	237.93	20	11.90	$P < 0.001$
	Month	38.18	11	3.47	$P < 0.001$

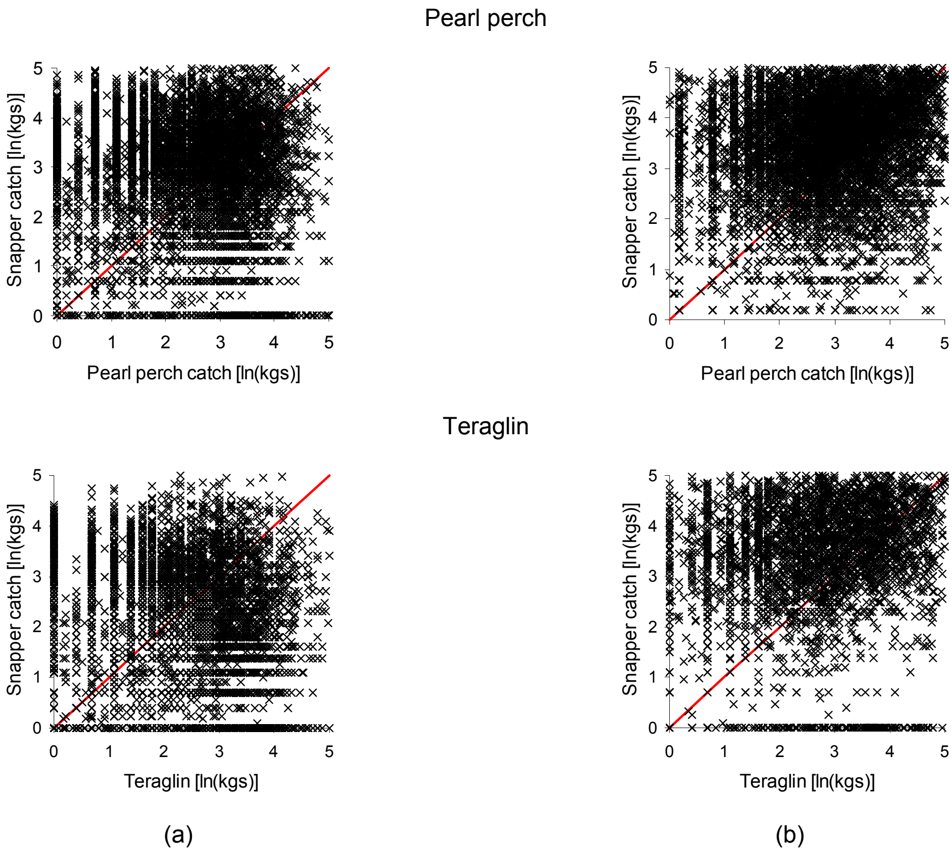
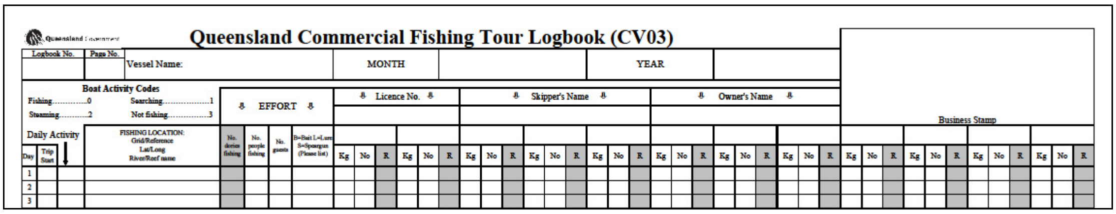


Figure 9 Snapper catch as a function of associated pearl perch and teraglin catch from the charter (a) and commercial (b) sectors of the RRFF from logbook data. All variables have been log-transformed

The following extracts from commercial and charter logbooks were provided by Doug Zahmel, Fisheries Logbook Coordinator, Fisheries Queensland.


Queensland Commercial Fishing Tour Logbook (CV03)

Logbook No.	Page No.	Vessel Name:	MONTH		YEAR	

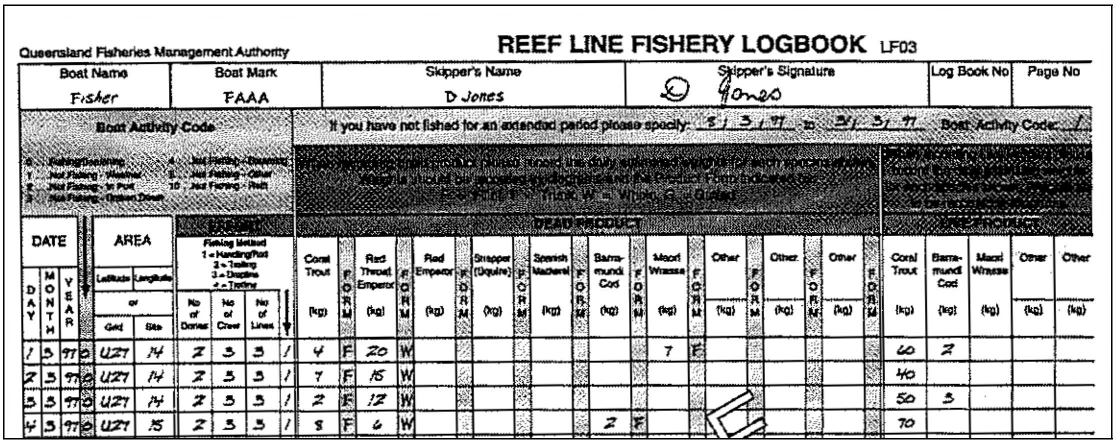
Boat Activity Codes
Fishing.............0 Searching.....................1
Steaming...........2 Not fishing...................3

EFFORT | Licence No. | Skipper's Name | Owner's Name | Business Stamp

Daily Activity | Day | Trip Start | FISHING LOCATION: Grid/Reference Lat/Long River/Reef name | No. divers fishing | No. people fishing | No. guests | B=Bait L=Lure S=Spearguns (Please list) | Kg | No | R | Kg | No | R | Kg | No | R | ...

Day 1, 2, 3

Figure 10 Extract from the Queensland Commercial Fishing Tour Logbook, used to record daily catch from charter operators in the RRFF. The CV03 is similar to previous versions CV01 and CV02.


Queensland Fisheries Management Authority
REEF LINE FISHERY LOGBOOK LF03

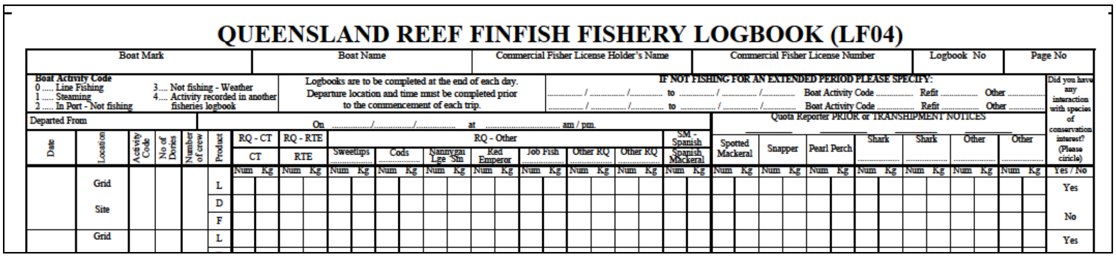
Boat Name	Boat Mark	Skipper's Name	Skipper's Signature	Log Book No	Page No
Fisher	FAAA	D Jones	D Jones		

Boat Activity Code
If you have not fished for an extended period please specify: 5 / 3 / 97 to 31 / 3 / 97 Boat Activity Code: 1

DATE (DAY, MONTH, YEAR) | AREA (Latitude, Longitude or Grid, Site) | EFFORT: Fishing Method (1 = Handline/Rod, 2 = Trolling, 3 = Dropline, 4 = Trotline), No of Dories, No of Crew, No of Lines | DEAD PRODUCT: Coral Trout (kg), FORM, Red Throat Emperor (kg), FORM, Red Emperor (kg), FORM, Snapper (Squire) (kg), FORM, Spanish Mackerel (kg), FORM, Barramundi Cod (kg), FORM, Maori Wrasse (kg), FORM, Other (kg), FORM, Other (kg), FORM, Other (kg), FORM | LIVE PRODUCT: Coral Trout (kg), Barramundi Cod (kg), Maori Wrasse (kg), Other (kg), Other (kg)

DAY	MONTH	YEAR	Grid	Site	No of Dories	No of Crew	No of Lines	Method	Coral Trout (kg)	FORM	Red Throat Emperor (kg)	FORM	Barramundi Cod (kg)	FORM	Maori Wrasse (kg)	FORM	Live Coral Trout (kg)	Live Barramundi Cod (kg)
1	3	97	U27	14	2	3	3	1	4	F	20	W			7	F	60	2
2	3	97	U27	14	2	3	3	1	7	F	15	W					40	
3	3	97	U27	14	2	3	3	1	2	F	12	W					50	3
4	3	97	U27	15	2	3	3	1	8	F	6	W	2	F			70	

Figure 11 Extract from the Queensland Line Fishery Logbook, used to record daily catch from commercial fishers operating in the RRFF. The LF03 was in operation from July 1997 to July 2004.


QUEENSLAND REEF FINFISH FISHERY LOGBOOK (LF04)

Boat Mark	Boat Name	Commercial Fisher License Holder's Name	Commercial Fisher License Number	Logbook No	Page No

Boat Activity Code
0 ..... Line Fishing 3.... Not fishing - Weather
1 ..... Steaming 4.... Activity recorded in another fisheries logbook
2 ..... In Port - Not fishing

Logbooks are to be completed at the end of each day. Departure location and time must be completed prior to the commencement of each trip.

IF NOT FISHING FOR AN EXTENDED PERIOD PLEASE SPECIFY:
...../...../..... to ...../...../..... Boat Activity Code .... Refit .... Other ....
...../...../..... to ...../...../..... Boat Activity Code .... Refit .... Other ....

Departed From | On ...../...../..... at .... am / pm.

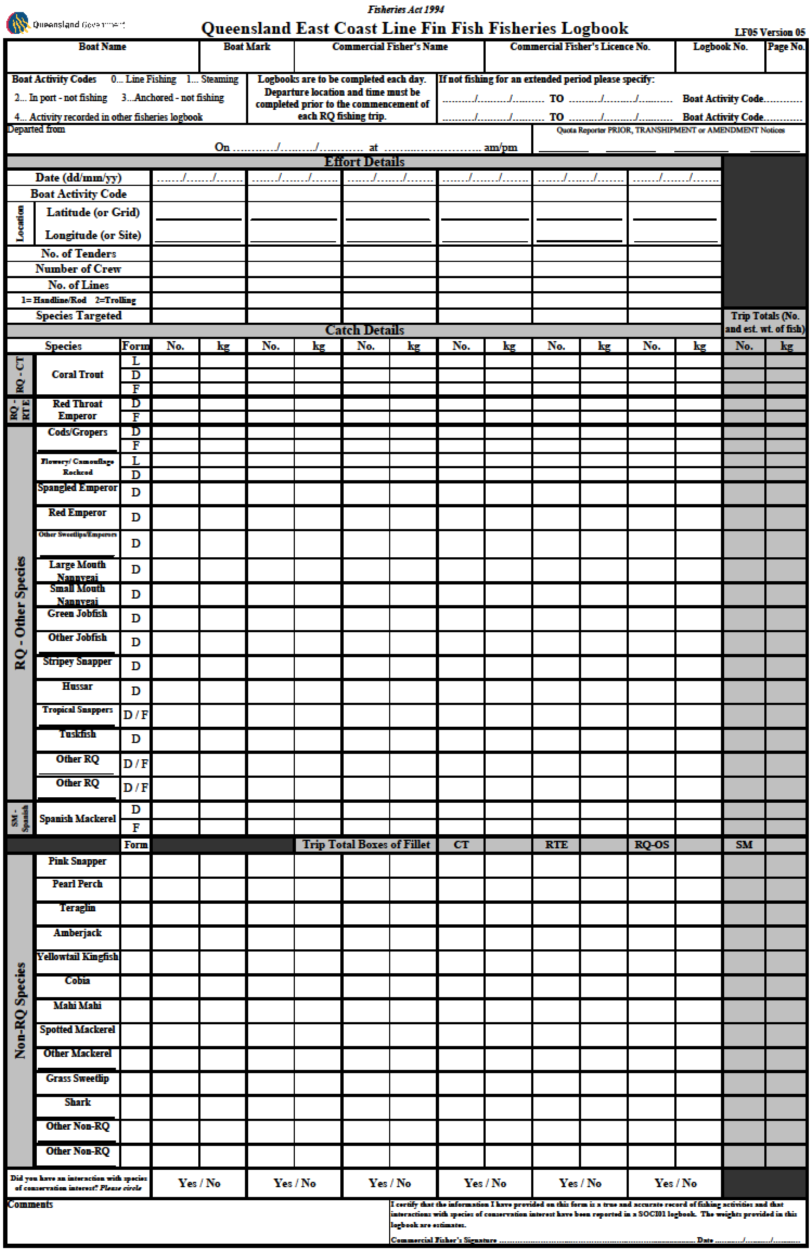
Quota Reporter PRIOR or TRANSHIPMENT NOTICES

Date | Location | Activity Code | No of Dories | Number of crew | Product | RQ - CT (CT) | RQ - RTE (RTE) | RQ - Other: Sweetlips, Cods, Nannygai Lge 'Stn, Red Emperor, Job Fish, Other RQ, Other RQ | SM - Spanish (Spanish Mackerel) | Spotted Mackeral | Snapper | Pearl Perch | Shark | Shark | Other | Other | Did you have any interaction with species of conservation interest? (Please circle)

Num Kg | Yes / No

Grid / Site / Grid | L / D / F / L | Yes / No / Yes

Figure 12 Extract from the Queensland Line Fishery Logbook, used to record daily catch from commercial fishers operating in the RRFF. The LF04 was in operation from July 2004 to July 2007.



Fisheries Act 1994

Queensland Government

Queensland East Coast Line Fin Fish Fisheries Logbook

LF05 Version 05

Boat Name	Boat Mark	Commercial Fisher's Name	Commercial Fisher's Licence No.	Logbook No.	Page No.

Boat Activity Codes 0... Line Fishing 1... Steaming 2... In port - not fishing 3...Anchored - not fishing 4... Activity recorded in other fisheries logbook

Logbooks are to be completed each day. Departure location and time must be completed prior to the commencement of each RQ fishing trip.

If not fishing for an extended period please specify:
........./........./......... TO ..../........./......... Boat Activity Code..........
........./........./......... TO ..../........./......... Boat Activity Code..........

Departed from On ..../........./......... at .... am/pm

Quota Reporter PRIOR, TRANSHIPMENT or AMENDMENT Notices

Effort Details

Date (dd/mm/yy)	...../...../.....	...../...../.....	...../...../.....	...../...../.....	...../...../.....	...../...../.....
Boat Activity Code						
Location – Latitude (or Grid)						
Location – Longitude (or Site)						
No. of Tenders						
Number of Crew						
No. of Lines 1= Handline/Rod 2=Trolling						
Species Targeted						

Catch Details

Group	Species	Form	No.	kg	No.	kg	No.	kg	No.	kg	No.	kg	No.	kg	Trip Totals (No. and est. wt. of fish) No.	kg
RQ - CT	Coral Trout	L														
		D														
		F														
RQ - RTE	Red Throat Emperor	D														
		F														
RQ - Other Species	Cods/Gropers	D														
		F														
	Flowery/ Camouflage Rockcod	L														
		D														
	Spangled Emperor	D														
	Red Emperor	D														
	Other Sweetlips/Emperors	D														
	Large Mouth Nannygai	D														
	Small Mouth Nannygai	D														
	Green Jobfish	D														
	Other Jobfish	D														
	Stripey Snapper	D														
	Hussar	D														
	Tropical Snappers	D / F														
	Tuskfish	D														
	Other RQ	D / F														
	Other RQ	D / F														
SM - Spanish	Spanish Mackerel	D														
		F														
		Form			Trip Total Boxes of Fillet			CT		RTE		RQ-OS			SM	
Non-RQ Species	Pink Snapper															
	Pearl Perch															
	Teraglin															
	Amberjack															
	Yellowtail Kingfish															
	Cobia															
	Mahi Mahi															
	Spotted Mackerel															
	Other Mackerel															
	Grass Sweetlip															
	Shark															
	Other Non-RQ															
	Other Non-RQ															
	Did you have an interaction with species of conservation interest? *Please circle*		Yes / No		Yes / No		Yes / No		Yes / No		Yes / No		Yes / No			

Comments

I certify that the information I have provided on this form is a true and accurate record of fishing activities and that interactions with species of conservation interest have been reported in a SOCI01 logbook. The weights provided in this logbook are estimates.

Commercial Fisher's Signature .... Date ..../........./.........

Figure 13 The Queensland Line Fishery Logbook, used to record daily catch from commercial fishers operating in the RRFF. The LF05 has been in operation from July 2007.

APPENDIX 3.11 HISTORICAL RECREATIONAL CATCH AND EFFORT INFORMATION FOR ROCKY REEF SPECIES AND ITS IMPLICATIONS FOR STOCK ASSESSMENT AND HARVEST STRATEGY DEVELOPMENT

Summary

A variety of information is available to examine the historical changes in recreational rocky reef catch since the early 1990's when a range of more accurate methods of catch estimation were adopted. While there may be some debate about the accuracy of the historic Queensland Fish Board (QFB) records, the close correlation of boat registration and the catch records for some species suggests that they are a valuable index of changes in catch although their use for either pearl perch or teraglin is limited by the lack of consistent reports for these species. Available evidence confirms that these data are still a useful historic indicator of snapper relative abundance but we believe that efforts should be made to determine events though time that may have impacted on the QFB records. A key recreational data issue for the most recently collected (since the 1990's) data is the interpretation and analysis of "zero" catch records of rocky reef species (or group of species). The attribution of a zero catch to a fishing trip that had no chance of catching a particular species will severely bias catch rate estimates, as will the elimination of zero catches from any analysis. Significant management changes for snapper including lowering of bag limits (from 30 to 4) and increases in MLS (from 25 to 35cm) have had a significant impact on recreational catch rates effectively lowering both the mean and variance in catch rate as these changes were introduced. These changes have the potential to cause a change in future stock status assessments. In particular, the recent introduction of a maximum MLS and associated bag limit of one snapper above this size for recreational anglers has the potential of adversely impacting future assessments unless the extent of discarding of larger fish above the bag limit and MLS can be included in the assessment. The impact of management changes on discarding is even more dramatic for teraglin where catches in excess of the bag limit were historically more common. The RFISH data (from diaries) is of limited value for teraglin due to the low numbers of this species recorded by diary respondents and the high relative standard error of the estimates. The fact that recreational anglers report larger numbers of snapper in these surveys and that diary respondents are predominantly from south-east Queensland where snapper are the main target offshore species results in the snapper catch being more precisely estimated than other rocky reef species (as reflected in a higher relative standard error). We recommend that future research should attempt to determine differences in catch rates and other fishery parameters for daytime versus night time anglers, as well as catch rates of fishers using trailerable vessels leaving and returning from ramps versus catch rates of fishers from privately moored vessels (those that cannot be surveyed from boat ramps).

Introduction

Recreational fishers take the majority of the catch of rocky reef species in southern Queensland (particularly snapper, pearl perch and teraglin) and recent stock assessments and recreational catch surveys (Higgs 1999, Higgs 2001, McInnes 2006, McInnes 2008, Allen *et al.* 2008, Campbell *et al.* 2009) have confirmed this over a number of years. As such, it is important that estimates of recreational catch and effort should be as accurate and precise as possible and that all possible sources of bias are identified and accounted for in any analysis or fishery assessment.

Recent recreational catch data (collected since 1990) comes from basically two sources; firstly from research surveys conducted as part of more localised research work, and secondly from larger scale state-wide phone and fishing diary surveys of recreational anglers. The objectives of the former surveys have often been to allow the estimation of catch, effort or catch rates for particular species or areas while the latter are designed more for obtaining demographic information as well as state-wide estimates of catch. There have been a number of different methods applied to the research surveys including bus route methods, roving creel surveys, access point catch surveys and aerial surveillance estimates of effort (see Pollock *et al.* 1994). Each of these methods has its own particular issues with respect to accuracy and precision and each can potentially provide biased estimates if underlying assumptions of the surveys are not fully understood.

Recreational catch information prior to the 1990's is very limited and indices of catch are often inferred from boat registration data, other population demographic data or from Queensland Fish Board records. The latter have been used extensively in stock assessments and other studies correlating catch with environmental measures (Halliday and Robins 2007).

In this chapter we discuss the data available to assess the recreational component of the rocky reef fishery, particularly as they relate to the three main target species of snapper, pearl perch and teraglin. We also describe the management arrangements for the rocky reef fishery, and discuss how changes to these arrangements may have impacted on the data that are used in stock assessments. It is recognised that changes in historical management arrangements have dramatic impacts on all sectors in the fishery but non-recreational fishery issues are also discussed in other chapters of this report as they pertain to both the commercial and charter sectors.

In this chapter we have not considered the catch data held by various fishing clubs, which could also provide useful indices of stock abundance. This is an area that has received some investigation in the past and clearly warrants further research to determine if these data can provide an alternative source of representative catch rate data for incorporation in fishery assessments.

Historical Management Arrangements

The extent to which management changes have impacted the recreational catch (and indeed the catch of other sectors) is an area of debate among stakeholders in this fishery but an understanding of these management changes is necessary to fully understand potential changes to recreational catch and effective fishing effort over time and how these changes may have affected the value of those rates as an index of stock abundance. The following is a brief account of the development of management that may have affected rocky reef fisheries.

Line fishing for rocky reef fin fish species, and other line caught species, was only restricted prior to 1979 by general fisheries management interventions. Size limits had been in place on snapper for decades being introduced at a size of 10 inches and subsequently changed to 25cm with the introduction of metric measurement in Australia in 1960's. Prior to 1984, there were no limitations on commercial harvesting of these fish other than the requirement for a person to hold a licence, the issue of which was not restricted. In 1984, limited licensing of commercial fishing boats was introduced with the advent of primary and tender fishing boat licences. Licences issued under the *Fishing Industry Organisation and Marketing Act (FIOMA) 1984* were restricted with no further primary boat licences to be issued. In 1987, further restrictions were applied to commercial fishers through licensing, with a general 'freeze' on the grant of new tender boat licences, a process that was later adopted into law in 1993.

The Offshore Constitutional Settlement (OCS) came into force in 1987, at which time responsibility for management of rocky reef fin fish species, and others, was delegated by the Commonwealth Government to the Queensland Government. The jurisdiction which was previously limited to a distance of 3 nautical miles for the baseline of Queensland was replaced by a jurisdiction line set further to sea which largely encompasses the distribution of rocky reef fin fish species off the coast of Queensland. The jurisdictional arrangements were further refined in 1995 but the change had minimal effect on the management of this species group. Specific details including fish species and boundaries of the Queensland jurisdiction on the east coast are contained in the *Queensland Government Gazette* of 10 February 1995. These amendments caused further changes in the licensing arrangements for commercial fishing, to allow for the inclusion of additional active fishers who had operated in adjacent waters now the responsibility of the State, who had previously held Commonwealth licences.

The Queensland Fish Board (QFB), which was responsible for marketing fisheries product, collected catch information from 1936 until 1981. This included some recreational catch and not all commercial fishers marketed their catch through the QFB. After the closure of the QFB no catch data were collected on any species in the RRFFF until the introduction of the CFISH compulsory commercial logbook system in 1988. This system records daily catch and effort information from all commercial fishers but it was not until the mid 1990's that catch and in some cases effort data were collected from the recreational fishery.

Prior to 1988, there were no significant restrictions on the quantity of fish recreational fishers could take. In addition, recreational fishers were able to sell fish surplus to their personal requirements. An amendment of the *Fishing Industry Organisation and Marketing Act 1984* restricted the sale of recreationally caught fish to a limit of 50kg of whole fish to be sold per permit with a limit of 12 permits to be available to each fisher annually. Further amendments to the legislation in 1990 removed altogether the capacity of recreational fishers to sell any part of their catch.

Catch and effort information was collected from the charter boat fishery by way of a voluntary logbook established in 1993/4 which later became compulsory in 1996.

In 1993, a suite of new management arrangements were introduced for line fisheries. The arrangements included measures such as new minimum/maximum fish size limits, bag limits on recreational fishers and further limitations on licences for commercial operators (QFMA 1998). Following the introduction of the new reef line fishery arrangements in 1993, the previous general line fishery endorsement (L) authorizing commercial line fishing activities was replaced by a range of area-based endorsements (L1 – L9). The main changes to rocky reef management arrangements at this time included an increase in the snapper minimum legal size from 25 to 30cm, an increase in the teraglin MLS from 40 to 45 cm and the establishment of a 30cm MLS for pearl perch. A 30 per person bag limit was also established for snapper and a bag limit of 10 was introduced for pearl perch and teraglin.

Line fishers endorsed with an L1 symbol can effectively fish in all state-managed coastal and offshore waters south of the GBR and are restricted to using rod-and-reel or hand line fishing gear and methods under the same restrictions as recreational fishers.

The introduction of the *Fisheries Act 1994* prompted a review of the management arrangements for the RRFFF. The *Rocky Reef Fish Fishery Discussion Paper* was released by QFMA in 1998 seeking public input on sustainability and access issues in the RRFFF prior to the development of a management plan. The management plan for the RRFFF was never developed due to structural changes to the fishery management agency in Queensland (then the QFMA, now the Department of Agriculture, Fisheries and Forestry (DAFF)).

In December 2002, the management agency further increased the minimum size limits for pearl perch and snapper from 30cm to 35cm. Possession limits were also decreased from 30 to 5 for snapper, and from 10 to 5 for pearl perch and teraglin. The minimum legal size of teraglin was also reduced from 45 to 38 cm at this time.

An investment warning was issued by the then Department of Primary Industries and Fisheries (now DAFF Queensland) for the RRFFF in September 2003 to warn those with a current interest or considering investing in the fishery that increases in commercial catch levels or fishing effort may not be recognized as 'historical involvement' when developing future management arrangements.

The introduction of the CRFFF Management Plan in 2003 resulted in further changes that affected the RRFFF and its management requirements. Several species formally listed and managed as rocky reef fish changed to be managed under the CRFFF plan. These include ruby snapper *(Etelis carbunculus*), flame snapper *(Etelis coruscans*), gold band snapper *(Pristipomoides multidens/P. typus*), rosy jobfish *(Pristipomoides filamentosus/P. sieboldi*) and southern fusilier *(Paracaesio xanthura*). Fishers operating under L1, L6 or L7 symbols but without an 'RQ' authority to take coral reef fin fish are now precluded from taking the above species and indeed any designated CRFFF species. Any CRFFF species that are caught must be immediately returned to the water. Similarly RRFF fishers are precluded from retaining Spanish mackerel unless their license is endorsed with the appropriate SM symbol. Both RQ and SM symbols have been allocated to the fishers able to demonstrate an historical involvement in the respective fisheries.

Following a number of stock assessments from 2006 to 2008 and significant stakeholder consultation which highlighted concerns of the sustainability of snapper an interim 6 week closure was implemented in March/April 2011 with a total ban on the harvest of snapper, pearl perch and teraglin by all sectors. Further rocky reef management was introduced in September 2011 which saw a lowering of the recreational snapper bag limit from 5 to 4 and a maximum size limit of 70cm introduced for recreational anglers (only one fish greater than 70cm could be retained). Management of pearl perch and teraglin remained unchanged.

Recreational Catch Information

Information prior to 1990

The earliest historical reports of catches from the rocky reef fishery were of large catches of snapper taken from offshore reefs in southern Queensland in the late 1800's (Welsby). Apart from these reports and others made by early naturalists, historical catch data for the RRFFF have not been collated until the establishment of the Queensland Fish Board (QFB) in the 1930's. It is, however, widely accepted that the catch must have increased dramatically over time given the increase in population, boat registrations and fishing technology (Ferrell & Sumpton 1997). Early records from newspapers and other information sources (including historic personal logs of retired commercial fishers) are available, but these have not been collated and analysed, although they are the subject of current research by the University of Queensland (Ruth Thurstan, personal communication).

The QFB maintained catch records between 1936 and 1981. These data indicate a fairly significant increase in the catch of *Pagrus auratus* during the late 1940's following the end of the Second World War (see Sumpton 2002). Before this time, the larger specimens of this species (known then commonly as "snapper") contributed the majority of the catch until the 1950's, when snapper harvest declined being replaced by smaller individuals (known commonly then as "squire"). There are no records of fishing effort during this period and there is some doubt about the criterion used to distinguish snapper (larger mature *Pagrus auratu*s) from squire (smaller *Pagrus auratu*s) (Sumpton 2002). Recreational fishers were also able to market fish through the Fish Board up until the late 1980's and there is uncertainty about the proportion of the commercial catch that was sold through the fish board, since in some areas many commercial fishers directly marketed their catch outside the Fish Board. The QFB did not keep consistent records of pearl perch, with only limited recording of catches of this species for several years during the 1950's. There are no records of teraglin recorded although it is likely that teraglin were included in the generic category of Jew, which was predominantly mulloway. Given the similarity in current catch trends of snapper and pearl perch over recent years it would seem reasonable to assume that catches of pearl perch mirrored those of snapper. However we would advise caution as pearl perch are generally found further offshore than snapper and thus their fishery may have been more likely to develop later than snapper. This recent development of the pearl perch fishery is even evident in the CFISH commercial data (see Appendix 3.10) which shows increasing catches of pearl perch, particularly over the last decade.

Fish Board records are used extensively as an index of change in catch over time for a number of species for which quantitative stock assessments are used. While there may be some issues surrounding the use of these data as an index of commercial catches for the reasons previously stated, they have proven to be a good index for some species. In the case of barramundi, good correlation has been obtained between environmental flows and Fish Board records of catch, suggesting the utility of the data for that species at least (Halliday and Robins, 2007). These authors also provide a useful summary of the utility of Queensland Fish Board records. There is also a good correlation between boat registrations and catch for a number of species recorded by the QFB. Of the three rocky reef species being studied in this report only snapper is reported consistently in fish board records and as such we were unable to readily find any historical recreational catch data for either teraglin or pearl perch prior to the 1990's. As mentioned earlier, we were able to collect some data from retired commercial fishers who kept records of their catches during periods as early as the 1950's when catches of over a tonne (40 cases each of 40 pounds) of teraglin (as an example) were reported but it was impossible to determine how representative these catches were of the general fishery conditions at the time and as such we did not progress any detailed analysis of these data. Other sources of information that we have not considered here are newspapers and other historical documents but these are being analysed by the University of Queensland and may provide indices of change over a longer time period.

Research surveys after 1990

Recreational catch information has also been gathered by a number of on-site research surveys but only two have provided information on the rocky reef species being discussed here. These surveys and their results are described in detail in Ferrell and Sumpton (1997) and Sumpton (2000) but some key features of the methods and pertinent results are described below.

The first survey was a random stratified catch (and catch rate) survey of recreational boat anglers returning to seven different access points (boat ramps) during daylight hours from Tweed Heads to Mooloolaba over a 12 month period during 1994/1995. Effort information was independently obtained from aerial surveillance of offshore waters at the same time as the catch survey. There was no assessment of Moreton Bay fishing effort during that survey although catch information was collected. The ramp locations were chosen after the pilot surveys of ramps and after consultation with enforcement officers and fishing club members who confirmed the most popular ramps used by offshore anglers who targeted rocky reef fish. While non-random selection of ramps is considered a possible source of bias in determining catch rates, the fact that there were well over 100 ramps in the survey area necessitated a compromise. The assumption was that the skill of anglers did not vary significantly among ramps. It was also recognised that non-random selection of ramps would heavily bias any estimates of effort obtained from the survey. However, effort was assessed independently of the ramp survey using aerial surveillance during the same survey period (although on different days). Generally an occupant from each vessel returning to boat ramps was surveyed, except at times when there were too many vessels to allow a total coverage. The overall percentage of missed interviews was less than 5% of those vessels returning, although on some weekends it reached 10% at the larger 4 lane ramps (e.g. Raby Bay). This survey provided estimates of catch and effort.

Table 1 Numbers of snapper released by recreational anglers (per angler/trip) in 1995/96. Standard errors are in parentheses.

Species	First Quarter	Second Quarter	Third Quarter	Fourth Quarter	Total
Snapper (offshore)	5.00 (1.22)	4.80 (1.80)	5.75 (2.77)	1.00 (1.00)	4.98 (0.98)
Snapper (inshore)	5.22 (0.88)	8.35 (1.46)	7.11 (0.96)	7.81 (1.02)	7.30 (0.59)

A potential source of bias in catch rate determination that includes released fish as well as harvest relates to the spatial segregation of juveniles and adults. This is particularly relevant to snapper where release rates are higher in inshore areas (such as Moreton Bay) (Table 1). The fact that teraglin and pearl perch were not reported in embayment fisheries such as Moreton Bay suggests that this feature of their fisheries may not be as much of an issue but it is known that teraglin size (in particular) is particularly depth stratified with smaller fish caught in shallower near-shore waters (See Appendix 3.3).

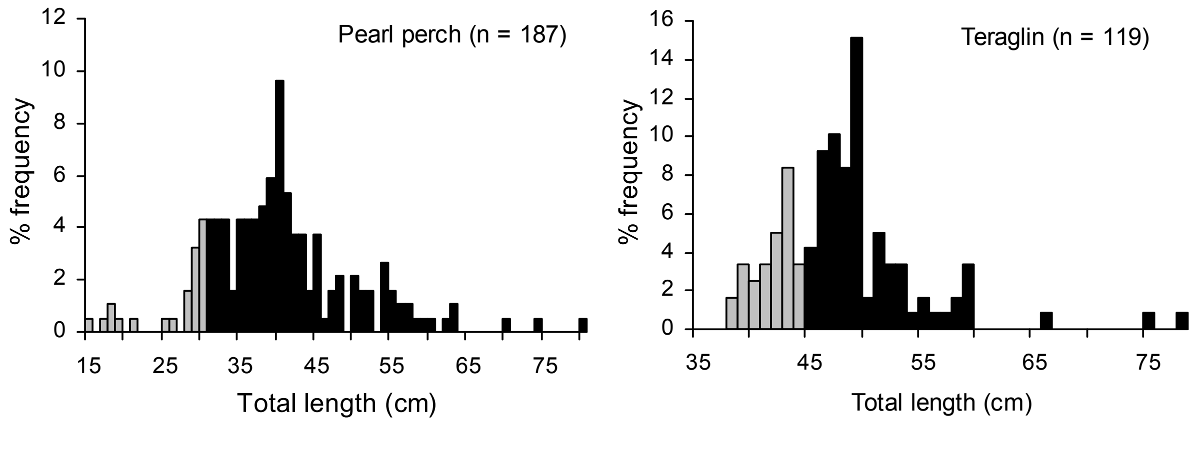


Figure 1 Length frequency of recreationally caught pearl perch and teraglin during on site boat surveys of line fishers during 1994 and 1995. Grey bars indicate fish that were smaller than the 1993 MLS.

While there were not large numbers of either species measured during these surveys the size frequency distributions (Figure 1) broadly reflect those obtained from other recreational and charter samples obtained during more recent years by the AMU (See Appendix 3.1 and Appendix 3.3).The relatively small proportion of undersized fish of both species during the 1994/95 survey was partially a reflection of the absence of these fish from Moreton Bay (an area of high fishing effort). The minimum legal size had also only recently been set for both species at 30cm for pearl perch and 45 cm for teraglin. Snapper showed even higher proportions of undersized fish retained particularly for those fishers who fished inside Moreton Bay (Ferrell and Sumpton, 1997). Subsequent surveys during 1999 showed a dramatic increase in compliance and it was hypothesised that the high levels of undersized fish during the 1994/95 survey was related to a time lag needed for the regulation changes to be communicated effectively to the recreational sector rather than an ongoing compliance issue (Sumpton, 2000).

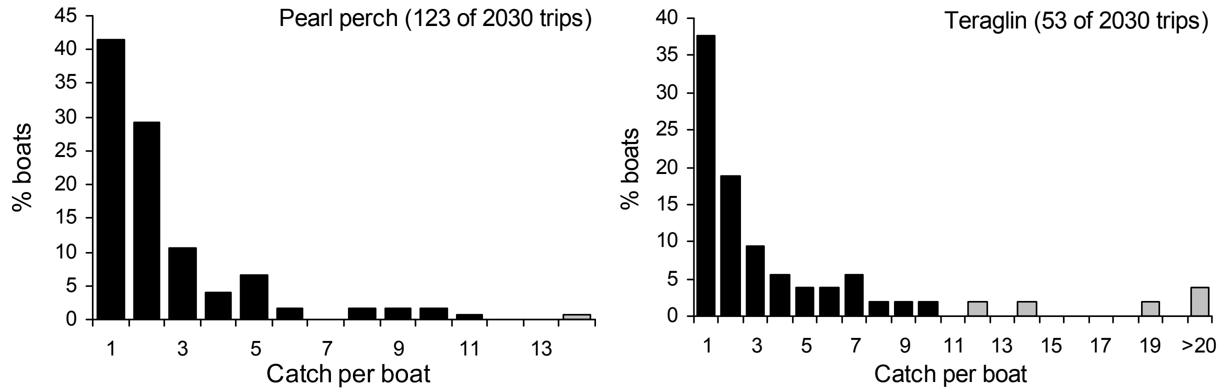


Figure 2 The percentage of recreational fishing trips that landed pearl perch and teraglin that retained various catches during surveys of boat ramps in 1994 and 1995. Grey bars show those trips when the current bag limit of 5 fish per person would have been exceeded.

During 1994 and 1995 over 90% of all offshore fishing trips failed to land either a pearl perch or teraglin, reflecting a lack of targeting of these species at the time and the generally lower abundance of these species compared with the main target species (snapper). Figure 2 shows the distribution of various catch sizes for pearl perch and teraglin and suggests that bag limits have had the greatest impact on teraglin catch rates. The current bag limit of 5 would have been exceeded on over 10% of fishing trips where teraglin was reported but less than 2% of fishing trips where pearl perch were reported. This has implications for future catch rate assessments that may use harvested catch as an index of abundance and does not include released fish, particularly in the case of teraglin. Obviously, catch rate interpretation is less of a concern if releases are included in the catch rate analysis but there is always the issue of recall bias when dealing with released fish. If bag limits are to reduce further over time this issue would be exacerbated.

The survey conducted in Moreton Bay during 1999 (Sumpton 2000) only measured 14 pearl perch, and no teraglin were reported. This survey, therefore, does not provide any useful information for these two species. This is not surprising given that the survey was designed to target recreational blue swimmer crab fishers who were fishing in Moreton Bay, an area that is not fished for either of the two species of rocky reef fish. Snapper, however, were reported in relatively large numbers during this survey with over 487 measured and this survey does provide useful catch size structure and catch rate information for the Moreton Bay component of the snapper fishery in particular.

RFISH program surveys (Diary and phone Surveys:- 1996/7, 1998/9, 2001/2 and 2004/5)

State-wide surveys of recreational anglers using a telephone survey to estimate participation followed by a year long diary program to estimate recreational catches have been conducted at regular intervals in Queensland. Telephone surveys have been conducted in 1996, 1998, 2001 and 2004, with diary programs conducted the following year with the co-operation of a sample of anglers identified from the phone surveys. Generally, more than 4500 angler volunteers have contributed to each of these surveys but many discontinued their diaries throughout the survey year.

The number of anglers who target a particular species is one of the outputs from the telephone survey. Numbers of anglers that had targeted snapper fell from 18,500 to 14,300 from the 1996 to 2001 surveys, before increasing back to 16,700 in 2004. Pearl perch were less commonly targeted and showed a similar trend with anglers declining from 3,700 to 1,800 before an increase to 2000 anglers over the same time period.

The most recent Recreational Fishing Information System (RFISH) diary survey, conducted in 2005 indicates that approximately 328,000 snapper and 148,000 pearl perch were harvested (caught and kept) by recreational fishers in Queensland in 2005 (Table 2). The total harvest weight for snapper in 2002, based on the average weight of a fish harvested was between approximately 170 t and 230 t. The snapper harvest declined significantly in 2002 in comparison to surveys conducted in 1997 and 1999. This would appear to be a result of an increase in the number of fish released, since the total number of fish caught has remained stable. The 2002 survey was conducted before the introduction of the increased size limit, suggesting that even at the previous size limit (30 cm) fishers may have been catching a large proportion of undersized fish and releasing them.

Obviously, successive increases in MLS have impacted on the average size of fish in the catch and this is particularly the case for snapper where MLS has increased from 25 to 35cm from 1993 to 2003. The average weight used for the 1997, 1999 and 2002 surveys was based on the figure estimated from research conducted during the mid 1990's and is the most precise due to the high sampling intensity and large numbers of fish recorded from all sectors and there were no change in MLS between 1994 and 2002. The 2005 estimate is the one for which we have the least confidence as it is based on a figure derived during 2006. The full impact of the increase in MLS that occurred just over a year prior to the survey would also have impacted over the 2 years immediately after the increase as selectivity and growth effects influenced the resultant size structure of the catch.

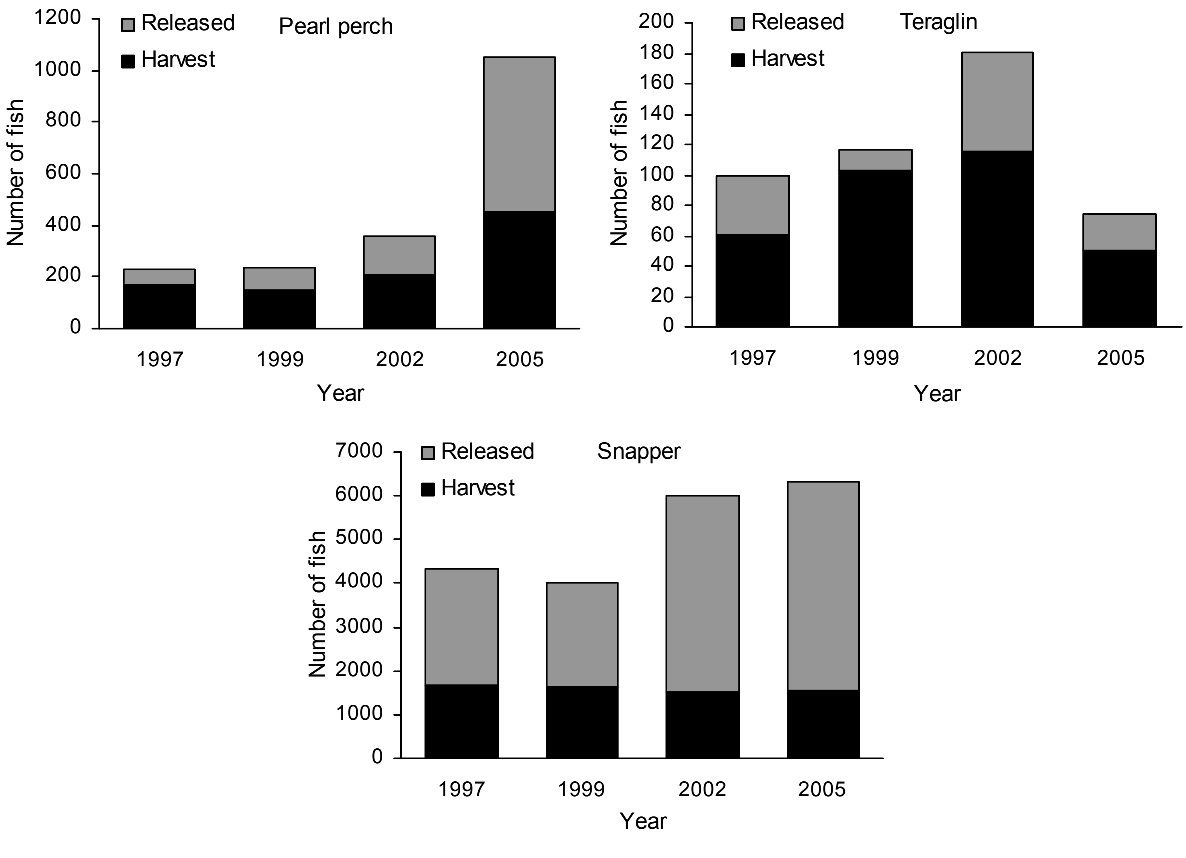


Figure 3 Raw numbers of Snapper, pearl perch and teraglin harvested and released by RFISH diary participants from 1997 to 2005.

The differences in the RFISH figures indicate that the number of pearl perch caught decreased by approximately 30% between the 1999 and 2002 surveys. A similar reduction can be seen in the number of fish harvested while the proportion of fish released appears to have remained stable.

Table 2 Estimated recreational catch of snapper and pearl perch from the 1997, 1999, 2002 and 2005 RFISH diary surveys (Insufficient teraglin were reported by diarists to enable the reliable estimation of total catch). Relative standard errors (%) shown in brackets.

Snapper	1997	1999	2002	2005	2008[#]
Number caught	1 327 000	1 284 000	1 253 135	1 218 000	164 953
	(6.9%)	(9.0%)	(6.6%)	(8.2%)	
Number released	750 000	757 000	956 695	891 000	127 654
	(6.7%)	(9.2%)	(7.3%)	(8.2%)	(17.1%)
Number harvested	577 000	527 000	296 440	328 000	37 299
	(8.6%)	(10.4%)	(7.6%)	(9.7%)	(24.9%)
Harvest weight (tonne)	519[a]	474[a]	267 [a]	525 [b]	

Pearl perch	1997	1999	2002	2005	2008[#]
Number caught		109 000	74 000	356 000	16 906
		(21.8%)	(13.9%)	(14.2%)	
Number released		44 000	32 000	208 000	11 622
		(31.1%)	(16.6%)	(15.9%)	(42.1%)
Number harvested		65 000	42 000	148 000	5 284
		(18.1%)	(13.8%)	(13.2%)	(39.9%)
Harvest weight (tonne)		76[c]	50[c]	192[d]	6.8[d]

[a] Using an average weight of 0.9 kg per fish based on the average weight of a snapper caught during research conducted from 1994 to 1996.
[b] Using an average weight of 1.6 kg per fish, estimated from charter logbook data.
[#] Estimates for the 2008 survey are only for boats launching from the Moreton region (refer Webley *et al.* 2009).
[c] Using an average weight of 1.2 kg based on catches measured during the mid 1990s.
[d] Using an average weight of 1.3 kg based on catches of pearl perch from 2006 to 2010

None of the RFISH recreational surveys sampled sufficient teraglin to provide a reliable estimate of total catch for this species. RFISH diary respondents have reported fewer than 200 of these fish in any given survey period, confirming the minor importance of this species compared to other species of rocky reef fish.

The issue of whether catch rates determined from the early RFISH surveys represent an accurate index of abundance is hotly discussed and the determination of an appropriate sampling frame is difficult to determine for some species. It is obviously no use including the “zero” catch of fishers who have no chance of catching a particular species. It is a well known fact that many species’ distributions are heavily clumped rather than distributed uniformly throughout the fishing grounds, even on their favoured habitat. The utility of these surveys is very much species dependent but the fact that the majority of the survey respondents lived and fished in southern Queensland means that species such as snapper are more likely to be representatively sampled, although the notion of a representative sample is difficult to determine and requires a through understanding of the sampling frame as well as detailed knowledge of how that frame was sampled.

This is less of a problem for species such as snapper that are found over the widest range of habitats compared with either teraglin or pearl perch (see Appendix 3.9). Fishers are also able to target particular species depending on the type of bait/gear that they use. There are different methodologies applied to the various recreational catch estimates that further complicate the interpretation of trends. For some species (such as snapper) where different data sets reinforce each other there can be increased confidence in the estimates derived from these surveys. This may not be the case for all species. One of the apparent anomalies in the RFISH data was the large catch of grassy sweetlip in 2005. Whether this represents better targeting or greater availability of this species is unknown but the fact that this species is one that is used to determine a rocky reef fisher is important in determining the overall catch rates as it was often caught without an associated catch of snapper.

An analysis of the catch of diarists showed that 35% of those who caught grassy sweetlip did not catch any snapper at all throughout the period they completed their diaries. This percentage of fishers was reduced to 17% and 22% respectively for those fishers who caught pearl perch and teraglin but did not catch snapper. It is thus clear that spatial and temporal fishing patterns as well as targeting practices of anglers can affect the likelihood of catching particular species or groups even though the individual species may be classified as “a rocky reef species”. We modelled different ways of deriving catch rates based on a range of assumptions about what constituted a fishing trip capable of catching a rocky reef species. These ranged from only including catches that reported a particular species of interest to the most expansive assumption where catches of all trips that recorded one of the species defined as a rocky reef species were used to calculate catch rates. Under these scenarios catch rate estimates varied by over an order of magnitude for each of the three species (Table 3) but snapper was still the most precise estimate, reflecting the high targeting preference and higher abundance and more widespread distribution of this species. The variance was obviously further increased when released fish were included in the catch rate estimates and this effect was proportionally greater for snapper reflecting the high release rate for that species.

Table 3 Estimated ranges of catch rates (fish per trip) obtained from recreational catches recorded in RFISH diaries from 1997 to 2005. Highest rate is average of all fish caught on trips when any of the particular species were either retained or released. Low catch figures are averages for all catches where any one of the 10 rocky reef species were caught.

Species	1997	1999	2002	2005
Teraglin	5.25 - 0.56 x 10^{-3}	4.33 - 0.95 x 10^{-3}	6.03 - 0.80 x 10^{-3}	2.74 - 0.24 x 10^{-3}
Pearl perch	3.32 - 1.54 x 10^{-3}	3.95 - 1.39 x 10^{-3}	4.31 - 1.42 x 10^{-3}	5.16 - 2.16 x 10^{-3}
Snapper	6.24 - 15.32 x 10^{-3}	6.02 - 14.88 x 10^{-3}	6.05 - 10.44 x 10^{-3}	5.64 - 7.45 x 10^{-3}

RFISH program surveys (Diary and phone surveys, National methods:- 2000 and 2010)

There have been two national surveys, similar to the RFISH surveys, conducted. Results from the National Recreational and Indigenous Fishing Survey (NRIFS), undertaken in 2000, indicate that the Queensland recreational sector harvested 232,000 snapper. Snapper represented about 2% of the total finfish harvested in the recreational fishery nationally. Snapper catch in Queensland was the third highest comprising 18% of the national snapper catch. Reliable estimates of pearl perch and teraglin were not available from the 2000 NRIFS survey as they were grouped with a number of other species. The NRIFS snapper harvest estimate is approximately half the RFISH-estimated catch for 1999 and also significantly less than the 296,000 RFISH-estimated harvest for 2002.

At the time of drafting this report a more recent recreational survey (2010/11) was currently being analysed and reported. This survey utilised similar methods to the earlier NRIFS survey (Phone and diary survey) but more contact was maintained with fishers in order to minimise recall bias.

RFISH program (Bus route survey of Moreton region:- 2007/08)

Readers are referred to Webley *et al.* (2009) for a complete discussion of this survey and its methodology although it is based on standard and well established techniques that are applied widely throughout the world to assess recreational fisheries. It is important to note that this survey was designed to collect information from vessels that left from, and returned to, boat ramps in southern Queensland during daylight hours only. In addition, it did not collect any catch or effort information from vessels that were moored at private jetties or marina berths. In southern Queensland effort from this part of the fishery most likely contributes a significant (but unknown) proportion of the total fishing effort. Likewise, no information was collected from fishers returning from their fishing trips during night time hours. Once again, these fishers can contribute a significant (but again unknown) proportion of the effort on rocky reef species. This limitation is applicable to all the historical research surveys that have used onsite methods to estimate rocky reef fish catch rates as none have been able to address either the night-time or fishing platform issues identified above. There have been attempts to assess the night time catches but logistic and safety constraints precluded their completion (Ferrell and Sumpton 1997). It is clear that any estimate of total catch or effort from this survey would clearly underestimate the total catch of many species fished in the area.

Catch rates obtained from surveys conducted at different times over the life of a fishery can provide valuable information on the relative abundance of a particular species providing all features of the fishery (including impact of technology and fishery management changes) can be factored into the analysis, provided that catch rates achieved from all types of vessels and trip types can be standardised for changes in effort due to technology and other factors.

Discussion

There are 10 fish that are classified as rocky reef species for management purposes. These species include the three primary target species by management and the AMU as the following: snapper (*Pagrus auratus*), pearl perch (*Glaucosoma scapulare*), teraglin (*Atractoscion aequidens*). Secondary rocky reef species include samsonfish (*Seriola hippos*), amberjack (*Seriola dumerili*), yellowtail kingfish (*Seriola lalandi*), mahi mahi (*Coryphaena hippurus*), cobia (*Rachycentron canadum*), grass emperor (*Lethrinus laticaudis*) and fryingpan snapper (*Argyrops spinifer*). Despite this classification there are other species, particularly those managed under the Coral Reef Finfish Fishery (CRFFF) which are probably more likely to be encountered when fishing some southern rocky reefs. Example of these species include venus tusk fish, pigfish and various lutjanids, lethrinids and serranids, which were often seen in association with snapper during our BRUVS surveys (see Appendix 3.9) and research ramp surveys as well as recorded in logs of commercial L1 fishers that hold CRFFF "other species" quota. This often causes confusion, particularly amongst recreational fishers who access both rocky reef and coral reef species caught in the same locations but which have different management arrangements. We have already described how many of the diary respondents caught species classified as rocky reef species in isolation from each other and many clearly "specialised" in a small suite of particular species. Grassy emperor in particular were a common species taken by offshore line fishers in southern Queensland often without catching other rocky reef species, suggesting habitat segregation. Pelagic species including mahi mahi, *Seriola* spp. (amberjack etc) and cobia were often caught without recording other rocky reef species.

The numbers of snapper reported by RFISH diarists is over an order of magnitude higher than pearl perch catches, with relative standard errors reflecting the higher precision of any snapper estimates compared with other species, adding confidence to the estimates of the recreational catch for at least this rocky reef species.

The stratification of the earlier RFISH surveys which results in sampling being distributed according to fisher population density effectively means that the majority of diary participants are from the high population districts of southern Queensland. This results in even more accurate and precise catch estimates of species such as snapper and other species where the catch is largely restricted to more southerly waters where a high proportion of diary participants would be fishing.

The attribution of a zero catch to a trip that had no chance of catching a particular species will severely bias catch rate estimates. Including catches for trips such as these that have no possibility of catching a particular species may result in grossly deflated catch rate estimates. Likewise, only including catches when a species is actually caught has the potential of over-estimating sustainability, as unsuccessful trips that may have targeted that species are eliminated from the analysis and hyperstability of catches and catch rates becomes more likely. When a stock is in decline it is more likely that the number of such zero catches would increase. It is well known that it is possible to target some species of rocky reef fish while at the same time having a low probability of catching some of the other species. Different fishing techniques are often very species specific and sometimes size selective as well. The fact that we have shown that snapper in particular are more widely distributed on the fishing grounds over a range of habitats (see Appendix 3.11) confirms demersal fishing in many areas of the southern rocky reef fishery still has a high probability of catching this species. While a thorough analysis of this was beyond the scope of this report it is important to recognise that determining what constitutes a fishing trip likely to catch a particular species of interest is critical and warrants careful consideration and scenario modelling in any stock assessment that seeks to use catch rates as an index of stock abundance.

The handling of zero catches is not as problematic for the 1995/95 on-site survey data as the assumption that interviews of fishers at boat ramps were obtained from a random sample of all fishers who were fishing offshore irrespective of their targeting behaviour. Effort estimates were obtained from counts of offshore fishing boats independent of the catch survey and also independent of any targeting preference. Thus, these catch rate estimates are less likely to be biased. Other on-site surveys that have adequate design would similarly provide better estimates of catch rates and would also be more likely to produce more accurate and precise estimates of released fish as recall bias would be reduced.

Bag limit changes will clearly influence the resultant catch rates obtained in any form of survey and based on catch rates obtained prior to the introduction of the 5 bag limit for teraglin and pearl perch, the former species is the one most likely to be impacted as it had the highest proportion of fishing trips where catches exceeded 5 per person. In some cases, catches of more than double the bag limit were reported in earlier surveys prior to the lowering of the bag limit. This observation of some individual high catches has also been reported in the charter fishery on the Gold Coast where very large catches were historically reported (Ray Joyce personal communication). This same level of relatively high catches was also reported, particularly for snapper where the bag limit (even when it was as high as 30 fish per person) was regularly achieved by some anglers (Ferrell and Sumpton, 1997). Pearl perch appears less of a problem here as recreational catch rates of this species appear never to have been of the same order as snapper and thus catch rate estimates through time are less prone to bias caused by reducing bag limits.

Bag limits being exceeded causing biased catch rate estimates are less of a problem when harvested fish as well as released fish are included to determine the catch rate as opposed to a harvest or retained catch rate. However, both precision and accuracy are often compromised when releases are included, largely due to recall bias. Fishers are less likely to remember a fish that they released, particularly if the numbers released are greater than the numbers caught. This is particularly relevant for the species we are considering here, all of which can be released in large numbers depending on the area fished and time of year. Analysis of the raw data from each of the earlier RFISH surveys showed that it was not uncommon for anglers fishing in inshore waters to release greater than 20 snapper per trip. In contrast, numbers of teraglin and pearl perch released were not as great, again confirming the importance of snapper.

We had little confidence that the design and intensity of the earlier RFISH surveys had any ability to provide reasonable estimates of any of the fishery parameters for teraglin in terms of either catch or effort. Likewise onsite surveys encountered few individuals of this species and QFB records of this species are indeterminate. The fact that so few are reported indicates that this is probably not a priority species. We are still uncertain about the historical importance of this species as some personal commercial logs of this species showed very large catches suggesting that at least in areas in south Queensland it was once a more important species than its current low catch status would suggest. The QFB records do not provide any evidence to confirm this, as teraglin was probably included in the generic “Jew” category.

Catch estimates for the other secondary species of rocky reef fish also suffer from relatively high relative standard error, apart from grassy sweetlip which has clearly been a species that has increased in popularity in recent years in both the commercial and recreational sectors.

The 2005 estimates of recreational catch are often questioned as being grossly overestimated. While there may be some issues in the average weight of fish of some species used to expand catch rates to overall harvest weights due to the proximity of the survey to management changes (largely changes to MLS) made in 2003, ongoing data collected by the AMU and other sources add confidence to these weighting factors. Likewise, 2005 was also a very high catch year when virtually all forms of fishery data were examined, including CFISH data (see Appendix 3.10). Of greater concern is the disparity between catch and release of some species across the 2002 and 2005 surveys. We did not have access to the weighting factors used to scale these estimates but this warrants further investigation given differences in the raw sampled data on catch rates.

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APPENDIX 3.12 IMPACTS OF MANAGEMENT AND ENVIRONMENTAL FACTORS ON ROCKY REEF SPECIES IN THE GOLD COAST CHARTER FISHERY

Summary

While they are important target species for general recreational fishers, snapper, pearl perch and teraglin are also important fish for charter boat fishers, which operate from the Gold Coast to the southern Great Barrier Reef. Management changes in December 2002 that increased the minimum legal size of snapper from 30 to 35 cm and decreased the recreational bag limit from 30 to 5 per person had a positive impact on the fishery in the short term but the effect of a recent reduction in the bag limit from 5 to 4 and a maximum of 1 fish over 70cm, which was introduced in 2011 is still to be assessed. The Australian Marine Life Institute (AMLI) has been collecting charter catch data from a subset of charter boats on the Gold Coast since 1993. These data have been used in stock assessments for the snapper fishery (Campbell *et al*. 2009) and have proven a valuable additional source of catch data and index of relative abundance. Standardisation of this charter catch per unit effort (CPUE) for the three main rocky reef species using generalised linear models indicated that there was generally only a small influence of most environmental factors incorporated into the models and that standardisation only marginally changed the raw catch rate estimates. There were some broad trends for the three main species with catch rates generally declining with increasing current and rougher weather conditions. Spatial and temporal factors were not as consistent between species but there was a tendency for higher catch rates during the middle of the year (the presumed spawning season for some species) and a time when weather conditions are more favourable for offshore fishing. Catch rates of pearl perch increased with depth while the opposite was the case for teraglin. Changes in the business structure of parts of the Gold Coast charter fleet which saw movement towards shorter fishing trips and greater numbers of anglers per trip have altered the effective fishing effort in this fishery. While standardisation for these factors is simple in the AMLI data subset, it is difficult to standardise for these factors when trying to analyse the compulsory collected charter CFISH information from the entire fishery where records are mainly catch per boat per day without standardisation for number of anglers or fishing time. The AMLI sample of the Gold Coast fleet is still a valuable representative sample of the snapper catch from the Gold Coast region but may be unrepresentative of the pearl perch catch due to the low number of catches of this species recorded in the database. In addition, recent trends in the data that show a trend to obtaining samples from charter vessels fishing in shallower water results in size structure and catch rates for teraglin not being a good index of the population due to the size stratification that occurs with depth. Recent declines in participation rate in the AMLI program have also further eroded the value of these data for the other main target rocky reef species as business conditions have further deteriorated.

Introduction

The impact of charter boats on fish stocks has been recognised around the world for many years in both freshwater and marine environments (Sutherland 1974, McEachron and Matlock 1983). Often the charter catch can make up a large proportion of the recreational catch in some areas and for some species and catch rates are also often greater on charter boats compared to private recreational fishing boats. In Australia, the growth and consequent potential influence of the charter fishing sector is well recognised (Anon 1998; Johnson 1998). In Queensland, the recreational (charter and general recreational) catch of a range of rocky reef species is greater than that of the commercial sector, confirming the importance of non-commercial fishers in this fishery (see Appendix 3.11). In New South Wales Johnson (1998) suggested the charter fishery was having a significant impact on fish stocks in localised areas such as the Solitary Islands Marine Park. In Queensland, catch rates from a sample of the charter fleet in southern Queensland have been used in recent stock assessments as an index of snapper relative abundance (Campbell *et al.* 2009). These data have been collected by the Australian Marine Life Institute (AMLI) since 1993 and provide an accurate estimate of catch and effort as data are not based solely on logged catches of participants but from on-wharf observers collecting information from a subset of the fleet.

There have been a range of different management changes introduced in recent years to manage the rocky reef fishery in Queensland (see Appendix 3.11 for detailed description) and these have had an impact on the charter sector as well as other users of the resource. The main changes that have impacted the charter fishery have been an increase in the snapper MLS from 25 to 30cm in 1993 with a subsequent increase to

35 cm and a lowering of the bag limit to five in December 2002. Teraglin MLS was increased from 40 to 45 cm in 1993 and then reduced back to 38cm in 2002. A 30cm MLS was established for pearl perch and a 10 fish per person bag limit was introduced for each of pearl perch and teraglin in 1993. Further management changes occurred in December 2002 with an increase in the MLS for pearl perch from 30cm to 35cm and a reduction in size limit for teraglin from 45 to 38cm. Possession bag limits also decreased from 30 to 5 for snapper, and from 10 to 5 for pearl perch and teraglin. More recently (2011) there has been a further reduction in the bag limit of snapper from 5 to 4 and a maximum of one snapper above 70cm allowed to be retained by recreational fishers. Each of these changes had the potential of significantly impacting the viability of all fishing sectors in both the short and long term.

There are many factors that may influence the catch rates of line fishers on charter vessels, many of which relate to angler skill, environmental conditions, fishing gear and the behaviour of the targeted species. It is recognised that climate change will operate to alter the distribution and fisheries availability of many species through range shifts. Climate change may also act not only on the biology of the fish but also on fisheries by altering the catchability of particular species because of their susceptibility under different environmental conditions. For example, the predicted increase in the speed of the East Australian Current (EAC) may dictate subtle changes in fishing practices affecting the catchability of individual species. Complicating all this is the observation that many charter operations offer a tourist experience where targeted efficient fishing is a secondary consideration, and operators may not seek to maximise catches but rather offer a more complete tourist experience involving observing marine mammals and other on-water experiences. Some charter fishers will also often move away from areas when they are experiencing elevated catch rates in order to protect their fishing stocks for future charters. These practices serve to reduce the value of charter catch rates as an index of relative abundance of fished species.

This chapter examines the daily catch records of a relatively localised charter fishery operating off the Gold Coast in southern Queensland, particularly examining the importance some of the factors in determining catch rates of three of the main target species – snapper, pearl perch and teraglin. We also discuss some of the potential impacts of climate change on these fisheries as they relates to the logistics of fishing practices rather than just biology. There have been a range of studies that have described the predicted impacts of climate change on species distribution but none have looked at the changing environment and its impact on the ability of anglers to catch fish. As mentioned earlier, the predicted increase in strength of the EAC may impact on the ability of fishers to fish as well as having an impact on the behaviour and ecology of particular targeted species.

In this chapter we only analyse the pearl perch, and some of the teraglin length data collected by the AMLI, since AMLI snapper length information has been previously analysed (Sumpton *et al.* 2006). In addition, the Fisheries Queensland Assessment and Monitoring Unit have been collecting charter length information from the Gold Coast charter fleet since 2009 and these data have been analysed as part of other chapters of this report (see Chapters 2 and 3).

Methods

As part of an ongoing independent fisheries monitoring program, the Australian Marine Life Institute (AMLI) have been collecting fish catch, effort and environmental data from a sample of the Gold Coast charter boat fleet since 1993. This normally involved an observer (usually Mr Ray Joyce) checking the catch of vessels at the wharf after the completion of each fishing trip. At this time all fish were identified to species level, enumerated, and on some occasions their total lengths were measured to the nearest centimetre.

Information on fishing activities including number of anglers on board, fishing time, bait and fishing location were recorded as well as a range of environmental data including water temperature, current speed and direction, wind speed and sea conditions on the fishing grounds. When Ray Joyce or another AMLI representative was not at the wharf to measure catches, skippers and deckhands were asked to measure their catch and record details of their fishing trips in voluntary logs which were later collected and entered into a database. The sample fraction for catch information was estimated at over 40% of the total charter landing from boats operating from the region during the period 1993 to 2010, although this percentage varied from year to year and not all vessels have maintained their association with the program. In fact there has been a recent decline in the participation rate corresponding to a decline in general business conditions in this fishery. Direct observations and interviews with boat skippers showed that about 20% of passengers did not participate in fishing either due to seasickness or other reasons but this was not accounted for in the models as the assumption was that this was not a systematic difference among boats.

The collection of observer-based catch and effort information on a daily basis coupled with the recording of abiotic data enabled an assessment of the factors affecting rocky reef species catches by way of a Conditional General Linear Model (CGLM). To account for the inflated numbers of zeros in the catch two-part generalised linear models were fitted using GenStat v11.1. A binomial generalised linear model with the logit link (McCullagh and Nelder 1989) was used to model the proportion of zeros and the gamma distribution, with the log link, was used to model the non-zero catch. Residual plots indicated the suitability of these models. The resultant adjusted means from each model were then combined (via multiplication) and the standard formula for the variance of a product (Goodman 1960) was used to calculate the standard errors. Only effects which were significant ($P < 0.05$) in both the binomial and gamma models were retained in the final model runs.

The total number of angler hours was used as a covariate in the analysis. This was further adjusted by factors added to the model with catch of each species as the dependent variable. Boat identifier, fishing location, lunar phase, month, sea-conditions, current strength and depth were all initially included as factors. Lunar variables were initially included as a luminance scale as well as a luminance value advanced by 7 days to take into account the differing effects on catch rate of a "making" and "falling" moon but as these factors were not significant they were excluded from final models. The fact that not all boats fished at all locations during all months and years meant that the interactions involving these factors were likewise not included in the final models. Sea conditions were determined as follows Calm = wind less than 5 knots with no swell, Slight = wind 5 - 12 knots and waves less than 1m, moderate = wind 12 – 20 knots and waves less than 2m, rough = wind > 20 knots and waves > 2m. Current speed was reported in knots as estimated by vessel skippers and depth was recorded in metres from on board depth sounders. Location was divided into 5 broad areas as shown in Figure 1.

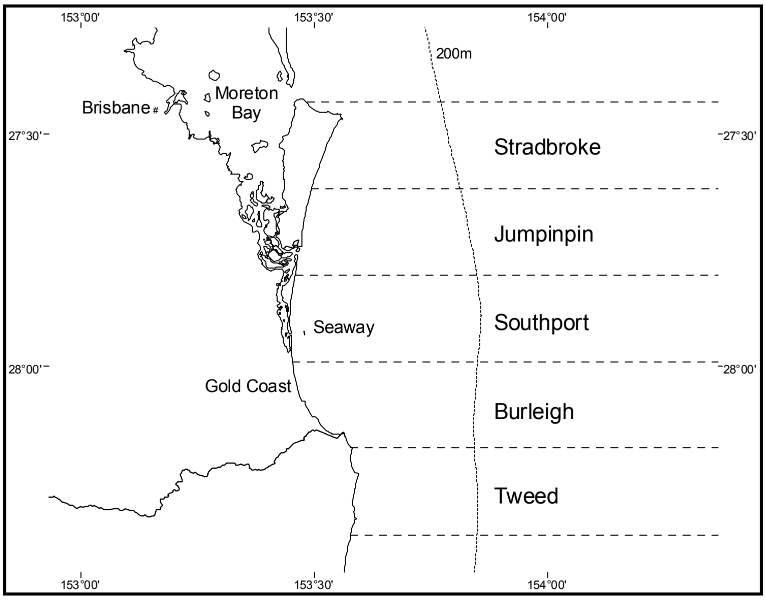

Figure 1 Regions fished by the Gold Coast offshore charter fleet and used in the analysis of snapper, pearl perch and teraglin catches. The 200m line represents the approximate outer extreme of fishing activities.

In early investigative model runs, interactions were also included but most were eventually excluded as the deviance ratio of the interactions were more than an order of magnitude less than the deviance ratio of one or both of the individual terms. The only interaction that was considered to be influential was the depth and sea condition interaction for snapper but for consistency the final model terms for all species were:- year + location + month + depth + current speed + sea-conditions + day/night.

Results

There has been a decline in the contribution of the main target species (snapper) to the overall catch, since 1993 (Figure 2). Throughout most of the period "Other" species have made up the majority of the catch with considerable annual variation between 24% and 76% of the reported catch. This 'other' species category consists of a wide variety of fish including cobia (*Rachycentron canadum*), jacks (*Seriola* spp), mackerels (*Scomberomorus* spp) sweep (*Scorpis lineolatus*), theodore butterfish (*Nemipterus theodorei*), venus tuskfish (*Choerodon venustus*), black spot pigfish (*Bodianus vulpinus*) tailor (*Pomatomus saltatrix*), and jobfish (*Pristipomoides* spp), The proportion of the pearl perch catch ranged from 2% to 14%, with higher proportions recorded in earlier years (1994 to 1997). Teraglin varied in importance more than the other two species between 7% to over 50% with the importance of this species to the charter fleet peaking in more recent years.

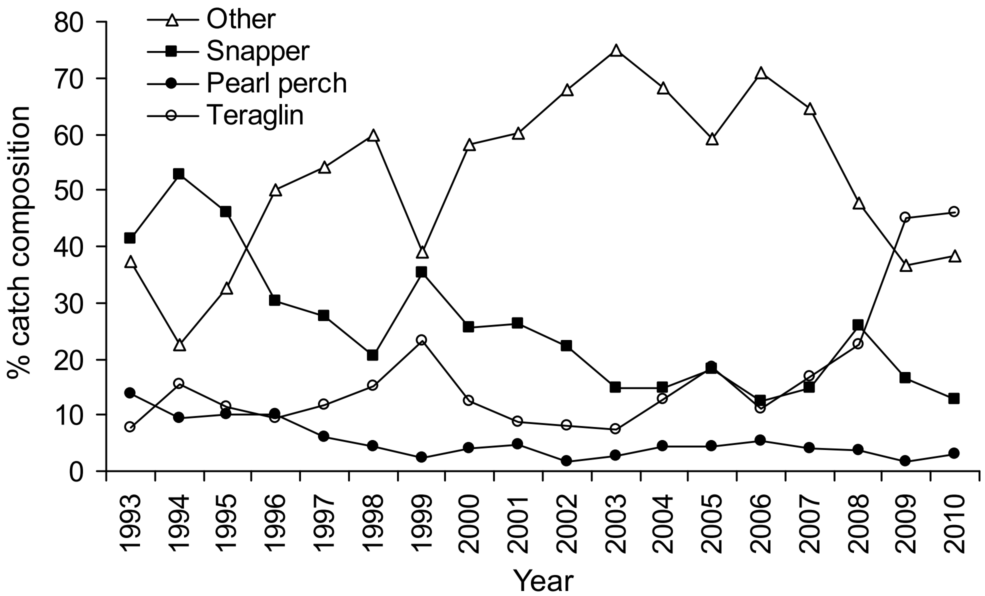

Figure 2 Summarised catch composition from the AMLI sampled offshore charter boat fishery of the Gold Coast from 1993 to 2010.

The CGLM analysis showed that the factors used in the analysis explained 27% of the variation in snapper catch rates. All factors used in the final model were significant ($P<0.05$) in explaining part of the variation in all species. Despite this, only the depth and sea condition interaction was significant for most species. Depth was the single factor to which the largest variation in catch rate could be attributed (10%). Whilst factors such as current and sea state were statistically significant they explained less than 1% of the total variation in catch rate for each species.

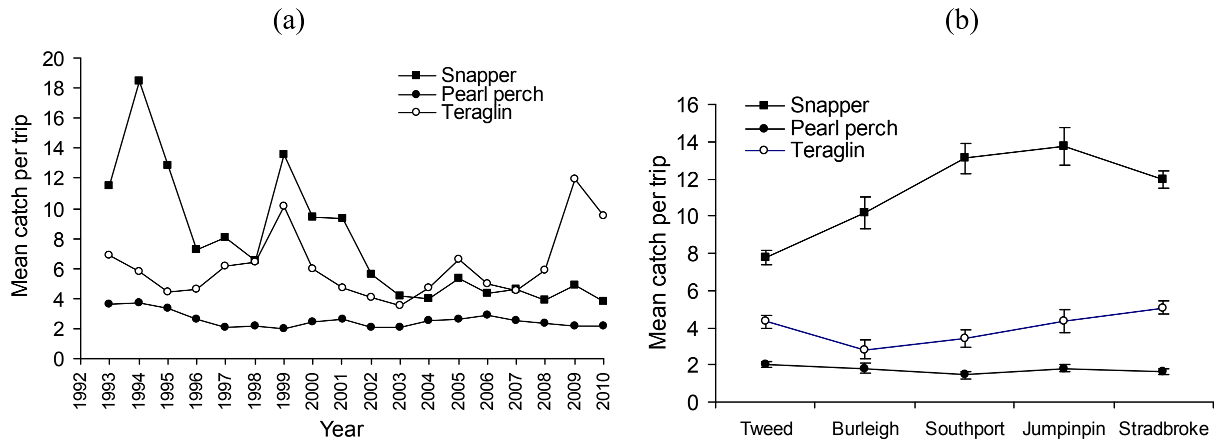

Figure 3 Standardised catch rates (fish/per trip) of the Gold Coast offshore charter fleet (a) from 1993 to 2010 and (b) in particular regions from Tweed Heads to Stradbroke Island. 95% confidence intervals are shown as vertical bars.

A significant peak in teraglin catch rates was evident in 1999, with fish per trip rising to 14 fish from 8 fish in the previous year (Figure 3a). Following 1999, catch rates of this species declined rapidly until 2001 where catches remained fairly constant at approximately 3.5 fish per trip for the next 3 years. Catch rates have increased dramatically more recently. Catch rates of snapper have declined over time after relatively high catch rates during the early 1990's and a strong peak in 1999 which also corresponded to high catch rates of teraglin. Pearl perch catch rates were lower than the other two species and have slowly declined over time with much less variation than the other two species. There was no consistent trend in the location effects among the species with catch rates not differing significantly among regions for pearl perch (Figure 3b). There was an increasing trend of snapper catch rates with decreasing latitude while teraglin catch rates showed an intermediate latitudinal effect. Seasonality in catch rate was likewise not consistent amongst the three species (Figure 4a) although summer had generally the lowest catch rates for all species. Snapper catch rates were generally higher during the late autumn and winter months with a clear peak in July. Lowest catch rates for snapper were during the late summer. Teraglin had a bimodal seasonal distribution with the highest catch rates in spring and autumn with a trough corresponding to the peak in snapper catches in mid-winter. The warmer months had the lowest pearl perch catches and this species' catch rates peaked in autumn and spring.

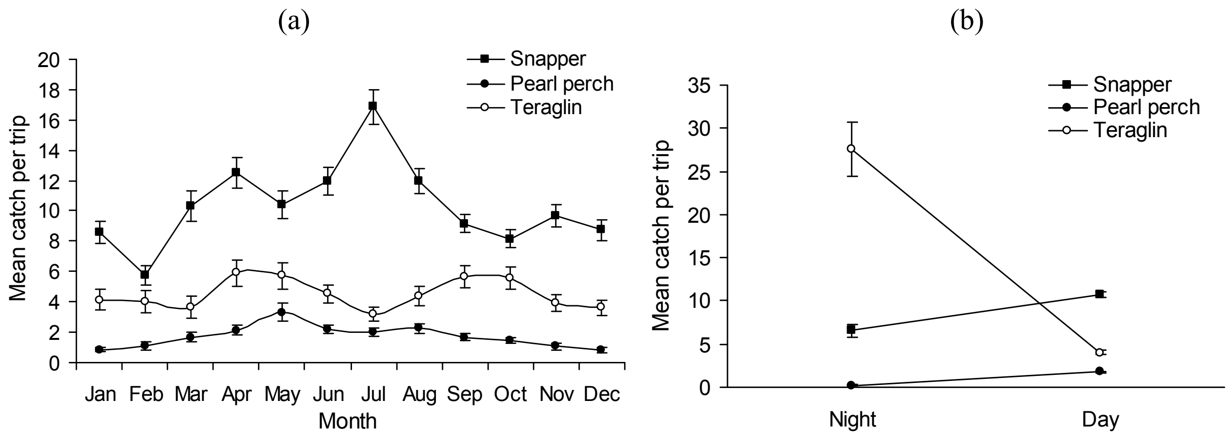

Figure 4 Model predictions of (a) seasonal variation in mean catch rates (fish/trip) and (b) diurnal variation in catch rates of the Gold Coast offshore charter fleet from 1993 to 2010. 95% confidence intervals are shown as vertical bars.

Significantly ($P<0.05$) higher catch rates of both snapper and pearl perch were obtained on charter fishing trips conducted during the day (Figure 4b). In contrast, teraglin catch rates at night were approximately 7 times the day time catch rates.

Sea conditions had a relatively consistent effect on catch rates of all species with the highest predicted catch rates during calm to slight weather conditions (Figure 5a).

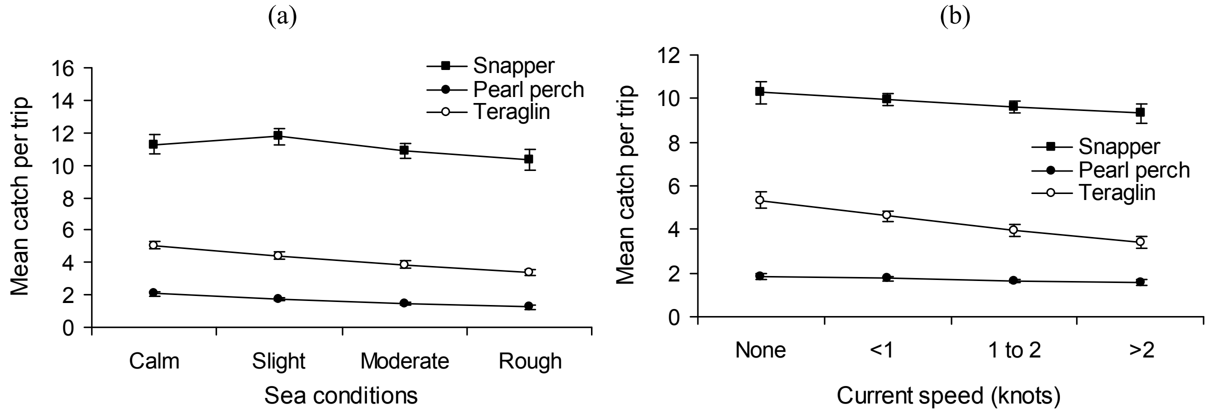

Figure 5 Model predictions of (a) mean catch rates (fish/trip) of the Gold Coast offshore charter fleet for various sea states from 1993 to 2010. Calm = wind less than 5 knots with no swell, Slight = wind 5 - 12 knots and waves less than 1m, moderate = wind 12 – 20 knots and waves less than 2m, rough = wind > 20 knots and waves > 2m. (b) mean catch rates for various current speeds. 95% confidence intervals are shown as vertical bars.

Current speed had a minor impact on snapper catch rates (Figure 5b) with a decreasing trend as current strength increased. There was no significant ($P > 0.05$) effect of current on pearl perch catch rates but current did have a large impact on teraglin catch rates, with significant declines in catch rate with increases in current.

Catch rates of snapper did not vary as much with depth compared to the other species although there was a significant increase in catch rates with increasing depth. Teraglin catch rates were significantly higher in shallower waters, steadily declining with depth (Figure 6a) whereas the opposite was observed for pearl perch which were rarely caught in the shallowest depths fished.

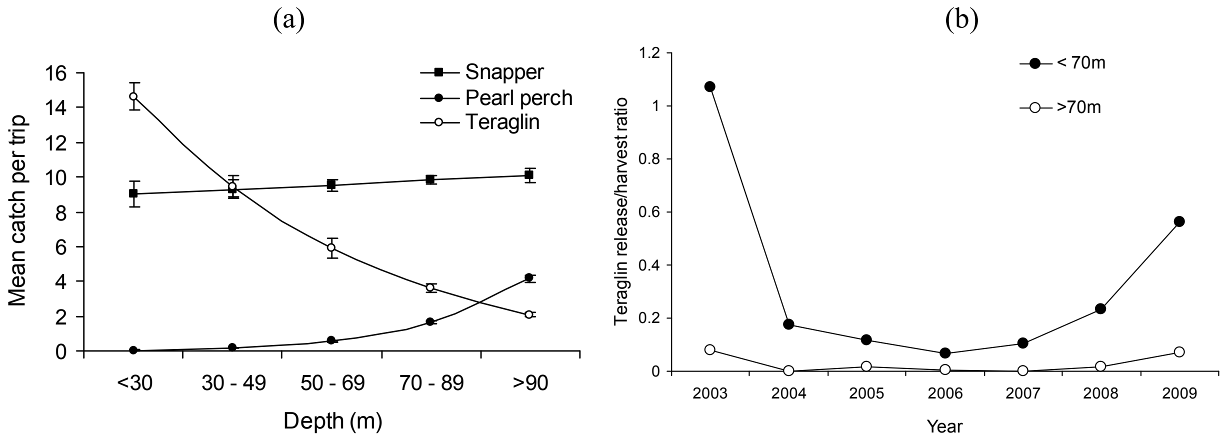

Figure 6 Model predictions of (a) mean catch rates relative to depth of the Gold Coast offshore charter fleet from 1993 to 2010. (b) ratio of the number of teraglin released compared with the number retained (harvested) from a sample of Gold Coast charter vessels fishing two depth ranges. NB – MLS was reduced from 45 to 38cm in 2003.

The effects of decreasing the MLS on teraglin can clearly be seen in Figure 6b where the release ratio declined in 2004. It is interesting to note that in recent years the ratio of release to retained teraglin has again increased as increasing numbers of smaller fish continue to be landed by the Gold Coast charter fleet. The release rate was also dramatically higher in water less than 70m deep reflecting smaller size of this species in shallower waters closer to shore.

The fishing operations of many of the Gold Coast charter fleet have changed dramatically over the last 20 years with a trend to fishing shallower water as well as reducing average time on the fishing grounds and increasing the average number of anglers per boat (Figure 7). Some of these trends have been quite dramatic with average depth fished declining by over 25% from 77m to 55m.

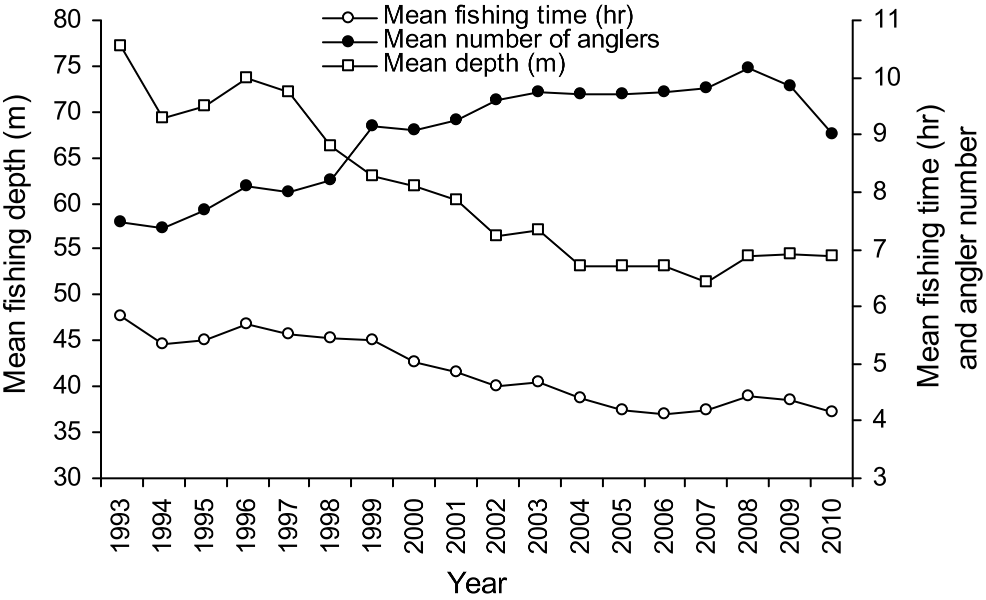

Figure 7 Change in various trip characteristics of the AMLI sample of the Gold Coast charter fleet since 1993.

The pearl perch length frequencies are generally dominated by smaller size classes with few fish (<5%) larger than 50cm being landed by the sampled fleet (Figure 8). 2006 and 2008 were the years that had the highest proportion of larger fish in the catch. Sample sizes during 2004, 2008 and 2009 were low (<250 fish) and may not therefore be an unbiased representative sample.

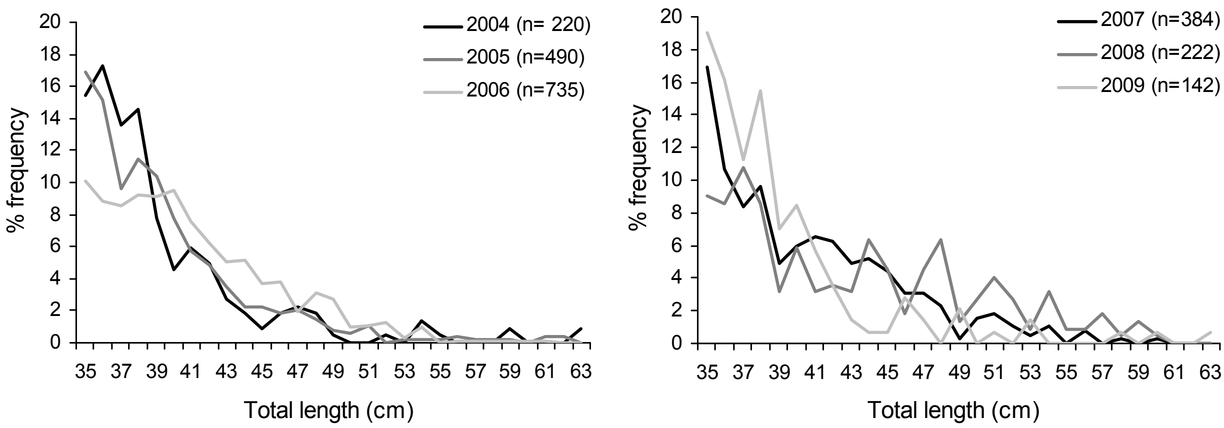

Figure 8 Yearly length frequencies of the harvested AMLI sampled charter boat catch of pearl perch from 2004 to 2009. Sample sizes are shown in brackets after each year.

The pearl perch discard ratio also suggests recruitment of smaller pearl perch to the fishery occurs during the autumn months when the release rate peaks (Figure 9). The large confidence intervals, particular during autumn, suggest considerable annual variation and lack of any consistent statistical trends apart from the significantly lower release rates that occur during the summer months when they are half those of the April to June period.

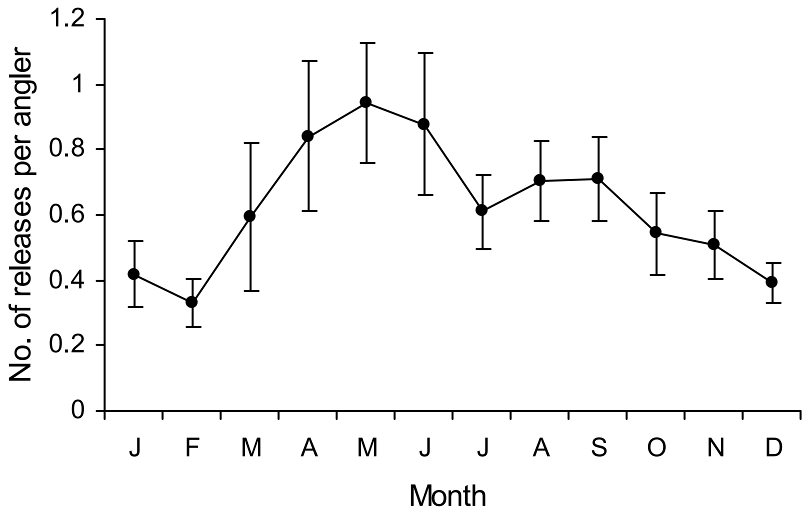

Figure 9 Monthly variation in the number of pearl perch released per angler on AMLI sampled charter boats fishing on the Gold Coast between 2004 and 2009. Vertical bars are 95% confidence intervals.

Discussion

Annual catch rates of Gold Coast snapper and teraglin were more closely correlated than those of pearl perch with both peaking in 1999. This may be due to a number of reasons but an influx of snapper and teraglin recruits on the Gold Coast in 1999, possibly as a result of favourable spawning conditions in previous years appears most likely as snapper length data analysed previously showed larger numbers of smaller snapper caught in 1999 (Sumpton *et al.* 2006). Large catches of snapper and teraglin may have also resulted from a decrease in charter boats targeting pearl perch whose catches were shown to be higher in deeper water. Several factors may affect the seasonal variation of catch rates for charter boat operations. These include, favourable weather conditions for fishing during certain periods of the year; seasonal fish behaviour such as spawning, when fish aggregate making them more susceptible to capture; increased targeting of certain species during particular times of the year based solely on seasonal migration; and periods when charter boat trips are more popular among tourists and locals. For snapper and pearl perch, higher catch rates were obtained during the middle of the year when weather conditions were more favourable and operators were more likely to fish further offshore, and teraglin had relatively low catch rates during this period. It is also the spawning season for snapper and traditionally a time of elevated snapper catch rates. Sumpton *et al.* (2006) also noted that catches of jobfish and other more tropical species were low during the cooler months of winter, reflecting likely temperature effects on distribution.

The overall average charter catch rates were higher than those of the average boat-based recreational angler (e.g. 0.8 snapper/angler/day) (Ferrell and Sumpton 1997) confirming results of overseas studies (McEachron and Matlock 1983) which have shown superior average catches of charter boats when compared with normal recreational boat angling. The Gold Coast charter catch of snapper has been previously shown to be largely based on smaller and younger individuals (Sumpton *et al.* 2006, Campbell *et al*. 2009). This may be due to the stocks being heavily fished, and/or the targeting of areas where fish are smaller or alternatively related to differential fishing selectivity. It is known that this species grows to over twice the average size landed by the fleet. A similar situation also exists for both pearl perch and teraglin which also have abbreviated size structures consisting of relatively few larger fish (See Appendix 2.1 and Appendix 3.2) for a detailed description of size structure of these species).

One of the past issues for the Gold Coast charter fleet and recreational fishers in the area was the competition between the fleet and New South Wales (NSW) commercial trap fishers. The number of NSW trap fishers allowed to fish in Queensland waters has now declined to zero but trapping is still widespread in adjacent northern NSW waters. Fishers (from all sectors) claim that traps are more efficient at catching snapper than line fishing and that traps are responsible for depleting stocks in localised areas. The observed lower snapper catch rates from the two regions closest to the QLD/NSW border (Burleigh and Tweed) support this view. On the other hand, no such spatial trend was evident for the other two species, although this probably relates more to the lower vulnerability of pearl perch and teraglin to trap fishing as commercial trap fishers note that both these species are not an important component of their trap catches (Peter Bolic, personal observation). The different management regimes in place in QLD and NSW are also a concern as any changes in management in either jurisdiction will cause flow on effects in the other and will be most evident in the areas immediately either side of the border. The current 5cm difference in MLS creates additional compliance uncertainties among the fishing community adjacent to the Qld/NSW border.

Commercial line fishing effort on the Gold Coast is very low particularly in water <100m depth where there is normally considerable competition among the sectors that access the fishery. While CFISH records show reasonable commercial teraglin catches there is little evidence of widespread catches of commercial fishers when discussing commercial effort in the region with charter operators and experienced recreational fishers. The results of the catch rate analysis have highlighted a number of important factors that influence the catch of the three species. As expected depth, location and boat were the most important, but the most productive fishing grounds for both snapper and pearl perch were certainly in the deeper areas (>70m). This is an interesting result because an earlier analysis of the AMLI data during the 1990's showed that the most productive snapper fishing grounds were in 50 to 69m (Sumpton *et al.* 2006). This result supports anecdotal information suggesting the recent depletion of inshore areas with fishers moving further offshore to areas previously comparatively lightly exploited. It also further raises concerns about hyperstability in this fishery. Despite this, there has been a trend in the Gold Coast charter sector towards fishing in shallower water most likely to offset fuel and other business costs. While catch rates of teraglin are highest in these waters the size of this species is generally smaller in shallow water and this is clearly exemplified in the data which show that the lowering of the MLS resulted in an increase in the viability of fishing in this area (at least in the short term.

Highest catch rates for snapper and pearl perch were achieved on fishing trips occurring during the day with the opposite being the case for teraglin. Teraglin tend to leave the sea bottom during the night to feed on pelagic fish, making them more susceptible to capture in fisheries at this time (Sumpton *et al.* 1998). For all species, catch rates were highest in waters with lower current velocities. Sea condition was not found to have a statistically significant impact on catch rates of any species although there was a declining trend in catch towards rough sea states. Calm weather conditions with small swell, light winds and high visibility, are favoured by charter boat fishing operations for obvious reasons. Fishing trips may have been shorter, less frequent and it may have been harder for anglers to reach fishing areas in poor weather conditions, leading to overall lower catch rates.

The relative importance of the three main target species to the overall catch (as reflected in the unadjusted catch composition) has changed since 1993 although this does not necessarily represent a change in relative abundance of these species as these changes are not reflected in the standardised yearly catch rates. The latter better reflect changes in the relative abundance than the raw proportional contribution of particular groups to the overall catch as a range of factors not necessarily related to stock abundance will impact the targeting practices of various boats that make up the charter fleet. Over the last decade many of these have related to business conditions.

The considerable variation in catch rate among charter boats reflects different targeting strategies, the skill of boat skippers and other business characteristics not necessarily related to fishing. Generally, charter skippers will attempt to equally share catches among different charters by altering fishing locations and/or imposing their own bag limits and size limits (Ray Joyce pers. comm.). Therefore their behaviour is quite different to operators in the commercial and recreational fishery, where most participants generally try to maximise catches (although there is an increasing tendency to target larger fish or specific trophy species by some sections of the recreational fishing community). For these reasons, analysis of the factors influencing catch rates may be somewhat biased because when catches are initially high during the early part of a charter some skippers may change position or alter fishing practices in some other way in an effort to reduce catches of that species or move to another target species.

The seasonal nature of the snapper fishery is still noticeable for the charter fishery with greatest catches during winter and spring. Charter boats respond to demand and are also more likely to fish rougher weather than many recreational boats due to their larger size and the greater skill level of their skippers as well as general business structure which seeks to maximise the number of days fished. These effects plus the previously discussed tendency for skippers to "influence" catches again affects how representative seasonal catch rates are of the general relative abundance of these species.

An important issue that this current project seeks to address is the post-release mortality of the discarded catch (of snapper, pearl perch and teraglin) from charter boats and the fishery generally (See Appendix 3.5 to Appendix 3.7). Charter operators do not allow the retention of undersized fish by their clients but the fate of smaller undersized fish that are caught and discarded is an important issue and steps should be taken to minimise this mortality. Discussions with charter fishers, recent data collected by AMLI and by this current project have shown that at times the discard rate of some species can be higher than 90%. Some charter operators are adept at only fishing areas where larger individuals of target species dominate, while others take particular care to ensure that fish are handled according to best practice and are treated for barotrauma before release thereby optimising their survival. These practices however are not universal and observations have shown that some operators do not treat fish for barotrauma, merely releasing the fish in a condition that would reduce its subsequent survival. Observations on board vessels as well as scientific studies have suggested that discard mortality could be virtually 100% for some species at certain depths. We have shown that with best practice, survival of released snapper, pearl perch and teraglin can be very high (See Appendix 3.5 to Appendix 3.7) but it is important that fishers adopt best handling and barotraumas treatment practices to enhance survival. However, best handling practices will only be effective if they are adopted widely by all sectors. The wide variation in handling and release practices among fishers suggests that ensuring widespread adoption of these protocols may be challenging and it may be wise to use lower estimates of post-release survival in stock assessment models to account for this uncertainty.

Prior to this current research, the biology and population dynamics of many of the species (apart from snapper) that contribute to the rocky reef fishery were poorly understood and this has been an impediment to the sustainable management of this fishery. Most of the fish targeted by the Gold Coast charter fleet are temperate species that are at the northern extremes of their distribution and are therefore fished in NSW as well as Queensland (such species include snapper, pearl perch and teraglin). It is important that wherever possible consistent and complementary management approaches are pursued by both states in order that this fishery is managed sustainably. Tropical species at the southern end (mainly tropical cods and snappers) of their range also make up a significant proportion of the catch but there are fewer cross-jurisdictional issues for those species.

The AMLI data are not particularly representative of the pearl perch catch as there are many trips where this species is not recorded largely because the charter skippers fish closer to shore in order to reduce fuel and other costs. Pearl perch are known to be more abundant in the deeper areas (>30m) of the fishery on the Gold Coast and elsewhere in their distributions. Economic conditions can therefore clearly influence catch rates and this may not necessarily relate to any particular change in abundance or other sustainability issues for these species, but be more related to targeting preferences. Recent change to the dynamics of the sampled fleet in terms of fishing time and number of anglers further exacerbate this issue. While data standardisation can adjust for these issues it is more difficult to incorporate important factors such as depth effects into models if these data are not available.

Large numbers of teraglin are regularly reported by Gold Coast charter operators and this is one species that may be representatively sampled by this fishery. While, teraglin are caught in all depth ranges with high catch rates of smaller fish in shallower water, larger fish are commonly found deeper. Standardised catch rates from the Gold Coast Charter fleet may therefore provide a useful index of relative abundance for teraglin, particularly if operators remain fairly consistent through time. These targeting practices can dramatically influence resultant catch rates. We saw evidence of charter vessels exploiting small scale abundances of particular species (for example the number of charter vessels fishing teraglin at Square Patch in October 2011).

Likewise at a finer scale, seasonal change in the unadjusted species composition in the fishery of the Gold Coast only partially reflects the differential seasonal availability of species. While some species may be caught all year round fishers will take advantage of the seasonal availability of fish such as cobia and target such species even when traditional “bread and butter species” such as teraglin and snapper are still available. This ability of the fishery to selectively target species when they are available is a limiting factor when considering changes in catch rate and the use of catch rates as indices of abundance, at least on small spatial scales. Catch rates for species such as pearl perch may decline merely because charter operators are targeting other species. This issue of targeting is a significant problem in this and other fisheries, and one which is difficult to address under current catch reporting and other business arrangements. The use of fishery dependent data such as the AMLI data is thus useful to validate trends evident from other data sources.

It is widely accepted that a small subset of a fleet can still exhibit catch rates that are representative of the catch of the entire fleet or more importantly their catch rates may provide a useful index of a species' relative abundance. These vessels should characteristically be those that are fairly long term participants whose effort can at least be standardised so that a reasonable time series of annual indices can be calculated from their catches. It is still an area of contention whether the Gold Coast charter fleet meet these criteria as the nature of the fleet has changed over recent time both in terms of targeting preferences as well as areas fished. The movement to half day charters by some operators as well as competitive business pressures has seen changes to fishing practices among many operators. The global financial crisis and increasing fuel prices have caused many structural changes in the fishery as operators seek to further minimise costs and remain viable. The data showing the changes in catch rates with depth suggest that for both teraglin and pearl perch these changes could have a dramatic effect on catch rates. This would be further exacerbated by the varying size structure with depth for many species, particularly teraglin which are smaller in shallower water and caught at higher catch rates in these areas.

Changes in fishing power of vessels are also known to have a dramatic effect on catch rates which is why fishing effort data has to be standardised for these changes in order to obtain a reliable index of a species' relative abundance. The sampled charter fleet on the Gold Coast has exemplified dramatic changes in response to a number of influences including:- changes to areas fished in response to species availability as well as deteriorating business and other economic conditions. It is possible to account for many of these variations in our assessment models; however, the data needed to standardise are not always available for the entire charter fleet in Queensland where data is reliant on compulsory logbook information. The observed reduction in fishing time and the increase in numbers of anglers are clearly a reflection of the need to maintain business viability in the face of rising cost pressures. The effect of these two changes could cancel each other as one is an effective increase in effort while the other is an effective decrease. Analysis of the total effect, however, showed that the effect of both was to cause an overall effective decline in effort. It is recognised that changes in fishing characteristics may be partially driven by changes in the sampled vessels (as operators enter and leave the fishery) and there were clearly changes in the characteristics of individual vessels that were maintained throughout the study period.

Longer term analysis of catch data, as yearly averages, still provides a better index of abundance as it is unlikely that the nett effect of changing targeting practices would leave species such as snapper, pearl perch and teraglin as less than fully exploited in the region given high overall levels of general fishing effort in the region.

The compulsorily collected CFISH charter data do not contain information on length of fishing trip or effective fishing hours and there is a limited number of records where the number of anglers is recorded. If there are changes in any of these parameters over time due to economic circumstances (or other reasons) then the lack of these data may hide changes in effective effort since what constitutes “a day's effort” may vary dramatically over time. The Gold Coast charter fleet clearly exemplifies this fact as night time fishing trips and the longer full day trips have been replaced by two trips per day by some operators. The range of practices that individual businesses adopt is clearly diverse and discussions with many charter operators have confirmed this. The current recording practices in the CFISH logs therefore clearly lack precision and may also offer biased assessments over time if conditions change and are unaccounted for in any assessment.

The Gold Coast charter fleet (and charter businesses generally) have been resilient in terms of taking advantage of the seasonal availability of particular species by changing to targeting these species. Under climate change scenarios which predict strengthening of the EAC and the latitudinal movement of species ranges there will be an expected shift of tropical species such as lutjanids and lethrinids further south to the Gold Coast fishery. At the same time temperate species such as snapper, pearl perch and teraglin may become less abundant as they are already at the northern extreme of their distributions in southern Queensland and their ranges are expected to move south. The species most at risk from a Queensland perspective is teraglin as this species has the most restricted northerly distribution and may be further displaced south by any climate change impact.

In addition to latitudinal shifts there may be changes in distribution longitudinally related more to depth. We know little about the temperature requirements and fine scale habitat preferences for many of our rocky reef species but it is reasonable to assume that changes in temperature as well as current conditions that are known to occur with relatively small changes in depth may shift species distribution longitudinally as well as latitudinally, particularly given the pattern of reefs that tend to run roughly parallel to the shore line. The ecological processes that would advantage one species over another under this scenario are poorly understood but the small scale depth variation in community composition noted off the Sunshine Coast (see Appendix 3.9) suggests that significant changes could occur over relatively small spatial longitudinal scales. The expected increase in current speed of the East Australian Current could impact both on species distribution as well as subtly influencing fishing ability as we have found that catch rates of all species were lower under high current conditions and we speculate that this is largely due to logistic difficulties in fishing under these conditions.

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