Fisheries

Monitoring the relative abundance and biomass of South Australia's Giant Cuttlefish breeding population


Julian Finn, Museum Victoria

MA Steer, S Gaylard and M Loo

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FRDC TRF PROJECT NO. 2011/054

SARDI Aquatics Sciences
PO Box 120 Henley Beach SA 5022

February 2013

Final Report for the Fisheries Research and Development Corporation

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South Australian Research and Development Institute
SARDI Aquatic Sciences
2 Hamra Avenue
West Beach SA 5024

Telephone: (08) 8207 5400
Facsimile: (08) 8207 5406
http://www.sardi.sa.gov.au

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Author(s):	MA Steer, S Gaylard (EPA) and M Loo
Reviewer(s):	T Fowler and J Tanner
Approved by:	T Ward Science Leader – Fisheries
Signed:	
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NON-TECHNICAL SUMMARY

2011/054 Monitoring the relative abundance and biomass of South Australia's giant cuttlefish breeding population

PRINCIPAL INVESTIGATOR: Dr MA Steer
ADDRESS: SARDI (Aquatic Sciences)
PO Box 120
Henley Beach SA 5022
Telephone: (08) 8207 5400

OBJECTIVES:

1. To develop a 'standard' methodology that can be used in the on-going monitoring and assessment of the unique cuttlefish population and the environment in which they aggregate to spawn, and
2. To develop a preliminary understanding of whether there have been declines in abundance of the spawning aggregation, and the causes of any decline observed.

OUTCOMES ACHIEVED TO DATE

This study has refined an existing survey method (see Hall and Fowler 2003) that can be used in the on-going monitoring and assessment of the unique cuttlefish population and the environment in which they aggregate to spawn. This study also verified that the annual spawning aggregation had indeed declined from a peak of approximately 183,000 animals in 1999 to 18,530 in 2012. Given the inter-connectivity of the marine environment, coastal industries and lack of understanding regarding the history of the spawning population, providing definitive answers to the cause of the decline was difficult. This project considered an extensive range of potential factors (i.e. environmental irregularities, increased predation pressure, industrial pollution, fishing pressure) and undertook a preliminary evaluation to assess their relative likelihood in contributing to the cuttlefish decline. This exercise relied on simple statistical analyses and can be considered a 'first cut' approach that identifies those factors that require more rigorous investigation. This approach provided a foundation in which a subsequent FRDC project (2013/010) can build on, as it aims to incorporate the identified factors into more complex population simulation models that will 'test' the responsiveness and viability of spawning population to the potential drivers.

This outcomes of this report and the refined survey methodology will be taken up by the South Australian Government Giant Cuttlefish Working Group, which consists of representatives from Primary Industries and Regions SA (PIRSA), South Australian Research and Development Institute (SARDI), Department of Environment, Water and Natural Resources (DEWNR), Environmental Protection Authority (EPA), Department of Planning, Transport and Infrastructure (DPTI), South Australian Tourism Commission (SATC), Whyalla City Council (WCC) and the Conservation Council of SA (CCSA) and was established during the course of this project (July 2012) to coordinate a whole-of-government response to concerns about the decline in the northern Spencer Gulf population of giant Australian cuttlefish (*Sepia apama*) at the Point Lowly breeding aggregation. This working group was established to consider the relevant existing information; identify gaps in knowledge and research; consider management responses; establish an on-going monitoring system that addresses population abundance, habitat condition and water quality; engage with community groups and key non-government stakeholders; and provide up-to-date advice to relevant ministers.

Each winter tens of thousands of giant Australian cuttlefish (*Sepia apama*) aggregate on a discrete area of rocky reef in northern Spencer Gulf to spawn. This is the only known dense aggregation of spawning cuttlefish in the world. A series of anecdotal reports that have filtered in through various media sources has indicated that the 2012 spawning aggregation appeared to be significantly reduced compared to previous years. There is considerable speculation as to why breeding cuttlefish have “failed to turn up” on the Point Lowly Peninsula spawning grounds, with proposed reasons including natural variation in their population dynamics, over-fishing by both the commercial and recreational fishing sectors, localised pollution by coastal industrial development, and environmental irregularities. Structured cuttlefish surveys, where the data have been made publicly available, have not occurred since 2005 (see Steer and Hall, 2005), therefore, it is has not been possible to ascertain the magnitude of the annual variation in cuttlefish abundance and biomass. Furthermore, there has not been any routine environmental monitoring within the broader northern Spencer Gulf area to investigate any potential causal links between local environmental conditions and cuttlefish aggregative behaviour.

This project refined a previously developed survey methodology for estimating cuttlefish abundance and biomass and incorporated a habitat and water analysis component to be carried out as part of a potential on-going monitoring program. Simplifying the cuttlefish surveys and the production of a standard operating procedure (Appendix 3) opens up the opportunity for other agencies to undertake their own surveys or to collaborate together (e.g.

BHP Billiton, PIRSA, Santos, Conservation Council) and ensure the continuity of the data. With the appropriate training and expert supervision it may also be possible to enlist qualified volunteers to contribute to data collection through recreational dive clubs, and community or school groups. Enlisting diverse groups to undertake the surveys, however, raises issues around quality control and assurance of the collected data. Ensuring that divers are appropriately trained or accompanied by experts who have contributed to the surveys in the past would ensure greater scientific rigor in data collection and result in meaningful estimates of cuttlefish abundance and biomass. Appropriately archiving habitat images would also facilitate audits, or re-analysis, if required to investigate data integrity. Similarly, the EPA, the peak agency for monitoring and assessing South Australia's water resources, could be used for the on-going analysis of water samples to ensure that the appropriate systems and practices were in place for the delivery of high quality environmental data.

This project also explored whether the observed decline in cuttlefish abundance and biomass correlated with a range of potential 'contributing' factors, which included: water temperature, weather conditions, pollution, predators, prey, habitat, disease, fishing pressure and tourism. This section also investigated the history of the spawning population and reviewed our current understanding of the species' population dynamics. Of the investigated abiotic influences local rainfall was the only factor found to inversely correlate with peak cuttlefish abundance and biomass. However, it was unknown whether the underlying dynamics related to changes in coastal salinity, localized pollution through terrestrial run-off, or a direct influence on water clarity, all of which may deter aggregating cuttlefish from the coastal environment. No clear association was made between the decline of cuttlefish abundance and the investigated biotic influences such as: predator and prey abundance; habitat condition; and fishing intensity. There was also insufficient long-term observations of cuttlefish around the breeding site to definitively rule out that the rapid population 'explosion' observed in the late 1990s was an extraordinary natural phenomenon.

Our current lack of knowledge of cuttlefish population dynamics and their proximate cues for spawning in northern Spencer Gulf limits our ability to identify a definitive cause for the decline. This study, however, identified some avenues of research for developing a more robust understanding of the underlying factors that shape the spawning aggregation. These avenues related to gaining more information about the movement and migration of the cuttlefish on and off the 'iconic' spawning grounds, the structure of the northern Spencer Gulf

population, and local trophodynamics. Strategies are currently in place to investigate these key knowledge gaps over the next few spawning seasons.

KEYWORDS: giant Australian cuttlefish, spawning, aggregation, population decline, survey methodology.

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This project grew considerably from constructive conversations and suggestions from a wide variety of people. We thank SARDI's Matthew Lloyd, Damien Matthews, John Dent, Ben Stobbart, BHP Billiton's consultants James Brook, Karina Hall, David Wiltshire and Emma Cronin for assistance in the field; Neil 'Chikko' Chigwidden, Kathryn Wiltshire (SARDI), and Warwick Noble (EPA) for gear and technical assistance; Jim Phillips (Santos) for site access; SARDI's Leo Mantilla, Emma Brock, Simon Goldsworthy, Graham Hooper, Cameron Dixon and Angelo Tsolos, and Australia's Bureau of Meteorology for data provision and analysis; Mark Doubell (SARDI-Oceanography) for oceanographic modeling; Bronwyn Gillanders (University of Adelaide), Karina Hall (NSW DPI), Tony Bramley (Whyalla Dive Services), Kathryn Warhurst (Conservation Council), Scoresby Shepherd and Tony Fowler (SARDI) for data interpretation; Heather Riddell (SARDI); Terry Price, Cathy Parker and Joanna Tsoukalas for media relations; Julian Finn (Museum of Victoria) for providing spectacular images; and the Giant Cuttlefish Working Group consisting of members from PIRSA, SARDI, DEWNR, EPA, SATC, DPTI, Whyalla City Council and the Conservational Council of South Australia for constructive advice.

This report was reviewed by Dr Tony Fowler (SARDI), Dr Jason Tanner (SARDI), anonymous (FRDC), and formally approved for release by Assoc. Prof. Tim Ward (SARDI) and Prof. Gavin Begg (SARDI).

1. GENERAL INTRODUCTION

1.1. Background

Each winter tens of thousands of giant Australian cuttlefish (*Sepia apama*) aggregate on a discrete area of rocky reef in northern Spencer Gulf, South Australia, to spawn (Figure 1.1A). This is the only known dense aggregation of spawning cuttlefish in the world, and as such, the site has been identified as an area of national significance (Baker 2004). Historically, this aggregation supported a small bait fishery, where reported catches were generally less than 4 t per annum. However, in the mid-1990s, commercial fishing pressure intensified and by 1997 the annual catch had increased to 250 t, representing >95% of the State's total catch (Hall and McGlennon 1998). Such rapid exploitation was presumably in response to the potential for cuttlefish to develop into a profitable 'niche' market and had the capacity to further expand (Hall 2002). Like other cephalopods, cuttlefish are short-lived and only experience one reproductive period at the end of their lives (Hall 2002). Therefore, there is no accumulation of spawning biomass from one generation to the next and little buffer against years of poor recruitment or over-exploitation (O'Dor 1998). Consequently, the rapid increase in cuttlefish catch raised considerable concern about the sustainability of the resource, particularly because fishers were targeting spawning animals, thus placing the population at a high risk of localised extinction. This concern was shared amongst user-groups, including the recreational dive and eco-tourism sectors, and the film and television industry, which also relied on the unique spawning aggregation as a source of income (Hall 1999).

In 1998, a fishing closure that encompassed approximately 50% of the spawning area was implemented to ensure that a proportion of spawning animals were protected from fishing (Figure 1.1B). As that fishing season progressed, further concern was raised over the effectiveness of the partial closure, as fishing effort was shifted to other areas of the aggregation that were equally susceptible. Consequently, the closure was reviewed and expanded to include most of the main spawning grounds for the remainder of the season (Figure 1.1C). For the subsequent five years (1999 to 2003), the main spawning grounds were closed to fishing for the duration of the entire spawning season, i.e. from 1st March until 30th September. In 2004, the closure was once again reviewed and amended to protect all cephalopods (including southern calamary *Sepioteuthis australis* and octopus) and to remain full-time (Figure 1.1C). This closure effectively prevented the fishery from expanding beyond a negligible bait commodity with the subsequent State-wide commercial catches rarely exceeding 10 t per year (Fowler et al. 2012). Although the threat of the commercial and recreational fishery had been significantly reduced, the State Government further expanded the cephalopod closure ahead of the 2012 breeding season to encompass the south-eastern side of the Point Lowly Peninsula (Figure 1.1D). This extension was implemented as a precautionary measure to offer greater protection to spawning cuttlefish as there had been a series of anecdotal reports suggesting that cuttlefish numbers had declined considerably in recent years.

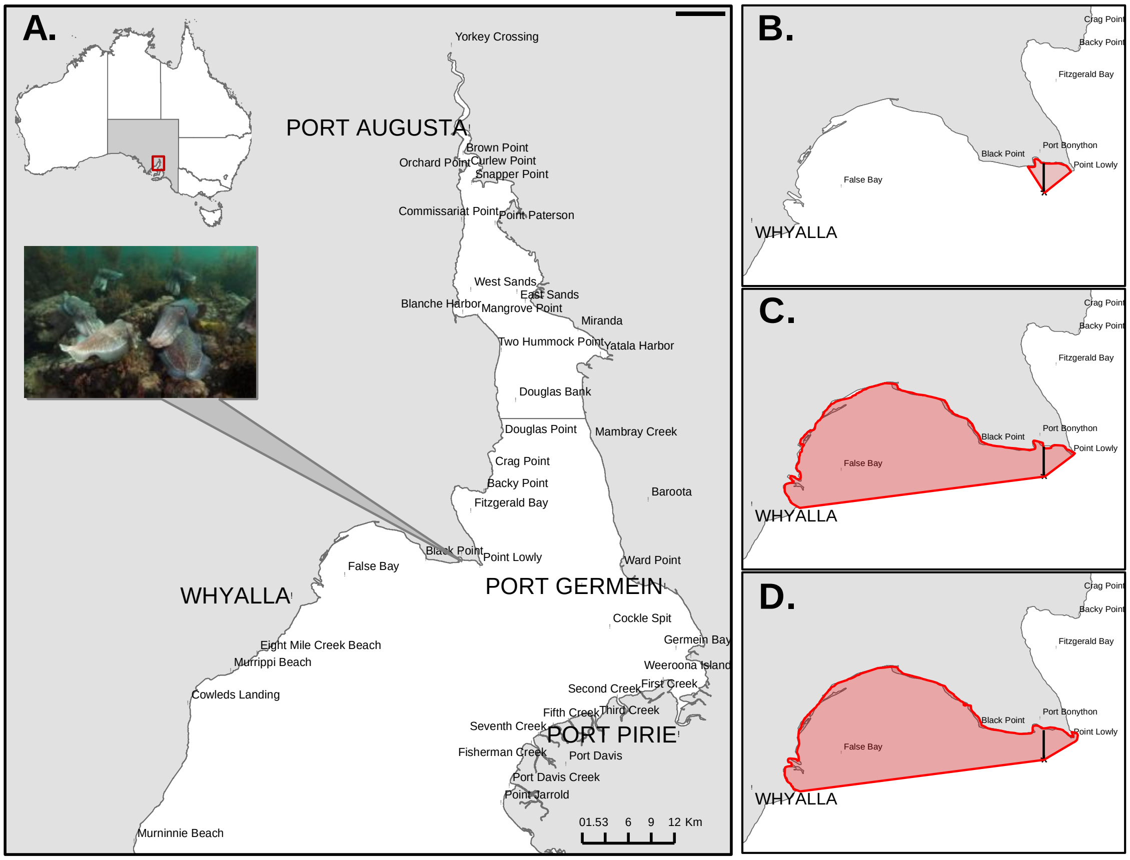

Figure 1.1. (A.) Location of the cuttlefish aggregation site at Point Lowly, northern Spencer Gulf. (B.) The area of the first fishing closure implemented at the beginning of the 1998 spawning season. (C.) Reviewed closure mid-way through the 1998 spawning season. (D.) The extension of the closed area to encompass the eastern tip of Point Lowly implemented prior to the 2012 spawning season. (*Photo Credit: Julian Finn, Museum Victoria).*

1.2. Need

A series of anecdotal reports, that have filtered through various media sources, has indicated that the 2011 spawning aggregation appeared significantly reduced. There is considerable speculation amongst the community as to why breeding cuttlefish had “failed to turn up” on the Point Lowly spawning grounds, with proposed reasons including: natural variation in their population dynamics; localised pollution by coastal industrial development; fishing and environmental irregularities. In order to effectively respond to this decline, it is important to determine whether the reduction in cuttlefish numbers is reflective of an ongoing trend, and if so, what has caused it. Cuttlefish surveys have been carried out from 1998 to 2001 (see Hall and Fowler 2003), 2005 (Steer and Hall 2005), and from 2008 to 2011 (Hall 2009, BHP Billiton 2009, Hall 2010, 2012), however, there has not been any structured, routine environmental monitoring within the broader northern Spencer Gulf area to investigate potential causal links between local environmental conditions and cuttlefish aggregative behaviour.

1.3. Objectives

1. To refine a previously developed survey methodology that can be used in the on-going monitoring and assessment of the unique cuttlefish population and the environment in which they aggregate to spawn.
2. To develop a preliminary understanding of whether there has been a decline in abundance of cuttlefish at the spawning aggregation, and the cause(s) of any decline observed.

2. REFINING THE EXISTING CUTTLEFISH SURVEY METHODOLOGY

2.1. INTRODUCTION

An underwater visual survey method is currently used to estimate the abundance and biomass of spawning giant Australian cuttlefish around Point Lowly. This method was developed in 1998 as part of an extensive FRDC-funded study that investigated the fishery biology of *S. apama* in northern Spencer Gulf (Hall and Fowler 2003). The main objectives of this survey design were to gain a greater understanding of the dynamics of the spawning aggregation and to provide an annual population estimate for use in fishery management. Annual surveys were completed by the South Australian Research and Development Institute (SARDI) from 1998 to 2001 as part of its cuttlefish stock assessment program (Hall and McGlennon 1998, Hall 1999, 2000, 2002). Such annual surveys, however, were subsequently abandoned as a series of fishing closures implemented from 1998 onwards effectively reduced the fishery to such a low level that there was no requirement for on-going stock assessment. In 2005, the Coastal Protection Branch of the South Australian Department for Environment and Heritage (DEH) commissioned SARDI to undertake a 'snap-shot' survey in response to anecdotal concerns over a decrease in cuttlefish abundance (Steer and Hall 2005). The survey design was also used by BHP Billiton from 2008 to 2010 as part of their Olympic Dam Environmental Impact Statement Project (Hall 2009, BHP Billiton 2009, Hall 2010). Santos also adopted the survey design to undertake a series of small scale assessments from 2008 – 2011 in response to concerns about groundwater contamination (SEA 2008, 2009, 2010 and 2011). Although the methodology of the survey was originally developed to be used by SARDI to assess the impact of commercial and recreational fishing on the unique spawning aggregation its extension and use by other government agencies and private industries to address conservation issues has been advantageous.

The capacity for multiple agencies to undertake cuttlefish surveys has proven beneficial as it has collectively provided a time-series of data that has extended over 12 years. Although all of these surveys have been based on the original design established by Hall and Fowler (2003), over time there have been some inconsistencies in the way the data have been collected, analysed and interpreted. These have related to site access, misunderstanding of the strata boundaries and the iterative calculations that are used to estimate error variances. Although these inconsistencies have been minor and have not appeared to compromise the overall trends in the population assessment, there is a need to establish a 'standard methodology' that simplifies the process and ensures future surveys remain robust. Refining the existing methodology would also explore whether more cost effective sampling techniques, such as video analysis, can to be incorporated into the survey design.

Historically, the primary focus of the surveys has been to estimate the abundance and biomass of the spawning cuttlefish. The long-term trend has indicated that the cuttlefish aggregation has sequentially declined since 1999 (Hall 2012). The cause of this decline is unknown, however, it has been speculated that it may be due to changes in one or several of; the habitat, water quality, fishing pressure, climate, or predator/prey abundance. In response to this speculation it seems logical to, at least, incorporate an assessment of the spawning habitat and water quality as part of a standardised survey. Successful natural resource management often relies on accurate biological surveys that range from a simple census of a key species to a comprehensive evaluation of an entire ecosystem. Including both habitat and water quality assessment into the survey design will lead to a more comprehensive on-going evaluation of the spawning area.

The strength of a good survey design can be assessed by its simplicity, ease of repeatability, cost effectiveness and data integrity. The objective of this study was to refine the existing survey methodology developed by Hall and Fowler (2003) to a level that could be easily adhered to by multiple agencies/organisations and would ensure that the data remains comparable through time. Refining the method used to estimate cuttlefish abundance and biomass was done over three consecutive field trips undertaken in May, June and July 2012. The practicability of integrating a concurrent assessment of the habitat and ambient water quality of the cuttlefish spawning area was also explored. This section of the report details each component of the methodological approach separately, sequentially addressing the establishment of the survey sites; habitat characterisation; estimating cuttlefish abundance and biomass; and analysing ambient water quality.

2.2. SITE DESCRIPTION

Overall, 13 sites have been surveyed to estimate the abundance and biomass of giant Australian cuttlefish around the greater Point Lowly area (Hall and Fowler 2003). Eleven of the sites are concentrated within a continuous 10 km stretch of coastline that extends from False Bay to Fitzgerald Bay (Figure 2.1). This coastline is renowned for supporting the highest densities of spawning cuttlefish and is characterised by shallow fragmented bedrock reef, which provides an ideal substrate upon which cuttlefish can attach their eggs. The additional two sites are located outside of the main aggregation area; OneSteel Wall and

Backy Point. The OneSteel Wall site (previously referred to as “BHP Billiton Wall”) is located 15 km south west of the main aggregation area and encompasses a section of the breakwater that borders the settlement ponds of OneSteel’s pellet plant facility which was constructed in the late 1960s. Historically, this breakwater has supported relatively high densities of cuttlefish during the spawning season. Backy Point is approximately 10 km north of the main aggregation area, and is also characterised by a fringing rocky reef that has supported relatively high densities of spawning cuttlefish in the past. Access to two of the sites (i.e. OneSteel Wall and Santos Jetty) has often been restricted due to shipping traffic, whilst Backy Point has not been regularly surveyed over the years. Consequently, 10 of the 13 sites form the basis of the cuttlefish population assessment (Table 2.1).

The relative spawning area of each of the 13 sites has been calculated from aerial photographs and ground-truthed via a series of underwater transects to verify the extent of the rocky, spawning, substrate (Hall and Fowler 2003). The habitat characteristics of all sites were also qualitatively assessed and four main habitat types were identified: shallow (<1 m) bare bedrock; broken slabs of bedrock dominated by urchins (*Helocidaris erythrogramma*), sponges and low turfing algae (depths 1 to 5 m) which was referred to as “urchin habitat”; patchy reef covered in dense stands of brown and green algae (depths 4 to 8 m) which was referred to as “algal habitat”; and sand/seagrass dominated substrate that typically occurred in depths >7 m (Hall and Fowler 2003). The original survey design partitioned each of the sites into “strata” based on their habitat characteristics and calculated a stratum-area that would form the basis of the areal expansion of cuttlefish abundance and biomass estimates (Hall and Fowler 2003).

The original survey sites were also classified on the basis of their fishing history. This was relevant at the time of the study as there was a need to assess the relative effectiveness of the fishing closures that were introduced at the start of the 1998 spawning season. The spatial and temporal extent of the closure, however, changed over the course of the four year study (1998 to 2001) and as a result the classification of the survey sites became overly complicated with some sites being open to fishing in one season and closed the next, resulting in a confusing “open-closed area” classification. The legacy of these classifications has remained within the contemporary surveys despite the significant reduction of the cuttlefish commercial catch since 1998.

One of the first steps in this project was to clarify the parameters of the sites to simplify on-going surveys. The inclusion of a habitat assessment component in future surveys precludes the need to rely on the original strata habitat classifications, but rather allows a simple delineation of the sites on the basis of depth. It is, therefore, proposed that the original definition of “urchin habitat” be replaced with “shallow” (1-2 m), and “algal habitat” replaced by “deep” (3-6 m). The within-site stratum-area estimates can subsequently be consolidated to provide a single area estimate for each site. Furthermore, the historic fishing classifications can be disregarded as they have become largely redundant.

Figure 2.1. Location of the sites around Point Lowly that have been used to survey cuttlefish.

Table 2.1. The refined details of the survey sites for future cuttlefish surveys. Details include the GPS location of each site, it's estimated area of available spawning habitat, the number of transects required and level of access. Red text identifies the sites that have been identified as redundant.

Site	GPS	Spawning Area (m^2)	% of Total Spawning Area	Survey	Depth Delineated	No. Dive Transects	Access?
OneSteel Wall	32 59'39.7"S, 137 37'01.2"E	3,348.00	0.6	No	No	4 shallow	N/A
False Bay	32 59'13.4"S, 137 43'10.1"E	18,685.04	3.5	Yes	No	4 shallow	Boat/Shore
Black Point	32 59'27.3"S, 137 43'13.1"E	96,875.35	18.2	Yes	Yes	4 shallow, 4 deep	Boat/Shore
3rd Dip	32 59'37.2"S, 137 44"08.9"E	76,859.81	14.5	Yes	Yes	4 shallow, 4 deep	Boat/Shore
WOSBF (West of SANTOS Boundary Fence)	32 56'45.6"S, 137 44'51.3"E	114,406.60	21.5	Yes	Yes	4 shallow, 4 deep	Boat/Shore
Stony Point	32 59'44.0"S, 137 45'17.5"E	86,506.20	16.3	Yes	Yes	4 shallow, 4 deep	Boat/Shore
SANTOS Jetty	32 59'33.9"S, 137 45'45.6"E	18,232.50	3.4	No	No	4 shallow	N/A
SANTOS Tanks	32 59'36.9"S, 137 46'15.0"E	39,062.43	7.4	Yes	Yes	4 shallow, 4 deep	Boat
Pt Lowly West	33 00'00.1"S, 137 46'56.3"E	21,225.12	4.0	Yes	Yes	4 shallow, 4 deep	Boat/Shore
Pt Lowly Lighthouse	33 00' 00.3"S, 137 47'09.3"E	13,566.85	2.6	Yes	Yes	4 shallow, 4 deep	Boat/Shore
Pt Lowly East	32 59'43.2"S, 137 47'03.7"E	12,196.14	2.3	Yes	No	4 shallow	Boat/Shore
Fitzgerald Bay	32 58'53.6"S, 137 46'48.4"E	7,881.58	1.5	Yes	No	4 shallow	Boat/Shore
Backy Point	32 54'56.4"S, 137 47'11.4E	22,360.00	4.2	No	No	4 shallow	N/A
	Total	*531,205.62*					

2.3. HABITAT CHARACTERISATION

Characterising the sub-tidal habitat at each site was not a priority in the original survey design (Hall and Fowler 2003). This was because the focus of the research was to provide general biological information and describe the life history of cuttlefish to ensure that it was sustainably harvested. The relatively isolated stretch of rocky reef that fringes Point Lowly is considered to be an essential feature in attracting large numbers of spawning cuttlefish to the area as it provides substrate upon which cuttlefish can attach their eggs and seek shelter within northern Spencer Gulf. Given the strong association between spawning cuttlefish and the local substrate it is important to understand the impact of any shifts or large-scale changes in its condition on spawning success. Such changes may include: algal blooms as a function of coastal eutrophication; increased sedimentation resulting from inclement weather, vessel traffic or run-off from land based developments; or changes in the benthic community composition. Such changes might compromise spawning success by either preventing the cuttlefish from attaching eggs to the substrate, or creating sub-optimal conditions for embryonic development. The objective of this section was to develop an efficient means of characterising the condition of the spawning habitat which could be easily integrated into an on-going monitoring program that would contribute to our understanding of cuttlefish spawning dynamics.

This study compared the effectiveness of using underwater photo-quadrat and remote video techniques to characterise the cuttlefish spawning habitat. These two techniques have been successfully used in other studies that have assessed shallow reef ecosystems and both provide permanent images that can be archived for future reference.

2.3.1. Underwater Photo-Quadrat Surveys

The underwater photo-quadrat methodology used for this component of the survey is similar to the standardised procedure used by the Reef Life Survey organisation to monitor reef ecosystems (http://reeflifesurvey.com/files/2008/09/rls-reef-monitoring-procedures.pdf). At each site (excluding OneSteel Wall), four replicate 50 m transects were laid out perpendicular to the shoreline. Each transect typically started at <1 m depth and were haphazardly distributed along the shoreline, generally within 20 m of each other. Sequential digital photographs were taken at 5 m intervals across the length of each transect on scuba using a hand-held camera. Efforts were made to photograph an area of at least 0.3 m x 0.3 m perpendicular to the substrate and it was important to capture the graduations of the transect tape in the field of view to provide a scale of reference (Figure 2.2A). Water depths at the beginning and end of each transect were also recorded.

2.3.2. Remote Video Surveys

A towed waterproof video camera secured within a protective cage was used as an alternate method to characterise the habitat of the main cuttlefish spawning sites. The video camera was connected to a portable digital recorder that was integrated with a GPS system and a GeoStamp® audio encoder that was capable of recording continuous time and positional data. At each site, two video transects were undertaken parallel to the coastline, one within the 1-2 m depth range and the other in 3-6 m. The video camera was mounted at a 45° angle and lowered over the side of the vessel to approximately 0.5 m above the sea floor. The camera's field of view was approximately 1.5 m^2. The vessel then either idled or drifted (depending on the strength of the prevailing wind) along the transect for three minutes covering a distance of approximately 100 m. The depth of the camera was manually adjusted according to the benthic topography. The digital video footage was played back through a computer monitor. The footage was paused every 18s (approximately every 10 m along the transect path) and the screen image was captured.

2.3.3. Method Comparison

The percentage cover of the various algal functional groups, sponges, corals, and substrate types (Table 2.2) was digitally quantified from the images from the photo-quadrat and surface video surveys using image analysis software (Image-Pro Plus® 7.0). Each functional group was digitally traced and its area calculated. To estimate the relative percentage cover of each habitat type it was necessary to quantify the field of view for each captured image. The graduations on the transect tape visible in each photo-quadrat image was used as a scale of reference (Figure 2.2). The width of each captured image from the video transects was estimated to average 1.56 ± 0.05 m (see section 2.4.2). The field of view was calibrated for each image and formed the basis from which the relative percentage of each habitat type was calculated. All benthic invertebrates visible within the images were also identified to the lowest taxonomic level possible, counted, and their relative abundance quantified (m^2).

Non-metric, multi-dimensional scaling was used to compare the habitat characteristics of each site determined from the two methodologies. The statistical program Primer (v5.2.9) was used to run the analysis. The habitat data were arranged into a matrix with each row representing a survey site and characterisation method; and a column for each of the habitat variables. Prior to the analysis, the data matrix was standardised and transformed using the fourth root transformation, after which a similarity matrix that compared the sites and methodologies was generated using the Bray-Curtis similarity coefficient. The ordination was then done on the similarity matrix to identify whether the habitat characterisation of each site differed as a function of the method used. The analysis of similarity test (ANOSIM) was used to test whether the two habitat characterisation methods yielded significantly different results.

Table 2.2. Classification codes used to characterise the habitat.

GROUP	CODE	DESCRIPTION	EXAMPLE
ALGAE	BRBRANCH	Brown Highly Branced Robust Algae	*Cystophora* sp., *Sargassum*, *Acroarpia*
	BRFLAT	Robust Brown Algae w/ Large Flat Blades	*Ecklonia, Durvillaea*
	BRENC	Brown Encrusting Algae	*Ralfsia*
	BRFOLI	Brown Foliaceous Algae	*Halopteris, Cladostephus*
	BRMEM	Membranous Brown Algae	*Scytosiphon*
	GLOBE	Lobed Green Algae	*Dictyosphaeria*
	GFOLI	Green Foliaceous Algae	*Caulerpa* spp., *Cladophora*
	GMEM	Membraneous Green Algae	*Ulva* spp.
	RENC	Red Encrusting Algae	*Sporolithon*
	RFOLI	Red Foliaceous Algae	*Plocamium, Phacelocarpus*
	RROB	Red Lobed Algae	*Osmundaria*
	RMEM	Membraneous Red Algae	*Gloiosacchion*
	TURF	Turfing Algae	*Ectocarpus, Sphacelaria*
	HINCK	Hincksia	*Hincksia*
SUBSTRATE	SAND	Sand	Sand
	SEAGRASS	Seagrass	*Posidonia, Amphibolis*
	ROCK	Rock	Rock
	RUBBLE	Rubble	Rubble
BENTHIC INVERTEBRATES	AMOSP	Amorphous Sponge	*Darwinella* sp.
	DISP	Discreet Sponge	*Polymastia*
	GAST	Gastropod	*Haliotis* sp.
	BIV	Bivalve	*Pinna, Atrina*
	COLASC	Colonial Ascidian	*Didemnum*
	OASC	Solitary Ascidian	*Polycarpa*
	URCHIN	Sea Urchin	*Centrostephanus* sp.
	STAR	Starfish	Ostreasteriidae
	CORAL	Coral	Scleractinia

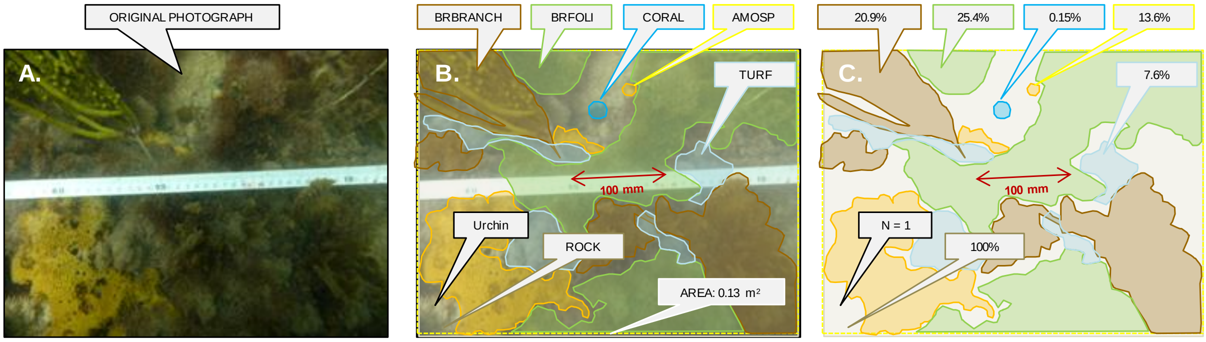

Figure 2.2. An example of the how estimates of the percentage cover of the various habitat functional groups were determined from a photo-quadrat. (A.) An underwater photo-quadrat image. (B.) Identification of the habitat functional groups using the classification codes in Table 2 and image analysis software. (C.) determining the relative percentages of the functional groups.

Both habitat characterisation methods appeared to be relatively inter-changeable as the interpretation of the captured images were statistically similar (p = 0.064) (Figure 2.3). The similarity of the sites were mainly based on the relative proportions of rock, brown highly branched robust algae, and brown foliaceous algae which accounted for approximately 30.5%, 20.4% and 12.9% of the similarity, respectively. False Bay, Backy Point and Point Lowly East each had sufficiently different habitat characteristics to separate them from the main contiguous spawning area located along the western side of Point Lowly (Figure 2.3). These three sites typically exhibited extensive patches of seagrass and bare sand. These two habitat types also contributed to a departure between the two habitat characterisation methods for these three sites (Figure 2.3). The video transects often included extensive stretches of seagrass which were not captured to the same extent by the photo-quadrat method. The degree of dissimilarity between the two methods for these two habitat types accounted for <22.3% difference, however the difference was not large enough to statistically separate them.

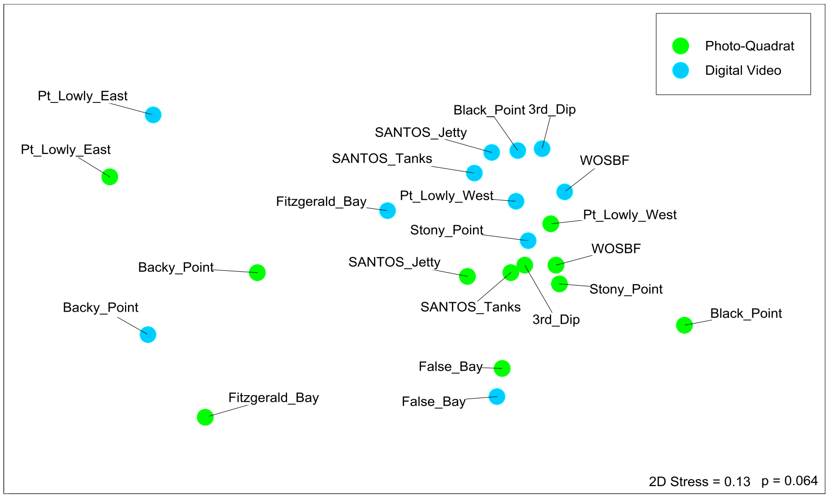

Figure 2.3. Non-parametric MDS plot that compared the habitat characteristics of the sites using the two image-capture methodologies.

2.4. CUTTLEFISH ABUNDANCE AND BIOMASS

A recent study that investigated the movement patterns of cuttlefish on the spawning grounds indicated that individual cuttlefish exhibited lower than expected residence times (approx. 19 days) given the relatively long breeding season (3–4 months) (Payne et al.

2010). This result suggests that the spawning population is comprised of highly transient individuals rather than being formed through a steady accumulation of animals to a seasonal peak in spawning activity. This dynamic consequently indicates that density-based surveys that have been carried out in the past to estimate abundance and biomass have under-estimated actual population size as they have not accounted for individual residence times and the turn-over of individuals on the spawning grounds (Hall and Fowler 2003, Payne et al. 2010). Despite the transient nature of the cuttlefish, the spawning population has historically exhibited a distinct peak in late May/early June and it is the quantification of this peak that has provided comparable estimates of abundance and biomass through time (Hall and Fowler 2003). Although, these estimates are unlikely to reflect the actual population size, they are still meaningful as they adequately describe the inter-annual trends that reflect the overall status of the population. In some cases the assessment of the cuttlefish population has been constrained to a single 'snap-shot' survey (Steer and Hall 2005). Although these snap-shot surveys have been justified from an understanding of the 'peak' through time (Hall 2012) there is a need to increase the temporal resolution of future surveys for two reasons. The first relates to the dynamic nature of the cuttlefish spawning aggregation as it is possible that future 'snap-shot' surveys may not coincide with peak spawning as the population may respond to a changing global climate. Secondly, given the considerable reduction in the size of the cuttlefish population it is important to increase the survey intensity to improve the accuracy and precision of the overall population estimate. To accommodate this and ensure that the data remain comparable through time it is important to undertake multiple surveys throughout the spawning season. It is suggested that in all future assessments at least three surveys be carried out over the spawning season, spanning late May, mid June and early July.

Surface video technology accurately quantified habitat condition (section 2.3) and may provide an alternate method for estimating cuttlefish abundance and biomass. Video technology is an attractive alternative to diver-based surveys as it eliminates the potential occupational health and safety risks associated with shallow water scuba diving, is more cost-effective through reduced personnel and time in the field, and also provides a visual record that can be archived for future reference. The objective of this section was, therefore, to investigate whether calibrated surface video surveys could be used as an alternative to the established underwater visual surveys for estimating cuttlefish abundance and biomass throughout the spawning season. Furthermore, this section also aimed to explore whether the statistical iterations and calibration methods that have been previously used to estimate cuttlefish abundance, biomass and the associated error variances could be simplified without compromising the overall result.

2.4.1. Underwater Visual Census

As in the existing survey methodology developed by Hall and Fowler (2003), four 50 x 2 m belt-transects were completed at each site, generally in depths of <3 m. For some sites, where the spawning habitat extended to depths >3 m, an additional four transects were carried out within the 3 to 6 m depth zone (Table 2.1) To efficiently use time and resources, up to four SCUBA divers systematically contributed to the survey. All cuttlefish encountered within the belt-transects were counted, their mantle length (ML) estimated to the nearest centimetre using a calibrated slate and their sex noted. This provided an estimate of the average density of cuttlefish per 100 m^2. An estimate of the average weight per 100 m^2 was also calculated by converting mantle lengths to weight using an appropriate length-weight relationship (Table 2.3). To correct for any observer bias, each diver estimated the ML of up to an additional 30 cuttlefish underwater, upon completion of the survey. Each animal was subsequently captured, using a dip-net, and its length was verified either underwater or at the surface. A diver-specific correction factor was calculated via model II regression analysis and incorporated into the weight conversions to improve the accuracy of the biomass estimate.

2.4.2. Calibrated Remote Video Survey

The same underwater video camera system that was used to characterise the habitat in section 2.3 was used to survey cuttlefish abundance. It was, however, fitted with two lasers mounted on the camera frame. These lasers were mounted parallel to each other to project beams at a width of 353 mm. These laser beams provided a fixed scale of reference upon which to calibrate the video's field of view and approximate the size of encountered cuttlefish (Figure 2.4). At each site, two video transects were undertaken parallel to the coastline, one within the 1-2 m depth range and the other in 3-6 m. Four additional depth-stratified transects were carried out at Black Point during the May survey as this site supported the highest densities of cuttlefish and provided the best opportunity to test the effectiveness of using the video system to survey cuttlefish abundance. The orientation of the video camera remained at a 45° angle and it was lowered over the side of the vessel to a depth approximately 0.5 m above the sea floor. The camera's field of view was estimated to cover an average width of 1.56 ± 0.05 m, as determined by the laser beam scale of reference. The vessel then either idled or drifted (depending on the strength of the prevailing wind) along the transect for five minutes covering an average distance of 149.2 ± 5.9 m.

The digital video footage was played back through a computer monitor. The footage was paused every time a cuttlefish was observed and the screen image was captured. The GPS position, depth and time was recorded for each encountered cuttlefish and its ML measured in reference to the calibrated laser beams using image analysis software (Image-Pro Plus® 7.0) (Figure 2.4). Where the laser beams were difficult to discern, the image's average width (1.56 m) was used to calibrate estimates of cuttlefish size. Direct measurements were not always possible as the orientation of the cuttlefish to the camera made it difficult to get a lineal measurement. It was also noted whether the cuttlefish was obscured from view.

The relative abundance of cuttlefish was calculated from the transect length and average field of view to establish a density estimate per m^2. An estimate of the average weight per m^2 was also calculated by converting mantle lengths to weight using an appropriate length-weight relationship (Table 2.3).

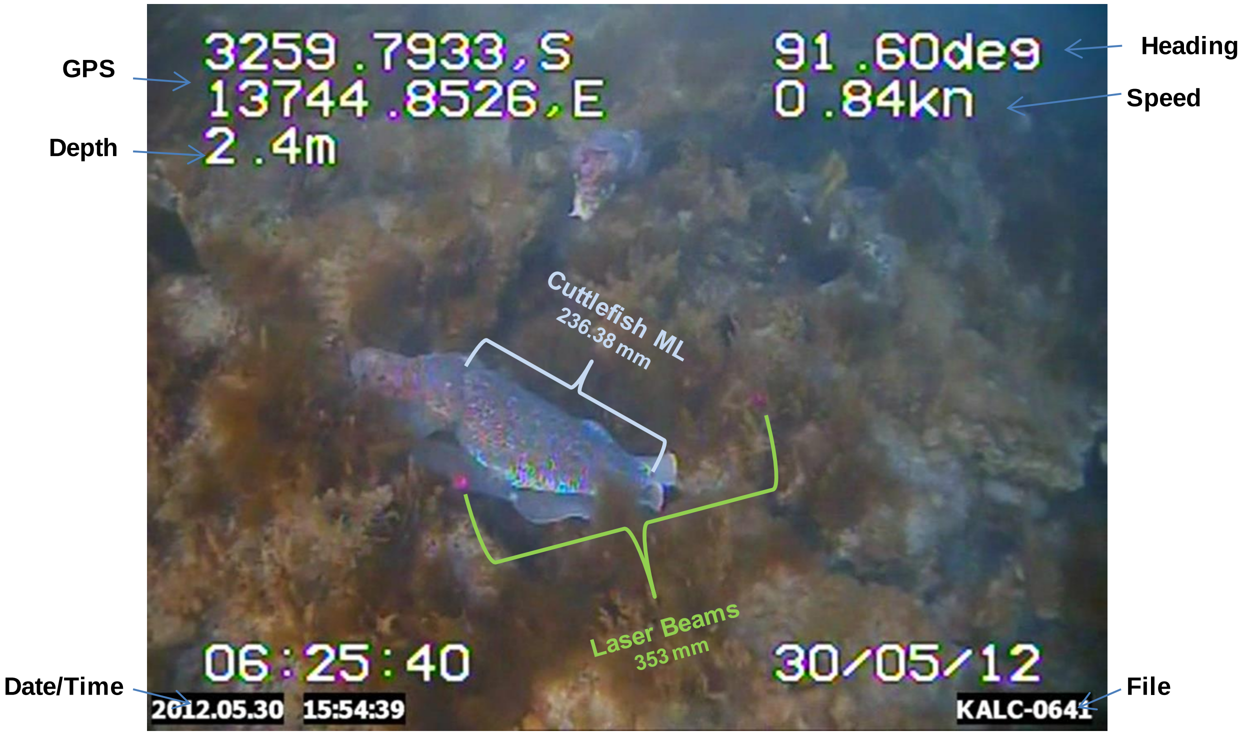

Figure 2.4. A screen image of two cuttlefish captured from underwater video camera footage. The image contains embedded positional information collected using an integrated GPS system and a GeoStamp® audio encoder. Note the laser beam reference points.

Table 2.3. Sex-specific length weight relationships from Hall (2002) used to calculate biomass estimates from cuttlefish size (ML) data.

SEX	EQUATION
MALE	weight (g) = 0.0005*ML $(mm)^{2.695}$
FEMALE	weight (g) = 0.0007*ML $(mm)^{2.645}$
UNKNOWN	weight (g) = 0.0006*ML $(mm)^{2.675}$

2.4.3. Method Comparison

Estimates of Abundance

A total of 101 cuttlefish were identified in the video footage over the course of the three surveys. Of these, 12 (11.8%) were partially obscured. Furthermore, there were seven occasions when extensive ink trails were encountered suggesting that the camera had either scared cuttlefish out of the field of view, or that it was residual ink remaining in the area as a result of some other disturbance. Divers successfully identified 432 cuttlefish, of which 35 (8.1%) were obscured from view (e.g., were sheltering within a den) preventing their size from being estimated, and the sex could not be confidently determined for 26 (6.0%) individuals.

A three factor analysis of variance (ANOVA) was undertaken to explore the variance among mean estimates of cuttlefish density across sites, sampling months and survey method. Estimates of cuttlefish abundance inferred from the surface video tows were significantly lower than the diver estimates (method $F_{2,\ 277} = 22.03$, MS = 6.94, $p < 0.01$) (Figure 2.5). The degree of under-estimation was relatively consistent over the course of the three surveys (method*month, $F_{2,\ 277} = 0.60$, MS = 0.19, $p = 0.55$), ranging from 61% in May to 87% in June (Figure 2.5). The magnitude of the difference between the two survey methods was not consistent across the spawning sites and did not reflect patterns in abundance (method*site, $F_{9,\ 277} = 3.78$, MS = 1.19, $p < 0.01$) (Figure 2.6). The video surveys did not consistently detect more cuttlefish in areas of high abundance (i.e. False Bay and Black Point). Conversely, there were occasions when the video estimates were greater than the diver counts in areas of low cuttlefish abundance (i.e. WOSBF in May and Santos Tanks in June), however, these estimates were typically influenced by one or two individuals (Figure 2.6).

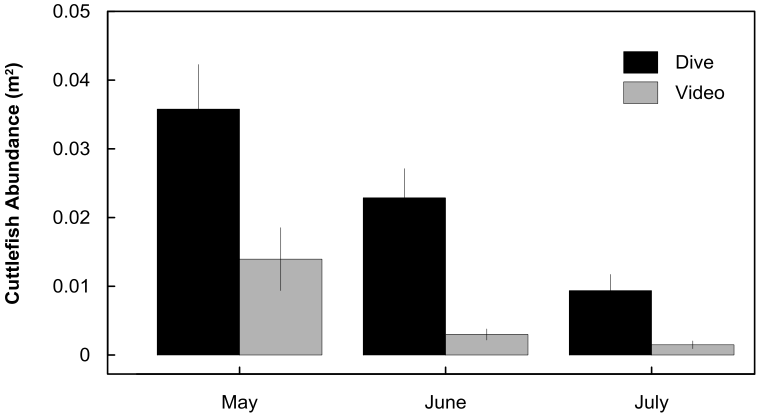

Figure 2.5. Comparison of mean cuttlefish abundance (± se) estimated from underwater video and dive surveys from May through to July.

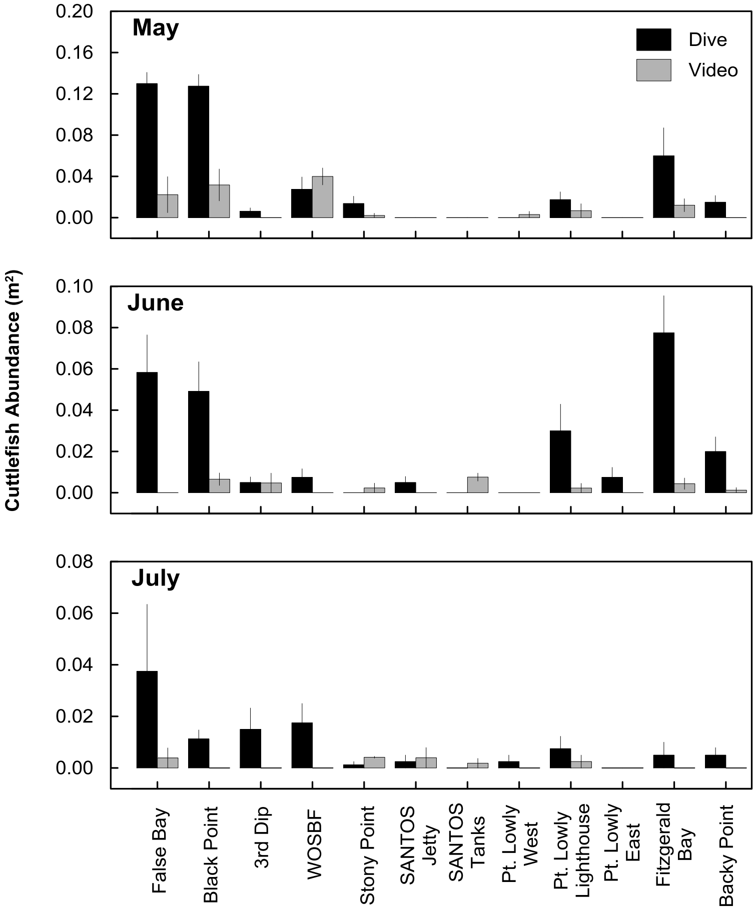

Figure 2.6. Comparison of mean cuttlefish abundance (± se) estimated from underwater video and dive surveys from May to July at each survey site.

Estimates of Biomass

In previous surveys a diver-specific correction factor has been used to account for some of the inherent biases associated with estimating cuttlefish size underwater to provide a more accurate estimate of spawner biomass. Correction or “calibration” dives were often carried out at the end of the survey and typically extended the field work commitment by approximately one day, thus increasing the total cost of the program. A comparison of the size distributions of the surveyed cuttlefish as determined from the raw diver estimates and the Model II calibrated data collected during this study yielded similar results (Mann-Whitney U: Z = -1.381, p = 0.167) indicating that calibrating the raw data may not be essential in improving the ‘estimate’ of biomass (Figure 2.7). Estimates of cuttlefish size from the video footage were significantly smaller than the raw diver estimates (Z = -2.748, p = 0.006), but similar to the Model II calibrated distribution (Z = -1.765, p = 0.078) (Figure 2.7). Despite the differences in size distributions from the three methods their respective modes and size ranges were relatively comparable (Figure 2.7).

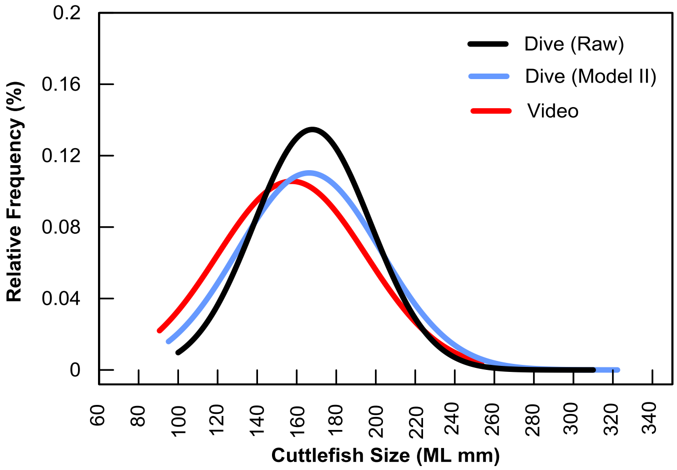

Figure 2.7. A comparison of the size distributions of cuttlefish determined from diver, calibrated diver (using a model II regression) and underwater video surveys.

Estimates of cuttlefish biomass inferred from the surface video tows were significantly lower than the raw and Model II adjusted diver estimates (method $F_{2, 475}$ = 11.51, MS = 2227.9, $p < 0.01$) (Figure 2.8). Both diver estimates were similar, further indicating that the Model II calibration method does not add significant value to the overall estimate of cuttlefish biomass. The video method consistently under-estimated biomass in each of the three months (method*month, $F_{4, 475}$ = 1.14, MS = 221.0, p = 0.34), differing from the diver methods by 59% in May to 91% in June (Figure 2.8). The magnitude of the difference between the raw diver and video survey methods was not consistent across the spawning sites (method*site, $F_{22,\,475} = 1.84$, MS = 355.3, $p = 0.013$) (Figure 2.9).

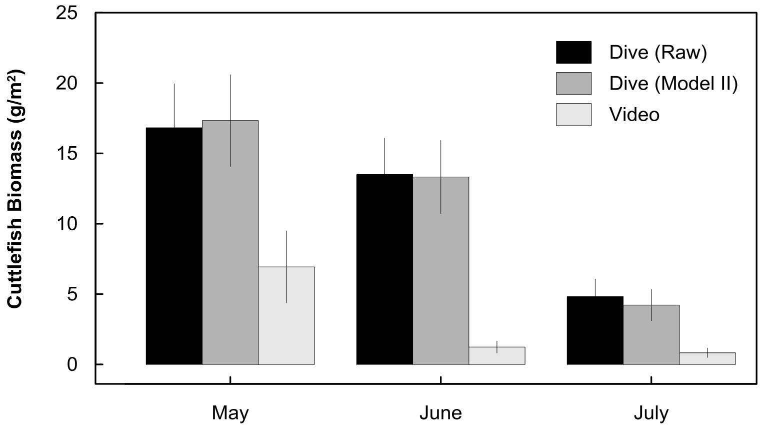

Figure 2.8. Comparison of mean cuttlefish biomass (± se) estimated from underwater video, dive and diver calibrated surveys from May to July.

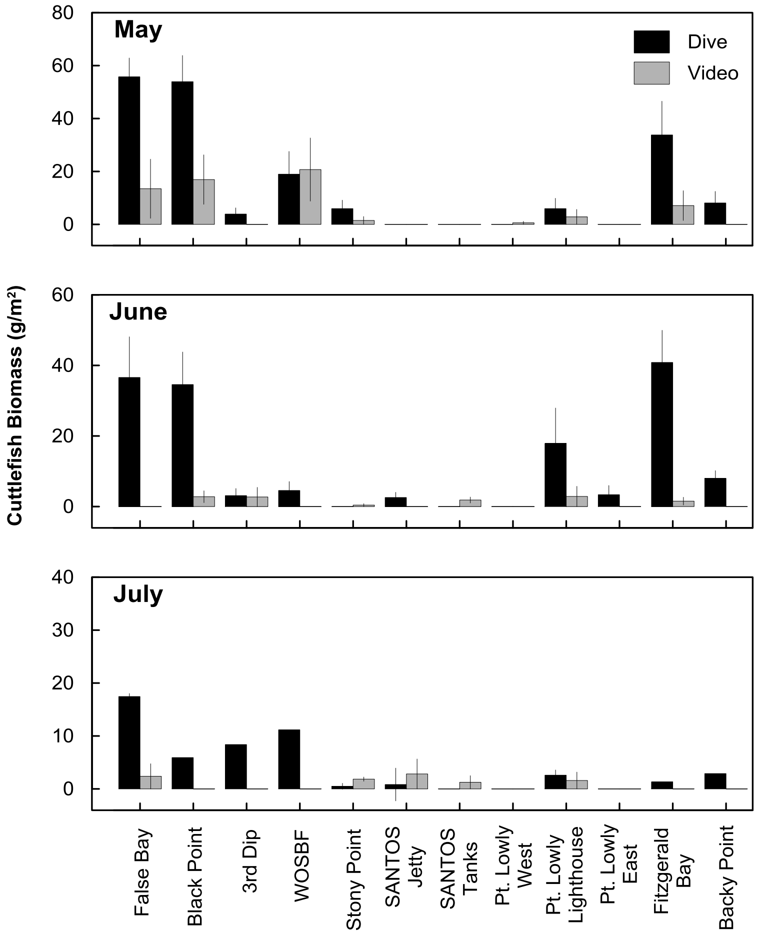

Figure 2.9. Comparison of mean cuttlefish biomass (± se) estimated from underwater video, dive and diver calibrated surveys from May to July across each of the survey sites.

Areal Expansion

In refining the existing survey methodology it is important to ensure that the data obtained remains comparable with the historic dataset. Previous estimates of cuttlefish abundance and biomass have been scaled-up to reflect the relative proportion of spawning area at each site (Hall and Fowler 2003). Abundance estimates are calculated for each site by multiplying the average density of cuttlefish per m^2 by the corresponding area of spawning substrate (Table 2.1). Similarly, biomass estimates are calculated using the average weight of the cuttlefish per unit area. Total abundance and biomass of the entire aggregation area are extrapolated from these site estimates and an annual estimate generally corresponds with the peak in spawning activity over the season. In this study, the peak in cuttlefish spawning activity occurred in May (Figures 2.5 and 2.8). Error variances were also calculated for each of the estimates of cuttlefish abundance and biomass. The computation of this error in the original survey is complex as it incorporates the inherent variance associated with cuttlefish counts, estimates of cuttlefish size, diver biases, spawning area and stratified habitat types (Taylor 2001). The current study took a more simpler approach by only propagating the error terms associated with mean cuttlefish counts and biomass from the replicated transects and ignoring all other implications.

Both the expanded estimates of abundance and biomass along with the associated error terms derived from the refined methodology did not significantly depart from the original Hall and Fowler (2003) methodology (Figure 2.10). Estimates of abundance and biomass were almost identical for both methods differing by <0.01% and 3.3%, respectively (Figure 2.10). The associated error terms were relatively comparable for the estimates of mean abundance differing by 13.3%, however, the error variance was reduced by 33.9% for mean biomass (Figure 2.10). Using underwater video to quantify the Point Lowly cuttlefish population did not appear to be an adequate alternative, non-diving method, as it under-estimated cuttlefish abundance and biomass by 54.2% and 57.5%, respectively (Figure 2.10).

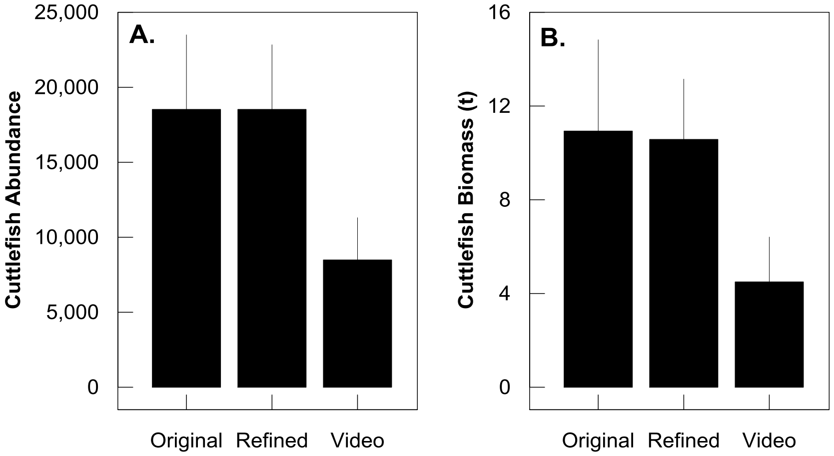

Figure 2.10. Comparison of the overall estimates of cuttlefish abundance and biomass (± se) using the original (Hall and Fowler 2003), refined and underwater video survey methods.

2.5. AMBIENT WATER QUALITY

In productive, oligotrophic (nutrient poor) marine waters, such as those of South Australia, sampling for water chemistry, particularly inorganic nutrients is often confounded by rapid uptake of nutrients by biological material that results in a number of parameters frequently below the limit of detection (Guildford and Hecky 2000). A well-developed monitoring program that includes water chemistry should still be a fundamental part of assessing many ecological processes that potentially impact on biological communities, including variation in nutrient limitation. Using water chemistry in conjunction with habitat characterisation would show the nutrient dynamics that biological information alone cannot determine. Additionally using habitat characterisation alone may not be a proactive way to manage impacts as in many circumstances changes in habitats as a result of increases in nutrients are hard or slow to reverse.

Eutrophication is the process where there is an increase in the rate of supply of organic material to an aquatic system (Nixon 1995). The increase in rate of supply is often governed by the supply of nutrients into a system, which can often be altered by human activities. Cloern (2001) suggests that the response to increased nutrients in marine systems is often not limited to increases in water column chlorophyll but extends to macroalgae, seagrass epiphytes and filamentous algae. In the Whyalla to Fitzgerald Bay area, the seasonal blooms of *Hincksia sordida* and potentially *Ulva* spp., as well as water column chlorophyll are likely to be linked to local nutrient dynamics. Eutrophication has been linked to the degradation of coastal ecosystems throughout the world and have been highlighted as being in need of urgent action to reduce its impacts on seagrass and reef systems, including in South

Australia (Anon 1990; Gabric and Bell 1993; Zann 1995; EPA 2003, EPA 2008; Waycott et al, 2009).

It is well known that northern Spencer Gulf has a long history of heavy industrialization with various large facilities located in the region for over 100 years; much of this time largely without environmental controls. In recent years, environmental controls are in place and the impact from these facilities is lower. There have been numerous studies on the metal contamination and its effects on biota throughout northern Spencer Gulf published during the 1980-1990s (e.g. Ward and Young 1982; Harbison and Wiltshire 1993; and others). Additionally the Environment Protection Authority (EPA) has undertaken a number of studies throughout this area including metal uptake in *in-situ* razorfish and sediments (Corbin and Wade 2004) and in translocated mussels (Gaylard et al. 2011), which further investigated the metal status of the region. It was not considered necessary that an ongoing monitoring program focused on cuttlefish throughout the False Bay to Fitzgerald Bay region should replicate this work. A review of these data and assessment of the likelihood of impacting the cuttlefish has been undertaken in Section 3.3.4.

The ambient water chemistry program has been limited to assessing the potential risk of eutrophication on the nearshore waters and how this may vary between sites. Traditional nutrient sampling programs have focused on the dissolved inorganic nutrients as a potential risk factor for eutrophication (e.g. Thompson et al. 2009). However, there is a significant body of work that suggests while inorganic nitrogen is readily available to plants and algae (e.g. Seagrasses and *Hincksia sordid* blooms), it is rapidly assimilated resulting in no detectable inorganic nitrogen in the water (Iizumi and Hattori 1982; Hemminga, Harrison et al. 1991; Udy and Dennison 1997; Romero et al. 2006). Using the total nitrogen concentration can be a more reliable indicator of eutrophication, particularly in oligotrophic environments where inorganic nitrogen is rapidly removed.

2.5.1. Water chemistry collection

Quantifying water chemistry at each site was undertaken by sampling water at each location to provide a snapshot of water nutrient concentration. Inorganic nutrients (total ammonia, oxidized nitrogen and orthophosphate) were sampled using three replicate samples of 150 ml, which were field-filtered through 0.45 µm filters into prewashed plastic containers. Total nutrients (total nitrogen and total phosphorus) were sampled using three replicate unfiltered 150 ml samples into prewashed PET containers. A multi-parameter sonde (YSI 6920 v2) was used to log water quality parameters including electrical conductivity, pH, dissolved oxygen and chlorophyll *a* at 10 second intervals for a total of approximately 2.5 mins at each location. In order to calibrate the fluorescence from the sonde to chlorophyll concentration, a 2.0 litre water sample for chlorophyll was collected in the morning and afternoon of each day in which sampling occurred. These samples were filtered using a 0.45 µm filter at the end of each day. All samples were frozen and analysed within the recommended laboratory holding times.

In the event of values being below the reporting limit, the censored value was substituted with ½ the reporting limit (Ellis and Gilbert, 1980). This arbitrary method does have its limitations (see Helsel 1990) but it was considered unbiased compared to methods that substitute for the reporting limit or a zero value (Helsel 1990). All water samples were analysed by SARDI Aquatic Sciences, however, due to financial constraints only water samples from May were analysed.

The analysed water chemistry data were assessed and the magnitude of a number of parameters were inconsistent with similar monitoring throughout the northern Spencer Gulf by the EPA throughout 2012 and historical monitoring in the region (EPA unpublished data). There are two potential explanations for this, the first relates to problems associated with collecting the water samples and subsequent storage, secondly it is possible that there were subtle differences amongst the analytical laboratories employed to undertake the work. This has resulted in the inability to compare results from this program to historical or other data sets. In the future, if comparison to other significant data sets is required for the interpretation of results then it is recommended that the same laboratory or identical methods and inter-lab duplicate samples should be collected.

Results from a cluster analysis using the Euclidean distance of the water chemistry data (ammonia, total nitrogen, salinity, chlorophyll and turbidity) for each site throughout the May sampling event demonstrated some subtle differences amongst the sites with respect to water quality (Figure 2.11). The site that was most different to the rest was Backy Point which was grouped on its own.

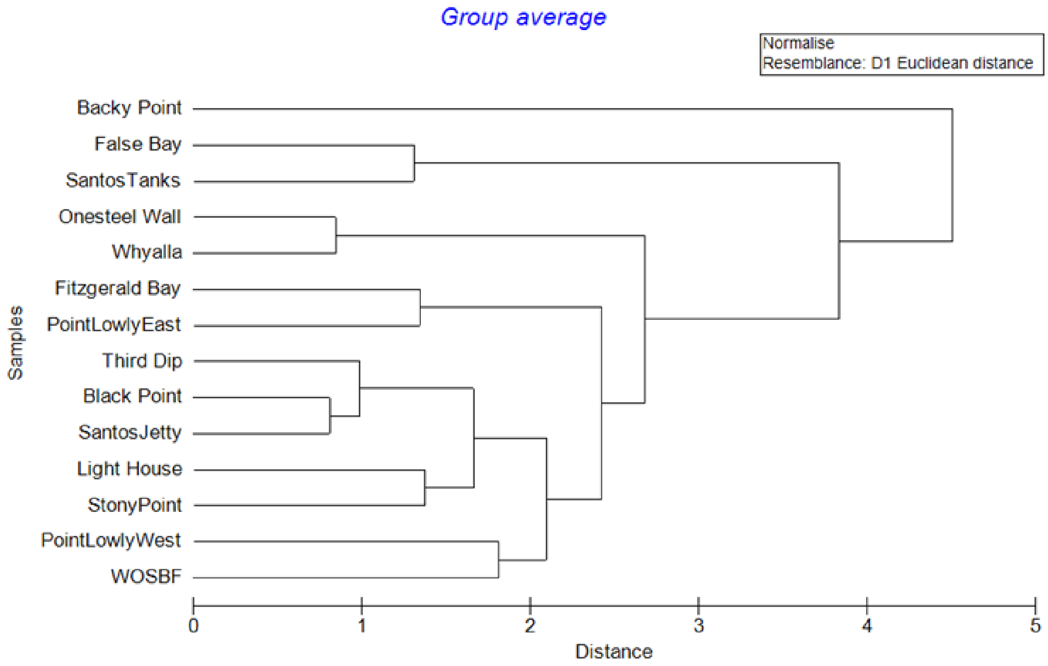

Figure 2.11. Cluster analysis of the water chemistry data collected from the May 2012 survey.

Backy Point had the highest total nitrogen and ammonia concentrations during May (Figure 2.12). Additionally, there was a general increase in total nitrogen concentrations between Point Lowly West to Backy Point. It is unknown whether this was due to a localised phenomenon or natural variability. This pattern was not replicated with ammonia concentrations, which varied throughout the region (Fig. 2.12). These results highlight the need for further data collection to identify relative differences between sites, and whether they are consistent over time or a function of natural variability throughout the region. Additionally, coupling this nutrient data to habitat characterisation will show whether elevated nutrient concentrations are having an influence on the habitat such as smothering from ephemeral macroalgae.

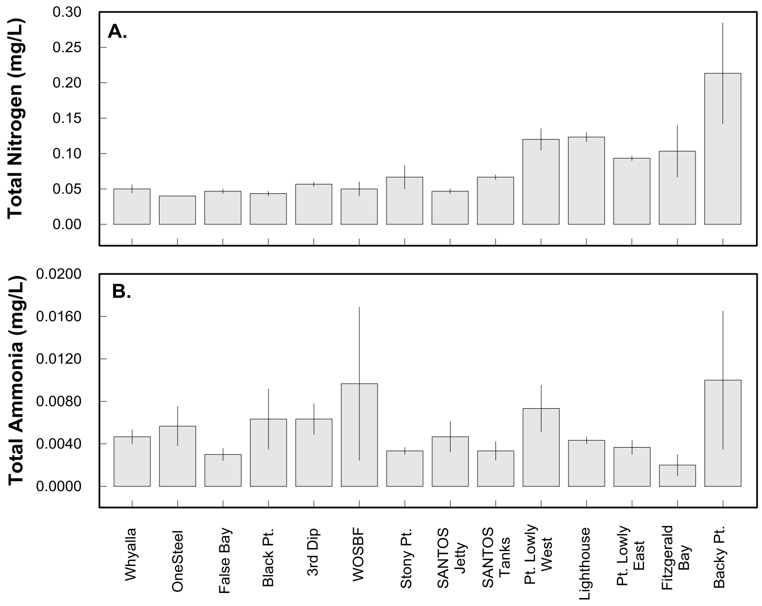

Figure 2.12. Total Nitrogen (A.) and Ammonia (B.) (± s.e.) determined from replicate water samples collected from each site during the May 2012 survey.

2.6. DISCUSSION

Documenting and interpreting trends in the size of the giant Australian cuttlefish population is more informative than determining their actual numbers and collective biomass, provided the methods used to collect the data remain consistent through time. The original survey methods established by Hall and Fowler (2003) were thorough and complex, particularly in the assessment of fine-scale spatial changes in population size in relation to the various strata boundaries and fishing history, as well as calculating the propagation of the error estimates to comprehensively account for numerous sources of inherent variation. Although, at the time, this level of complexity was required given the dynamic changes in fisheries management and paucity of knowledge regarding the biology of the species, it now appears overly excessive for an on-going monitoring program. The current study has refined the existing methodology to a level where the surveys are more streamlined without compromising the integrity and comparability of the population estimates.

The refinements relate to the re-description of the strata to be depth rather than habitat specific, and the removal of the historic fishing classifications for each of the survey sites. Furthermore, the total number of sites required to provide comparable population estimates was reduced from 13 to 10, removing three that had not been routinely surveyed throughout the years (i.e. OneSteel Wall, Santos Jetty and Backy Point). Unfortunately the surface video surveys could not be adequately relied on as a substitute for the dive surveys as the method significantly under-estimated cuttlefish abundance and biomass. This is not surprising given the behaviour of female cuttlefish, which spend a considerable proportion of their time obscured from view laying eggs within dens. Also, on numerous occasions, ink trails were encountered that suggested that the towed camera had scared the cuttlefish out of the field of view, which may have contributed to the under-estimation. The video footage, however, was valuable in characterising the spawning habitat as these results were statistically similar to those from the photo-quadrat method.

Eliminating the calibration dives from the survey has been the most notable refinement. Extrapolating the estimates of biomass using the original propagation of errors which included the diver-calibrated estimates of cuttlefish size did not differ significantly from the refined method, which simply calculated the mean and variance of the raw diver measurements. The negligible difference between the two estimates is unlikely to influence the interpretation of the overall trend in relative population size and as such can be omitted from future surveys. This will reduce the fieldwork commitment and also ensure that the spawning cuttlefish are not physically disturbed, which is particularly relevant during periods of low abundance.

At least three surveys are required to be carried out during the main spawning season (May to July, inclusive) to ensure that the ‘peak’ in spawning is captured, as it is the temporal comparison of this peak that constitutes the basis of the population analysis. Snap-shot surveys have been relied on in the past and have been justified from an understanding of the stability of the peak through time (i.e. occurring late May/early June between 1998 and 2000) (Hall and Fowler 2003). The peak in early June was validated in 2012 when BHP Billiton carried out a partial resurvey of six sites in July 2011 and found a reduction in the overall abundance of cuttlefish (Hall 2012). The results of the current study also identified peak abundance in late May/early June further supporting the temporal stability of the spawning population (Figure 2.5). However, given the trends in global climate and the regime shifts observed in other species (Walther et al. 2002) it seems prudent to undertake a series of surveys that extend across the spawning season. This would improve the overall assessment of the population, particularly if the timing of ‘peak’ abundance became irregular. Increasing the intensity of the surveys to extend across the main spawning period is also essential when the population is considerably reduced, as it contributes to improving the accuracy and precision of the overall population estimate.

given the considerable reduction in the size of the cuttlefish population it is important to increase the survey intensity to improve the accuracy and precision of that the overall population estimate.

An assessment of the spawning habitat and water quality has been incorporated into the survey design. Although the surface video can be adequately used to characterise the habitat, it is more amenable and cost-effective to incorporate the photo-quadrat methodology into the dive surveys. This would simply involve using a waterproof digital camera and taking a series of standardised *in-situ* photos along the transect line that is already used to estimate cuttlefish abundance (Appendix 2). The regular collection of water samples at each of the survey sites also serves to complement the habitat assessment. It is important that water sampling adheres to a standard methodology (Appendix 2) and given the inconsistencies identified in the analysis where there appeared to be laboratory-based differences, it is strongly suggested that the EPA is consulted in future analysis.

Simplifying the cuttlefish surveys and the production of a standard operating procedure (Appendix 2) opens up the opportunity for other agencies to undertake their own surveys or collaborate together (e.g. BHP Billiton, PIRSA, Santos, Conservation Council) and ensure the continuity of the data. Also, with the appropriate training and expert supervision it may be possible to enlist qualified volunteers to contribute to data collection through recreational dive clubs, and community or school groups (see Figure 2.13 for related media article). Enlisting diverse groups to undertake the surveys, however, raises issues around quality control and assurance of the collected data. Ensuring that divers were appropriately trained or accompanied by experts who had contributed to the surveys in the past would provide greater scientific rigor in data collection and result in meaningful estimates of cuttlefish abundance and biomass. Appropriately archiving habitat images will also facilitate audits, or re-analysis, if required to investigate data integrity.

Teens to work with professionals

By Jade WALKER

Working alongside scientific professionals could become a new part of Stuart High School's aquaculture program.

Following the puzzling decline in cuttlefish numbers, Minister for Fisheries and Agriculture Michael O'Brien called on the South Australian Research Development Institute (SARDI) last week to carry out immediate research.

In his announcement he also agreed to get the Stuart High School working alongside SARDI in a bid to find out more about the world phenomenon.

Year 10 aquaculture students at the school currently study a wide spectrum of marine biology to achieve their certificate II in aquaculture.

Aquaculture teacher Daryl Wishman said this program would give students a new opportunity.

"It gives them a great insight into the way scientific industry works and the way the fishing industry works," he said.

The school's aquaculture program offers a unique opportunity compared to other schools including an indoor finfish farm, fish processing and selling, and other marine related topics.

Mr Wishman said this new program would offer the students all the tools they needed to be employed in the aquaculture industry.

"It gives them a head start," he said.

Assistant principal Steve Walker who is concerned about the cuttlefish, was enthusiastic about getting the school to help where it could.

He said the door would be opened to further job opportunities through experience gained in the research they carried out.

To gain a better understanding for the giant cuttlefish, the school wanted to send the students on a snorkel trip out at False Bay last week.

However due to the scarce numbers of the animal, the students snorkelled out at the kingfish farms instead.

Mr Walker said the school would look to possibly include a scuba diving course into the aquaculture program next year.

Student Cori Anderson said if he was able to gain his diving licence through school it could help him gain a career path in the aquaculture field and would be encouraging for students to come to school.

Because the cuttlefish season is now over, students will not be able to start physical research until next winter.

In the meantime the school will plan what will need to be done.

Mr Walker said the research would include surveying of eggs and cuttlefish numbers and testing water temperature and salinity levels.

He also said after year 10 students finish at the school, they will still be able to stay involved with the program, which will count towards their South Australian Certificate of Education (SACE) points.

BEYOND CLASS: Stuart High School aquaculture students took the classroom to the sea last week to snorkel with the kingfish: (From left) Clinton Todd, Josef Mills, Payten Todd, Cameron Mudge and William Gibbs.

Figure 2.13. An article in the Whyalla News 01/09/2011 indicating that local student groups are willing to contribute in any on-going monitoring program.

3. EXPLORING THE 'CAUSE' OF THE CUTTLEFISH DECLINE

3.1. INTRODUCTION

Although the intention of the historic cuttlefish surveys has deviated from being a fisheries assessment tool to having a conservational focus, the overall value and integrity of the information has remained consistent. This is despite a number of agencies undertaking their own independent assessment of the giant Australian cuttlefish population and is largely due to their collective reliance on the methodological foundation established by Hall and Fowler (2003). As such the time series of survey data can be considered sufficiently robust and reflective of the trends in cuttlefish abundance and biomass. In synthesising the historic survey data and including the most recent assessment (Chapter 2), it is clear that the annual cuttlefish spawning aggregation around Point Lowly has declined from a peak in abundance of approximately 183,000 animals in 1999 to 18,530 in 2012, representing a 90% reduction in population size over 13 years (Figure 3.1). Estimates of biomass displayed a similar trend, falling by approximately 95% over the same time period (Figure 3.1).

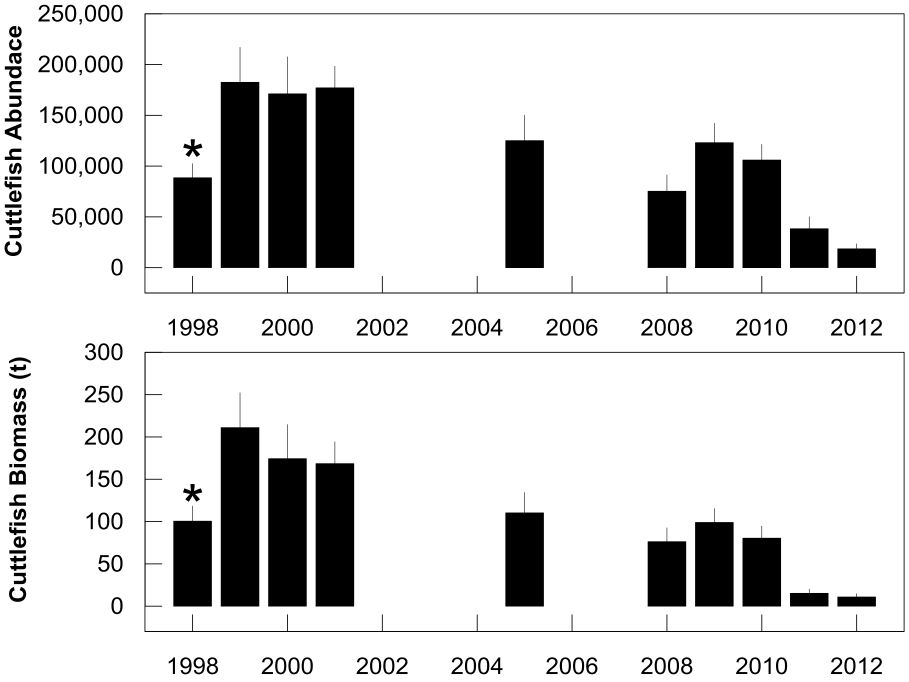

Figure 3.1. Annual estimates of total abundance and biomass (± se) of giant Australian cuttlefish aggregating around Point Lowly during peak spawning from 1998 to 2012. ***** The fishing closure was not implemented until 1999, therefore the 1998 estimates were reflective of a population that was heavily fished.

The nature and extent of this decline has become a concern for many South Australians and given the iconic status of the species, it has also attracted considerable media attention (Figure 3.2). The obvious questions that have been frequently asked by the community is "what has caused this decline over the years?" and "will the local cuttlefish population recover?". These are very challenging questions to definitively answer as there most likely a suite of inter-connected factors driving the declines in cuttlefish abundance and biomass. This complexity is apparent when considering the range of factors that have been suggested by the general public, government agencies and non-government organisations, as potential contributors to the decline. Such speculation has included: natural variation; industrial pollution; fishing pressure; environmental irregularities; increased predation pressure; disease; seismic activity; tourism; and local aquaculture ventures. Consequently, there is a need to consider all possibilities and provide a preliminary evaluation upon which further investigation can be based. The strength of this, and future investigations, will depend on the availability and extent of supporting datasets.

The objective of this section of the report is to explore whether the observed decline in cuttlefish abundance and biomass correlates with any of a range of potential 'contributing' factors. Although, correlation does not imply causation, its use in this report is simply to take a 'first-cut' approach towards identifying any potential factors that may require further investigation. The factors that are considered can be grouped into four general categories that relate to: (1) the history of the spawning population, (2) abiotic influences, (3) biotic influences, and (4) population dynamics (Table 3.1). This report sequentially addressed each of these categories.

Table 3.1. The list of factors that were considered in this report as potentially contributing to the observed decline in the cuttlefish spawning population.

CATEGORY	FACTOR	SOURCE OF INFORMATION / DATA	ASSESSMENT
Historical	Spawning history	Anecdotal Reports	Qualitative
Abiotic	Water Temperature	CSIRO Australia	Quantitative
Abiotic	Onshore Winds	Bureau of Meterology	Quantitative
Abiotic	Rainfall	Bureau of Meterology	Quantitative
Abiotic	Pollution (Nutrients)	Coastal Industries	Quantitative
Abiotic	Pollution (Metals)	Coastal Industries	Quantitative
Abiotic	Pollution (Hydrocarbons)	EPA	Quantitative
Abiotic	Pollution (Noise)	Coastal Industries	Quantitative
Biotic	Predators (Dolphins)	Literature / Anecdotal	Qualitative
Biotic	Predators (NZ Fur Seals)	SARDI	Quantitative
Biotic	Predators (Snapper)	SARDI	Quantitative
Biotic	Predators (WA Salmon)	SARDI	Quantitative
Biotic	Predators (Yellowtail Kingfish)	Aquaculture licensees / PIRSA	Quantitative
Biotic	Prey (Western King Prawns)	SARDI	Quantitative
Biotic	Prey (Blue Crabs)	SARDI	Quantitative
Biotic	Habitat	Anecdotal Reports	Qualitative
Biotic	Disease / Parasites	PIRSA	Qualitative
Biotic	Fishing (Marine Scalefish)	SARDI	Quantitative
Biotic	Fishing (Spencer Gulf Prawn Fishery)	SARDI	Quantitative
Biotic	Tourism	Whyalla Dive Services	Qualitative
Biotic	Other Cephalopods (Calamary)	SARDI	Quantitative
Population Dynamics	Movement & Migration	Literature / Anecdotal	Qualitative

3.2. HISTORY OF THE SPAWNING POPULATION

It is possible that the observed decline in the cuttlefish population is part of a natural process and one hypothesis that needs to be considered relates to whether the spawning population has always aggregated around Point Lowly in the densities that were observed in the late 1990s (i.e. approx. 180,000 animals). Cephalopod populations, in general, are renowned for their considerable fluctuation in abundance (Boyle and Rodhouse 2005). These fluctuations can occur rapidly as evident in the ‘boom and bust’ fisheries for Japanese flying squid (*Todarodes pacificus*) and Argentine shortfin squid (*Illex argentines*) where shifts in the population size can occur over a few years (Rodhouse 2008). In these cases, the rapid expansion and contraction of the population appear to be influenced by environmental variability associated with El Niňo/Southern Oscillation events and ecological change caused by fishing other trophic levels (Rodhouse 2008). Similar examples exist for another species of cuttlefish (*Sepia offinalis*), where large inter-annual variation in recruitment appears to be driven more by environmental conditions than by spawning stock and fishing activity (Royer et al. 2006). Alternatively cephalopod populations can fluctuate widely over 10 to 20 year cycles, as observed in the Scottish *Loligo* spp. Fishery, which appeared to represent real fluctuations in squid abundance and were unrelated to trends in fishing effort (Boyle and Pierce 1994). It is the characteristic fast paced and dynamic life-history of cephalopods that enables them to respond quickly to local conditions.

Studies that attempt to explain inter-annual trends in cephalopod population dynamics have typically depended on datasets that extend over considerable time frames. In the case of the Japanese flying squid fishery the data extend back more than a century (Rodhouse 2001). The time-series of data that exists for the Point Lowly Giant Australian cuttlefish is comparatively short and there was no formal census of the spawning aggregation prior to 1998. Consequently, it is not certain whether the peak in cuttlefish abundance and biomass recorded in 1999 was a result of a rapid population 'explosion', or whether it was indicative of a natural population size that had persisted through time. If the peak did represent a population 'explosion' then it would be expected that, over time, it would decline to a lower level. The only way to address this question was to rely on the anecdotal reports from people who had observed the population prior to 1998, however, this also presented a number of uncertainties. For example, it is possible that the spawning aggregation was always there but was overlooked, or that large aggregations of spawning cuttlefish were observed but their relative densities may have been low in comparison to the tens of thousands surveyed in the late 1990s and early 2000s.

A newspaper article published in 1910 noted an accumulation of dead cuttlefish in northern Spencer Gulf as being a potential health concern to Port Germein residents; "*an alleged accumulation of cuttlefish in a decomposed condition lying on the esplanade"* (Adelaide Advertiser 27th August 1910). This appears to be the earliest published record of large quantities of cuttlefish in northern Spencer Gulf (B. Gillanders pers. comm.). A similar die-off was also reported by Yorke Peninsula residents in 1947 where cuttlefish were "*washed ashore in thousands, and litter the beaches so thickly that walking is made uncomfortable"* (The Mail, 6 September 1947). The accumulation of dead cuttlefish or cuttlebones on beaches in late winter and spring is not an unusual occurrence. In fact, it should be expected as it marks the end of the spawning season when cuttlefish naturally senesce. These die-offs do not reveal much about local population abundance, and are not a reliable indicator of mass aggregations as dead cuttlefish and remnant cuttlebones are capable of floating and accumulating over long distances depending on the tides and prevailing winds.

Commercial and recreational fishers have most likely been catching cuttlefish around Point Lowly for generations. One local fisher, who has been fishing the area since 1971, has been quoted in the Whyalla Times suggesting that *"Whyalla wasn't always blessed with a massive congregation of cuttlefish that has been seen in recent years"* (Alan Hall, President Australian National Sports Fishing Association of South Australia). Similarly, marine diver surveys commissioned by Santos in 1982 to provide baseline information of the Point Lowly area in the event of an unlikely oil-spill did not detect cuttlefish (Watson 1982). This information was unexpected, given the surveys were undertaken at a time (June) and in areas (Stony and Black Points) where cuttlefish were expected to have aggregated. The author of that report was recently contacted and she categorically stated *"that I only ever saw one cuttlefish at Lowly during all our surveys there. We worked in June and summers"* (J. Watson pers. com. 20 August 2012). In contrast, however, *"large numbers of cuttlefish"* were noted by a team of marine scientists who were diving around the Point Lowly area in 1986 (Prof. Rod Connolly (Griffith University) and Dr. Craig Proctor (CSIRO Hobart) pers. comm.).

Tracking the history of the Point Lowly cuttlefish is challenging, and although anecdotes and recollections have provided some interesting information, it still cannot be concluded that the numbers that were observed in the late 1990s represented the 'normal' population size. This paucity of information highlights the benefit of an on-going monitoring program to provide a greater understanding of the dynamics of the population. It is possible, however, that other sources of reliable information exist and have not been captured in this report which may come to light in the future.

Icon on squid row

Scientists can't find cuttlefish eggs

SARAH MENNIE
RURAL AFFAIRS REPORTER

Sunday Mail
21AUG2011

Sunday Mail
11MAR2012

Rock stars of the ocean

HEATHER KENNETT
RURAL AFFAIRS REPORTER

Whyalla no longer home of the cuttlefish

Whyalla News
14AUG2012

Whyalla News
18SEP2012

Are our cuttlefish extinct?

Grave concerns for cuttlefish

Whyalla News
18SEP2012

Ban zones expand

Cuttlefish fishing scuttled

SARAH MENNIE
RURAL AFFAIRS REPORTER

Sunday Mail
28AUG2011

Investigation into cuttlefish decline inconclusive

Whyalla News 02OCT2012

Figure 3.2. Collage of relevant media clippings.

3.3. ABIOTIC INFLUENCES

Abiotic influences encompass all non-biological, chemical and physical factors in the environment such as: temperature, water chemistry and climatic conditions.

3.3.1. Water Temperature

Cephalopods are typically short lived (i.e. sub-annual lifespan) and exhibit extreme plasticity in growth and longevity as influenced by ambient temperature (Forsythe and Hanlon 1988; Forsythe 2004). Many cephalopod species spawn over extended periods, consequently cohorts of developing embryos and resultant hatchlings experience different temperature regimes. For cephalopod species that spawn throughout spring and summer such as Southern Calamary *Sepioteuthis australis*, embryonic development accelerates as the ambient temperature increases resulting in progressively smaller hatchlings throughout the season (Steer et al. 2003; Pecl et al. 2004). The opposite occurs for species that spawn during winter (e.g. giant Australian cuttlefish *Sepia apama*), where as ambient temperature decreases the embryonic developmental time is increased and results in progressively larger hatchlings. In essence, temperature has the capacity to determine the species' entire life-history schedule, influencing important processes such as early survival, size at maturity, reproductive potential, and recruitment success, all of which are fundamental in determining the size and structure of a population (Pecl et al. 2004). Consequently, environmentally good conditions, where temperature favors growth and survival, can lead to a significant increase in the population, while environmentally poor conditions can result in reduced stock and an apparent population collapse (Boyle and Rodhouse 2005).

It has been speculated that water temperature around Point Lowly has been 'unseasonal' in recent years and may have altered or interfered with the timing of the spawning event. This speculation relates to the strong community perception that the cuttlefish start aggregating once the water temperature drops below 17 °C, the timing of which has occurred irregularly over the past few years (Bramley pers. comm.). Here we analyse the long-term trends in water temperature of northern Spencer Gulf and investigate whether there have been any irregularities that may have coincided with the decline in cuttlefish abundance and biomass.

Daily seawater temperature for northern Spencer Gulf was obtained from CSIRO's Marine and Atmospheric Research Remote Sensing Facility. The time series of data extended from January 1995 to December 2012. The number of days taken for the water temperature to drop below the daily average of 17 °C was calculated from January 1st in each of the years. Monthly averages were also calculated.

The years of 2001 and 2002 exhibited the greatest contrast in seawater temperature over the past 13 years having the warmest and coolest summer peaks at 29.7 °C and 25.8 °C, respectively (Figure 3.3). The coolest winters during which average monthly temperatures fell below 11 °C occurred in 1998, 2004, 2006 and 2010. The winter minima of 2003 appeared to be anomalously warm as temperatures remained above 14.5 °C (Figure 3.3). Peak summer temperatures have marginally declined from 28.6 °C in 2011 to 26.8 °C in 2012, whilst, winter minima have remained within 0.7 °C of each other over the past three years. The time taken for temperature to drop below 17 °C ranged from 116 days in 1998 to 147 days in 2005. This arbitrary 'spawning cue' did not statistically correlate with estimates of cuttlefish abundance and biomass (Figure 3.3). Similarly, annual averaged temperature did not correlate with declining cuttlefish numbers, nor did monthly averaged temperature lagged from 0 to 12 months prior to peak spawning (Figure 3.3). The resolution of these data suggests that seasonal temperatures have remained relatively stable over the last seven years and have had little influence on the spawning population. It is possible, however, that spikes, or pulses in temperature that have occurred over short periods (i.e. hours or days) may have had a greater effect and is an area of research that requires further investigation.

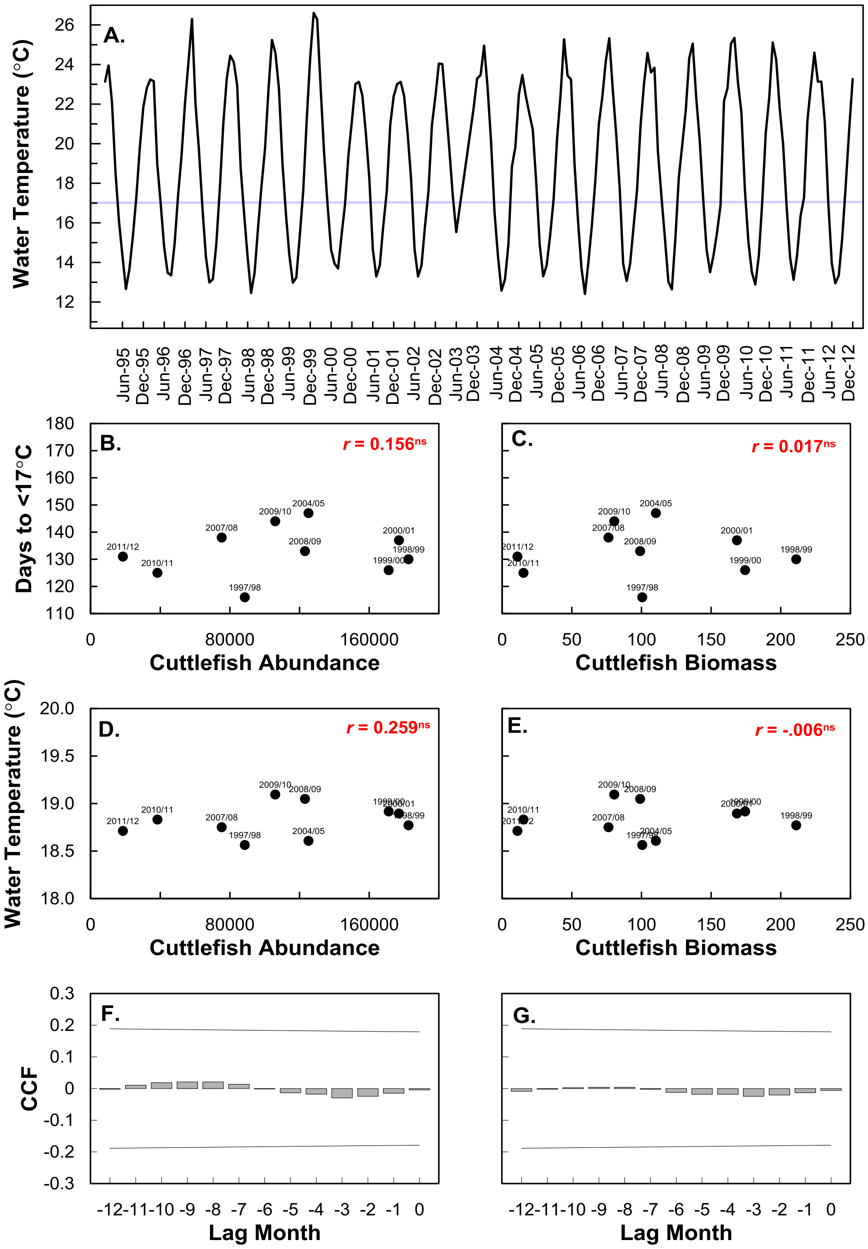

Figure 3.3. (A.) Monthly average sea-surface temperature for northern Spencer Gulf from July 1999 until May 2012. Cuttlefish abundance (B.) and biomass (B.) correlated with number of calendar days until mean sea temperature drops below 17°C. Cuttlefish abundance (D.) and biomass (E.) correlated with average annual sea temperature. Cross-correlation functions of annual monthly temperature with cuttlefish abundance (F.) and biomass (G.). Lines represent ± 2 standard error.

3.3.2. Onshore Wind

The mating behavior of giant Australian cuttlefish is heavily reliant on vision as males use elaborate colour displays to court females and fend off competitors. Smaller males are also capable of adapting their appearance and colouration to ‘impersonate’ females and avoid competitive interactions with dominant males (Norman et al. 1999). Similar visually-oriented mating behavior has been documented for other cephalopod species that aggregate to spawn in coastal environments (Sauer et al. 1997; Jantzen and Havenhand 2003). For the South African chokka squid (*Loligo reynaudii*), wave height, turbidity and sea temperature were identified as key parameters in controlling and determining spawning success (Roberts 1998). Periods of high turbidity arising from strong onshore winds and coastal swell were found to disperse spawning aggregations, presumably as a function of poor visibility (Augustyn et al. 1994; Roberts and Sauer 1994).

Long-term turbidity information is unavailable for the coastal waters around Point Lowly, however, it is possible to use wind strength and direction data as a proxy for water clarity. For example, it can be assumed that if Point Lowly is exposed to extended periods of strong onshore, southerly winds, then the local water conditions are likely to be rough and turbid. Historic records of daily wind speed (km/h) and direction were obtained from the Bureau of Meteorology. These data were obtained from the Whyalla Airport weather station, which is located approximately 20 km west of Point Lowly, for 1st July 1999 to 31st May 2012 and a monthly average was calculated. An index of onshore wind stress was also calculated by isolating the onshore southerly wind component using the following equation:

$$\text{Southerly wind component} = \text{wind speed} \times \cos\left(\text{wind direction} * \left((2\pi)/360^\circ\right)\right)$$

The average monthly wind direction for Whyalla was predominantly southerly during spring and summer and was more south-westerly during late autumn and winter. Occasionally the winter wind prevailed from the west-north-west (i.e. July 2002, May 2007 and August 2009) and was therefore blowing offshore at Point Lowly (Figure 3.4). Wind intensity is relatively stronger during summer with monthly averages frequently exceeding 20 km/hr compared with the lighter winter winds which rarely persist above 15 km/hr (Figure 3.4). No statistical correlation was found between cuttlefish population estimates and onshore wind stress on both an annual and monthly basis (Figure 3.4). This is likely due to the consistent nature of the winter winds that affect Point Lowly. Given the winter winds are typically light and are from a more westerly direction, it is likely that any tidal induced turbidity is either reduced, blown offshore or quickly settles, consequently providing adequate conditions for spawning cuttlefish.

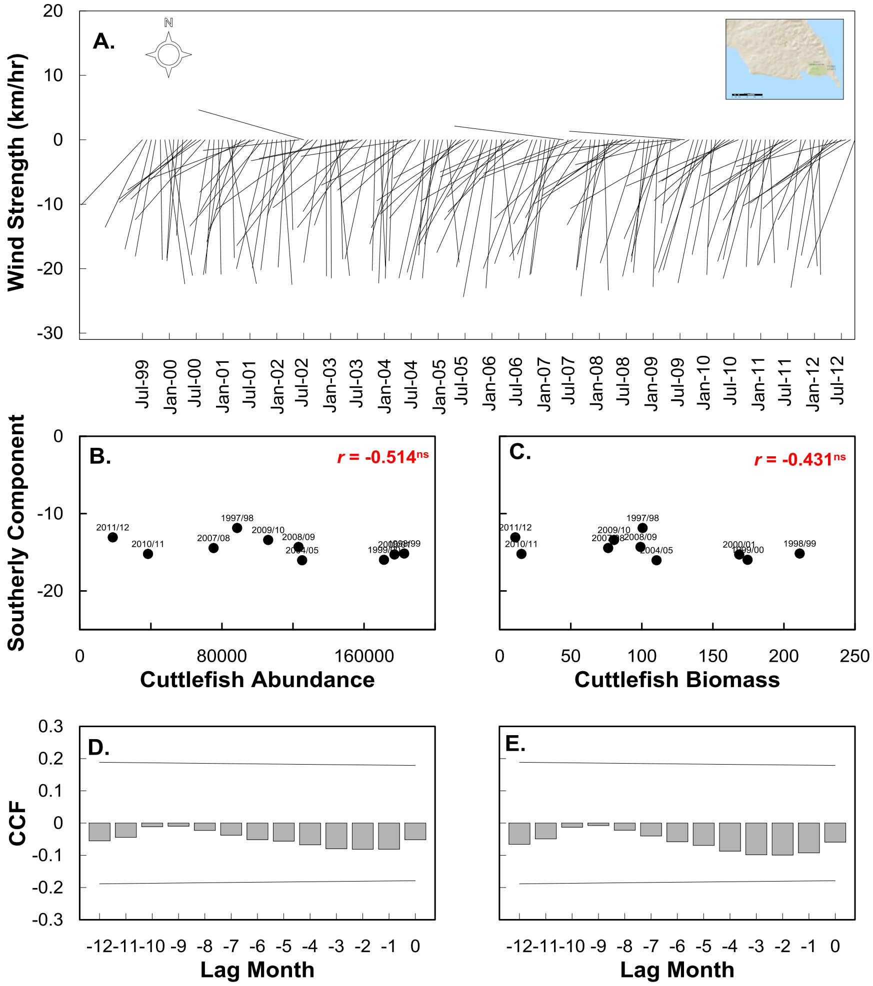

Figure 3.4. (A.) Average monthly wind strength and direction for Whyalla from July 1999 until May 2012. Correlation of average southerly wind strength with cuttlefish abundance (B.) and biomass (C.). Cross-correlation functions of averaged monthly southerly wind strength with cuttlefish abundance (D.) and biomass (E.). Lines represent ± 2 standard error.

3.3.3. Rainfall

Rainfall, fresh water run-off and river discharge have been suggested to affect the abundance of some coastal cephalopods, however, the evidence within the literature is limited (Pierce et al. 2010). An analysis of commercial landings of the common octopus (*Octopus vulgaris*) and cuttlefish (*Sepia officinalis*) in the Gulf of Cádiz (SW Spain) with rainfall, river discharge and sea surface temperature over 18 years produced varied results (Sobrino et al. 2002). Octopus abundance was found to correlate highly with rainfall from the previous season and various months of river discharge, whereas cuttlefish abundance did not correlate with any variable. This research concluded that, in comparison to octopus, cuttlefish in the Gulf of Cádiz appeared to be more adapted to an estuarine environment and were tolerant of episodic salinity fluctuations (i.e. euryhaline).

Spencer Gulf is substantially more saline than the adjacent continental shelf waters because of high evaporation rates, low precipitation and lack of inflow from creeks and rivers. Consequently, it exhibits a strong latitudinal salinity gradient increasing northwards and is characteristic of an inverse estuary (Nunes Vaz et al. 1990; Petrusevics 1993). The annual salinity range around Point Lowly is 40-43 ‰ with a typical peak in late autumn (BHP Billiton 2009). Long-term salinity information is currently unavailable. It has been suggested, however, that local rainfall has an influencing effect on cuttlefish abundance, with the recent drought being suggested by community members as a cause for the declining trend.

Average monthly rainfall data were obtained from Whyalla's Airport and Broadview weather stations maintained by the Bureau of Meteorology for July 1999 to June 2012. Over the past 13 years monthly rainfall has exceeded 80 mm three times, peaking at 97.6 mm in September 2001, 88.2 mm in January 2007, and 95.6 mm in February 2011 (Figure 3.5). The driest year was 2007/08 with an average of 15.7 mm of rainfall per month, 58.5% less than the relative wet 2010/11 monthly average of 37.9 mm (Figure 3.5). The magnitude of local rainfall over a period of one to five months prior to the cuttlefish spawning season inversely correlated with estimates of abundance and biomass (Figure 3.5). This suggests that periods of increased rainfall during late summer and autumn leads to a decrease in the cuttlefish spawning population in winter and vice versa. The underlying dynamic of this process may relate to changes in coastal salinity, localised pollution through terrestrial run-off, or a direct influence on water clarity, all of which may deter aggregating cuttlefish from the coastal environment.

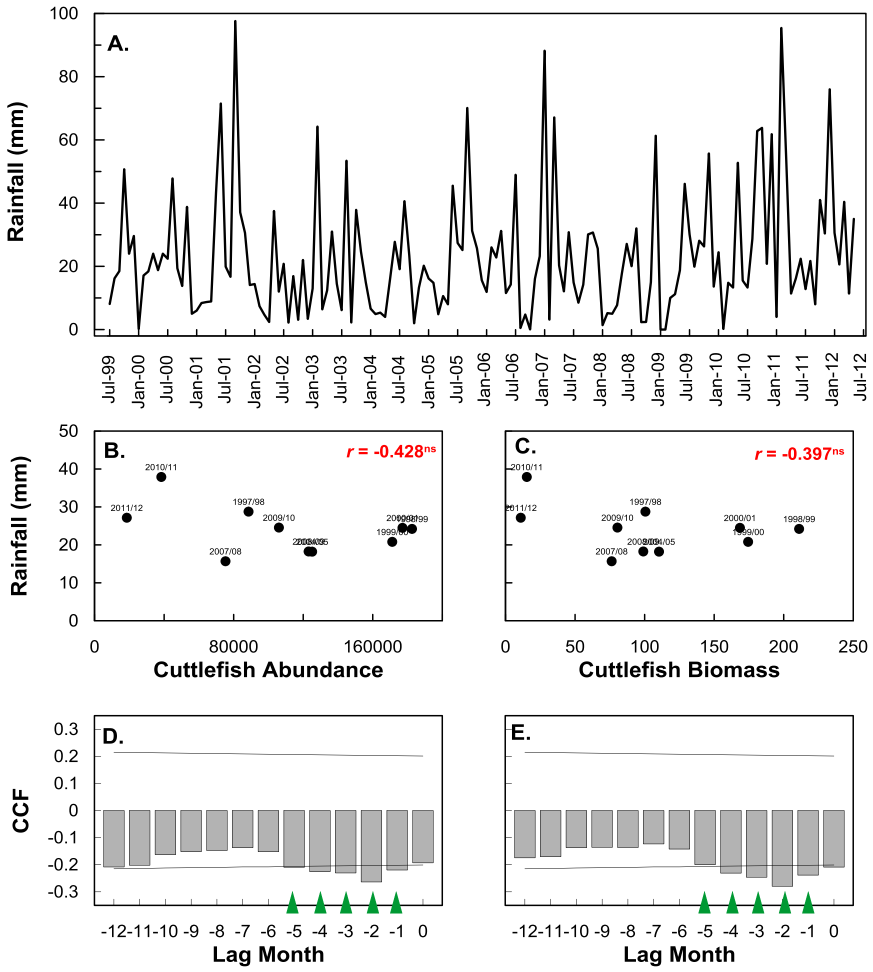

Figure 3.5. (A.) Monthly rainfall for Whyalla from July 1999 until May 2012. Correlation of monthly rainfall with cuttlefish abundance (B.) and biomass (C.). Cross-correlation functions of monthly rainfall with cuttlefish abundance (D.) and biomass (E.). Green arrow indicates significant correlation. Lines represent ± 2 standard error.

3.3.4. Pollution

Northern Spencer Gulf has had a long history of heavy industrialization dating back to the late 1800s, and for much of this time environmental controls on discharges to the marine environment did not exist. As a result there is a well documented legacy of metal contaminated sediments throughout the northern Spencer Gulf (e.g. Ward and Young, 1982; Ward et al. 1986; Harbison and Wiltshire 1993; and others). More recently the City of Whyalla has grown as a result of successful manufacturing and mining industries, becoming one of the largest regional centres in South Australia. Such growth has also lead to increased coastal pollution as a function of urban development through storm water and wastewater, as well as industrial discharges. As a consequence, coastal pollution is a concern in the community, particularly as Whyalla has been historically stained by fugitive ‘red dust’ emitted from the Steelworks, which resulted in a large community response.

There are numerous sources of coastal pollution that have the potential to impact the cuttlefish, of which the most notable is the Whyalla Steelworks which discharges ammonia into detention dams which flows into the nearshore environment each year. Further afield, the Port Pirie lead and zinc smelter has been established since the late 1800s and has discharged large amounts of metals into the nearshore environment. The Whyalla Wastewater Treatment Plant (WWTP) discharges treated effluent into mangrove lined tidal waters south of Whyalla and sea cage aquaculture activities which farm yellowtail kingfish (*Seriola lalandii*) within Fitzgerald Bay also contribute to pollutants in nearshore waters. The Santos hydrocarbon processing plant at Port Bonython is in close proximity to the cuttlefish spawning area and, with increases in mining in South Australia the shipping activities including trans-shipment loading of iron ore are increasing.

Large discharges into coastal waters are regulated by the EPA under the *Environment Protection Act 1993*. Many facilities are required to monitor their discharge and submit monitoring programs to the EPA in order to ensure the protection of the environment. In most circumstances discharge load data are also published on the Australian National Pollutant Inventory (NPI) website (www.npi.gov.au). Improvements in environmental practices can be regulated through the facilities’ environmental authorisation and environment improvement programs administered by EPA

3.3.4.1. Nutrients

Nutrients discharged into marine environments have had negative impacts throughout the world and are one of the major causes of significant seagrass loss along the Adelaide metropolitan coast (Shepherd et al. 1989; Fox et al. 2007; Bryars et al. 2011) and False Bay in Whyalla (Harison and Wiltshire 1993). In oligotrophic waters seagrasses are adapted to very low nutrient concentrations. When an additional nutrient source is introduced, fast growing algae use the nutrients and proliferate growing on seagrass leaves as epiphytes. This epiphytic algae can reduce the amount of light available to the seagrass leaves and may result in a reduction in seagrass biomass and extent, particularly from the deeper edges (Shepherd et al. 1989; Neverauskas, 1988).

The Whyalla Steelworks produces a number of effluent streams, including one from the coke ovens that contains a significant load of nitrogen. A proportion of the effluent is treated through an engineered reed bed, where some of it is recycled through biological processes. However, a proportion of the effluent flows into detention ponds within the steelworks and then into the marine environment. Since recording commenced in 1998/99 the facility has discharged between 110,000 kg and 270,000 kg of nitrogen each year with an annual average of 183,000 kg (NPI 2013).

The Whyalla WWTP treats sewage from the City of Whyalla and discharges treated effluent into the nearshore waters south of Whyalla. In 1998/99, the WWTP discharged approximately 50,000 kg of nitrogen into the gulf. In 2004/05, SA Water constructed a water reclamation plant to treat and recycle treated effluent, thereby significantly reducing their discharge into the gulf and in 2010/11 their nitrogen discharge was 9,900 kg (NPI, 2012).

The sea cage aquaculture farming of yellowtail kingfish (YTK) started in Fitzgerald Bay in the late 1990s, with an estimated annual production of 45 tonnes in 1999/2000. This sector rapidly expanded to a production of 1,100 tonnes in 2001/02 and peaked in 2009/10 at 2071 tonnes. Sea cage aquaculture results in nutrients being released into the water column, discharging an estimated 176-195 kg of nitrogen into the environment per tonne of fish produced (Fernandes and Tanner 2008). The total discharge of nitrogen in 2001/02 would have been in the order of 204,000 kg of nitrogen, increasing with the expansion of the industry to approximately 384,000 kg of nitrogen into Fitzgerald Bay in 2009/10. In 2009/2010, a disease outbreak reduced the production in Fitzgerald Bay to approximately 249 tonnes with the majority of fish being moved to other aquaculture zones such as Arno Bay (more in section 3.4.1).

A coupled hydrodynamic-biogeochemical model that was developed for Spencer Gulf by SARDI as part of an FRDC funded project (Middleton et al. 2009) was used to investigate the connectivity of anthropogenic inputs with the Point Lowly spawning grounds. This model simulates the transfer of nutrients (nitrate and ammonium) through the lower trophic levels of the ecosystem (i.e. phytoplankton, zooplankton and detritus) and includes a benthic component that represents nitrification and denitrification processes critical to nutrient cycling and ecosystem functioning in shallow water systems. The model has been calibrated and semi-validated from field measurements for nutrients and phytoplankton for the period of July 2010 to July 2011. Simulation scenarios were run to include additional sources of nutrients, including those derived from the monthly values provided by PIRSA Fisheries and

Aquaculture, SA Water WWTP’s and OneSteel. Despite some limitations and uncertainties regarding the input of anthropogenic nutrients and their breakdown into various nitrogenous compounds (i.e. nitrate and ammonium) their inclusion in the model simulations results in significantly higher concentrations and variability in the supply of nutrients to the Point Lowly region (Figures 3.6, 3.7). These increases in nutrients have a flow-on effect resulting in increased phytoplankton productivity. In particular, the delivery of large detrital material through the accumulation and aggregation of rapidly sinking dead phytoplankton and zooplankton to the benthic ecosystem appears to be increased and reaches a maximum during the months of June and July (Figure 3.7).

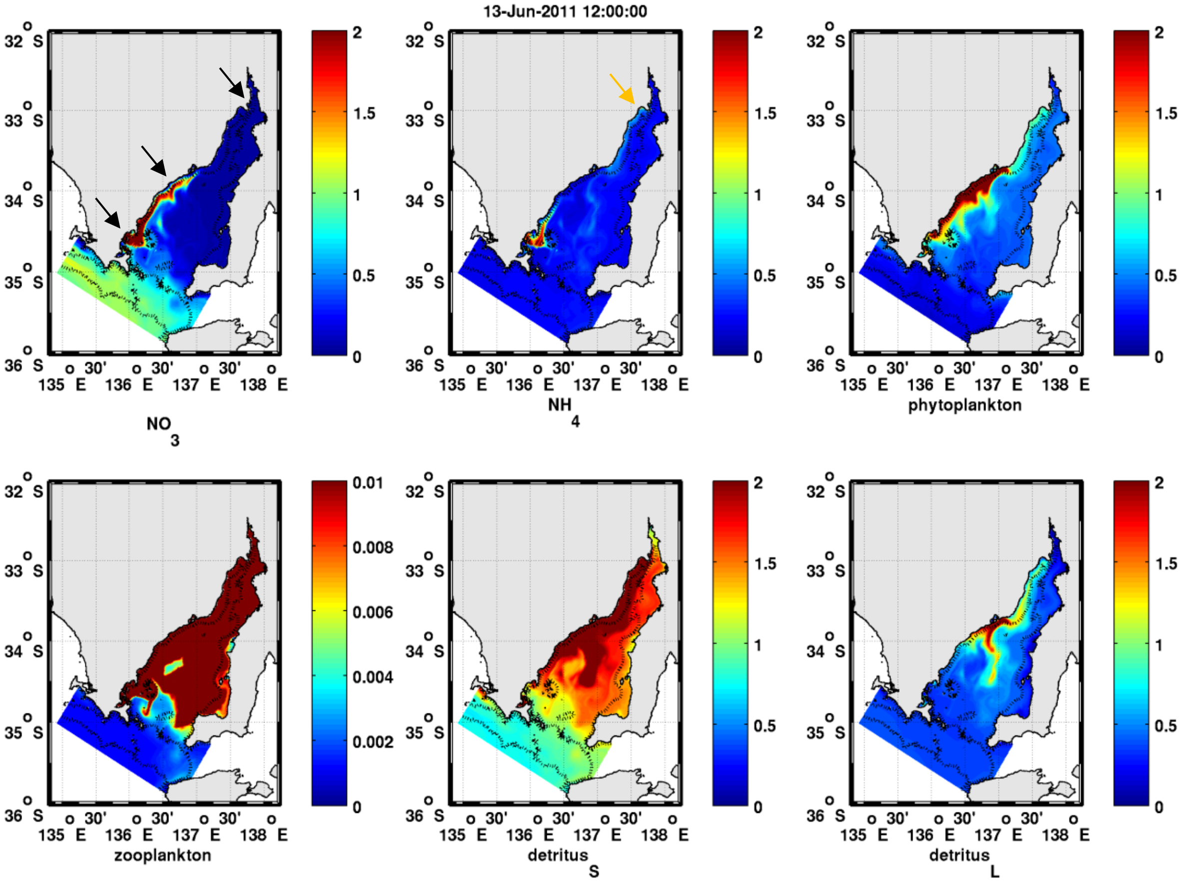

Figure 3.6. Snapshot of the daily, depth averaged concentration of nutrients (NO_3; nitrate, NH_4; ammonium) and ecosystem variables (phytoplankton, zooplankton, small and large detritus) from the coupled hydrodynamic model for June 12, 2011. Arrows show the approximate location of anthropogenic nutrient inputs from (black) aquaculture and (orange) wastewater treatment plants and OneSteel. All fields have common units of mmol N m^{-3}.

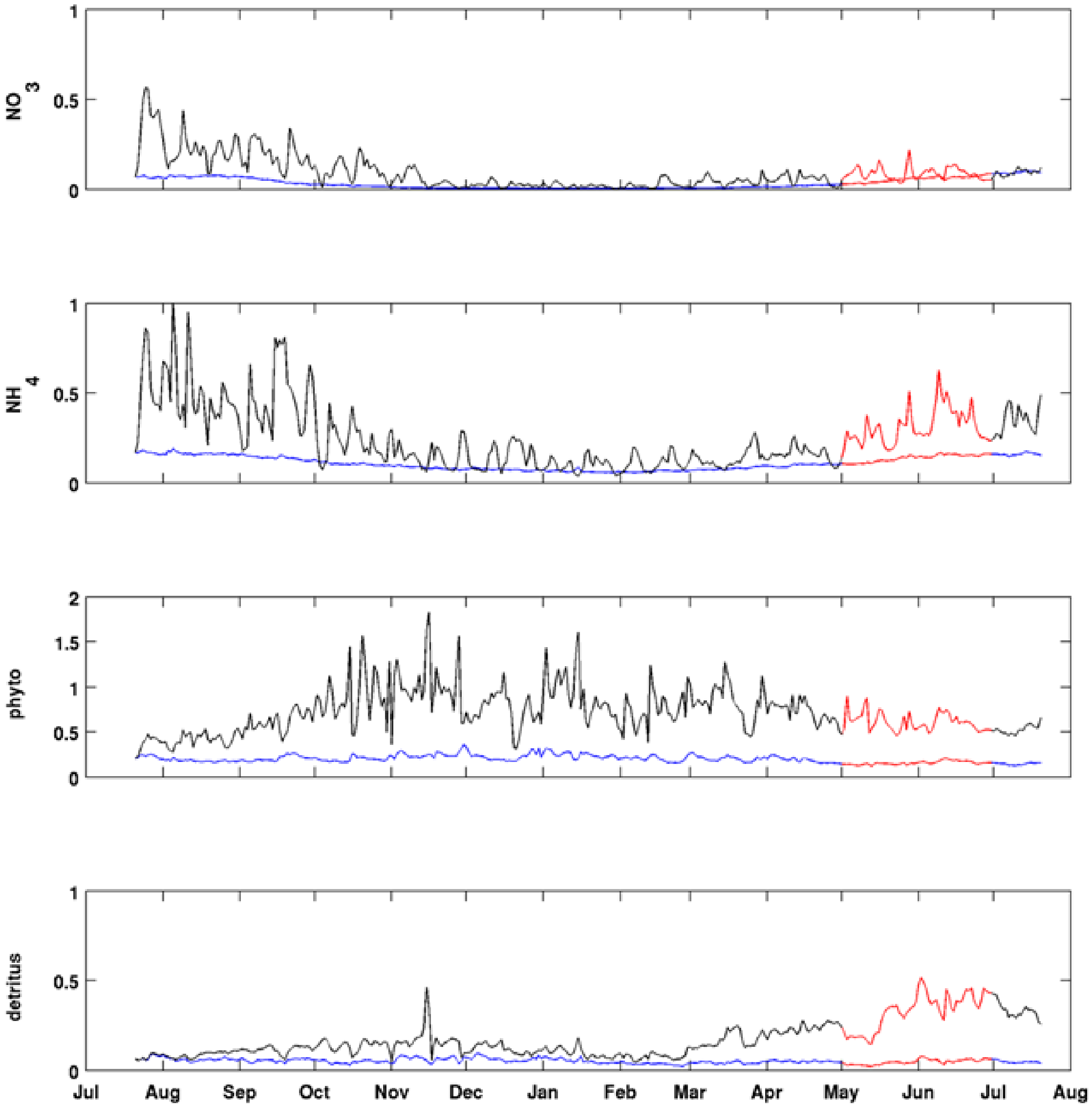

Figure 3.7. Time series of modelled daily average, bottom concentrations of nitrate (NO_3), ammonium (NH_4), phytoplankton and large detritus predicted by the Spencer Gulf biogeochemical model for 2010/11 at Pt Lowly. Blue and black lines represent the predicted concentrations for model scenario studies with nutrients supplied naturally from the model boundaries and nutrients supplied from the model boundaries as well as anthropogenic sources, respectively. Red segments indicate the months corresponding to the aggregation of cuttlefish of Port Lowly. All fields have common units of mmol N m^{-3}.

The environmental impact of nutrients throughout the False Bay and Fitzgerald Bay area has been the loss or degradation of approximately 20 km^2 of *Posidonia* seagrass, which has largely been attributed to the steelworks discharge (Harbison and Wiltshire 1993). It is also likely that nutrients from anthropogenic sources are reaching the spawning grounds between Black Point and Backy Point where they may be contributing to the sporadic *Hincksia sordida* blooms (Figure 3.8).

Given the long history of industrial discharges dating back to the pre-SCUBA era, there is a lack of information regarding the composition of these rocky reefs prior to industrial development. It is likely that the elevated nitrogen loads have resulted in a change in the condition of the rocky reef environment for an extended period of time. However there is no known link suggesting that a decline in habitat condition or blooms of *Hincksia sordida* across the spawning grounds have contributed to the decline in the cuttlefish population as this is likely to have been a prolonged state dating back many years prior to the cuttlefish decline. This conclusion is supported by the lack of significant correlation between the nutrient loads discharged and the decline in cuttlefish population (Figures 3.9, 3.10).

Figure 3.8. Unidentified sponges surrounded by *Hincksia sordida* at Stony Point 08/07/2011. Photograph S. Gaylard.

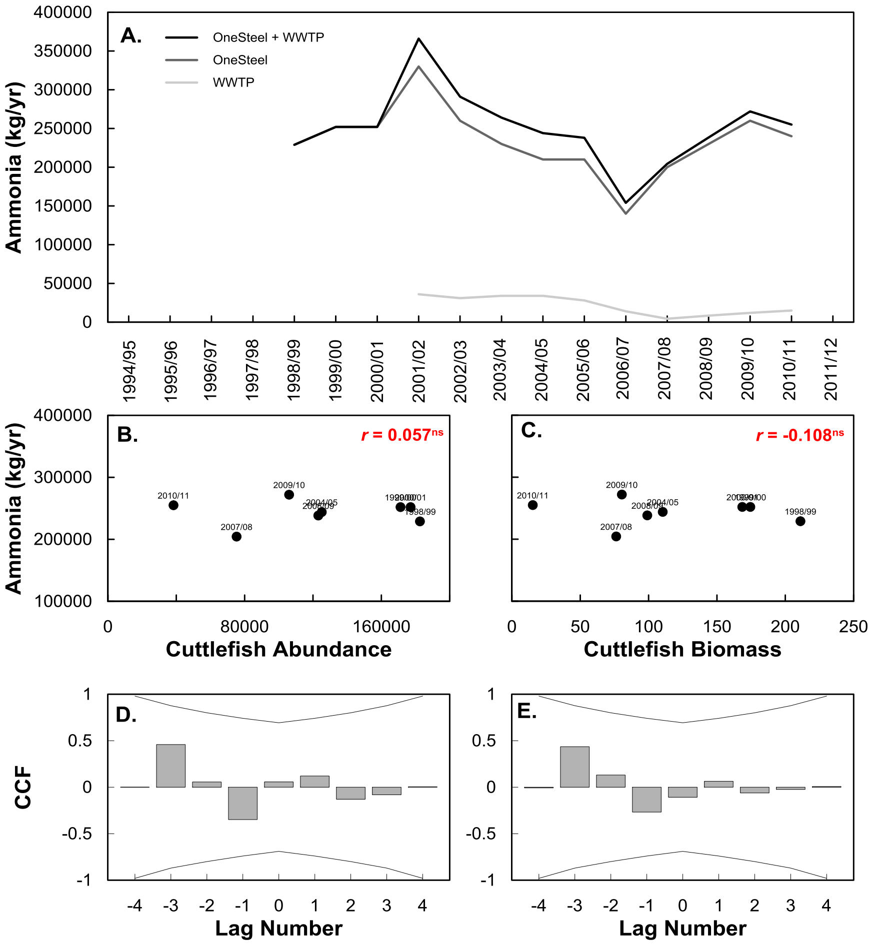

Figure 3.9. (A.) Annual reported ammonia input from Whyalla waste-water treatment plant (WWTP) and OneSteel from 1998/99 until 2010/11. Correlation of total annual ammonia input (WWTP and OneSteel combined) with cuttlefish abundance (B.) and biomass (C.). Cross-correlation functions of total annual ammonia input with cuttlefish abundance (D.) and biomass (E.). Lines represent ± 2 standard error.

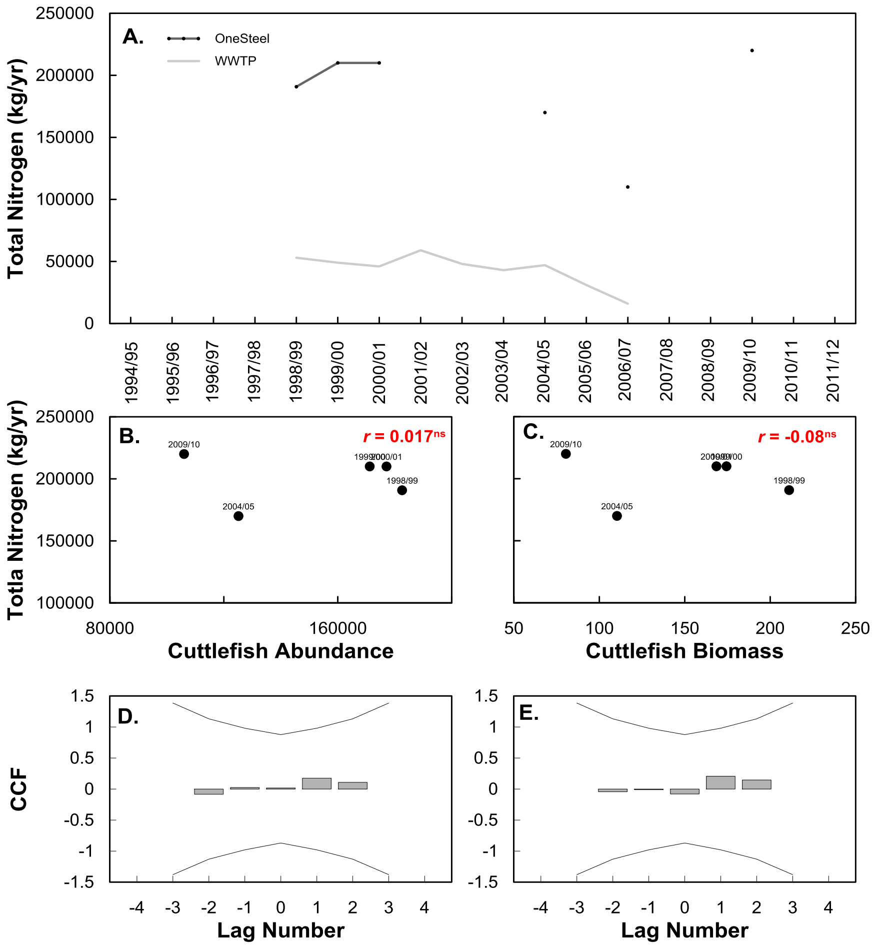

Figure 3.10. (A.) Annual reported nitrogen input from Whyalla waste-water treatment plant (WWTP) and OneSteel from 1998/99 until 2010/11. Correlation of total annual nitrogen input (WWTP and OneSteel combined) with cuttlefish abundance (B.) and biomass (C.). Cross-correlation functions of total annual nitrogen input with cuttlefish abundance (D.) and biomass (E.). Lines represent ± 2 standard error.

3.3.4.2. Metal Pollutants

The facility that discharges metals into coastal waters is the Whyalla Steelworks which in 2010/2011 discharged approximately 810 kg of zinc and 210 kg of manganese into the detention ponds and nearshore water (Figure 3.12). The other significant discharger of metals into coastal waters is the lead and zinc smelter at Port Pirie which in 2010/11 discharged 20,000 kg of zinc, 6,500 kg of manganese, 3,200 kg of lead, 350 kg of chromium, 320 kg of cadmium, 250 kg of copper, and 100 kg of nickel into First Creek near Port Pirie (NPI 2012). While these concentrations are significant reductions from historical discharges, which most of the published work on environmental impacts is based on, there still remains the potential for environmental impacts from these metals.

The majority of metals adsorb to the fine-size fraction of sediments and settle out in sheltered, low-energy depositional areas of the gulf, creating a sink of pollutants (Harbison 1984). An estimated 100 km^2 of sediment around Port Pirie is contaminated by lead, manganese and zinc, and a further 500 km^2 show elevated levels in metal concentration (Ward and Young 1982; Ward et al. 1986). Sediments throughout False Bay have also been shown to be contaminated with metals including lead, manganese and zinc (Harbison 1984). Uptake of metals by shellfish and other biota has also resulted in elevated metal levels often linked to proximity of discharge sources including the Port Pirie smelter and Whyalla steelworks (Ward et al. 1986; Corbin and Wade 2004; Gaylard et al. 2011). These findings are consistent with previous work which shows that the environmental impact of the metal discharges is confined to an area around the Port Pirie smelter (Ward and Young, 1982) and the Whyalla steelworks (Harbison 1984; Harbison and Wiltshire 1993). These studies suggest that the spawning area between False Bay and Fitzgerald Bay is unlikely to have been exposed to appreciable concentrations of metals.

A key factor that is lacking in any assessment of risks to the giant Australian cuttlefish is knowledge of causal links between a pollutant and a response in the cuttlefish. Literature reviews show that there is very little ecotoxicity information on the giant Australian cuttlefish. Cuttlefish are difficult to maintain under laboratory conditions resulting in expensive and potentially confounded test results.

Cephalopods (*Sepia officinalis*) can accumulate relatively high concentrations of cadmium, which can then be transferred to higher trophic levels (Bustamante et al. 1998; Bustamente et al, 2002). The primary route of exposure for the cuttlefish was through the dissolved fraction of the metal taken up through food and water, whilst uptake through exposure to contaminated sediments was very small (Bustamante et al. 2002). Cuttlefish (*Sepia officinalis*) have developed efficient detoxification mechanisms which means that cadmium does not greatly impact on the animal itself but has a high potential for transfer to higher trophic levels if the cuttlefish are predated upon (Bustamante et al. 2002). NPI records show that there are few discharges of cadmium into northern Spencer Gulf with the Port Pirie lead and zinc smelter being the only major source. According to the available data, there has been a steady decline in the discharge of cadmium into the nearshore waters at Port Pirie (Figure 3.11).

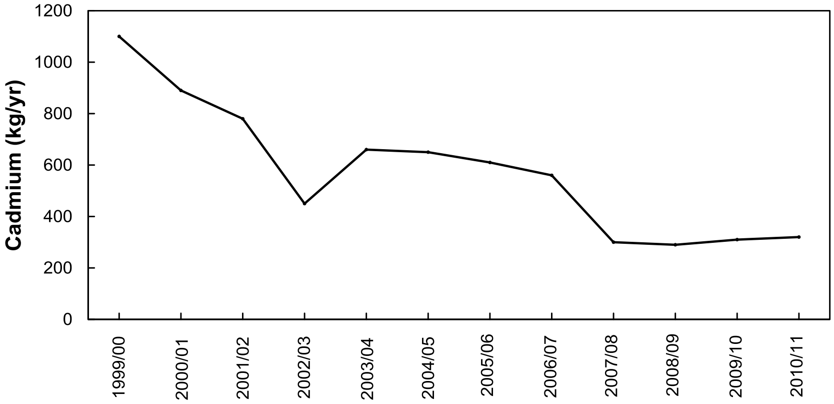

Figure 3.11. NPI recorded cadmium levels in Port Pirie (NPI 2012).

There were weak positive correlations between the cumulative load of lead, manganese and zinc discharged into northern Spencer Gulf to the decline in cuttlefish biomass in False Bay to Fitzgerald Bay area (Figure 3.12). Similarly, there was a weak positive correlation with zinc discharge loads and cuttlefish abundance. Discharges of heavy metals have declined over the past 13 years, however, the relative consequences of this decline on the cuttlefish population are unknown. There is little information on any other types of toxicants such as pesticides, herbicides, and pharmaceutical chemicals in northern Spencer Gulf. This makes it difficult to assess the likelihood of impact on cuttlefish from any trace amount of other toxicants.

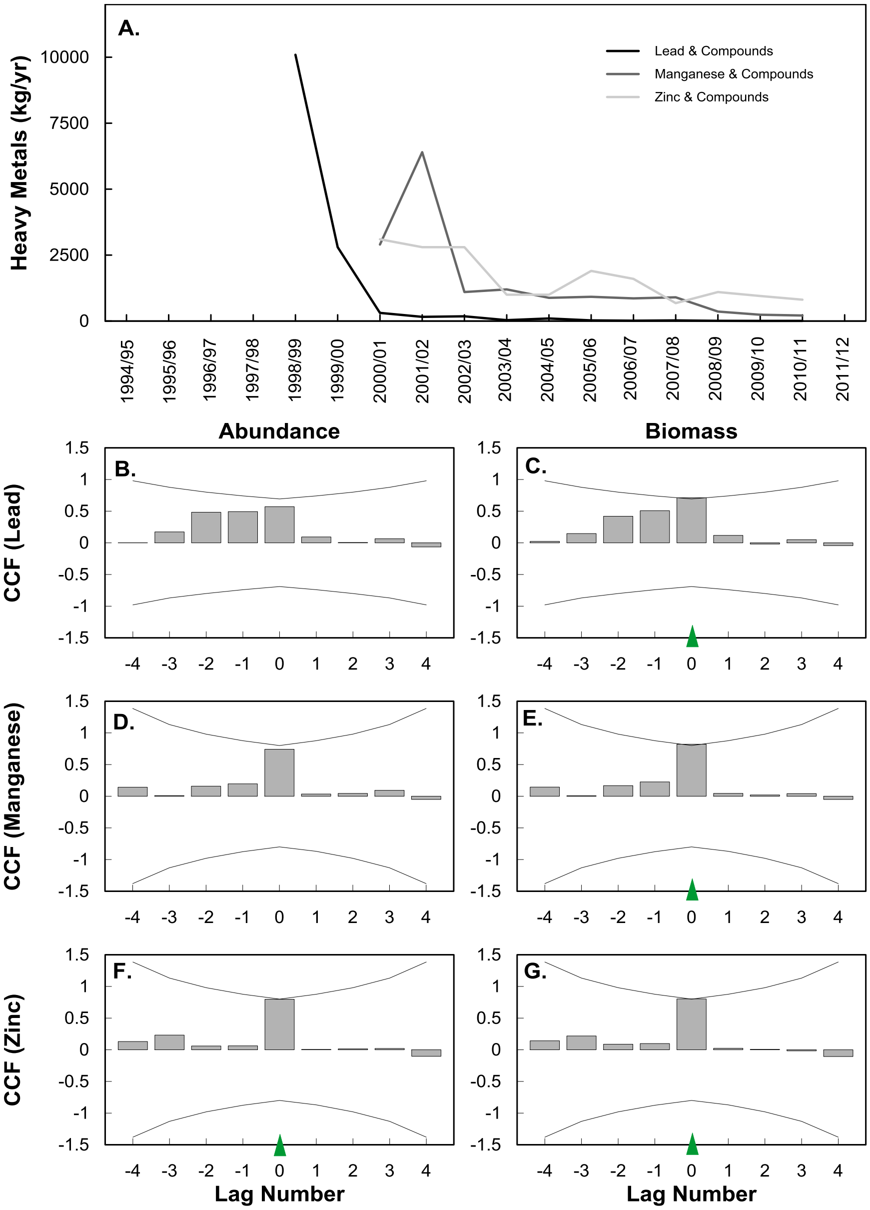

Figure 3.12. (A.) Annual reported cumulative heavy metal input from Whyalla waste-water treatment plant (WWTP) and OneSteel from 1998/99 until 2010/11. Cross-correlation functions of total lead input with cuttlefish abundance (B.) and biomass (C.). Cross-correlation functions of total manganese input with cuttlefish abundance (D.) and biomass (E.). Cross-correlation functions of total zinc input with cuttlefish abundance (F.) and biomass (G.). Green arrow indicates significant correlation. Lines represent ± 2 standard error.

3.3.4.3. Hydrocarbons

The Santos Ltd hydrocarbon processing facility is located adjacent to Point Lowly and was established in the early 1980s to export various petrochemicals. In 2009, Santos Ltd notified the EPA of hydrocarbon contamination at a number of locations under the Port Bonython hydrocarbon processing plant that were potentially intersecting with the intertidal environment. Under direction of the EPA, Santos installed a barrier wall to stop further hydrocarbon migration into the intertidal zone and monitoring programs were established to determine whether harm was occurring to the intertidal and subtidal environments, which specifically included the giant Australian cuttlefish.

Surveys between 2008 and 2011 indicated that there were significantly fewer cuttlefish but a significantly greater abundance of sea urchins directly adjacent to the Santos facility compared to locations further away. This result cannot be attributed to the presence of hydrocarbons or any other toxicant and is likely to reflect the difference in habitat structure, with less complex boulder reef adjacent the facility (SEA 2009, 2010 and 2011).

Investigative monitoring by the EPA has shown that while there have been isolated pockets of hydrocarbons observed within the intertidal zone, the areas directly adjacent to these pockets have populations of gastropods (including *Nerita atramentosa, Austrocochlea concamerata*), crustaceans (*Ozius truncatus*), fish and algae and at certain times have been observed to be reproducing or bearing eggs in the area (S. Gaylard pers. obs). *In-situ* samples of the hairy mussel (*Trichomya hirsuta*) from the intertidal zone, razorfish (*Pinna bicolor*) from the close subtidal zone and translocated blue mussel (*Mytilus galloprovincialis)* placed in the shallow subtidal adjacent the hydrocarbon pockets, showed no evidence for the presence of hydrocarbon residues.

3.3.5. Noise Pollution

Recent research has provided morphological and ultrastructural evidence of acoustic trauma in four cephalopod species (*Loligo vulgaris*, *Sepia offinalis*, *Octopus vulgaris*, *Illex coindetti*) that were subjected to low-frequency, controlled-exposure experiments (André et al. 2011). The trauma was manifested as permanent and substantial damage to the sensory hairs within the statocysts; the structures responsible for the animal's sense of balance and orientation. The low-frequency noise levels used in the experiment were considered to be analogous to 'marine noise' produced by shipping traffic, offshore industry, naval maneuvers and seismic surveys. The effect of these noise sources on cephalopods in natural conditions is yet to be ascertained, however, given their acoustic sensitivity it is possible that such organisms may actively avoid ‘noisy’ areas.

Northern Spencer Gulf contains a number of relatively large port facilities, two of which are in close proximity to the cuttlefish spawning grounds (i.e Whyalla and Port Bonython). Data on shipping traffic were obtained from Santos, which logged monthly vessel movement in and out of Port Bonython from January 1994 to October 2012. The port facility accommodates an average of 2.4 vessels per month, with each vessel remaining at berth for an average of 30.3 hrs. Annual vessel traffic peaked at 41 ships in 1995/96 and has remained relatively consistent (i.e. approximately 25-30 ships) over the past 16 years (Figure 3.13). Consequently, no statistical correlations with estimates of cuttlefish abundance and biomass were detected (Figure 3.13). The current level of shipping traffic and its relative proximity to the cuttlefish spawning grounds has not appeared to negatively impact the size of the cuttlefish aggregation. There are plans, however, to construct another jetty parallel to the existing one as part of a Bulk Commodities Export Facility in the future. This facility will significantly increase shipping traffic and loading activity within the area, and the extent to which this will affect the local cuttlefish population is unknown. Similarly, it is not known whether the current levels of shipping traffic and loading that occur further offshore from Whyalla interrupt potential movement and migration pathways of cuttlefish that enter and exit the Point Lowly spawning grounds.

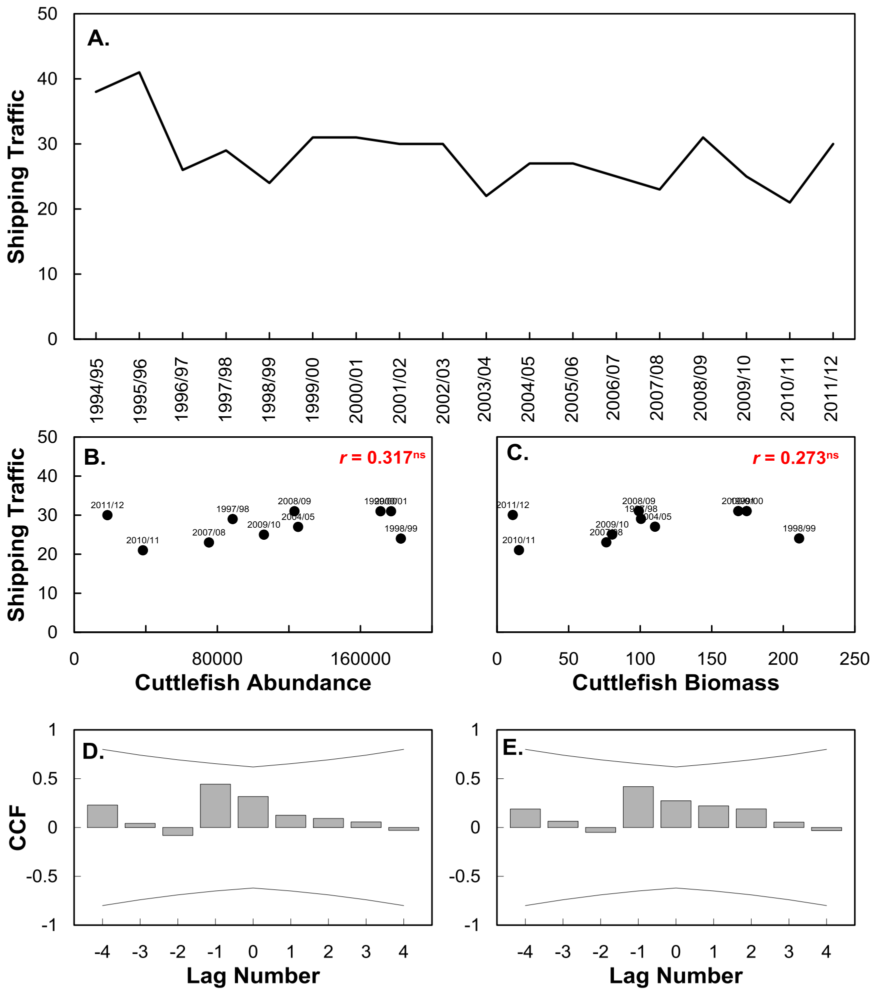

Figure 3.13. (A.) Annual shipping traffic at Port Bonython from 1994/95 until 2011/12. Correlation of annual shipping traffic with cuttlefish abundance (B.) and biomass (C.). Cross-correlation functions of annual shipping traffic with cuttlefish abundance (D.) and biomass (E.). Lines represent ± 2 standard error.

3.4. BIOTIC INFLUENCES

Biotic influences encompass all living things (i.e. plants or animals) that shape an ecosystem. Biotic factors also include human influences such as fishing and tourism.

3.4.1. Predators

Giant Australian cuttlefish are a food source for a variety of predators including dolphins, sharks, large fish, seals, and seabirds. It is likely that the large annual spawning aggregation of cuttlefish around Point Lowly would attract a variety of predators. Currently, predation rates are not known, however, local divers, scientists and fishers have directly observed common dolphins (*Delphinus delphis*), Indo-Pacific bottlenose dolphins (*Tursiops aduncus*), New Zealand fur seals (*Arctocephalus forsteri*), whaler sharks (*Carcharhinus* sp.), snapper (*Chrysophyrs auratus*), Western Australian salmon (*Arripis truttaceus*) and Yellowtail kingfish (*Seriola lalandi*) predating upon the cuttlefish aggregation.

3.4.1.1. Dolphins

Populations of Indo-Pacific bottlenose and common dolphins occur around Point Lowly (Gibbs 2010). Both species are known to predate upon giant Australian cuttlefish, with the Indo-Pacific bottlenose dolphin adapting specific local predatory behaviour for capturing cuttlefish (Finn et al. 2009). Two (<10 day) dolphin surveys were carried out around the Point Lowly and Fitzgerald Bay area in January and May 2010 as part of BHP Billiton's environmental impact assessment (Gibbs 2010). Multiple dolphins were repeatedly sighted over the course of the survey, indicating that they comprised a resident population. It was also observed that most of the dolphins scavenged dead fish from fishers and aquaculture sea-cages and had become attracted to small vessels. Anecdotal reports have since suggested that the resident population has increased in recent years. There are currently no estimates of local dolphin abundance.

3.4.1.2. New Zealand Fur Seals

New Zealand (NZ) fur seals have also been recently sighted in the area, leading to speculation about a possible contributing role in the decline of the cuttlefish population. These seals are generalist predators and cephalopods typically account for a considerable proportion of their natural diet (Harcourt et al. 2002). NZ fur seals are abundant in South Australia, representing approximately 84% of Australia's total NZ fur seal population (Goldsworthy et al. 2007). Most of the breeding colonies are found south of the gulfs, around Kangaroo, Neptune and Liguanea Islands, and they predominantly forage in near-colony and adjacent shelf/slope waters between south-east Kangaroo Island and south-west of Eyre Peninsula (Goldsworthy et al. 2007). Regular surveys carried out on Kangaroo and Neptune Islands from 1988 until 2006 have shown that the South Australian population has increased at a rate of approximately 6.8% per year (Goldsworthy et al. 2007). The potential increased frequency of NZ fur seal sightings in northern Spencer Gulf may reflect this population expansion, however, the relative abundance and foraging activity of these seals within the gulf is currently unknown.

The population estimates of NZ fur seals from Kangaroo Island were used as a proxy for relative abundance in northern Spencer Gulf as the data extends over the longest time period (i.e. 1995 – 2010) (Goldsworthy unpublished data). Although there has been a general increase in the NZ fur seal population it did not correlate with estimates of cuttlefish abundance and biomass at any temporal scale (Figure 3.14). Given that NZ fur seals have only recently been observed to haul-out in northern Spencer Gulf it is unlikely that they have had any historic influence on the cuttlefish population. Further work is planned to survey the relative abundance of fur seals within northern Spencer Gulf and determine their role in the local trophodynamics (FRDC Project 2013/010).

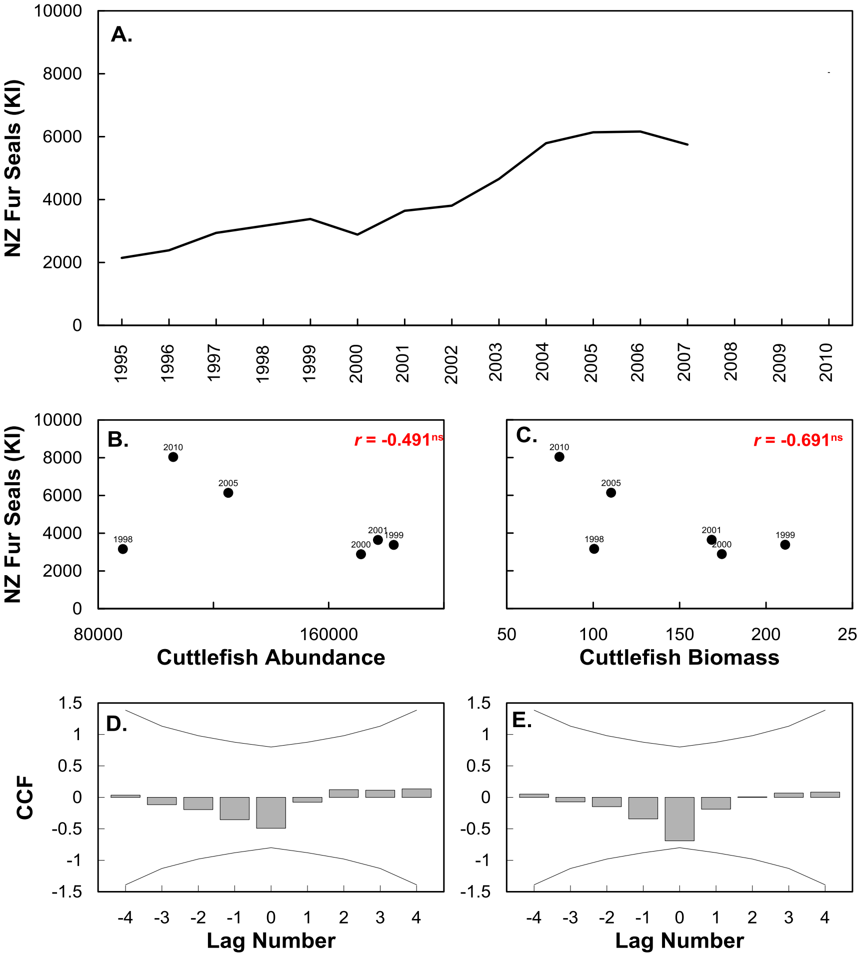

Figure 3.14. (A.) Estimates of annual New Zealand fur seal abundance on Kangaroo Island from 1995 until 2010. Correlation of annual NZ Fur Seal abundance with cuttlefish abundance (B.) and biomass (C.). Cross-correlation functions of annual NZ Fur Seal abundance with cuttlefish abundance (D.) and biomass (E.). Lines represent ± 2 standard error.

3.4.1.3. Snapper

Local commercial and recreational fishers have long suggested that the size of the cuttlefish aggregation is influenced by the abundance of snapper. Traditionally, snapper were targeted around Black Point, which is typically the area that has supported the largest densities of spawning cuttlefish (Hall 2012). Local fishers have suggested that the area was named ‘Black Point’ as a result of the ink expelled by cuttlefish as they were being heavily predated upon by large snapper. Commercial fishers are legislatively required to supply catch returns that report the details of their catch to SARDI on a monthly basis. Consequently, it is possible to explore detailed spatial and temporal trends in the commercial catch of snapper and any relationship with cuttlefish abundance. For this exercise, the commercial catch and effort statistics for snapper were obtained for northern Spencer Gulf (Figure 3.15) from July 1994 to June 2012. Catch and effort data are typically analyzed in the form of catch-per-unit-effort (CPUE) and is generally used as an index of fish abundance, where a proportionate change in CPUE is expected to reflect a corresponding change in abundance/biomass. This relationship, however, is not always reliable as trends in CPUE may be complicated by the underlying behaviour of the fishers, types of fishing gear used and fishing methods (Hilborn and Walters 1992). Snapper fishers typically target patchy aggregations of snapper throughout the gulf and, as a consequence, estimates of CPUE for these fishers tend to remain high despite a decline in snapper abundance (i.e. hyperstability). Total commercial snapper catch was, therefore, preferentially used as a proxy for snapper abundance in this section.

Despite a few moderate peaks in 2003/04 and 2010/11, the commercial catch of snapper in northern Spencer Gulf has generally decreased over the past 18 years, ranging from a peak of 128,267 kg in 1996/97 to 21,747 kg in 2005/06 (Figure 3.15). The most recent catch of 29,857 kg in 2011/12 was the second lowest over the past 18 years (Figure 3.15). The commercial catch of snapper did not correlate with estimates of cuttlefish abundance and biomass. There was also no evidence of any temporal correlation between the size of the cuttlefish and snapper populations in northern Spencer Gulf (Figure 3.15).

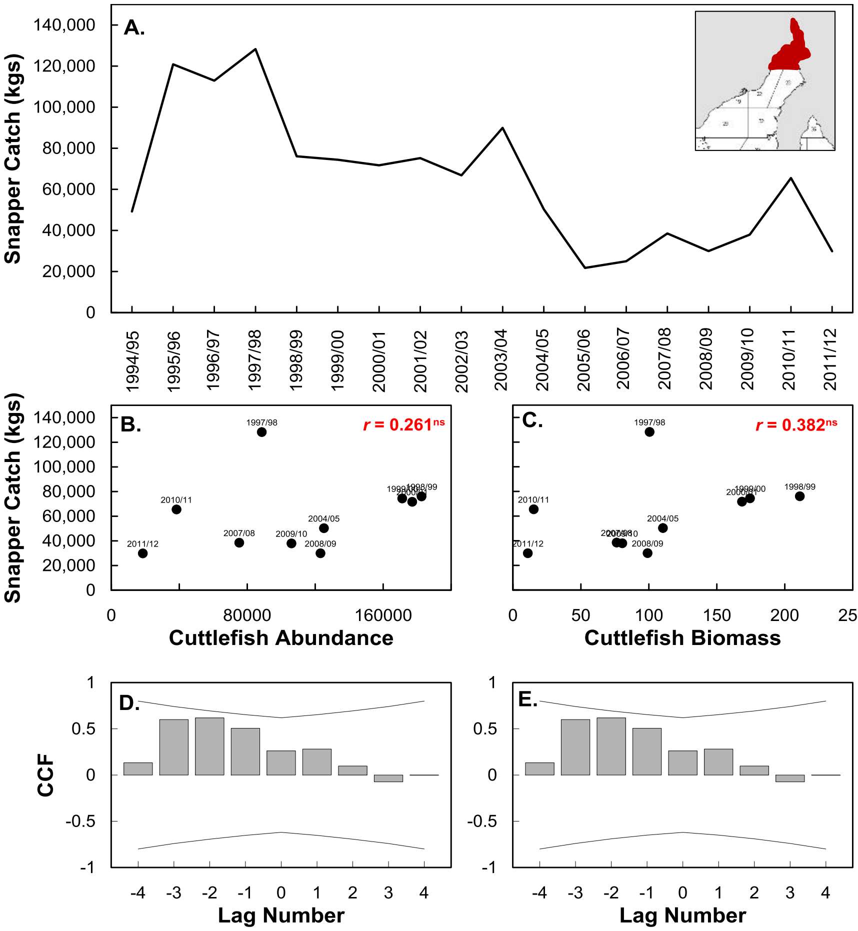

Figure 3.15. (A.) Estimates of annual commercial snapper catch in northern Spencer Gulf from 1994/95 until 2011/12. Spatial extent of data identified in the inserted map (in red). Correlation of commercial snapper catch with cuttlefish abundance (B.) and biomass (C.). Cross-correlation functions of commercial snapper catch with cuttlefish abundance (D.) and biomass (E.). Lines represent ± 2 standard error.

3.4.1.4. Australian Salmon

In 2005, the State Government implemented a series of netting closures along the south western and south eastern coasts of Spencer Gulf and also introduced a voluntary net buy-back scheme (Steer et al. 2009). These two initiatives were effective in removing a considerable amount of net fishing effort from Spencer Gulf including a number of fishers who had targeted Australian salmon. It has been speculated by some community members that the removal of the ‘salmon net fishing effort’ in the southern gulf has allowed the salmon population to increase and in turn increase their predation pressure on cuttlefish in the northern part of the gulf. Indeed, there was an immediate increase in abundance of Australian salmon after the implementation of the new management arrangements, with catch rates of the remaining fishers increasing from 48.0 kg.boatday^{-1} in 2005/06 to a peak of 111.3 kgs.boatday^{-1} in 2009/10 (Figure 3.16). This increase, however, was not sustained and decreased to 54.5 kg.boatday^{-1} in 2011/12 (Figure 3.16). Despite this recent increase in salmon abundance, there was no clear relationship with the decline in the cuttlefish population (Figure 3.16). Similarly, there was no indication that the salmon were effectively predating on the juvenile and sub-adult cuttlefish and thus compromising their recruitment onto the spawning grounds as no significant lags in the correlation analysis were detected (Figure 3.16).

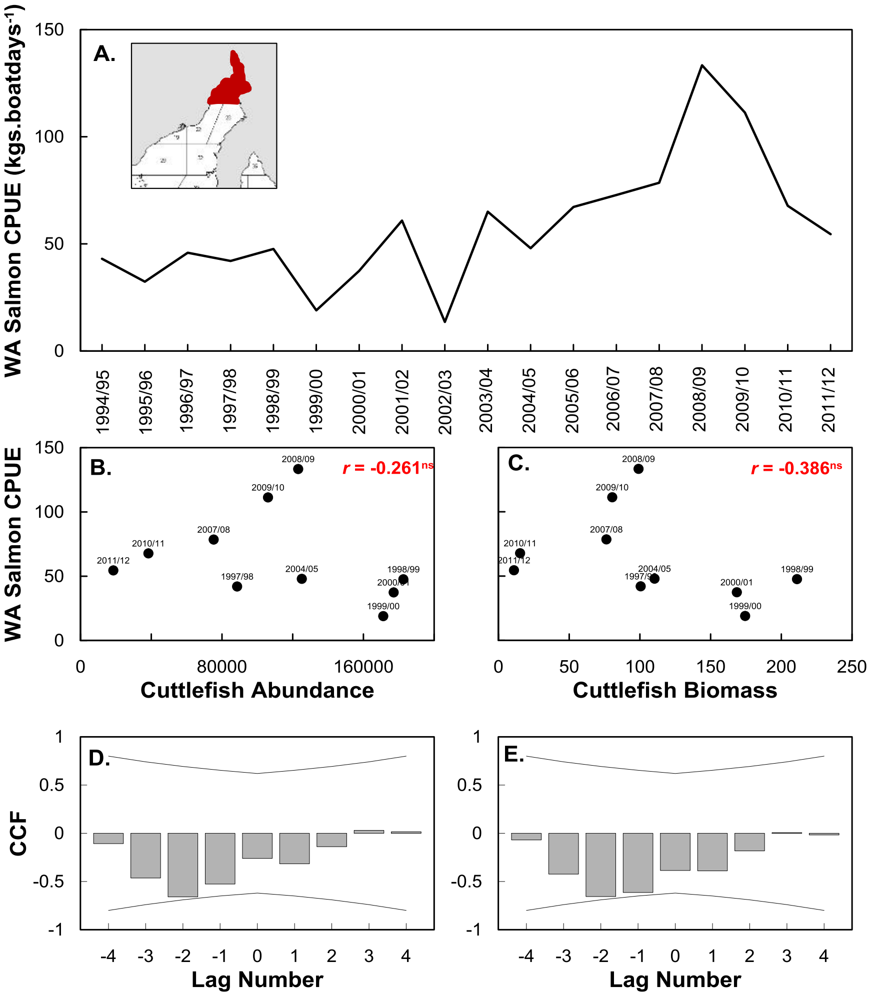

Figure 3.16. (A.) Estimates of annual commercial WA Salmon catch per unit effort (CPUE) in northern Spencer Gulf from 1994/95 until 2011/12. Spatial extent of data identified in the inserted map (in red). Correlation of commercial WA Salmon CPUE with cuttlefish abundance (B.) and biomass (C.). Cross-correlation functions of commercial WA Salmon CPUE with cuttlefish abundance (D.) and biomass (E.). Lines represent ± 2 standard error.

3.4.1.5. Yellowtail Kingfish

There are a number of aquaculture leases distributed throughout Spencer Gulf from Port Lincoln to Port Augusta that rear yellowtail kingfish in coastal sea-cages. Marketable 5 kg yellowtail kingfish are grown from small (approximately 5 g) fingerlings in these sea-cages over a two year period. These fish are maintained on a pellet diet that has been specifically developed to enhance growth and survival. Although sea-cages expose kingfish to pristine coastal waters there have been a number of escapement events of cultured fish into the natural environment (PIRSA). A number of these during the early 2000s alarmed the local community, who were concerned that escaped fish may negatively impact the natural ecosystem. Of particular concern, was the suggestion that escaped kingfish would effectively predate upon the juveniles of important commercial and recreational species of fish and invertebrates. These concerns, however, were dispelled in an extensive study which found that escaped kingfish were ineffective predators and were more likely to feed on items that resembled feed pellets (i.e. floating plant material) (Fowler et al. 2003).

Since 2001, aquaculture licensees have reported escapement events including the estimated number and biomass of fish lost. This information is publicly available on the PIRSA website (www.pir.sa.gov.au). A number of kingfish sea-cages are located in Fitzgerald Bay and have been in varying states of operation over the past ten years. These cages are in close proximity to the cuttlefish spawning grounds and escaped kingfish are still perceived as a potential ‘predation’ risk by the local community.

An examination of the kingfish escapee information with the cuttlefish abundance and biomass data revealed no clear relationship between the escape events and the declining cuttlefish population (Figure 3.17). It is not known, however, what effect the wild yellowtail kingfish population has on the cuttlefish aggregation as there are no available data.

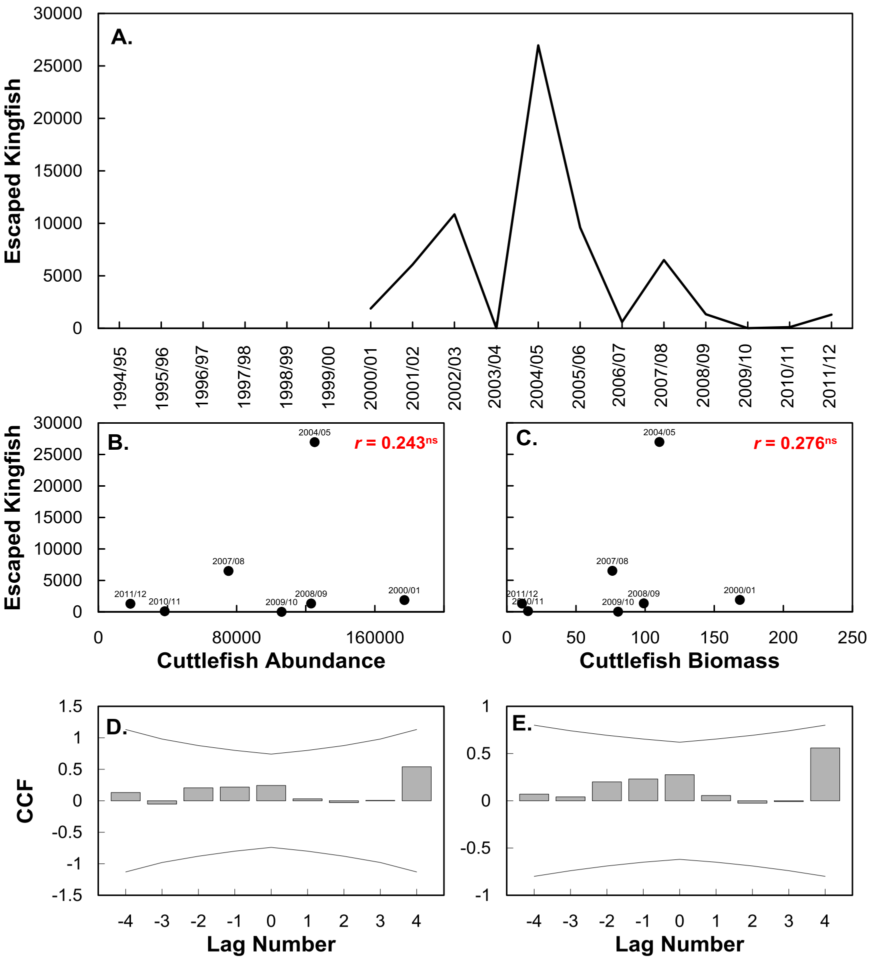

Figure 3.17. (A.) Estimates of annual estimates of escaped Kingfish from 2000/01 until 2011/12. Correlation of escaped Kingfish with cuttlefish abundance (B.) and biomass (C.). Cross-correlation functions of escaped Kingfish with cuttlefish abundance (D.) and biomass (E.). Lines represent ± 2 standard error.

3.4.2. Prey

All cephalopods are versatile opportunistic carnivores capable of capturing and consuming a wide variety of prey. Cuttlefish primarily feed on crustaceans, fish and other cephalopods, and it is common for juveniles to prey on crustaceans and then switch to fish and cephalopods as they grow larger (Castro and Guerra 1990). western king prawns (*Penaeus (Melicertus) latisulcatus*) and blue crabs (*Portunus armatus*) are likely to be common prey species of giant Australian cuttlefish as they are relatively abundant within northern Spencer Gulf. Since these two species support significant commercial fisheries, there is considerable data on catch and effort that can be interrogated to examine whether there are any patterns in relative prey abundance and the size of the cuttlefish spawning aggregation. For the purpose of this investigation these two prey species were considered proxies for identifying predator-prey relationships; however, it is acknowledged that the natural diet of cuttlefish is likely to consist of considerably more species.

3.4.2.1. Western King Prawns

Catch rates of western king prawns in northern Spencer Gulf peaked at 171.8 and 209.5 kg.hr^{-1} in 2001/02 and 2006/07, respectively, whilst in the intervening years catch rates were generally stable, averaging 100 kg.hr^{-1} (Figure 3.18). There were no clear relationships between prawn catch rates and estimates of cuttlefish abundance and biomass, regardless of the temporal comparisons (Figure 3.18). This suggests that the population fluctuations of these two species have been independent of each other.

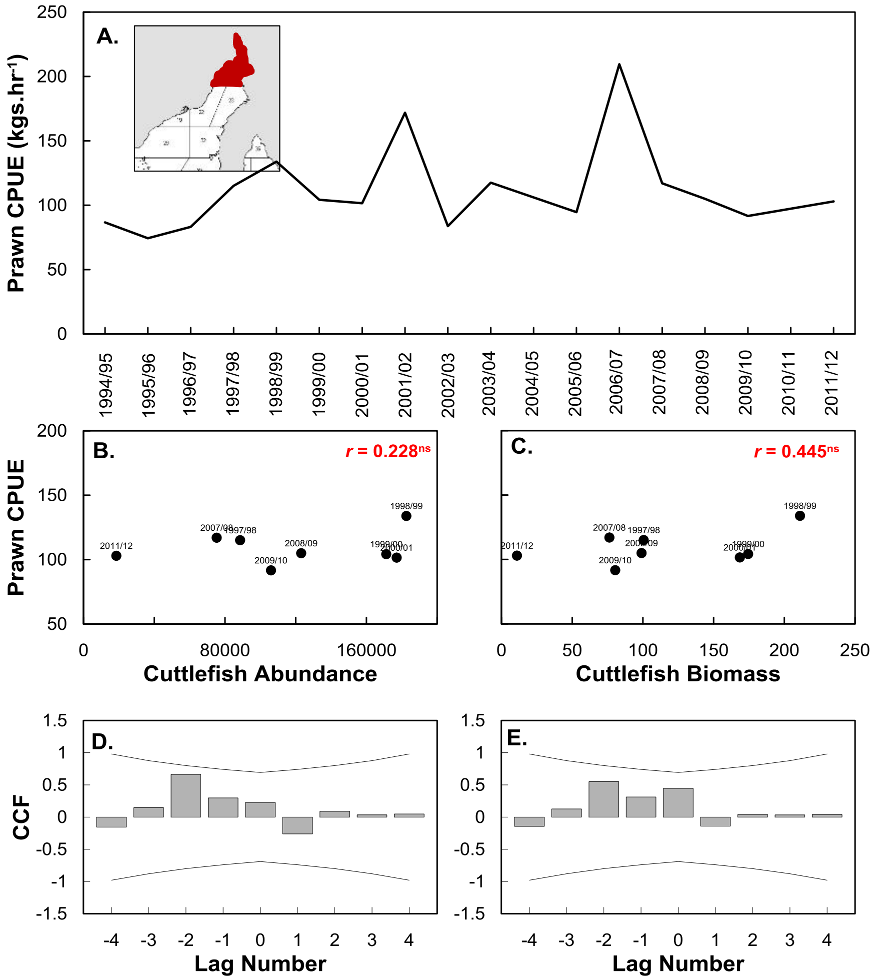

Figure 3.18. (A.) Estimates of annual estimates of commercial prawn catch per unit effort (CPUE) in northern Spencer Gulf from 1994/95 until 2011/12. Spatial extent of data identified in the inserted map (in red). Correlation of commercial prawn CPUE with cuttlefish abundance (B.) and biomass (C.). Cross-correlation functions of commercial prawn CPUE with cuttlefish abundance (D.) and biomass (E.). Lines represent ± 2 standard error.

3.4.2.1. Blue Crabs

Blue crab catch rates have displayed a consistent increasing trend over the past 16 years, rising from 301.3 kg.day^{-1} in 1996/97 to 614.0 kg.day^{-1} in 2011/2012 at an annual rate of approximately 21 kg.day^{-1} (Figure 3.19). This increase has been inversely proportional to the decline in cuttlefish abundance and biomass (Figure 3.19). This relationship was statistically significant both within a single year and lagged by one year (Figure 3.19), indicating that there may be a predator-prey relationship between these two species. In this case it appears that the abundance of blue crabs is mediated by cuttlefish predation pressure, and given cuttlefish numbers have declined in recent years, the blue crabs are experiencing higher rates of survival. Clearly, this is the most simplistic ‘preliminary’ explanation, as trophodynamics are considerably more complicated than this paired-species example. Further multi-species trophic modeling would be required to gain a more detailed understanding of the food-web complexities.

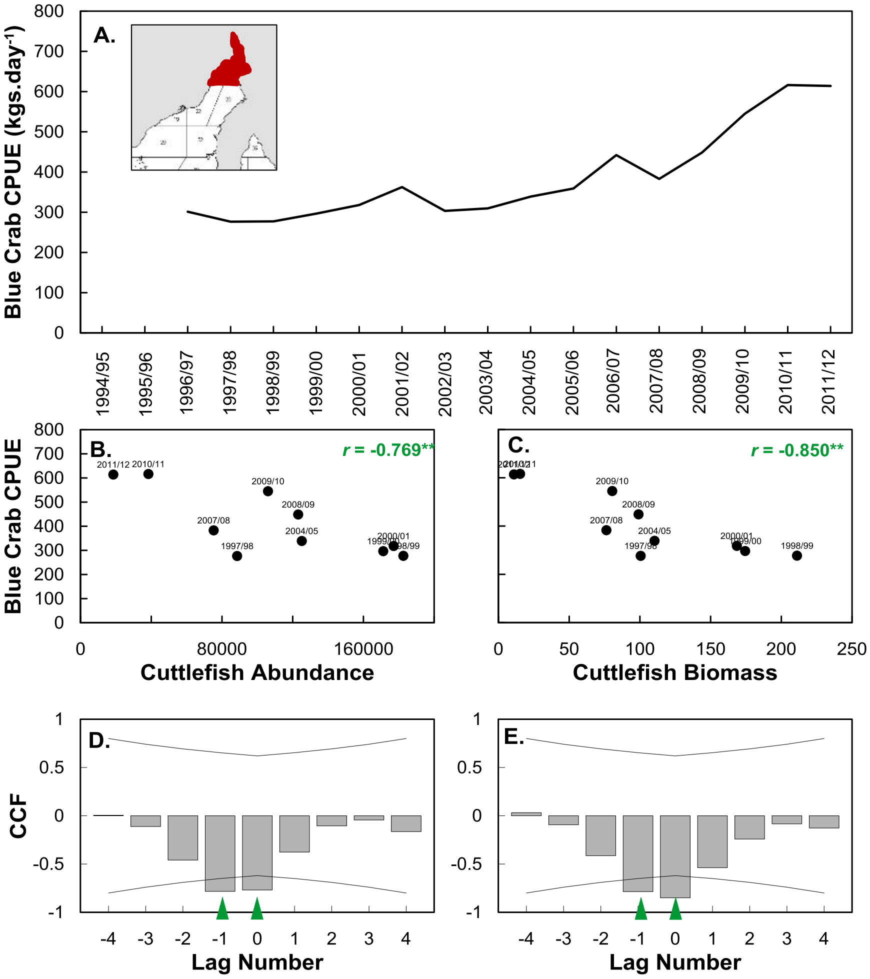

Figure 3.19. (A.) Estimates of annual estimates commercial Blue Crab catch per unit effort (CPUE) in northern Spencer Gulf from 1994/95 until 2011/12. Spatial extent of data identified in the inserted map (in red). Correlation of commercial Blue Crab CPUE with cuttlefish abundance (B.) and biomass (C.). Cross-correlation functions of commercial Blue Crab CPUE with cuttlefish abundance (D.) and biomass (E.). Green arrow indicates significant correlation. Lines represent ± 2 standard error.

3.4.3. Habitat

The sub-tidal rocky reef fringing from Black Point to Point Lowly is unique in northern Spencer Gulf and its heterogeneous structure along with its west to east aspect, are likely to be the underlying factors that attract high densities of spawning cuttlefish to the area. The plate-like fragmented slabs of bedrock that comprise the reef create numerous dens and crevices in which the female cuttlefish attach their eggs. These dens are vital for successful reproduction and recruitment as they provide both a stable structure for egg attachment over a long embryonic developmental period (up to four months) and a refuge for resultant hatchlings.

OneSteel Sea Wall

Artificial structures have also provided suitable substrates for cuttlefish to spawn, the most significant of which has been the OneSteel (formerly BHP Billiton) sea wall in Whyalla (Figure 2.1). This wall consists of boulderous rock armoring that runs parallel with the coastline to protect the Whyalla Steelworks' port facility and settlement ponds from the prevailing sea. Construction of this sea wall began in the early 1940s and has been altered numerous times over the years, with the most recent northern extension carried out from 1993 to 1996. Fortuitously, this sea wall has provided an ideal spawning substrate for cuttlefish and has supported various densities of spawning animals from 1998 to 2010. Since 2006, however, sections of the northern wall have been progressively filled with slag, which has compromised its capacity to support spawning cuttlefish. There has been some speculation that this process has had a negative effect on the overall spawning population, however, the southern section of the sea wall remains unaltered, and although cuttlefish have not been routinely surveyed on it, it is likely to provide an adequate spawning habitat. Although the overall spawning substrate along the sea wall has been reduced by back-filling, it can be expected that cuttlefish would still be able to find substrates upon which to attach their eggs, either on the southern section of the sea wall or on natural rocky reefs within northern Spencer Gulf.

Fast-Growing Macroalgae (*Hincksia sordida*)

Hincksia sordida, commonly known as "snot-weed", is a fast-growing, filamentous, macroalga capable of forming extensive 'opportunistic' blooms in shallow embayments throughout southern Australia (Figure 3.8). These blooms are a source of frustration for commercial and recreational fishers as the 'slimy' alga tends to smother baited hooks and adhere to fishing line. In July 2010, excessive amounts of *Hincksia* were observed on the reef at Point Lowly by local divers, fishers and environmental scientists. Although the seasonality and relative cover of this alga has not been quantitatively assessed, it was suggested by divers that it was particularly dense in 2010 and could have negatively affected both the spawning behaviour of the aggregating cuttlefish and subsequent embryonic development. It was suggested that the extensive growth of *Hincksia* prevented cuttlefish from securing their eggs to rocky surfaces, as most of the available substrate was covered in "slimy snot-weed". There were also reports of cuttlefish eggs becoming detached and free-floating in the water column (Tony Bramley pers. com). A habitat survey carried out by SARDI in late August 2010 did not detect excessive *Hincksia* around Point Lowly, and adjacent False and Fitzgerald Bays indicating that the bloom in the previous month was ephemeral (Steer unpublished data). Furthermore, numerous clutches of cuttlefish eggs were observed to be developing normally in the area (Steer per. obs.). Such transient growth is typical of *Hincksia* which is influenced more by nutrient availability than seasonal changes in temperature and light (Lavery and McComb 1991) and is therefore highly responsive to coastal eutrophication (Campbell 2001) (see section 3.3.5).

3.4.4. Disease and Parasites

There have been a number of potentially pathogenic organisms found to associate with cephalopods including; viruses, bacteria, fungi, and a host of parasites including nematodes, cestodes, monogeans, digeneans, acanthocephalans, polychaetes, hirudineans, and crustaceans (Hochberg 1983; Forsythe et al. 1991). Coastal cephalopods, like octops and cuttlefish, are considered to be more vulnerable to disease as they are more likely to be exposed to higher concentrations of contaminants from industrial and domestic run-off than species that inhabit oceanic waters (Pierce et al. 2010). Exposure to anthropogenic contaminants such as heavy metals, persistent organic pollutants (POPs) and excess nutrients, are known to increase the cephalopod’s susceptibility to disease or toxic accumulation. The release of large quantities of pollutants can cause immediate mortality, whereas lower level discharges can have a bio-accumulative effect potentially compromising an individual’s, or populations’, immunosuppression and reproductive success (Pierce et al. 2010).

Viruses and bacteria are prolific in the marine system, however, little is known about the vulnerability of giant Australian cuttlefish to such pathogens. Various studies have indicated that the ecological niche of a cephalopod species is more important than its phylogeny in determining the risk of infection (Gonzalez et al. 2003). The Point Lowly breeding aggregation is likely to be exposed to a variety of pollutants from coastal industries (see section 3.3.4) and further work is required to determine any ecotoxic effects. Similarly, the spawning population is in close proximity to commercial aquaculture facilities and in recent years there have been a number of issues raised regarding the health of yellowtail kingfish maintained in coastal sea-cages.

Yellowtail kingfish farming in South Australia experienced progressive and unusual mortalities between April 2011 and September/October 2012. While initial investigations ruled out notifiable and infectious disease, it became apparent that kingfish mortalities were most likely related to nutritional deficiencies. Investigations to rule out disease were conducted by independent veterinarians, researchers and PIRSA. A range of diagnostic tests were conducted, including histopathology, PCR, electron microscopy, cell culture and infectivity trials. The primary pathology contributing to mortalities was identified as chronic gut enteritis, with multiple associated (secondary) pathogens including coccidians, myxidia, cryptosporidia and mixed bacterial species, all of which are endemic to the area. These conditions were suggestive of poor immunocompetance. Epidemiological analyses ruled out a number of factors, with the resultant conclusion suggesting that nutritional deficiencies contributed largely to the mortalities.

3.4.5. Fishing

Marine Scalefish Fishery

A cephalopod fishing closure encompassing False Bay and most of Point Lowly (Figure 3.20) was implemented in 1998 as a precautionary measure to protect the spawning cuttlefish from over-exploitation. The timing and area of this closure has slightly altered over the years, extending from a seasonal to a full-time closure in 2004 and expanding to incorporate a small area east of Point Lowly in 2012. Although state-wide commercial catches of cuttlefish were significantly reduced as a result of this closure, there remains some low-level fishing activity for cuttlefish by the commercial and recreational sectors of the Marine Scalefish Fishery. With the exception of minor increases in 1999/00, 2006/07 and 2009/10, cuttlefish catch rates from the commercial sector have trended downwards over the past 14 years (Figure 3.20), declining from a peak of 253 kg.boatday^{-1} in 1997/98 to 77 kg.boatday^{-1} in 2010/11. Although the declining trend in the commercial catch rate of cuttlefish reflects the observed decline in population abundance and biomass, the two were not significantly correlated (Figure 3.20). This is most likely due to the fact that the catch of cuttlefish in northern Spencer Gulf by commercial marine scalefish fishers has been negligible (i.e. <10 t since 2003/04) since the implementation of the spatial closure. Contemporary commercial fishers target cuttlefish to use as snapper bait, and as there is no developed local market for cuttlefish, fishers generally self-regulate their catch to fulfill their bait requirements. Consequently, the current level of fishing activity from this commercial sector does not appear to be influencing the size of the cuttlefish spawning population.

Recreational fishers also catch cuttlefish and according to the latest statewide recreational survey these fishers landed a total of 1.5 t in 2007/08 (Jones 2009). This survey, which collected data from extensive telephone interviews and fisher diaries, has provided the only estimate of the recreational harvest of cuttlefish and as such it is not known what impact this sector has had on the northern Spencer Gulf cuttlefish population on an annual basis. Given that recreational fishers are also prohibited from fishing within the False Bay/Point Lowly closed area, and the most recent estimate of 1.5 t represents 36.5% of the local commercial catch in 2007/08, their overall impact is likely to be negligible.

The full extent of illegal fishing activity within the closed area is unknown. There have been reports of fishers targeting cuttlefish within the closure during the peak spawning period and since the implementation of the closure there have been four expiation notices issued by fisheries compliance officers. The last expiation notice was issued in June 2010 (PIRSA). Given the closed area is well defined by clear landmarks and the area can be easily surveyed from the shore by fisheries officers, concerned fishers and the local community, it is unlikely that illegal fishing has played a major role in shaping the Point Lowly cuttlefish population.

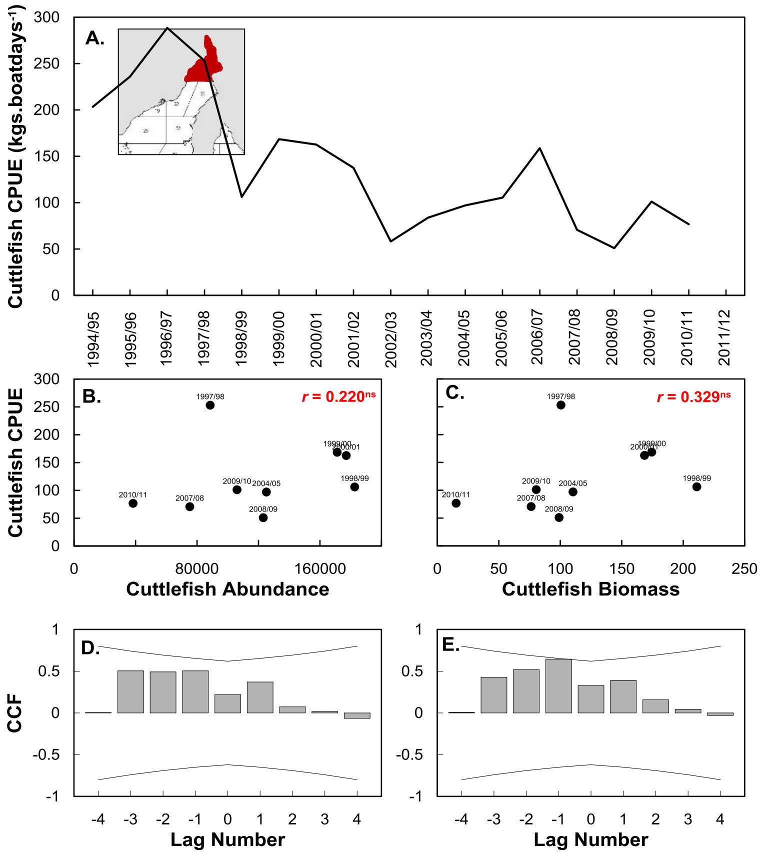

Figure 3.20. (A.) Estimates of annual estimates commercial cuttlefish catch per unit effort (CPUE) in northern Spencer Gulf from 1994/95 until 2011/12. Spatial extent of data identified in the inserted map (in red). Correlation of commercial cuttlefish CPUE with cuttlefish abundance (B.) and biomass (C.). Cross-correlation functions of commercial cuttlefish CPUE with cuttlefish abundance (D.) and biomass (E.). Green arrow indicates significant correlation. Lines represent ± 2 standard error.

Spencer Gulf Prawn Fishery

South Australia's prawn trawlers incidentally capture giant and nova cuttlefish when targeting western king prawns and discard them as by-catch. An extensive by-catch survey carried out by SARDI to assess the risk of potentially vulnerable species to trawling in Spencer Gulf indicated that the average catch of giant Australian cuttlefish by trawlers was 205.3 $g.ha^{-1}$ in weight and 0.5 ha^{-1} in number (Currie et al. 2009). This survey was undertaken in mid-February 2007 and the majority of the cuttlefish were incidentally trawled from mid-northern and northern parts of the gulf (Currie et al. 2009). Commercial prawn fishers are not required to record quantities of by-catch and as a consequence there are no data available on cuttlefish catch rates in this fishery. They are, however, legislatively required to log the details of each trawl shot including their start/finish times, area fished, depth, and estimated prawn catch. From this information it is possible to calculate spatial and temporal trends in fishing effort, a metric which can be used as a proxy for determining the relative effects of trawling on the giant Australian cuttlefish population. This investigative analysis only considered trawling activity that occurred north of Wallaroo (Fishing Blocks 1 to 20, inclusive (Figure 3.21)) as this area was considered most likely to have the greatest influence on the Point Lowly cuttlefish aggregation.

Trawl effort in northern Spencer Gulf peaked at 4,631 hrs in 1996/97 and subsequently declined to <1,000 hrs in 1998/99, a level that has been rarely exceeded over the past 12 years (Figure 3.21). Trawling activity did not correlate with the declining cuttlefish catch on an annual basis, however a significant positive correlation was detected between trawl effort and the strength of the cuttlefish population in the subsequent year (Figure 3.21). This relationship appears counter-intuitive as it suggests that an increase in trawl intensity in one year enhances cuttlefish abundance and biomass in the subsequent year. It is likely that this result is coincidental.

SARDI, in consultation with the Spencer Gulf Prawn Fishery, has recently integrated a cuttlefish by-catch monitoring program into its regular stock assessment surveys.

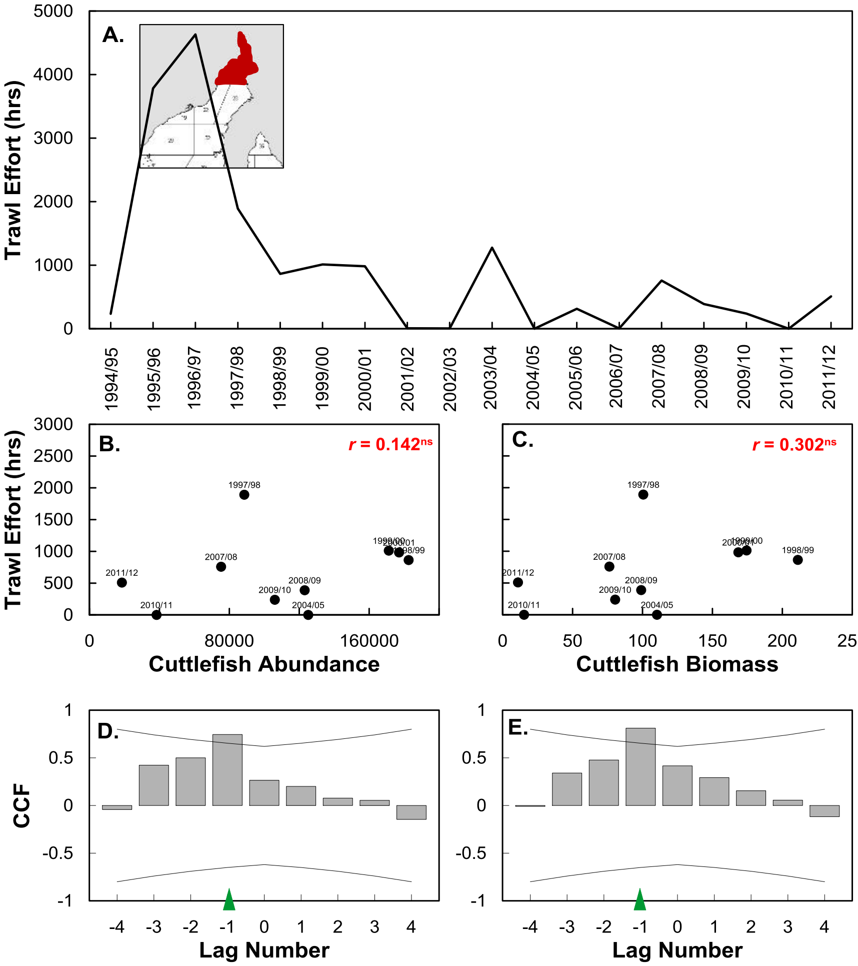

Figure 3.21. (A.) Estimates of annual estimates commercial prawn trawl effort in northern Spencer Gulf from 1994/95 until 2011/12. Spatial extent of data identified in the inserted map (in red). Correlation of commercial prawn trawl effort with cuttlefish abundance (B.) and biomass (C.). Cross-correlation functions of commercial prawn trawl effort with cuttlefish abundance (D.) and biomass (E.). Green arrow indicates significant correlation. Lines represent ± 2 standard error.

3.4.6. Tourism

The cuttlefish spawning aggregation in northern Spencer has attained iconic status over the past decade, and has been labeled “the premier marine attraction on the planet” by international cephalopod expert Professor Roger Hanlon (Woods Hole Oceanographic Institute, Massachusetts) and the “Cuttlefish Capital of the World” by the general public. Consequently, it has attracted large numbers of tourists, scientists and documentary film makers to the region to observe the spectacle. The spawning aggregation is easily accessed from the shore which means that tourists do not need to rely on a vessel or sophisticated dive equipment to observe the cuttlefish, as most of the spawning behaviour occurs in depths < 2 m and can be simply viewed with a mask and snorkel. This accessibility has contributed to the popularity of the spawning aggregation as a tourist attraction. High tourist traffic and diving activity have been suggested by some community members as having a negative effect on the spawning population, based on the assumption that the cuttlefish are 'spooked' by divers and either leave the area or do not successfully reproduce. The true observer effect is currently unknown; although there is very little change in their natural behaviour when they are surveyed and measured *in situ* by marine scientists, or filmed by documentary makers..

3.4.7. Other Cephalopods

The southern calamary (*Sepioteuthis australis*) co-exists with the giant Australian cuttlefish and has been observed to spawn on seagrass patches along the Point Lowly coast throughout the year (Steer pers. comm.). Calamary share a similar life-history to the giant Australian cuttlefish, so it would be expected that if there were any cephalopod-specific factors responsible for the decline in cuttlefish abundance then they would also affect the calamary population. Calamary are also commercially targeted by commercial and recreational fishers, and although the cephalopod closure prohibits their capture within the Point Lowly area, they are commercially harvested in open-access areas throughout northern Spencer Gulf (i.e. MFAs 11 and 21).

Commercial catches of calamary in northern Spencer Gulf have increased from 7.7 to 18.6 kg.fisherday^{-1} over the last ten years (Figure 3.22). This increase is inversely proportional to the rate of the cuttlefish decline. A similar relationship was also evident when the abundance and biomass of cuttlefish were compared with the previous year's catch rates for calamary (Figure 3.22). This suggests that there are no clear cephalopod-specific factors contributing to the observed decline as the estimates of calamary abundance did not display the same declining trend (Figure 3.22). Although the fine-scale patterns of distribution and abundance of calamary along the Point Lowly coast are unknown, it is likely that competition for space and resources between the two species is an influencing factor. The decline of the cuttlefish population may have provided an opportunity for calamary to occupy the area with reduced competitive interaction. Similar interactions between cephalopods and fish have been observed, particularly for squid where their short generation times and high fecundity allow them to opportunistically 'fill the gaps' within the ecosystem (Zeidberg and Robison 2007).

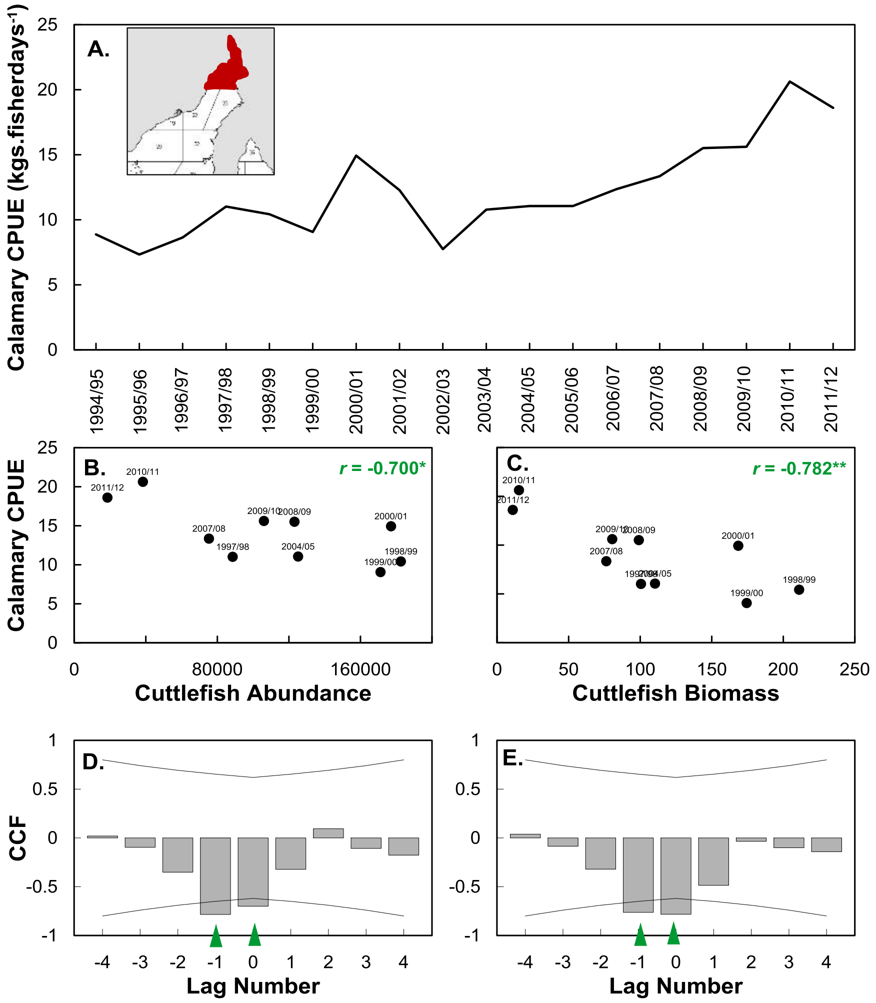

Figure 3.22. (A.) Estimates of annual estimates commercial calamary catch per unit effort (CPUE) in northern Spencer Gulf from 1994/95 until 2011/12. Spatial extent of data identified in the inserted map (in red). Correlation of commercial calamary CPUE with cuttlefish abundance (B.) and biomass (C.). Cross-correlation functions of commercial calamary CPUE with cuttlefish abundance (D.) and biomass (E.). Green arrow indicates significant correlation. Lines represent ± 2 standard error.

3.5. POPULATION DYNAMICS

The continuous rocky reef that fringes Point Lowly is considered to be the only area capable of supporting high densities of spawning cuttlefish in northern Spencer Gulf as the remaining coastline is largely dominated by mangroves, tidal flats and saltmarshes (Figure 3.23). However, the possibilities of the cuttlefish aggregating to spawn elsewhere, or widely distributing their spawning activity within Spencer Gulf, need to be considered as an alternate hypothesis in explaining the decline of the Point Lowly population.

Currently little is known about the movement and migration of cuttlefish on and off the Point Lowly spawning grounds. It is not known where the spawning adults come from and where the resultant hatchlings go. The area is devoid of adult cuttlefish outside of the spawning period and hatchlings are elusive during their early life-history as they adopt a cryptic holobenthic lifestyle. Recent molecular research has indicated that the cuttlefish that inhabit northern Spencer Gulf comprise a genetically discrete population that exhibits little, if any, inter-mixing with cuttlefish south of Wallaroo (Gillanders et al. unpublished data). So, if there is any extensive movement it appears to be confined within northern Spencer Gulf (Figure 3.23). Although the fragmented bedrock that fringes Point Lowly provides an optimal substrate for egg attachment and it is an area that is exposed to high current flow which would benefit embryonic development and hatching success, the underlying mechanism that attracts vast numbers of cuttlefish to this relatively small area is not understood.

The accumulation of cuttlefish on such a discrete stretch of reef may be a function of either direct or passive migration. Tagging studies of the common European cuttlefish (*Sepia officnalis*) in the English Channel have provided evidence of natal homing, where a high proportion of individuals returned to their place of origin to spawn (Boucaud-Camou and Boismery 1991). Similar inferences have also been made for the Californian market squid (*Doryteuthis* (*Loligo*) *opalescens*) through statolith trace element analysis (Warner et al. 2009). It is possible that individual *S. apama* exhibit a comparable innate capacity to migrate back to their natal origin. If this is the case, the large seasonal aggregations of spawning cuttlefish around Point Lowly would inherently identify the area as the most productive in northern Spencer Gulf. Alternatively, upon maturation, cuttlefish either embark on a set migratory pathway or move indiscriminately until they encounter appropriate spawning habitat. The west to east projection of Point Lowly into Spencer Gulf may simply intercept most of the migrating cuttlefish within the area, whereas adjacent, smaller, rocky reefs such as the OneSteel Wall, Fitzgerald Bay and Backy Point incidentally accommodate the ‘off target’ spawners.

In recent years, several coastal residents and local fishers have reported large quantities of cuttlefish turning up in areas where they were not expected, however, it is not known whether these animals were actively spawning. Douglas Point and Two Hummock Point, which are located approximately 20 km north of Backy Point, are two areas where locals have observed high numbers of cuttlefish in 2011 and 2012 (Figure 3.23). Similarly, commercial and recreational fishers have reported increased catches of cuttlefish around

Port Augusta during the last winter spawning season. Point Riley (approximately 6 km north of Wallaroo) has also been reported to support commercial quantities of cuttlefish in the past. Given these anecdotal reports it can be speculated that there are other areas within northern Spencer Gulf that can successfully accommodate smaller pockets of spawning cuttlefish, similar to those observed in Backy Point and Fitzgerald Bay, and more typical of *S. apama* that occurs outside of northern Spencer Gulf (Rowlings 1994) and other cuttlefish species worldwide (Hanlon and Messenger 1996).

So far the research on the aggregation around Point Lowly has overshadowed any attempt to explore and document other 'less productive' spawning areas within northern Spencer Gulf to determine their relative contribution to the overall population. If cuttlefish have a strong propensity to return to their natal area to spawn then it is possible that other spawning areas have become more productive over the past few years and have accounted for a greater proportion of the spawning population, resulting in a more diffuse spawning pattern and reducing the dominance of the Point Lowly aggregation. If movement and migration patterns are more passive, then unknown changes in the local hydrodynamics or proximate cues may have directed cuttlefish away from Point Lowly to spawn elsewhere.

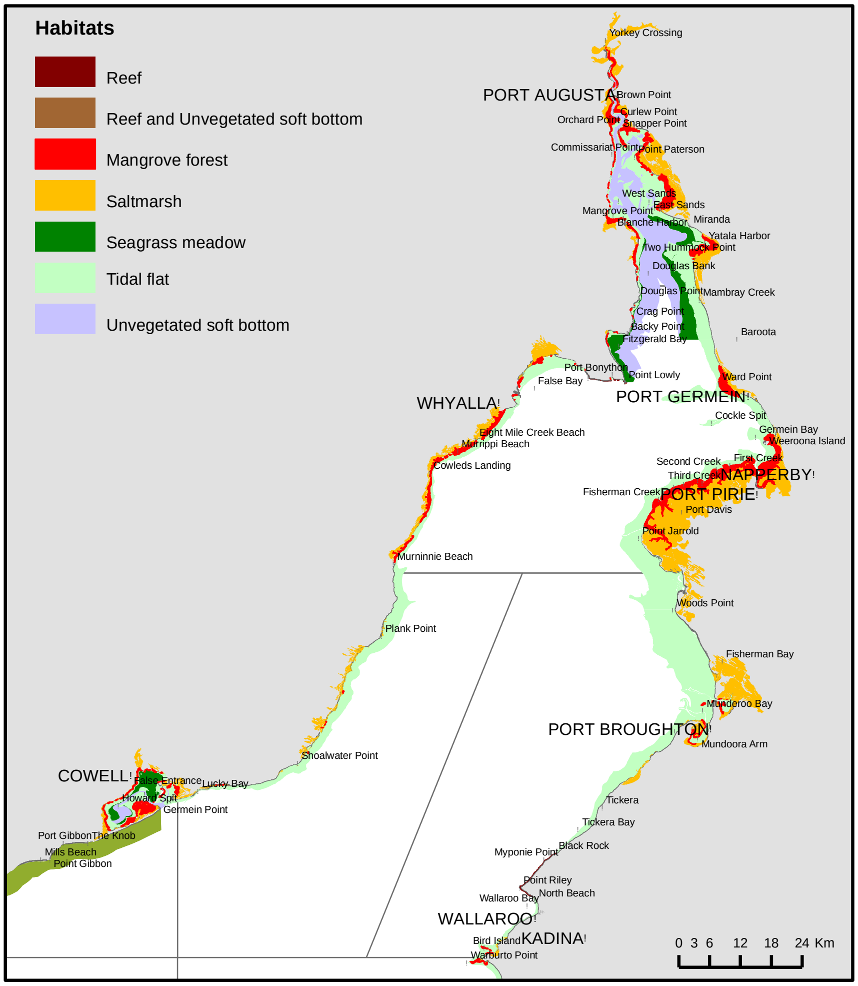

Figure 3.23. Coastal habitat map of northern Spencer Gulf (source data: Bryars 2003).

3.6. DISCUSSION

Despite a broad screening of the potential ‘causative’ factors, the underlying mechanism driving the recent reduction in the iconic cuttlefish population is unknown. There are insufficient long-term observations of cuttlefish around the breeding site to definitively rule out that the rapid population ‘explosion’ observed in the late 1990s was an extraordinary natural phenomenon. Relying on a lack of historical evidence, however, does not inspire confidence in this hypothesis and highlights the importance of maintaining an on-going standardised monitoring program to determine the extent of the natural variation in the spawning population. The lack of understanding relating to the ontogenetic movement and migration of cuttlefish on and off the spawning ground also limits our attempts to reconcile the observed trends in the spawning population.

Of the investigated abiotic influences rainfall was the only factor found to inversely correlate with peak cuttlefish abundance and biomass. Periods of increased rainfall during late summer and autumn appeared to decrease the size of the cuttlefish spawning population and vice versa. High rainfall may alter coastal salinity, increase pollution through terrestrial run-off, promote ‘opportunistic’ algal blooms or directly influence water clarity, all of which may deter cuttlefish from aggregating in the coastal environment. The ambient salinity of northern Spencer Gulf, however, is relatively high, typically maintaining levels above 40 ppt throughout the year (Nunes Vaz and Lennon 1986). Although, cuttlefish inhabiting northern Spencer Gulf are clearly physiologically adapted to high salinities, it is not known how tolerant they are to episodic fluctuations (Dupavillion and Gillanders 2009). Furthermore, the magnitude of the changes in salinity and the flow-on ecosystem effects as a result of heavy localized downpours are not, currently, understood. Investigative analysis of the influence of coastal pollutants around the Point Lowly area on the spawning aggregation yielded in-conclusive results, as weak positive relationships were identified between cuttlefish biomass and annual concentrations of metal pollutants (i.e. lead, zinc and manganese). There is also little information on any other toxicants (e.g. pesticide, herbicide, pharmaceutical chemicals etc.) in northern Spencer Gulf and, as such, it is difficult to assess the likelihood of impact on cuttlefish from any trace amount of other toxicants.

Predator-prey relationships effectively shape ecological communities. In simple systems, the predator-prey relationship results in coupled population oscillations (Begon et al. 1996). As prey numbers increase, predator numbers increase to a point where predation causes population decline in the prey item. In this investigation cuttlefish abundance and biomass did not appear to relate to estimates of abundance of a range of known predators. It is important to note, however, that trophic interactions are far more complex than specific isolated paired examples, but rather form part of multispecies systems, that are affected by environmental conditions. The interactive effects of the local dolphin and, more recent New Zealand fur seal populations, are unknown but may have a concomitant influence in regulating cuttlefish numbers, or shaping the community structure via other trophic pathways. Such cascading complexities are emphasised by the corresponding trends in blue crab and calamary abundance in the area, which could be indicative of shifts in the community structure as a result of either predator-prey or competitive interactions. There are numerous examples of higher predators targeting seasonal aggregations of spawning cephalopods around the world (Fields 1965; Smale et al. 1995; Bjorke 2001), so it is likely that the large annual spawning aggregation of cuttlefish around Point Lowly would also attract a variety of ‘opportunistic’ predators. A series of trophodynamic modeling projects are currently either planned (Goldsworthy pers. comm) or underway (Gillanders et al. FRDC Project 2011/205) to synthesise complex food web relationships within Spencer Gulf, which can be subsequently used to examine and assess potential cuttlefish predator/prey vulnerabilities.

4. GENERAL DISCUSSION

This study successfully refined the existing methodology that has been used to estimate the abundance and biomass of spawning cuttlefish around Point Lowly in the past (see Hall and Fowler 2003) to a level where multiple-agencies can undertake a more simplistic ‘standard’ approach in future population assessments. Maintaining an on-going monitoring program that provides robust and comparable estimates of cuttlefish abundance and biomass along with an assessment of the spawning habitat and water quality is an integral component of any associated research and resource management. These surveys will essentially provide the foundation on which other projects can build upon and also are critical to inform the greater community about the relative status of the population. Through the establishment of a transparent, refined methodology there is the potential to directly engage the community in the collection of the survey data. This will ensure that the community is kept up-to-date and informed about the trends in the cuttlefish population through time and about associated research. Furthermore, this process will also provide a vehicle by which the community can be more actively engaged in education and conservation programs specific to the giant Australian cuttlefish.

The complex and interactive nature of the marine environment and ecosystem processes made it difficult to identify a simple explanation for the observed decline in cuttlefish abundance. Of the investigated abiotic influences rainfall was the only factor found to inversely correlate with peak cuttlefish abundance and biomass. However, it was unknown whether the underlying dynamic related to changes in coastal salinity, localised pollution through terrestrial run-off, or a direct influence on water clarity, all of which may deter aggregating cuttlefish from the coastal environment. No clear association was made between the decline in the cuttlefish population and the investigated biotic influences such as predator and prey abundance, habitat condition and fishing intensity. One hypothesis, so far, relates to a lack of historical evidence of the large Point Lowly spawning aggregation pre-1986, suggesting that the observed peak in the late 1990s may have been a population ‘explosion’ and the current declining trend is part of a natural process. Indentifying a specific cause of the decline was made more difficult by the limited extent of our current knowledge regarding the population dynamics and proximate cues of the spawning cuttlefish in northern Spencer Gulf.

4.1. BENEFITS AND ADOPTION

This report has provided a ‘standard’ methodology that can be used in the on-going monitoring and assessment of the unique cuttlefish population and the environment in which they aggregate to spawn.

4.2. FURTHER DEVELOPMENT

The first-cut approach taken in this study, however, has identified some avenues of research that warrant further consideration that are likely to lead to a more robust understanding of the underlying factors that shape the spawning aggregation. The main area of interest relates to determining the relative contribution of the Point Lowly spawning aggregation to the greater northern Spencer Gulf population. The ontogenetic movement of cuttlefish on and off the main spawning ground and potential relationships with other smaller, diffuse, spawning pockets throughout northern Spencer Gulf is of key interest. Deciphering this relationship will also determine the relative conservation significance/value of the Point Lowly area and whether other areas within the gulf may need additional consideration. This objective currently constitutes a component of an FRDC funded study that is likely to begin in autumn 2013 (Gillanders et al. FRDC 2013/010). The development of an integrated model that assesses and evaluates the response of the northern Spencer Gulf cuttlefish population to environmental and anthropogenic factors is another key objective of the proposed project, which will extend directly from the findings of this report. The analytical approach, however, will be more sophisticated than the simple correlation analysis carried out in this ‘first cut’ investigation and will have the capacity to consider multiple interactive factors to investigate the viability (or extinction risk) of the population. Parallel projects are also underway to investigate the trophodynamics of key species of commercial and conservation significance in Spencer Gulf (i.e. Gillanders et al. FRDC Project 2011/205, Goldsworthy et al. FRDC 2013/011) and will be able to help ascertain the role the northern Spencer Gulf cuttlefish play in the gulf-wide food web. Given the recent sightings of New Zealand fur seals and the apparent increase in dolphin numbers in the northern Spencer Gulf, this is an area of research that has also been prioritised (Goldsworthy pers. comm.).

4.3. PLANNED OUTCOMES

The main planned outcome of this project was to develop a standardised methodology that can be used in the on-going monitoring and assessment of the unique cuttlefish population and the environment in which they aggregate to spawn. This was successfully achieved and a detailed manual has been provided in Appendix 3 of this report. This methodology will form the basis of all on-going cuttlefish surveys and can be easily adhered to by multiple agencies/organisations to ensure that the data collected remains comparable through time. This report will be made publically available on the SARDI Aquatic Sciences website (www.sardi.sa.gov.au/fisheries).

Given the sensitivities of this project and the need to ensure that any inferences made were well considered and justified, the communication of the results to the general public relating to the identification of a cause of the cuttlefish decline was delayed until this report was peer-reviewed. Upon release it is anticipated that the South Australian Government Working Group will co-ordinate a series of media releases to ensure the main findings of this research are widely disseminated. This group will also ensure that the relevant ministers are provided with up-to-date advice to ensure the delivery of the most appropriate cuttlefish management strategy.

This project considered an extensive range of potential factors (i.e. environmental irregularities, increased predation pressure, industrial pollution, fishing pressure) and undertook a preliminary evaluation to assess their relative likelihood in contributing to the cuttlefish decline. This exercise relied on simple statistical analyses and can be considered a ‘first cut’ approach that identifies those factors that require more rigorous investigation. This approach provides a foundation in which further research (i.e., Gillanders et al. FRDC 2013/010) can build on as it aims to incorporate the identified factors into more complex population simulation models that will ‘test’ the responsiveness and viability of spawning population to the potential drivers. Although a considerable component of this future investigation will rely on retrospective abundance and biomass information collected over a series of cuttlefish surveys, there is scope to up-date the population model with the results obtained from an on-going monitoring program that will conform to the methods described in Appendix 3. Furthermore, these surveys will provide an additional collaborative opportunity to collect/assess biological samples for related research projects.

4.4. CONCLUSION

This project refined a previously developed survey methodology for estimating cuttlefish abundance and biomass and incorporated a habitat and water analysis component to be carried out as part of a potential on-going monitoring program. Simplifying the cuttlefish surveys and the production of a standard operating procedure (Appendix 3) opens up the opportunity for other agencies to undertake their own surveys or to collaborate together (e.g. BHP Billiton, PIRSA, Santos, Conservation Council) and ensure the continuity of the data. With the appropriate training and expert supervision it may also be possible to enlist qualified volunteers to contribute to data collection through recreational dive clubs, and community or school groups. Enlisting diverse groups to undertake the surveys, however, raises issues around quality control and assurance of the collected data. Ensuring that divers are appropriately trained or accompanied by experts who have contributed to the surveys in the past would ensure greater scientific rigor in data collection and result in meaningful estimates of cuttlefish abundance and biomass. Appropriately archiving habitat images would also facilitate audits, or re-analysis, if required to investigate data integrity. Similarly, the EPA, the peak agency for monitoring and assessing South Australia's water resources, could be used for the on-going analysis of water samples to ensure that the appropriate systems and practices were in place for the delivery of high quality environmental data.

This project also explored whether the observed decline in cuttlefish abundance and biomass correlated with a range of potential 'contributing' factors, which included: water temperature, weather conditions, pollution, predators, prey, habitat, disease, fishing pressure and tourism. This section also investigated the history of the spawning population and reviewed our current understanding of the species' population dynamics. Of the investigated abiotic influences local rainfall was the only factor found to inversely correlate with peak cuttlefish abundance and biomass. However, it was unknown whether the underlying dynamics related to changes in coastal salinity, localized pollution through terrestrial run-off, or a direct influence on water clarity, all of which may deter aggregating cuttlefish from the coastal environment. No clear association was made between the decline of cuttlefish abundance and the investigated biotic influences such as: predator and prey abundance; habitat condition; and fishing intensity. There was also insufficient long-term observations of cuttlefish around the breeding site to definitively rule out that the rapid population 'explosion' observed in the late 1990s was an extraordinary natural phenomenon.

Our current lack of knowledge of cuttlefish population dynamics and their proximate cues for spawning in northern Spencer Gulf limits our ability to identify a definitive cause for the decline. This study, however, identified some avenues of research for developing a more robust understanding of the underlying factors that shape the spawning aggregation. These avenues related to gaining more information about the movement and migration of the cuttlefish on and off the 'iconic' spawning grounds, the structure of the northern Spencer Gulf population, and local trophodynamics. Strategies are currently in place to investigate these key knowledge gaps over the next few spawning seasons.

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APPENDIX 1

INTELLECTUAL PROPERTY

There is no intellectual property issues associated with this project.

APPENDIX 2

STAFF INVOLVED

Dr Michael Steer	(SARDI)	Principal Investigator
Dr Maylene Loo	(SARDI)	Co-Investigator
Dr Sam Gaylard	(EPA)	Marine Scientist

APPENDIX 3.

STANDARDISED SURVEY METHODS TO MONITOR THE SEASONAL SPAWNING AGGREGATION OF GIANT AUSTRALIAN CUTTLEFISH (*SEPIA APAMA*) AT POINT LOWLY

Julian Finn, Museum Victoria

OBJECTIVES:

- To estimate the peak in abundance and biomass of giant Australian cuttlefish on the Point Lowly spawning grounds;
- To assess the spawning habitat and water quality of the aggregation site.

Introduction:

This manual details the steps necessary to adequately collect the samples and data that will be used to estimate the abundance and biomass of seasonal spawning aggregation of giant Australian cuttlefish at Point Lowly, characterise the spawning habitat and assess ambient water quality, as part of an on-going monitoring program. To ensure the integrity and continuity of the data it is suggested that SARDI and the EPA coordinate data storage and analysis.

Given that diving is integral to the collection of field data it is essential that all participants are adequately qualified and trained to the standard recommended by their employer/institution/organisation. It is also essential that the appropriate risk assessments and safety procedures are followed at all times.

Handy contact numbers:

SARDI (Aquatic Sciences): (08) 8207 5400

Environment Protection Authority: (08) 8204 2004

Diver Alert Network Emergency: 1800 088 200

PIRSA Fishwatch: 1800 065 522

Santos (Port Bonython): (08) 8649 0171

Whyalla Dive Services: (08) 8645 0567

FIELD WORK

Field Survey Equipment:

- Personal dive equipment (in service).
- 50 m fiberglass transect tape.
- Slate, waterproof data sheets and pencils.
- Catch bag.
- Dive buoys.
- Waterproof digital camera (6+ megapixels) for photo-quadrats.
- Camera charger/spare batteries.
- Portable hard drive (1GB) to store images.
- Blank DVDs to backup images.

Water Quality Sampling:

(In collaboration / under advice of EPA)

- 60, 150 ml sampling bottles.
- 10, 100 ml Sterile-non-toxic syringes.
- 30, 0.45 μm filters.
- Multi-parameter Sonde (YSI 6920 v2) (to log conductivity, pH, dissolved O_2 and Chlorophyll *a*.).
- 0.45 μm Glass Fiber Filter (GF/F) paper.
- 2 ltr bottle.
- Vacuum filter.
- Forceps.
- Aluminum foil.
- Permanent marker.
- Sample labels.
- Sticky Tape.
- Esky with ice, or portable freezer.
- 20 lts of distilled water.

Timing of Surveys:

It is important to survey the spawning aggregation during its peak in activity. It is the quantification of this peak that provides the basis for the population estimates that can be compared through time. The spawning aggregation typically begins to form during May and starts dispersing in July. Three surveys should be undertaken spanning:

1. Late May
2. Mid June
3. Early July

Survey Sites

There are ten (10) survey sites distributed along the Point Lowly peninsula (Table 1, Figure 1). Seven of the ten sites contain two depth zones: Shallow (1 – 2 m) and Deep (3 – 6 m) (Table 1). All of the sites, with the exception of Santos Tanks, can be accessed from the shore, however, using a vessel is easier. Point Lowly has a well maintained public boat ramp.

Table 1. Survey site details.

Site	GPS	Spawning Area (m^2)	% of Total Spawning Area	Depth Delineated	No. Dive Transects	Access?
False Bay	32 59'13.4"S, 137 43'10.1"E	18,685.04	3.5	No	4 shallow	Boat/Shore
Black Point	32 59'27.3"S, 137 43'13.1"E	96,875.35	18.2	Yes	4 shallow, 4 deep	Boat/Shore
3rd Dip	32 59'37.2"S, 137 44"08.9"E	76,859.81	14.5	Yes	4 shallow, 4 deep	Boat/Shore
WOSBF (West of SANTOS Boundary Fence)	32 56'45.6"S, 137 44'51.3"E	114,406.60	21.5	Yes	4 shallow, 4 deep	Boat/Shore
Stony Point	32 59'44.0"S, 137 45'17.5"E	86,506.20	16.3	Yes	4 shallow, 4 deep	Boat/Shore
SANTOS Tanks	32 59'36.9"S, 137 46'15.0"E	39,062.43	7.4	Yes	4 shallow, 4 deep	Boat
Pt Lowly West	33 00'00.1"S, 137 46'56.3"E	21,225.12	4.0	Yes	4 shallow, 4 deep	Boat/Shore
Pt Lowly Lighthouse	33 00' 00.3"S, 137 47'09.3"E	13,566.85	2.6	Yes	4 shallow, 4 deep	Boat/Shore
Pt Lowly East	32 59'43.2"S, 137 47'03.7"E	12,196.14	2.3	No	4 shallow	Boat/Shore
Fitzgerald Bay	32 58'53.6"S, 137 46'48.4"E	7,881.58	1.5	No	4 shallow	Boat/Shore

Figure 1. Survey sites. (*Source: Google Maps*)

NOTE: Site Restrictions:

There are a number of restricted zones currently associated with the Port Bonython Jetty that MUST be adhered to. These are:

Zone 1: waters within 400 m of Port Bonython jetty

Vessels are not permitted in the area AT ALL TIMES, including skiing, aquaplaning or towing.

Zone 2: waters within 1 170 m of Port Bonython jetty

In Zone 2 a vessel is not permitted in the area while the berth operations signal at the end of the jetty is signaling a single red light flashing approximately every second.

Zone 3: waters within 2 nautical miles of the berth operations signal at the seaward end of the jetty

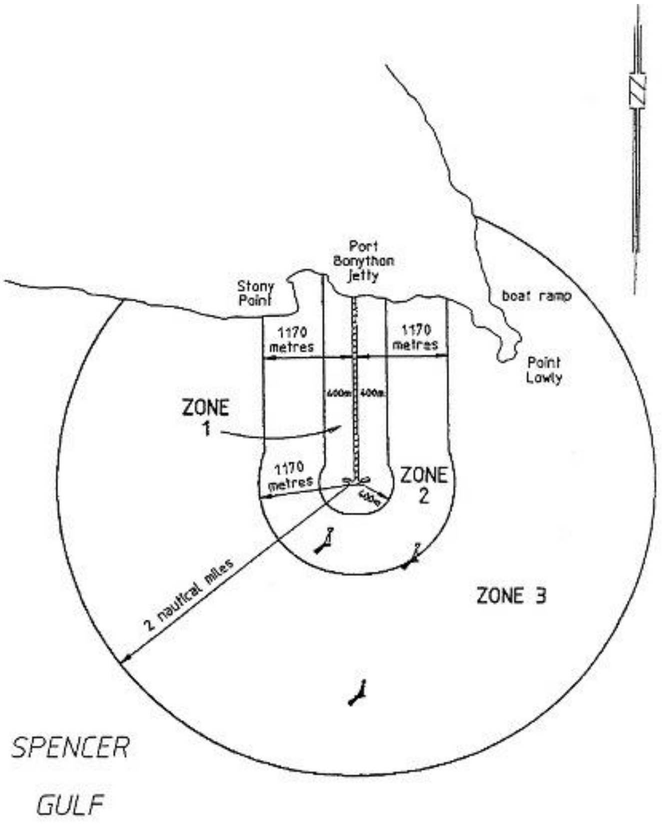
In zone 3 a vessel is not permitted in the area while the berth operations signal at the end of the jetty is signaling 2 red lights (in a vertical line 3 m apart) flashing each at an approximate rate of 1 flash per second (so that together they flash at an approximate rate of 2 flashes per second).

A maximum penalty of $1,250 applies for breaches of the restrictions.

Signage reminding boaters of the restrictions is on display at recreational boat ramps for the Upper Spencer Gulf (Pt Pirie), including Point Lowly and Whyalla.

Details on the legislation are available at:

http://www.austlii.edu.au/au/legis/sa/consol_reg/hanr2009322/sch5.html



Santos Security should be contacted prior to all field operations as matter of safety and courtesy (Phone: Santos – (08) 8649 0171).

Laying of the Transect

- Four (4) 50 x 2 m belt transects are to be undertaken within each depth zone at each site (see Table 1).
- Haphazardly lay out each transect over the rocky area within each site.
- Use either dive weights, or tie the end of the transect tape around a rock or a clump of algae to anchor it in position before running it out to 50 m.
- Extensive areas of seagrass and sand should be avoided, but if encountered alter the direction of the transect.
- Clearly record the date, survey site, start depth, finish depth, and divers involved for each transect on the datasheet (see Figure 5).

Counting and Measuring Cuttlefish

- Search the habitat 1 m either side of the transect tape for cuttlefish, ensuring that the underside of ledges and crevices are inspected.
- Record the size (mantle length (ML) in mm (Figure 2)) and sex of each cuttlefish encountered within the 50 x 2 m belt transect.
- Males can be distinguished from females by having longer marginal arms (banners), distinctive skin patterns and engaging in characteristic spawning behaviour (see Figure 3).
- Clearly record the size and sex of each cuttlefish on the datasheet, i.e. if a 110 mm ML male is observed then record "(M110)".
- Divers can generally get close enough to actively spawning cuttlefish to measure their size using the graduated scale on the datasheet, however, if this is not possible either approximate size or record the individual as "(F?)" to represent a female that was observed hiding deep within a den, or which otherwise could not be measured.
- If the size and sex of the cuttlefish cannot be determined then record "(?)".

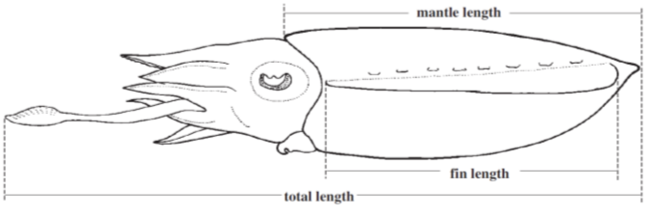


Figure 2. Schematic illustration of a cuttlefish (*Source:Jereb & Roper 2005).*

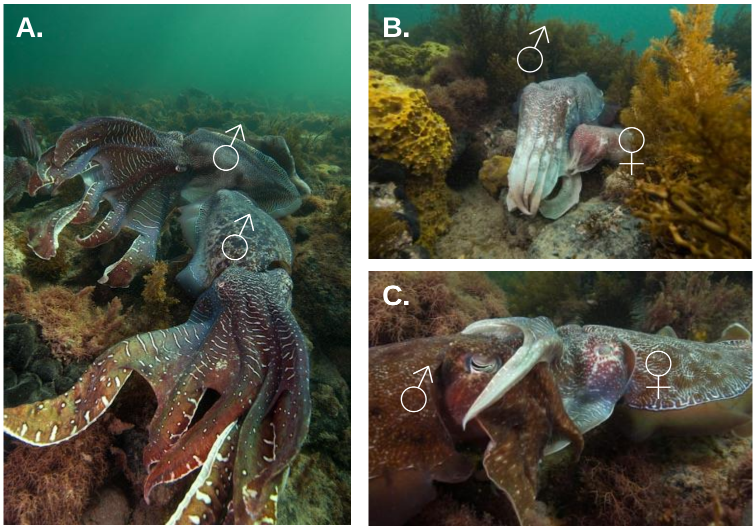


Figure 3. (A.) Two competing males, note the flared arms and marginal banners. (B.) male and female, note the size difference and smaller, retracted arms of the female. (C.) mating pair, note the receptive female with a more mottled skin pattern. (*Photo credit: Julian Finn, Museum Victoria)*

Taking Photo-Quadrats

- At the beginning of each transect take a clear photo of the datasheet which has recorded the date, diver, site and transect number to "bookmark" the sequence of images on the camera's memory card.
- Take a clear digital photograph at each 5 m interval along the transect tape. The 50 m transect will consist of 10 photo-quadrats positioned at the 5, 10, 15, 20, 25, 30, 35, 40, 45, and 50 m marks along the tape.
- Photos should be taken vertically-downward from a height sufficient to encompass an area of at least 0.3 x 0.3 m.
- Ensure that the graduations on the transect tape are clearly visible as this constitutes the scale of reference for the image and also identifies the sequence of the shots (Figure 4).
- Use an automatic flash where necessary.
- Use the highest digital resolution and largest image size possible.
- Save images in high resolution .jpg or .tif
- Archive the images to include the date, site, transect and distance along the transect using the following code:

MonthYear_Site_Transect#_Distance.

i.e. MAY12_WOSBFShallow_T2_D25.tif

- Back-up all images on a portable hard-drive and burn onto a DVD. Copy and send to SARDI for analysis.

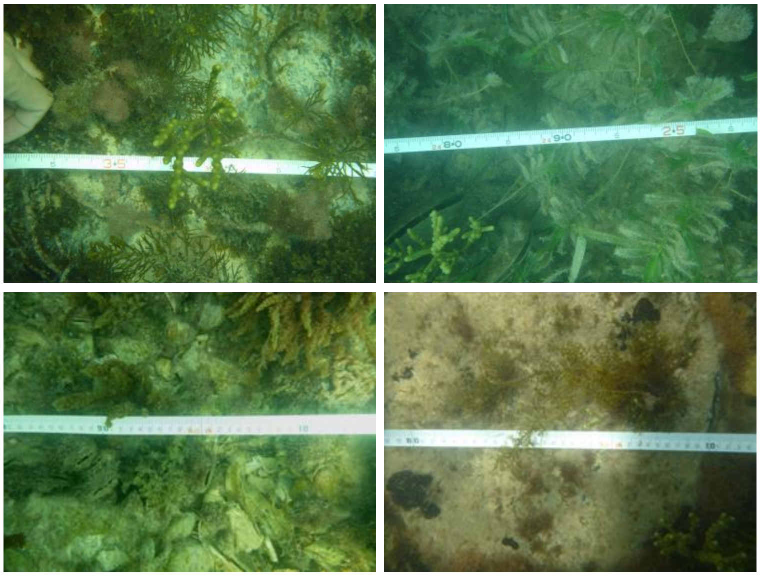


Figure 4. Examples of good photo-quadrat images. Note the graduated transect tape is clearly discernable. (*Photo credit: SARDI*).

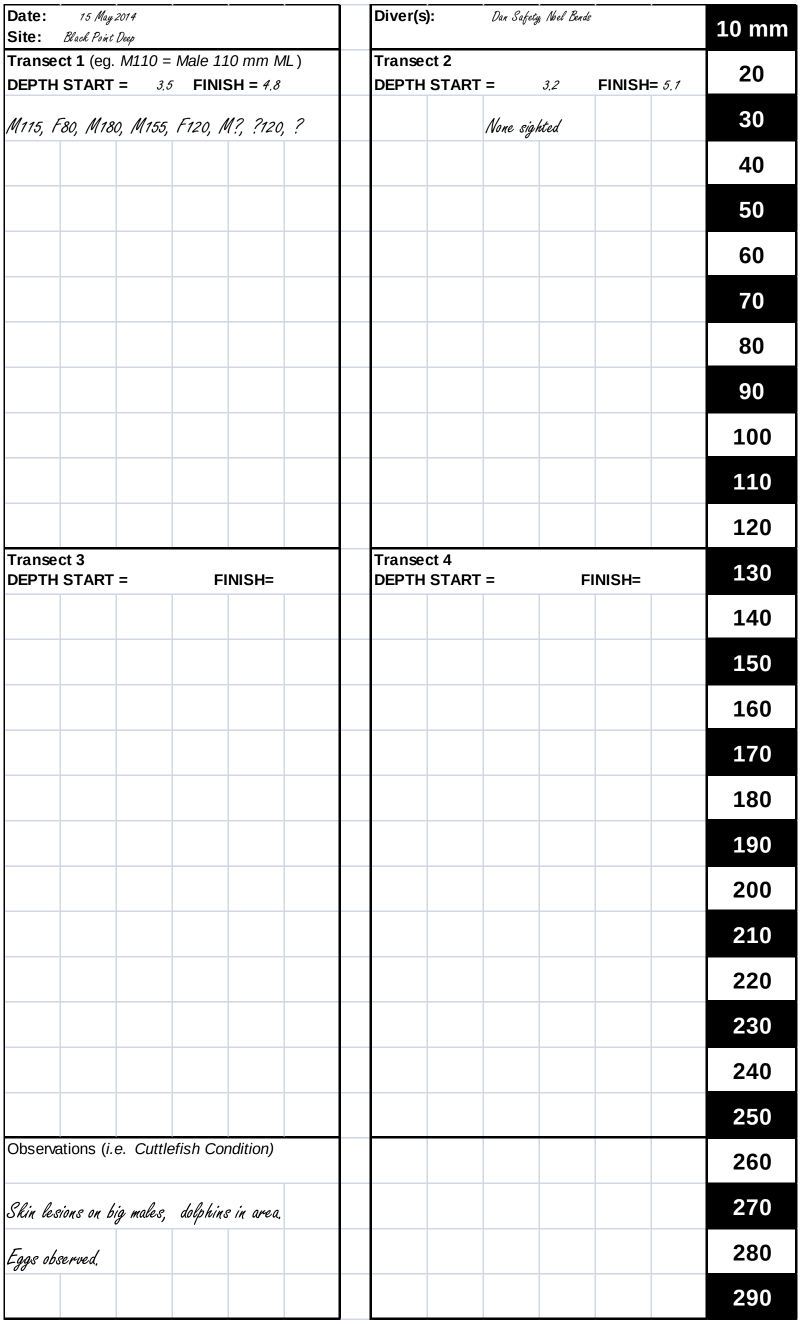
Collecting Water Samples (Under advice of EPA)

see http://www.epa.sa.gov.au/xstd_files/Water/Other/approved_methods.pdf for approved methods for analysis. It is recommended to consult with a commercial laboratory for advice regarding bottle and label requirements (some labs will provide bottles and labels) prior to sample collection.

- Water samples should be collected from a vessel.
- At each site collect six replicate 150 ml samples into prewashed containers from approximately 0.5 m below water surface. Three replicates from each site should be filtered through 0.45 μm filters and three unfiltered.
- Label each sample (i.e. WOSBF_Deep, 15MAY, Unfiltered A), place immediately on ice and store frozen. Ensure the label will not rub off or deteriorate when wet.
- Deploy the sonde at each site for 5-10 mins, ensure it is submerged, logging and save the file as the site name.
- DO NOT let the sonde probes dry out, rinse with distilled water and ensure the probes are stored moist.
- Collect a 2 L water sample in a pre-rinsed container, during the first and last sample of the day to be used to calibrate the sonde. Wrap containers in aluminum foil, label and store on ice before processing. These samples should be vacuum filtered through the GF/F-paper at the end of each day of water sampling. DO NOT touch the filter paper (use forceps), fold the paper and wrap in foil, label and freeze after use. Avoid any proximity to plant material (i.e. lettuce in sandwiches, seagrass etc.) during the filtering process as this may compromise the chlorophyll readings.
- All frozen water samples and GFF filters should be adequately labeled and provided to an approved laboratory facility within the recommended holding time.
- Once data are received from the laboratory send the file to the EPA for storage and interpretation if necessary.

Recording Data

- Ensure data/information is recorded clearly on the underwater datasheets (Figure 5).
- Use one sheet per survey site.
- Record “none sighted” if no cuttlefish were encountered within the belt-transect.
- Ensure the datasheets are collated and accounted for at the end of each day.
- If possible retain a copy and send the originals to SARDI.
- Alternately all data can be entered onto an excel spreadsheet and forwarded electronically to SARDI (Figure 6.).



Date: 15 May 2014
Site: Black Point Deep
Diver(s): Dan Safety, Noel Bends

Transect 1 (eg. *M110 = Male 110 mm ML*)
DEPTH START = 3.5 **FINISH =** 4.8
M115, F80, M180, M155, F120, M?, ?120, ?

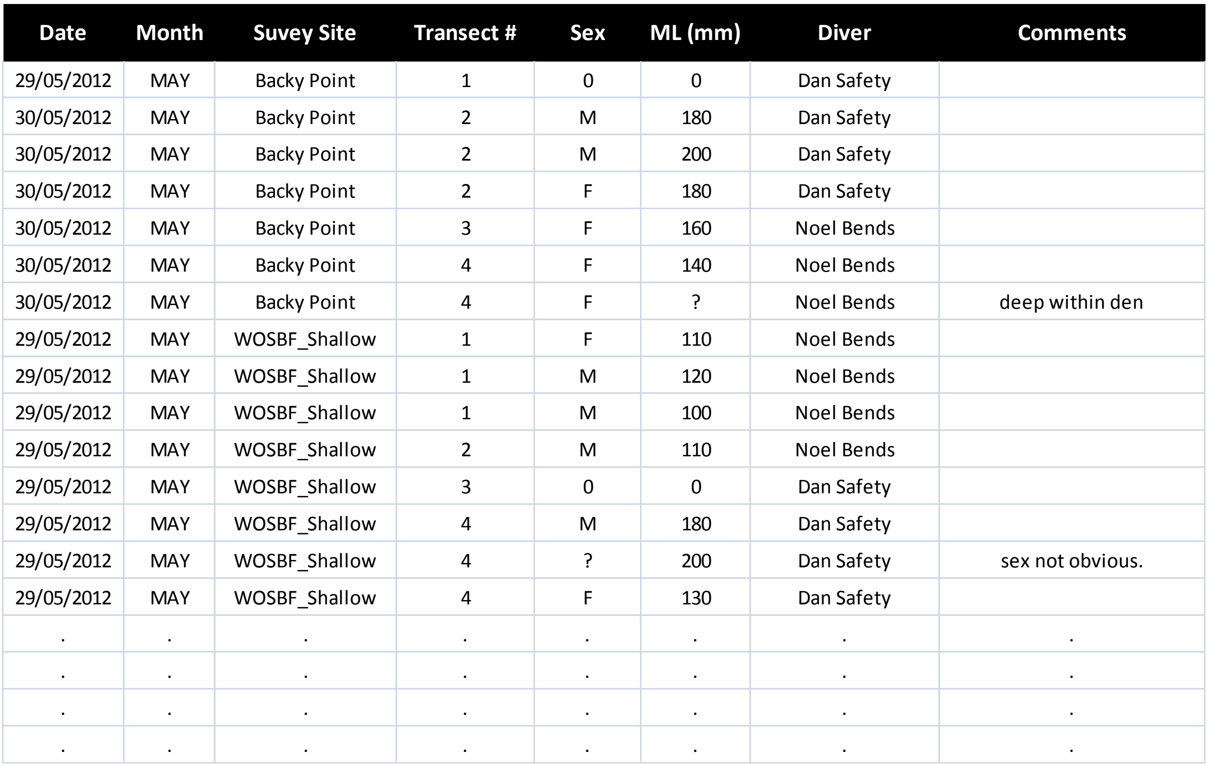
Transect 2
DEPTH START = 3.2 **FINISH=** 5.1
None sighted

Transect 3
DEPTH START = **FINISH=**

Transect 4
DEPTH START = **FINISH=**

Observations (*i.e. Cuttlefish Condition)*
Skin lesions on big males, dolphins in area.
Eggs observed.

Figure 5. Field datasheet example.



Date	Month	Suvey Site	Transect #	Sex	ML (mm)	Diver	Comments
29/05/2012	MAY	Backy Point	1	0	0	Dan Safety	
30/05/2012	MAY	Backy Point	2	M	180	Dan Safety	
30/05/2012	MAY	Backy Point	2	M	200	Dan Safety	
30/05/2012	MAY	Backy Point	2	F	180	Dan Safety	
30/05/2012	MAY	Backy Point	3	F	160	Noel Bends	
30/05/2012	MAY	Backy Point	4	F	140	Noel Bends	
30/05/2012	MAY	Backy Point	4	F	?	Noel Bends	deep within den
29/05/2012	MAY	WOSBF_Shallow	1	F	110	Noel Bends	
29/05/2012	MAY	WOSBF_Shallow	1	M	120	Noel Bends	
29/05/2012	MAY	WOSBF_Shallow	1	M	100	Noel Bends	
29/05/2012	MAY	WOSBF_Shallow	2	M	110	Noel Bends	
29/05/2012	MAY	WOSBF_Shallow	3	0	0	Dan Safety	
29/05/2012	MAY	WOSBF_Shallow	4	M	180	Dan Safety	
29/05/2012	MAY	WOSBF_Shallow	4	?	200	Dan Safety	sex not obvious.
29/05/2012	MAY	WOSBF_Shallow	4	F	130	Dan Safety	
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.

Figure 6. Example of an Excel data worksheet.

Date:
Site:

Diver(s):

Transect 1 (eg. *M110 = Male 110 mm ML*)
DEPTH START = **FINISH=**

Transect 2
DEPTH START = **FINISH=**

Transect 3
DEPTH START = **FINISH=**

Transect 4
DEPTH START = **FINISH=**

Observations (*i.e. Cuttlefish Condition)*

10 mm
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
270
280
290