Western Australian Marine Science Institution (WAMSI)
Node 3 Project 3.1.3

Stock assessment of targeted invertebrates at Ningaloo Reef

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Final Report by AIMS/CSIRO to WAMSI as contribution to deliverables for WAMSI project 3.1.3

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1. Executive Summary

Managing the sustainability of marine invertebrate populations that have been and continue to be extracted from the Ningaloo Marine Park (NMP) requires some baseline assessment of abundance and spatial distribution of the targeted organisms, This document reports the findings of research into the status of targeted invertebrate populations, with specific focus on lobster and octopus, along the length of the Ningaloo Marine Park during 2008-9. Detailed results of WAMSI Project 3.1.3 (Stock assessment of target invertebrates at Ningaloo Reef) are presented, but where appropriate the data on lobsters from two WAMSI studies (Projects 3.1.3 & 3.2.2d), is integrated, as these were purposely designed to be spatially complimentary, resulting in a more comprehensive stock assessment within the NMP.

Lobster

A series of field trips were made along the entire length of Ningaloo Marine Park (NMP) in May, July, and September 2008. Underwater visual census (UVC) at inner and outer reef sites within both recreational and sanctuary zones were undertaken from North West Cape (SZ) to the Turtle SZ at the southern end of NMP. In total, 132 lobsters from five species were counted from 265 transects and 18 separate locations (58 sites) along the entire coast of the NMP.

The results demonstrate; 1) very low abundances of lobster are found along all parts of the park with the exception of the mid-southern Cloates area; 2) five different species of lobster found along the coastline of the NMP; 3) the patchy nature of their distribution is tightly correlated with habitat characteristics; 4) sanctuary zones had significantly higher numbers of lobsters than recreational zones; 5) small effect between outer slope and inner lagoon population abundance.

Ningaloo once supported a commercial lobster fishery during the 60's - 80's that extracted approximately 25,000-35,000 individuals each year within a 6-month period. Today just 132 individuals could be found over vast areas of reef encompassing more than 132 km^2 (13.5 ha). It seems clear that the lobster population of the NMP is a shadow of both its carrying capacity and its former self. How long the lobster population has been at these low levels is unknown but their apparent loss from many areas of the Park may have already had a significant impact on the NMP reef ecosystem through a re-assortment of functional roles among biota.

Octopus

A number of different designs of octopus traps, including designs considered commercially effective on temperate species near Perth, were initially tested for their efficiency in a lagoonal area known to house a resident octopus population (Tantabiddi). However, this technique was abandoned following the failure of traps to catch octopus and direct sub- and inter-tidal visual surveys were selected as more appropriate to the tropical reef environment. Sub-tidal surveys on snorkel and SCUBA proved more successful and were done simultaneously with lobster surveys (see above). In addition to these, inter-tidal surveys were conducted in December 2008 providing total coverage of octopus habitat across a reef profile. In total, just 28 octopus from a single species (*Octopus cyanea*) were counted from 410 transects (265 sub-tidal & 145 inter-tidal) and 59 separate sites along the entire coast of the NMP.

Overall, observations were that; 1) octopus were very specific in their habitat requirements; 2) there were only a handful of small areas along the NMP that offer optimal habitat for inter-tidal octopus, marking them as vulnerable to human exploitation; 3) octopus are incredibly cryptic and difficult to survey visually. Estimates of their vulnerability would benefit greatly from details of the Ningaloo populations life history, and 4) *O. cyanea* numbers at Ningaloo are very low in comparison to those on other reef systems around the world.

While Ningaloo population densities appear to be much lower that those in other reef areas of the world, the failure of traps and cryptic nature of *O. cyanea* makes accurate estimates difficult irrespective of the techniques used. This, alongside the facts that fishers harvest them in the Park for bait and their presence is concentrated in quite small patches of inter-tidal reef habitat, suggests that their population is quite vulnerable to human exploitation. Their ability to withstand light harvesting by recreational fishers will be largely determined by their life history features. Attributes such as their rates of population turnover, degree of fecundity and patterns of growth would be instrumental in determining this and should be considered a future and pressing research prerogative.

1.1 Date
October 2009

1.2 Project Title and Number
Stock assessment of target invertebrates at Ningaloo Reef. WAMSI Node 3 Project 1 (WAMSI project reference no. 3.1.3)

1.3 Project Leaders
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1.5 Dates covered
May 2008 – October 2009

2. Key Findings and Recommendations

2.1 Objectives and Outcomes

WAMSI Node 3.1.3 subproject is one of four complimentary but independent subprojects aimed at investigating the benthic communities of Ningaloo Reef. It was specifically aimed at providing a better understanding of the targeted invertebrate population for effective management of the NMP. In the NMP, lobster and octopus are both targeted by fishers and divers. Lobsters are taken by recreational divers and occasionally by pots for human consumption. Octopus, although also taken for food, are primarily taken by recreational fin-fish fishers for bait. The specific objectives required for this project are:

1) A report on stock status for targeted invertebrate species along the length of Ningaloo Marine Park including octopus and lobster.
2) A characterization of habitats associated with high numbers of targeted species.
3) A comparison of stock abundance in relation to differing levels of visitor access.

In addition, a further 6 related questions have been put forward as important to the management of the NMP:

1) What is the species diversity of invertebrates at representative habitats in the NMP?
2) What is the relative abundance of these species and how do they compare with the "natural" abundance of these species on comparable reefs?
3) How does the abundance of these species change over a gradient of historical and human pressure?
4) Are current fishing regulations appropriate?
5) What should management targets be?
6) What species should be monitored regarding these species?

Each of these management objectives is discussed in detail within the body of the report and is additionally summarized in dot points following the report's general conclusions. Key findings are summarized in the executive summary above.

2.2 Implications for Management – Recommendations

This report highlights the paucity of current ecological information on these two invertebrate groups at Ningaloo Reef and provides hard data to back up anecdotal evidence of their decline in numbers over the years. Coupled with patterns of distribution and access to various areas, a case can be made to restrict (or stop) recreational fishing of these groups, at least until further pertinent information can be gathered. For both groups, the outlook remains uncertain. Patterns of clumped distribution further emphasise the vulnerability of these taxa to continuing recreational fishing pressure, particularly in the face of increasing visitor numbers projected for the Marine Park. Although the following recommendations entail strong action and our charter is to provide science rather than management, the following is an opinion based on the outcome of this report. Recommendations include:

1) Closing the Ningaloo Marine Park to recreational cray fishing until further notice. This would allow further investigations into their potential for recovery.

2) Support Fisheries WA puerulus collectors in Coral Bay and encourage other collectors further north, particularly Jane's Bay just south of Point Cloates (WA Fisheries link is Nick Caputi).

3) Restrict the taking of octopus bait in some currently fished areas to allow a natural population to exist. This would allow a proper assessment of the carrying capacity and regeneration of Ningaloo octopus populations.

4) Support further investigations on the life history of the main (targeted) octopus species *Octopus cyanea* as a means to understand both their role in the Ningaloo ecosystem and their vulnerability to fishing pressure.

5) Discussions with Fisheries WA inspectors at Ningaloo to be on the lookout for systematic harvesting of octopus on reef flats and potentially apply bag limits on recreational bait fishermen. Techniques used to take octopus also need to be policed and enforced (i.e. gidgees recognized as "spearing" which is illegal in designated "Special purpose -shore based fishing zones"). Remote cameras at selected reefs (e.g. Mildura Wreck especially) could be used to establish the extent of the problem and enforce laws.

6) Continued monitoring of these populations at selected sites using sensitive indicators such as increases in distribution, inter-annual fluctuations and increases in densities at critical sites.

2.3 Other Benefits

This project provides the first comprehensive census of the Ningaloo Marine Park's octopus and lobster populations and sheds light on their general ecology, habitat correlates and overall vulnerability to continued anthropogenic impact. The failure or success of various techniques and their refinement are also discussed. The report also identifies a way forward to reach research and sustainable management goals by providing ideas and suggestions for continued research directions for these two taxonomic groups. Gaps in our knowledge, how we can overcome these and the techniques necessary to address the short comings in our knowledge base are provided. Recommendations to management are also addressed based on the outcomes of the science generated.

2.3.1 Tool, techniques and information for improved ecosystem management

Layered maps identifying animal population and anthropogenic impact "hotspots" are provided to guide the choice of future monitoring sites and studies are provided, as are opinions on the best possible methodological approach to monitor lobster and octopus populations.

Compliance Issues

Non-compliance of sanctuary and special purpose (shore based fishing) zones appeared to be common-place during the fieldwork being conducted. In particular, we observed recreational reef fishing in the sanctuary zone at Winderabandi Point and the Pelican Pt area and spearing of octopus at low tide within sanctuary and special purpose zones near North West Cape and Pelican Point.

2.3.2 Forecasting for natural resource management decisions

In this case, the nature of the results indicate that population forecasts are likely to be dire without some management action, particularly for Ningaloo lobster populations. Quantitative evidence presented here from the Central Cloates area together with historical evidence supports the theory that, given the opportunity, the NMP could support very high numbers of (at least) Western Rock Lobsters. In the case of octopus, the approach used to gather abundance data must be treated with caution due to the difficulties involved in surveying behaviorally and visually cryptic animals. However, sound management decisions are based on a precautionary principle rather than a "let's just see what happens" approach. A different, more lateral approach to assess their vulnerability to human fishing pressure is discussed briefly in the body of the report and presented in detail in appendix A.

2.3.3 Impacts

The results from this report provide both baseline population information and a blueprint for future research and monitoring (techniques, suggested directions). In the case of management agencies, the nature of the results (i.e. very depauperate populations of both lobsters and octopus) are likely to have an impact on the management policy of DEC and WA Fisheries.

2.4 Problems encountered

Both octopus and lobster provided very significant challenges for accurate census and very low or zero counts at numerous sites compromised normal approaches at statistical analyses. The major problems encountered during the study were 1) determining an accurate method to deal with the cryptic and secretive nature of octopus during surveys, and 2) the nature of both the lobster and octopus data (large amount of zeros and general low abundances) severely restricting statistical power (or precluding it altogether).

While the technique for surveying lobster populations (transect swims) have been trialed extensively (and this made it easy to combine data with Babcock's CSIRO group who also assessed lobster using visual census), there is no template for octopus density surveys. Octopus density estimates are usually based on the bycatch of commercial fisheries. In the absence of this at Ningaloo a number of techniques were trialed (discussed in octopus research methodology & results) and the best method chosen. Regardless of the employment of the *only* successful method trialed (transects), it is unlikely that all individuals were spotted on transects. Essentially, an effective and accurate way to census octopus populations (if there is one) has yet to be designed. As a result, a completely different approach based on life history studies is currently underway as a post-graduate student project. Although this should go a long way to answering the question of how vulnerable octopus at Ningaloo are, it will still not provide an accurate answer to "what are the exact densities of octopus at Ningaloo locations?". The statistical issues were discussed in detail with resident AIMS statisticians. Some solutions were found (e.g. habitat / lobster data), however, octopus data is presented without statistics as the nature of the data precluded any statistics (parametric or non-parametric). Despite this, figures clearly show patterns of relative density at a number of spatial scales as well as between sub- and inter-tidal surveys.

3. Stock assessment of targeted invertebrates at Ningaloo Reef

A. Lobsters

3.1 General Introduction (lobsters & octopus)

Background

The Ningaloo Marine Park (NMP) is Australia's largest fringing reef and rates as one of the world's largest (MPRA CALM CCPAC 2005). Covering a total area of 4,566 km^2, it runs along 300 km's of Western Australia's coastline from Bundegi in the Exmouth Gulf (21°52.93'S, 114°08.95'E) to Red Bluff in the south (24°01.87'S, 113°26.25'E) and covers State and Commonwealth waters. The NMP has recently been listed for World Heritage Listing as a natural and unique environment of outstanding universal value (http://whc.unesco.org/en/tentativelists/5379/). In spite of the significance of Ningaloo to Australia and Australians, the abundance, diversity and composition of biota within the NMP is only beginning to be reliably quantified. In early 2005 the NMP was substantially extended and 34% of total Park area incorporated into limited or no take Sanctuary Zone areas under the revised Management Plan (2005-2015). Although areas of protection were chosen with the best available knowledge with a view to including the full spectrum of representative marine habitats, many of these decisions were made without in-depth knowledge of the biological communities that reside there. This project is part of addressing that shortfall in ecological and biological information. Specifically, it aims to provide a detailed inventory of targeted invertebrate populations along the length of the NMP, identify key areas and habitat types associated with healthy populations, and cross-reference this information with patterns of human usage.

Scientific and management rationale

Lobsters are considered to be an important biotic component on coral reefs (Tarr et al. 1996, Shears & Babcock 2002, Langlois et al. 2005). They provide important services to reef ecosystems by reworking sediment and consuming both live and dead plant and animal material (Joll and Phillips 1984, Jernakoff et al. 1993). As such they are an integral part of the food webs of coral reef systems. Nutrient cycling on coral reefs is known to be divided into two main food webs. The first is a detrital-based food web composed mostly of microscopic organisms that process up to 69% of primary productivity (Arias-Gonzalez et al. 1997). The second is that which we are usually more familiar with, the more visible primary and secondary consumer food webs. Organisms that control and mediate the collection, use and accessibility of resources at each of these trophic level are those which are most likely to play an important role in the functioning of ecosystems. Sitting at the apex of the detrital food chain and at the base of the consumer one, healthy lobster populations are likely to play important roles in the cycling of energy and materials through the NMP ecosystem. Any impacts on the integrity of these stocks may impact on the health of the NMP's ecosystem and the way it operates at a functional level. Understanding how an ecosystem you manage operates obviously makes for far more effective management because it identifies and recognizes the importance of different species to the ongoing health of the system.

From a management and visitor point of view, the loss of any biodiversity through localised extinction is worrying. Australian coral reefs are expected to have lobsters in them and many visitors see diving for and / or viewing lobsters as a very enjoyable part of their holiday experience at the NMP (*pers comm.* Claire Smallwood). Similarly, taking octopus for bait allows recreational fishers to have a better overall wildlife experience by being more self-sufficient. Thus, the effective management of these populations is an important part of an experience package that the NMP offers to visitors.

At a base level, management without knowledge is inefficient, at worst totally ineffective. This report alongside the recent CSIRO lobster report contribution (WAMSI 3.2.2) represents the first quantitative estimate of lobster and octopus populations along the Ningaloo coast. Considering decades of commercial and recreational fishing pressure on the Ningaloo lobster population and recreational pressure on the octopus, this scientific report is timely and will allow managers to make more informed decisions on the NMP in general and on these two important invertebrate groups in particular. The report also places today's population estimates into an historical framework by providing first-hand accounts (through personal interviews with commercial lobster fishers) of lobster catches in the 1960's-70's. This is of critical importance because it tells us where we were before in comparison to where we are now.

3.2 Materials & Methods

Site selection & sampling design

Species identification and quantification of lobster and octopus were undertaken at locations from Lighthouse SZ in the north to Turtle SZ in the south (Fig 1a-d, Table 1). Sampling of the NMP areas was designed in a hierarchical structure to enable analyses at different spatial levels of organization (Fig 2). Lobster data presented here is an amalgamation of both AIMS and CSIRO data in order to provide as comprehensive an overview as possible. Octopus data was solely based on surveys completed by AIMS.

AIMS surveys

Site selection was largely predetermined with the aim to balance five essential criteria, the need to consider / encompass; 1) the entirety of the NMP, 2) as many sanctuary / recreational zone borders as possible, 3) general trends in human usage patterns, 4) a stratified habitat approach to sampling, and 5) logistical field constraints. In total, 265 transects encompassing 58 sites at 17 separate locations were surveyed (71 transects in May, 48 in July, and 146 in September 2008 [Table 1]). In addition to these, 145 inter-tidal surveys were conducted for octopus. Transects were 5 x 100m underwater visual surveys (SCUBA or snorkel) at sanctuary and recreational management zones and at both inner lagoon and outer slope reefs. Visual estimates of percentage cover of major substrate and habitat categories were also recorded by divers. In areas with high or low abundance (e.g. Cloates Bay & Winderabandi for high; entire southern section for low), sampling was intensified to provide a more complete picture.

CSIRO surveys

During April 2008 a series of sites were surveyed for lobsters from Lighthouse Bay in the north to 3-Mile Sanctuary in the south. Sites that appeared to be suitable lobster habitat were chosen from a series of geo-rectified aerial photographs and loaded onto a hand-held GPS. At each site two divers entered the water and each diver swam a 5 x 100m transect, identifying, counting and estimating carapace length of any lobsters encountered. The narrower transect width allowed divers to target lobster habitat more effectively. The divers also recorded visual estimates of percent cover of major substrate and habitat categories.

Habitat stratification

Habitat data was also collected *in situ* for each transect in order to correlate lobster numbers to particular habitat types for each species found. Methodology for habitat data was modeled on that used by CSIRO's WAMSI lobster project to allow for cross-collaboration, increase replication and hence overall statistical power. Collection of this data incorporates both gross estimates of habitat cover and the more finer-scale contributions made by live corals using percentage measures (i.e. each transect = 100% gross cover & a further 100% component live coral cover)(Table 2). Alongside this, a minimum of 20 underwater landscape photos were taken for each transect swum to provide a permanent record of the representative habitat for each replicate. This provides a further opportunity to process habitat data (e.g. AIMS point census techniques from images) should the need arise. Latitude and longitudes of each transect were also recorded for mapping purposes and to ensure minimal overlap between CSIRO and AIMS data at the planning stages. Other data recorded for each transect includes diver identification, depth, visibility, bearing from transect start, date and time.

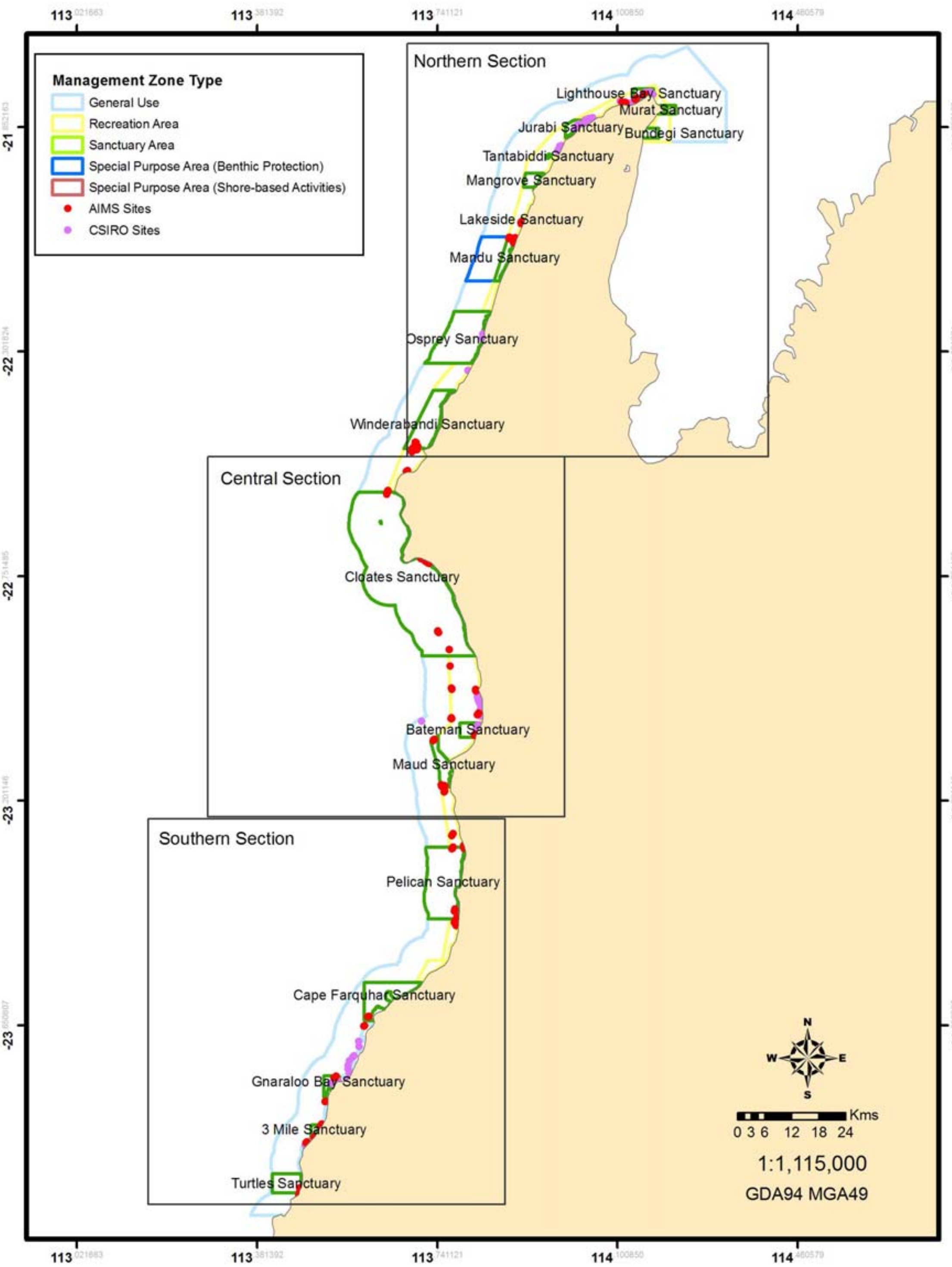

Figure 1a: Sampling sites for lobster and octopus throughout Ningaloo Marine Park.

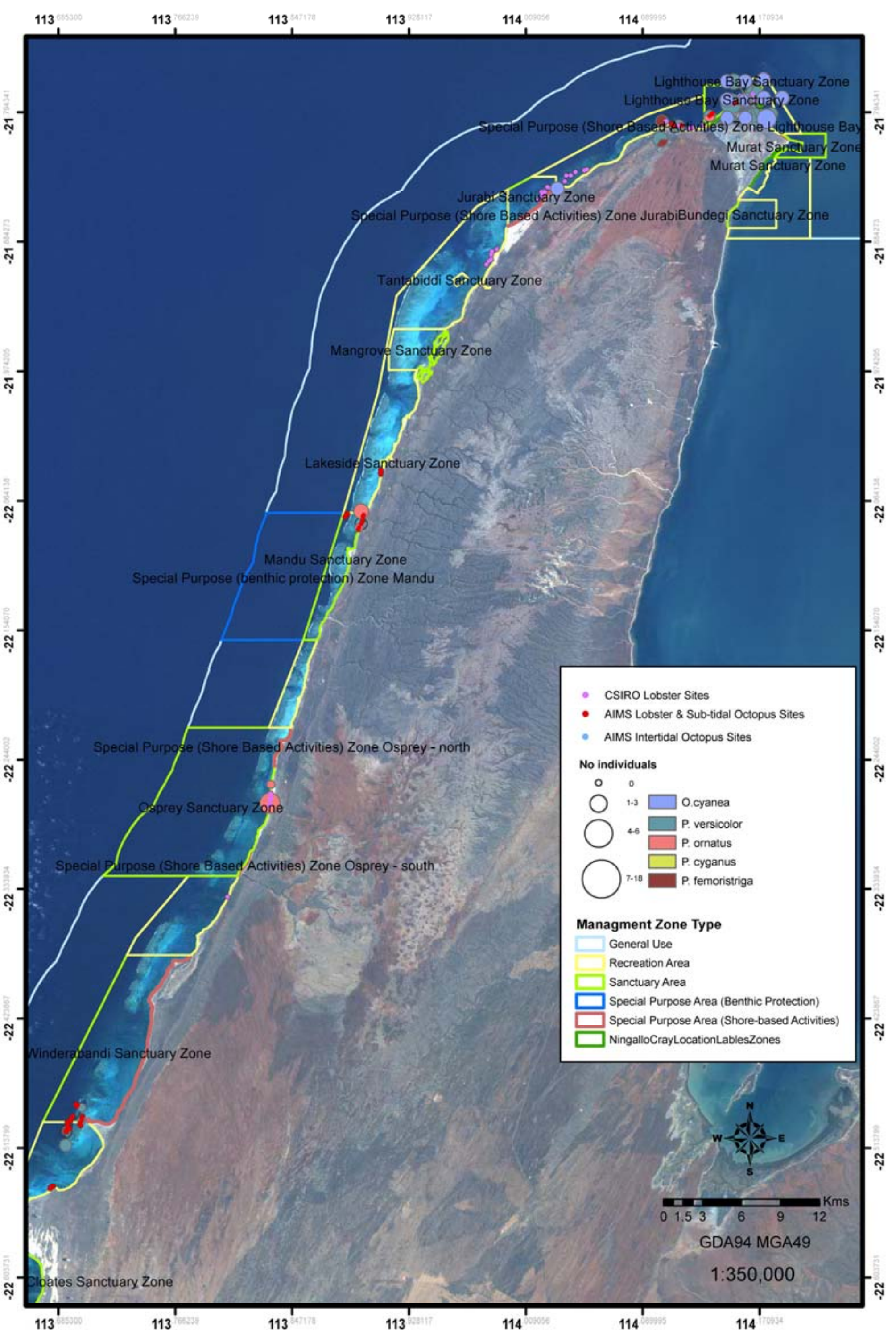

Figure 1b: Northern section of the NMP showing coverage of lobster CSIRO (pink dots) and AIMS (red dots), and octopus surveys by AIMS (blue dots). Circle sizes denote numbers of individuals and colours species type.

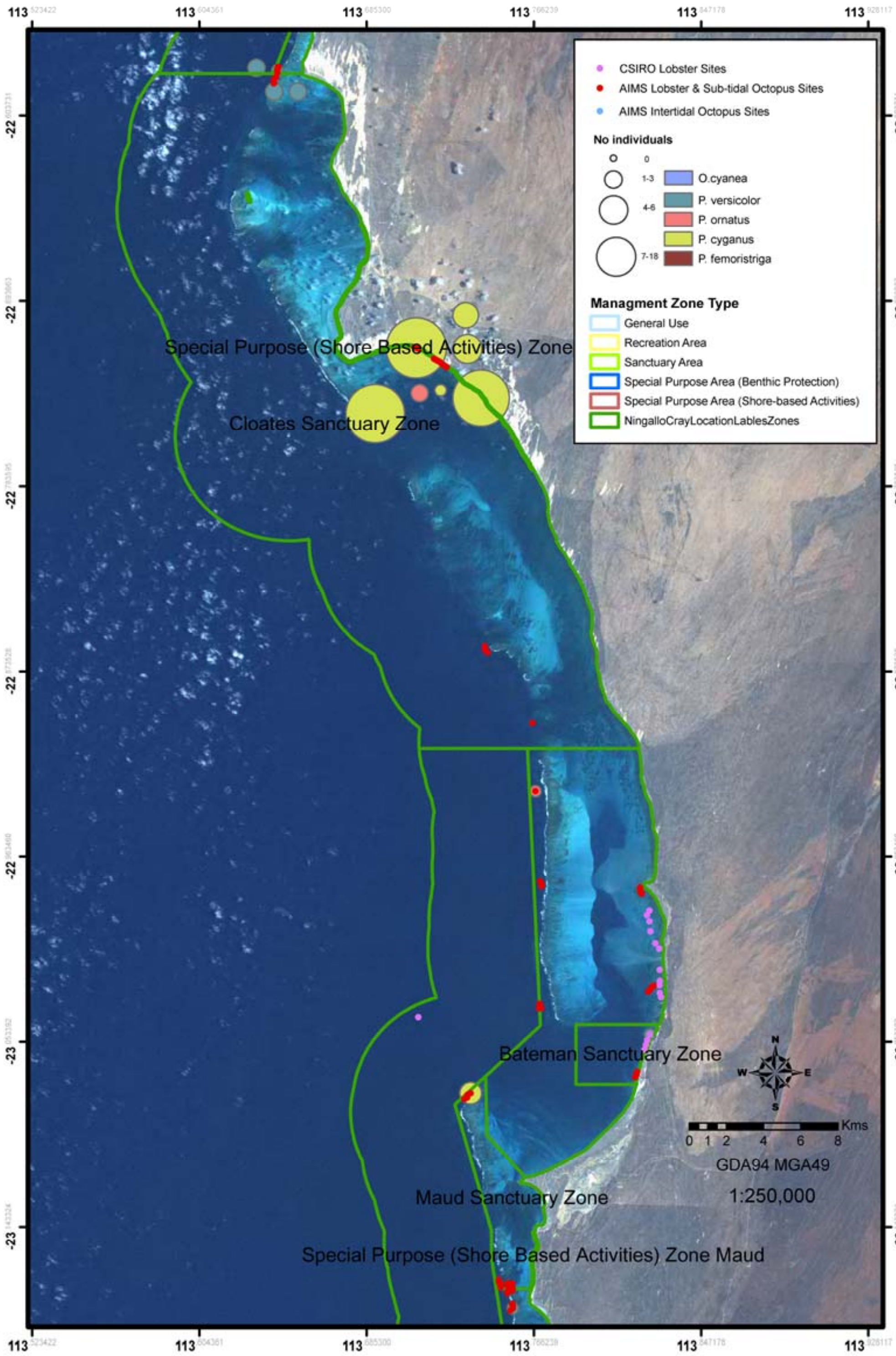

Figure 1c: Central section of the NMP showing coverage of lobster CSIRO (pink dots) and AIMS (red dots), and octopus surveys by AIMS (blue dots). Circle sizes denote numbers of individuals and colours species type.

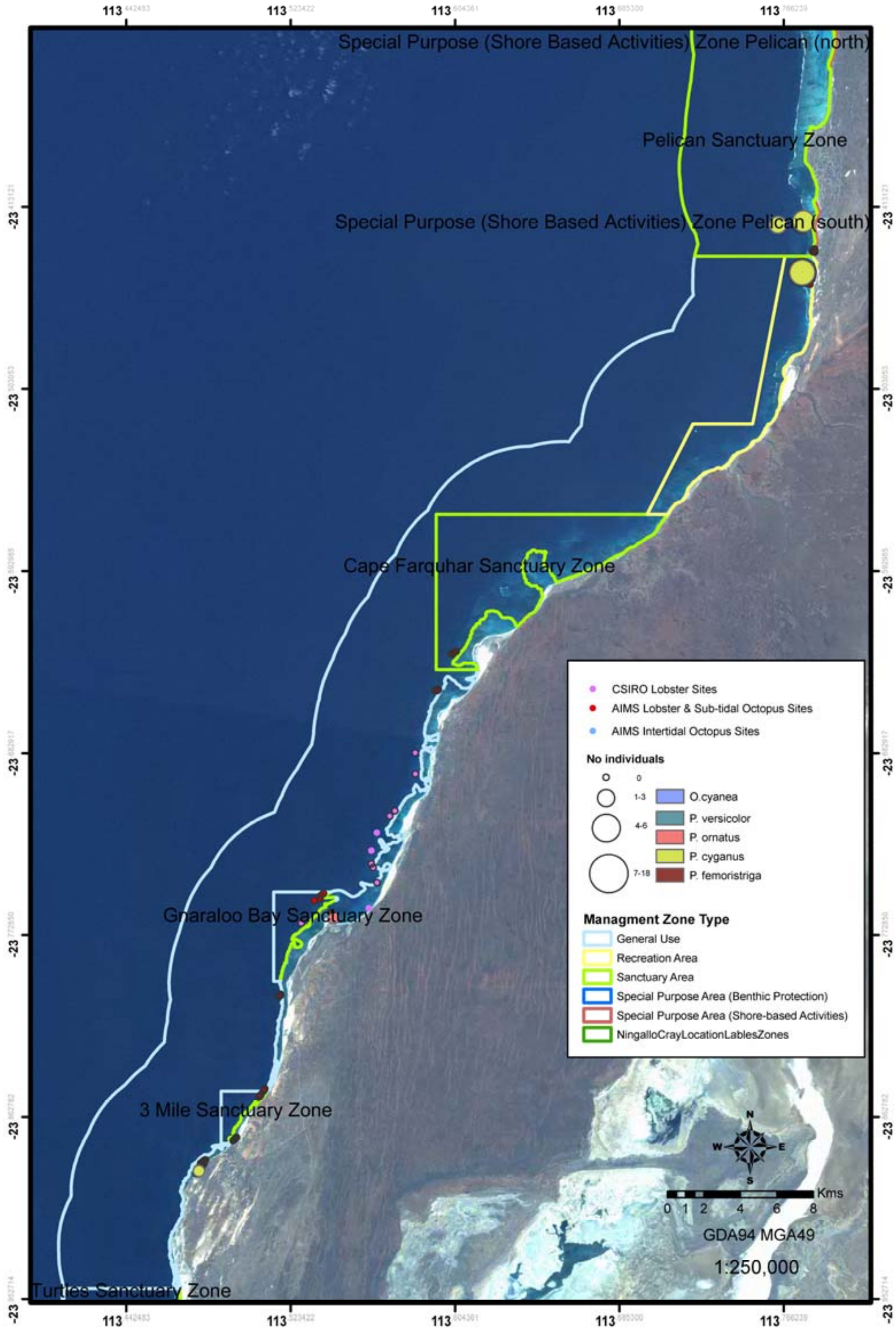

Figure 1d: Southern section of the NMP showing coverage of lobster CSIRO (pink dots) and AIMS (red dots), and octopus surveys by AIMS (blue dots). Circle sizes denote numbers of individuals and colours species type.

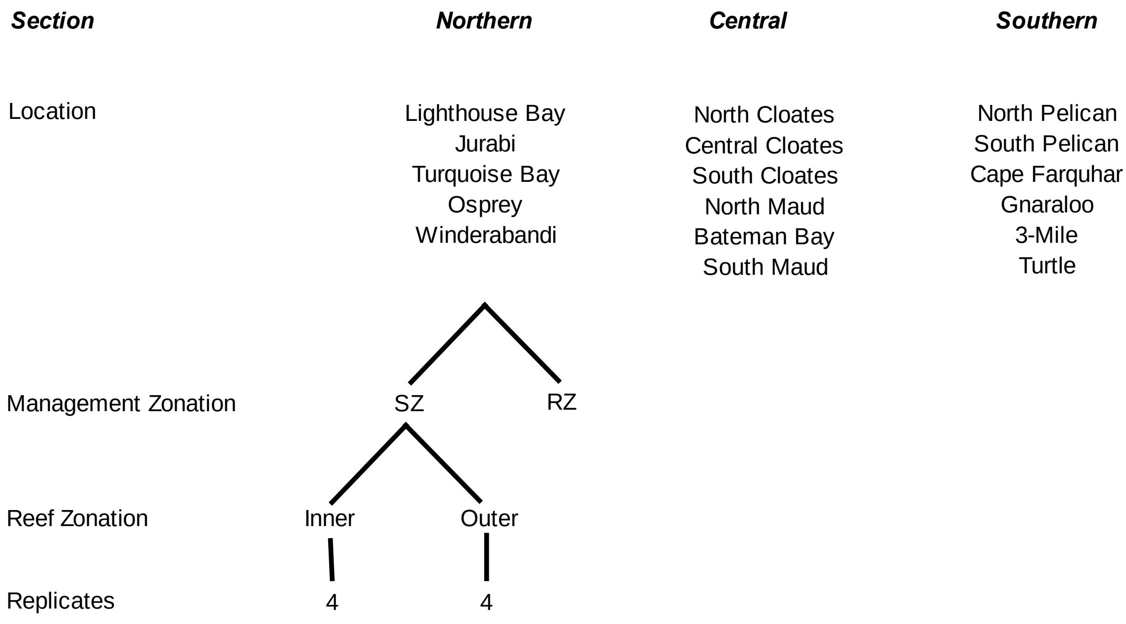

Figure 2: Sampling design employed for lobster and octopus surveys wherever logistically and geographically possible (e.g. no outer reef zones at Bateman Bay). In total, 58 separate sites (combinations of above) were surveyed using the hierarchical sampling design above.

Table 1: List of habitat characteristics used in lobster surveys. Each transect recorded percentage-cover of gross benthos and a further breakdown of live hard coral into morphological and taxonomic types.

***Gross benthos* (∑=100%)**	***Live hard corals component* (∑=100%)**
Live hard coral	*Acropora branching*
	Acropora digitate
Dead hard coral	*Acropora encrusting*
	Acropora foliaceous
Live soft coral	*Acropora plates*
Seagrass	*Other branching*
	Other digitate
Algae	*Other encrusting*
	Other foliaceous
Sand	*Other plates*
Rubble	*Coral mounds*
Boulders	*Free-living corals*
Bommies	
Pavement	
Consolidated rubble	

Exploratory analysis & statistical design

Statistical analysis was performed on raw counts following unsuccessful attempts to transform data ($\sqrt{x} + 0.5$ for counts; arcsine on habitat percentages) to meet the basic underlying assumptions of normality and homoscedasticity. Because of this, non-parametric tests were used to compare mean abundances across reef and management zones using Mann-Whitney tests for two independent samples, and Kruskal-Wallis tests for multiple independent samples. The relationship between lobster species and habitats was analysed and displayed using canonical redundancy analysis (Legendre & Gallagher 2001). Due to the large number of zeros and skewed nature of the data, data was transformed using Helligers transformation (Legendre & Gallagher 2001). Permutation ANOVA (ANOSIM with 999 permutations) was used to test for significance of eigenvectors and terms (i.e. habitats vs species).

Trends of lobster abundance in relation to visitor access were investigated for beach access. This was ascertained using field knowledge in conjunction with Google earth imagery to digitise points of access along the Ningaloo coastline (Fig. 3). In addition, an access "hotspot" spatial density index was generated by calculating the number of access points per unit area using a 5 x 5 km overlapping kernel. Two additional measures of site accessibility were added to the analysis using place names and road center lines databases provided by Geosciences Australia (accessed from www.ga.gov.au). For each lobster transect the Euclidian distance to the nearest; 1) beach access point density, 2) beach access point, 3) place name, and 4) road centreline was calculated. Each lobster transect was intercepted with the access "hotspot" spatial density index to get a value for the transect. The relationship between the total number of individuals found and the four above measures was tested using a zero inflated general linear model (general and hurdle form). A two stage Zero inflated model (stage 1 a poisson loglink model based on abundance looking at presence only sites, and stage 2, a binomial log likelihood distribution based on presence absence) was generated. This method was deemed the best possible approach because the data contained a large proportion of zero values (presence at 39 of the 265 sites). However, there are a number of caveats that need to be outlined concerning the analyses, specifically;

1) The results are based on only a small number of sites (39 of 265 sites) where data was present and should be interpreted with caution.
2) The results do not contain any stratification information with respect to habitat quality or sanctuary zones. However, habitat stratification at the level of "reef zone" was inbuilt into the sampling design (i.e. *a priori*) providing a reasonable measure of habitat homogeneity at a gross level between various sites / locations.
3) The variables used to assess site accessibly are proxies in the absence of data directly measuring actual numbers of visitors accessing the water at each access point (and hence potential fishing pressure for each of these sites).

4) Seasonal effects in relation to both visitor numbers and lobster abundance were not inbuilt into the analyses due to the data not being available (visitor numbers) and the nature of the (zero biased) data set (lobster abundance) and the non-repeating sampling regime employed (i.e. no seasonal trends measured at specific sites).

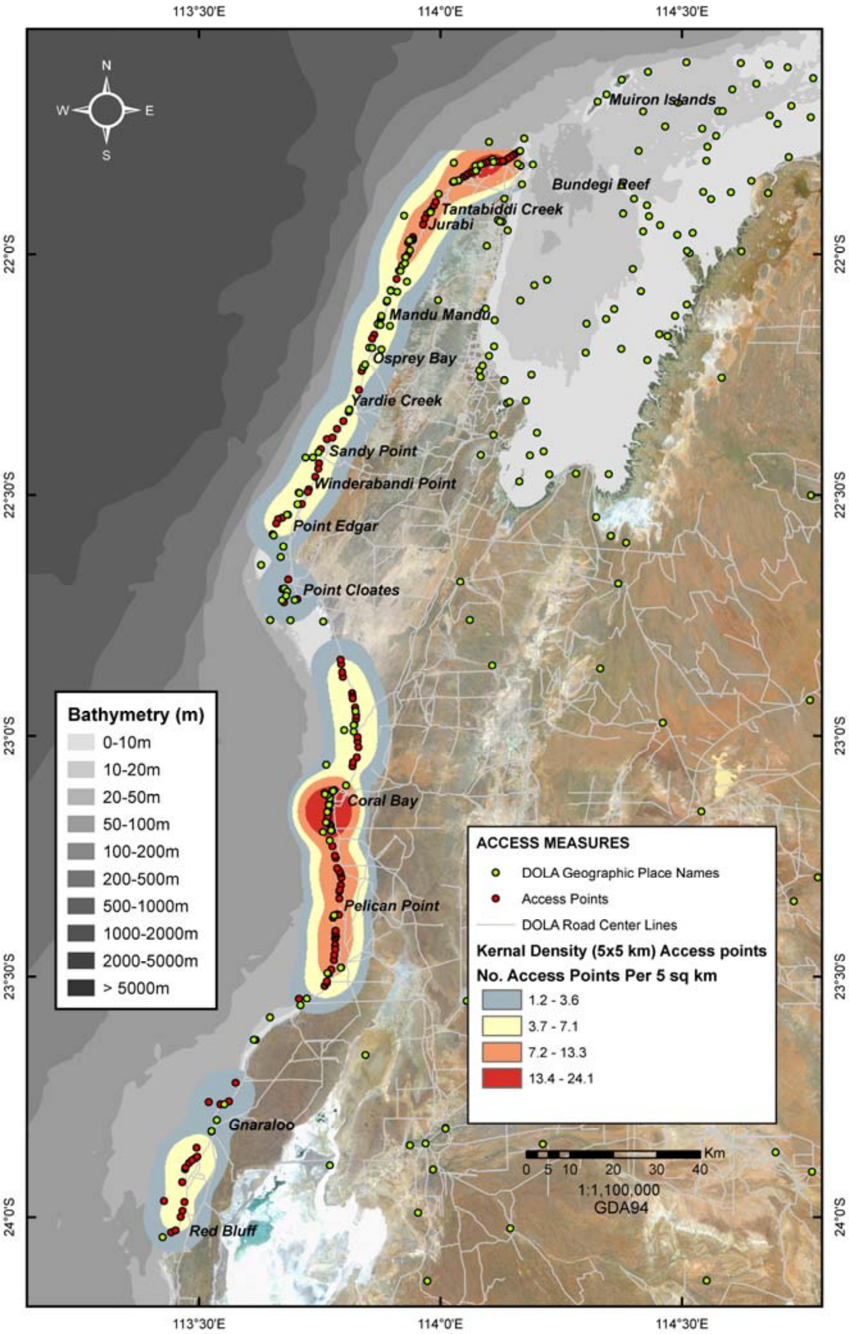

Figure 3: Visitor density map generated by combining information on 1) place names (green dots), 2) beach access points from personal field knowledge (red dots), & 3) road access centre lines (grey lines). Coloured layers along the coastline indicate an index of "access density" based on the above proxies. For example, Coral Bay has a place name, many access points and is close to a number of road centre lines indicating high visitor access (red layer with an index of 13.4 – 24.1). In contrast, Point Cloates has a place name but few beach access points or road access centre lines (grey layer with an index of 1.2-3.6).

In addition to quantitative data, some qualitative data is presented and discussed. In particular a recorded interview which took place in Cervantes on December 11th between Martial Depczynski and Len Annabel (see appendix B), and a thesis by Brooke Halkyard completed in 2005 on historical lobster fishing catches during the 1960's – 1970's. Len's accounts as a commercial lobster diver on the Ningaloo coast in 1974 closely mirror that of the data collected for Brooke's thesis. As such it provides two very important pieces of information. Firstly, the first primary account of the commercial lobster operations conducted by Nick Farinaccio, to my knowledge the only commercial fisher to be granted a licence to take lobster from Ningaloo Reef. Secondly, by providing numbers of divers working and days worked, areas fished, and approximate number of lobsters taken each day, it provides the only direct link to the status of the lobster populations back in 1974. Hence these accounts are invaluable in assessing not only the carrying capacity of lobster populations at Ningaloo Reef but provide a better idea of what the "natural" populations at Ningaloo are. Other anecdotal evidence was gleaned from talking to long-term residents of the area as the opportunities arose. Following this interview with Len, we ran a further small series of random surveys using the same techniques and in the exact locations where historical commercial lobster-fishing operations took place around the Waroora Station (southern section – see fig. 1d).

3.3 Results

In all, a total of 132 individuals from five different species were censused from 265 replicate transects and over 300km of reef coastline. The most common species found was the Western Rock Lobster - *Panulirus cygnus* (75) followed by the tropical lobsters - *P. versicolor* (37) and *P. ornatus* (15) and with the Spiny Lobster - *P. femoristriga* (4) and *P. penicillatus* (1) also being present (Fig. 4a-e). Considering the total area coverage from the 265 transects was over 132 km^2 (13.5 ha), this represents a single individual per km^2 or 0.5 per transect. Cross-correlation between AIMS and CSIRO data sets using the same methodology indicated a very close match (AIMS surveys 1.04 individuals / km^2 and 0.52 / transect; CSIRO surveys 0.88 individuals / km^2 and 0.44 / transect).

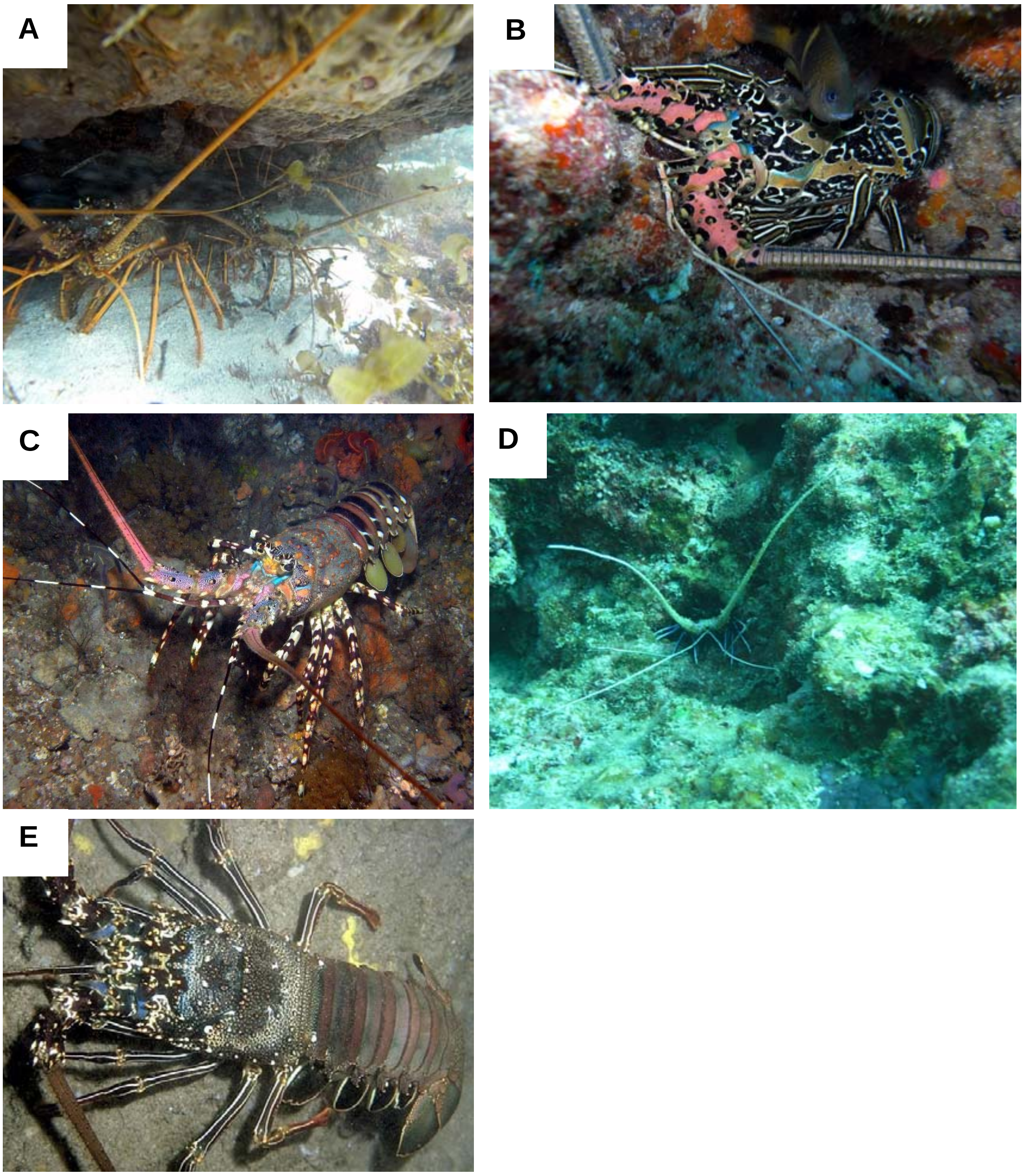

Figure 4a-e: Images taken *in situ* of the rock lobster species censused along the Ningaloo coastline; a) Western rock lobster - *Panulirus cygnus* (total n = 75), b) Painted rock lobster – *P. versicolor* (total n = 37), c) Painted cray – *P. ornatus* (total n = 15), d) *P. femoristriga* (total n = 4) and e) *P. penicillatus* (total n = 1).

Trends in relation to Park sections and locations

Mean numbers of individuals between the Northern, Central and Southern sections of the NMP differed considerably, as did those between the 17 locations (Fig. 5a-b). Non-parametric Kruskal-Wallis tests on raw data indicated a statistical difference between the Northern, Central and Southern sections ($p<0.05$) and between the various locations ($p<0.05$).

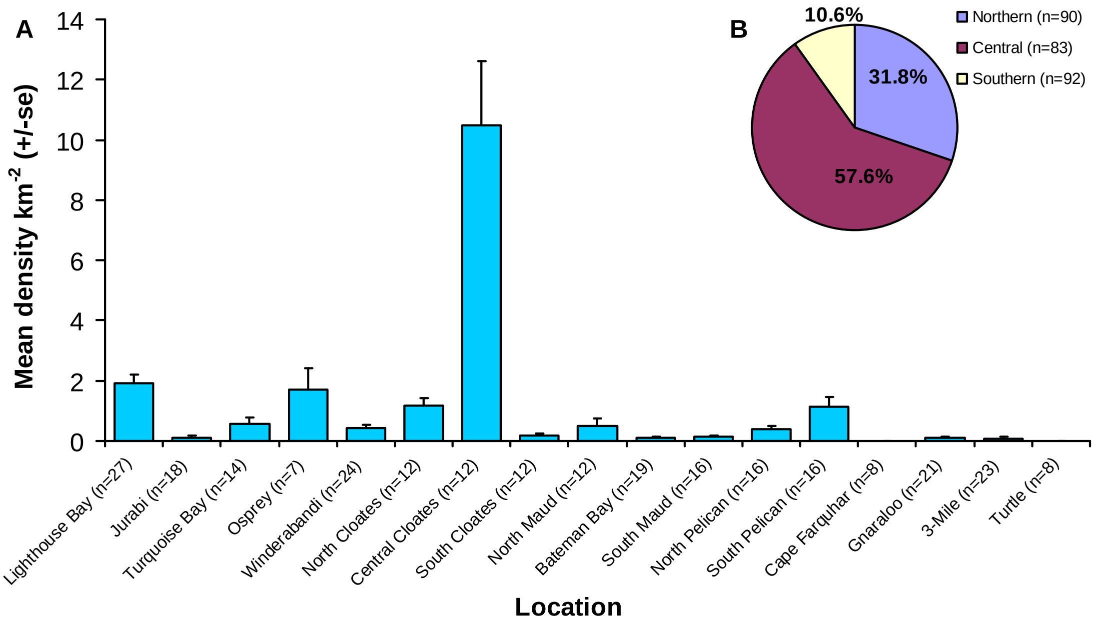

Figure 5a-b: Comparison in the mean density of lobsters km^{-2} for a) the 17 locations in a north to south direction (±se), and b) 3 sections of the NMP. Both sections and locations were statistically different ($p<0.05$).

It is clear from figure 5a that the comparatively high lobster abundances found at the Central Cloates location is disproportionately driving patterns in the data. Over 47% of all individuals surveyed were found at this exclusively inner reef / sanctuary zone location marking it as an obvious hotspot for NMP lobsters (*Panulirus cygnus* - Western Rock Lobsters mainly), but also having the secondary effect of masking other trends in the data relevant to the NMP as a whole. Lobster numbers were reanalyzed without the addition of Central Cloates data to reflect how lobster stocks are distributed throughout the rest of the NMP (Fig. 6a-b). Results indicate that both sections and locations still exhibited statistical differences ($p<0.05$). Results from here on are presented without Central Cloates data.

Geographical comparisons in species distributions indicate the general predominance of the painted tropical lobsters *P. versicolor* and *P. ornatus* in the northern section of the park. Central and southern sections are predominately composed of the Western Rock Lobster *P. cygnus* with a small contribution from *P. versicolor* (Fig 6b). Even with the exclusion of the Central Cloates data, there was wide variation in lobster numbers among locations. The general pattern was one of steadily decreasing numbers as you move southwards (left to right locations). Most locations (9 of the 14 that contained lobsters) contained a single species and only two locations contained more than two species (Lighthouse Bay in the Northern section and Central Cloates in the Central section).

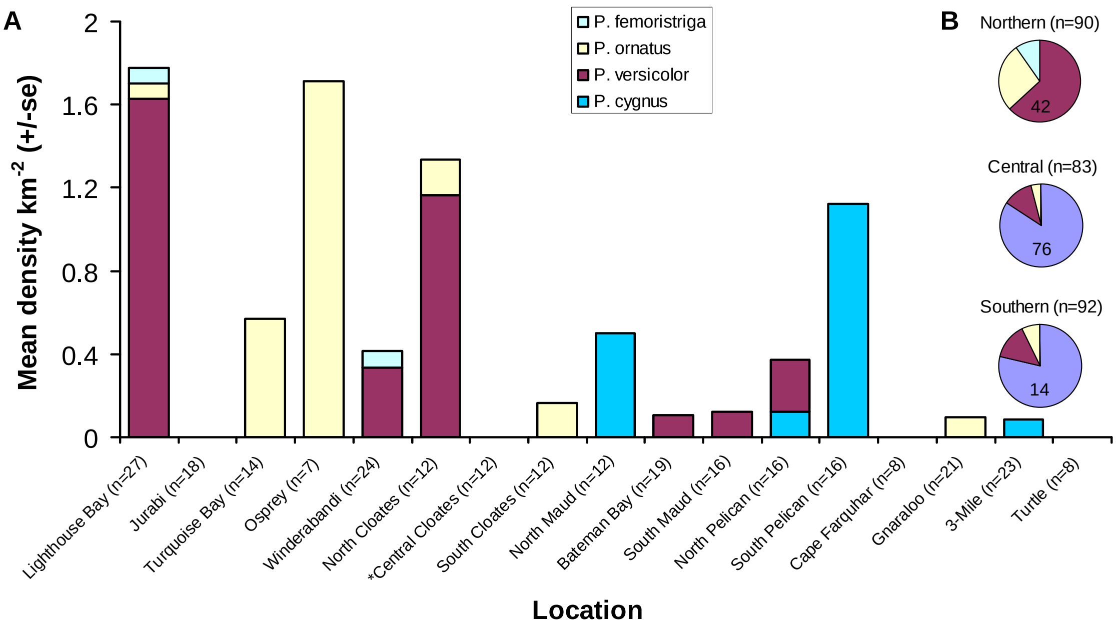

Figure 6a-b: Breakdown comparison in the mean density of lobster km^{-2} by species for a) 16 locations in a north to south direction, and b) 3 sections of the NMP. Central Cloates data has been removed from figure 5a and the analysis to provide a more realistic and general assessment of patterns in the Ningaloo Marine Park. Over 84% of all Central Cloates lobsters were *Panulirus cygnus* (64 individuals), with the remainder *P. versicolor* (9 individuals) and *P. ornatus* (3 individuals). Total numbers of individuals for each of the 3 sections of the NMP are shown at the bottom of pie charts (inclusive of Central Cloates data); n values refer to numbers of 5 x 100m transects collected for each of these locations and sections. Both sections and locations were statistically different ($p<0.05$).

Trends in relation to management and reef zones

Analysis at the next two levels of interest, management (sanctuary versus recreational) and reef (inner lagoon versus outer slope) zones was also analysed and presented without the dominating effect of Central Cloates data. Management zones were significantly different, reef zones were (marginally) not despite the obvious trend of higher numbers on outer slopes. (Fig. 7a-b). Both recreational and sanctuary zones were composed primarily of *P. versicolor*; inner lagoon reef zones held mostly *P. versicolor* and *P. ornatus* with outer slope sites composed equally of *P. versicolor* and *P. cygnus* (Fig. 8a-d).

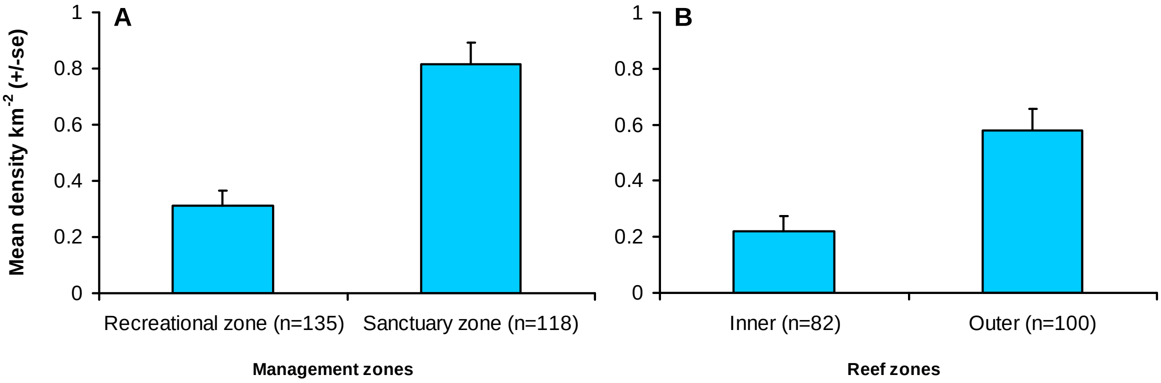

Figure 7a-b: Comparison in the mean densities of lobster numbers km^{-2} (±se) for a) management zones, and b) reef zones. Sanctuary zones supported higher densities overall, as did outer slope reef sites. However, only Management zones were statistically different ($p<0.05$) despite the large differences in reef zone means. Central Cloates data has been removed from the figures and the analyses to provide a more realistic and general assessment of patterns in the Ningaloo Marine Park. For the reef zones, only AIMS data was used so the total number of transects is lower. This is because the actual location of CSIRO transect's in relation to inner and outer reef zonation was difficult to determine accurately based on mapping latitudes and longitudes.

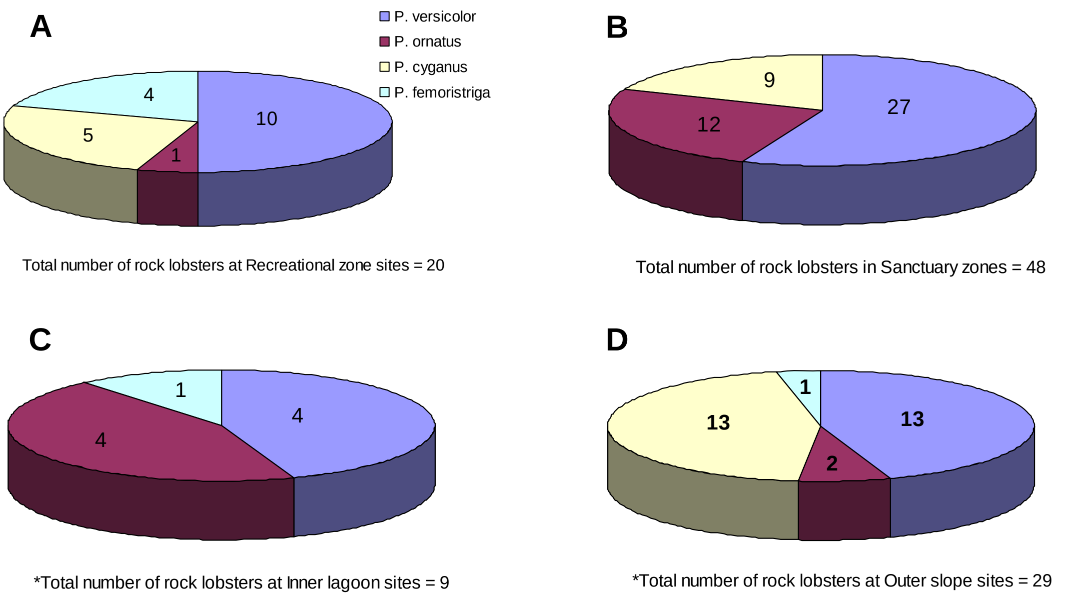

Figure 8a-d: Percentage breakdown comparison in the mean density of lobster species km^{-2} for; a & b) Management zones, and c & d) Reef zones. Numbers of individuals are given within the pie slices, total numbers given at bottom of each pie chart. Data presented is minus Central Cloates data for consistency. Total numbers marked with an * indicate AIMS only data (see caption in Fig 6 for explanation).

Trends in relation to habitat characteristics

The range of habitats surveyed at Ningaloo varied widely both geographically and between different reef zones (Fig. 9a-e). Considering the extremely low abundances and patchy nature of the lobster distribution at Ningaloo Reef, habitat correlates may be a particularly important component in deciphering distributional correlates. The Western Rock Lobster (*P. cygnus*) identifies most strongly with seagrass and boulder / reef ledge areas, particularly at inner lagoonal sites (Fig. 10). The tropical lobster (*P. versicolor*) favours outer slope sites where bommies with a high presence of both hard and soft corals exist. These areas are generally further characterized by a high degree of topographic relief (i.e. spur and groove reef valleys and crests) where consolidated and non-consolidated rubble accumulates as a result of high wave energy. Patterns of habitat characterisation in the two remaining species (*P. ornatus* and *P. fermoristriga*) were not as definitive. Both species were equally present at inner lagoonal and outer slope sites where varying combinations of algae, sand, live and dead hard coral is found. These sites tended to be calmer and less topographically complex than those typical for *P. versicolor* and were usually a mosaic of patch reefs separated by sandy areas (see Fig. 9a). In fact, the ANOSIM analysis identified "sand" as the only habitat correlate to be statistically significant (i.e. stand out on its own in relation to lobster / habitat relationships). Location drivers for the tropical lobsters (*P. versicolor* and *P. ornatus*) are predominantly in the northern and central sections of the NMP. In contrast, the Western Rock Lobster (*P. cygnus*) was found exclusively in the southern and (particularly) central sections of the NMP (e.g. old sanctuary Central Cloates area). This is of interest because the current accepted boundary for the Western Rock Lobster is North West Cape 50 km's north (e.g. Dept. Fisheries WA Fact Sheet 11).

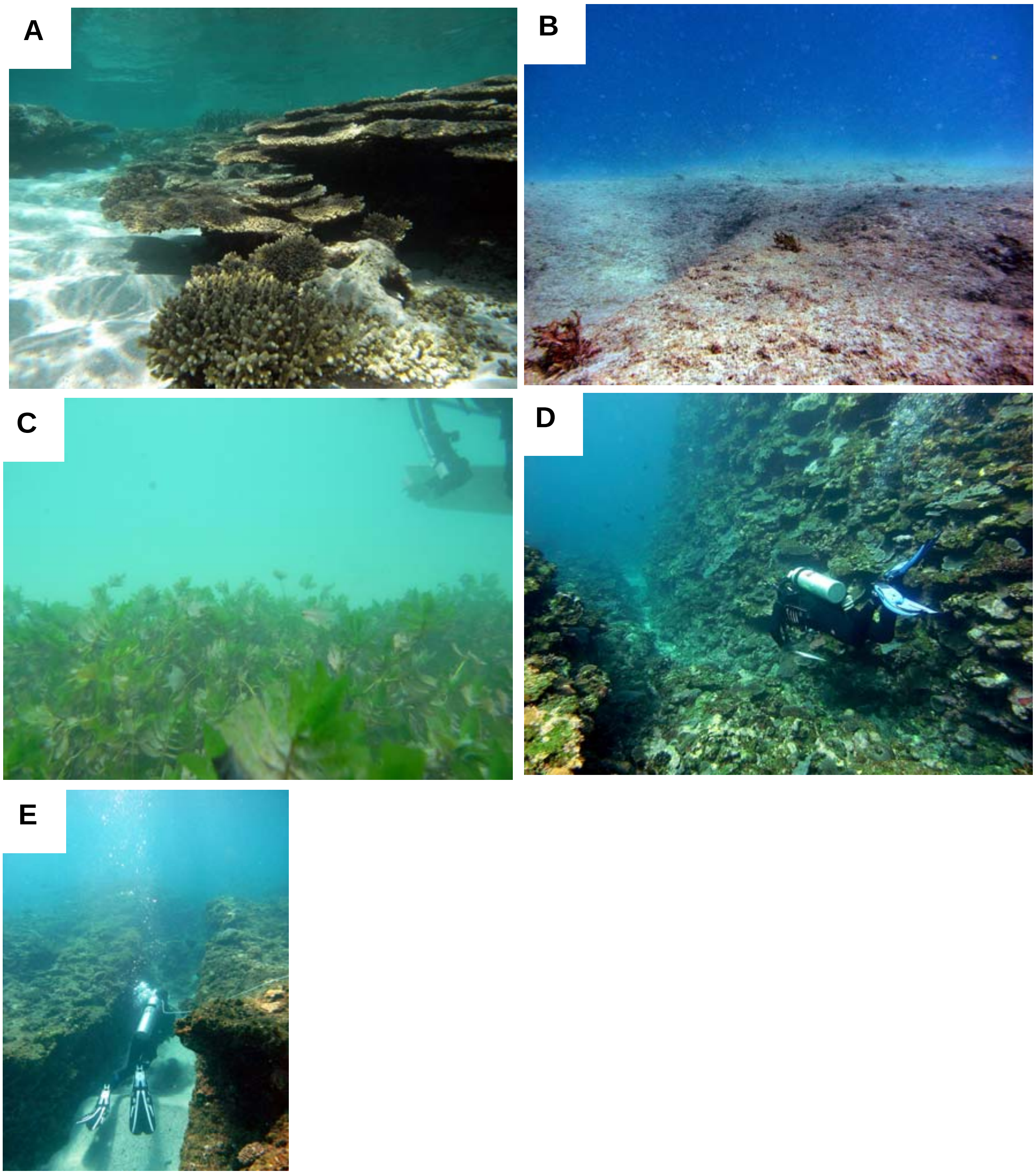

Figure 9a-e: Image series illustrating the range of habitats encountered and censused at the Ningaloo Marine Park including a) lagoonal coral reef, b) outer slope flat reef pavement, c) algal & seagrass beds, d) outer slope coral reef and e) outer slope spur & groove ledges.

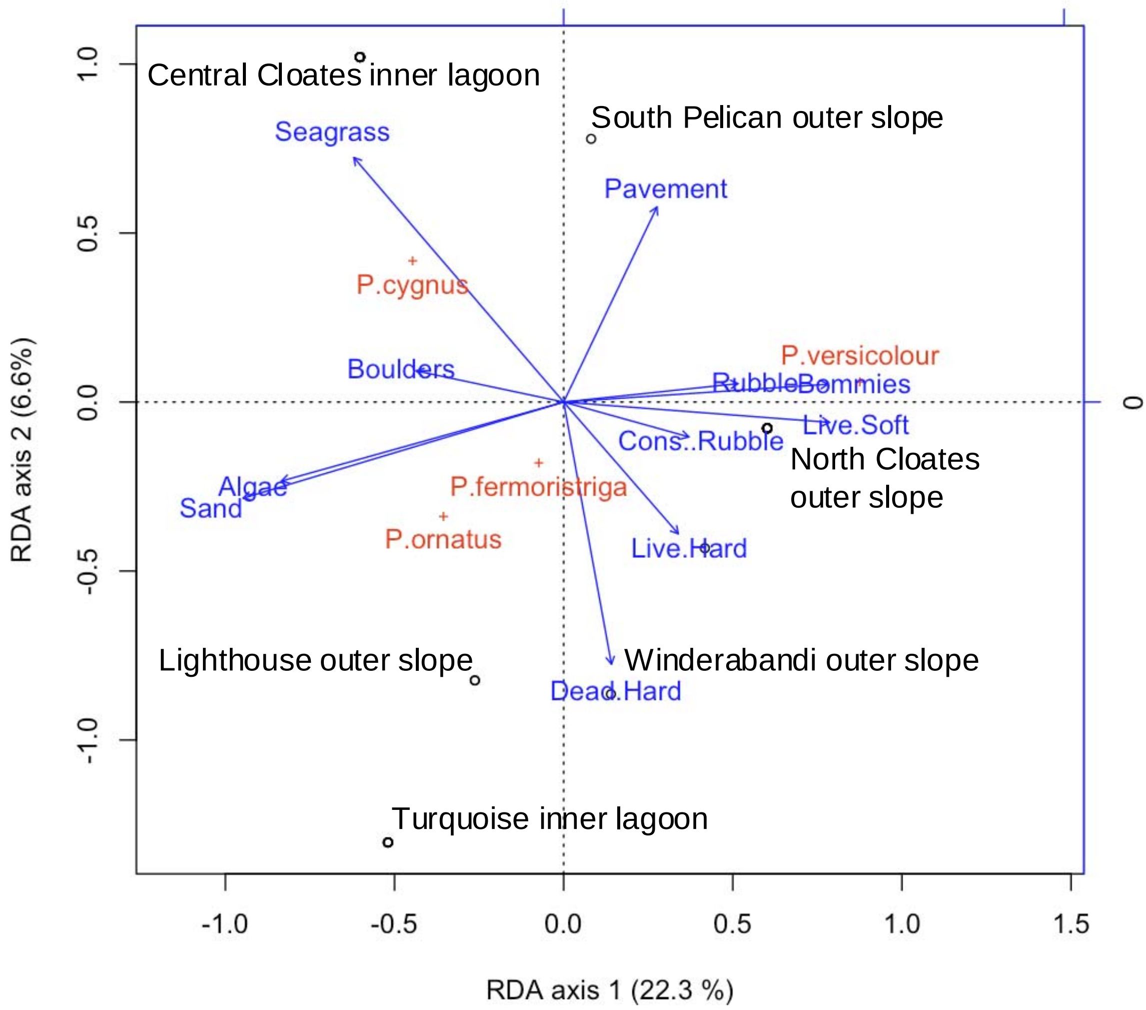

Figure 10: Canonical redundancy analysis (RDA) displaying the relationships between the four lobster species and respective habitats. Locations which strongly influenced the outcome of the analysis are marked within the plot. Analysis includes all AIMS and CSIRO surveys including Central Cloates data as the biplot demonstrates the relationships between lobsters and habitats. Permutation ANOVA (ANOSIM with 999 permutations) indicated no significant differences exist between habitat types and lobster abundance (for any species).

Trends in relation to visitor access

Some patterns emerged between lobster abundance and proxies of visitor access. Firstly, for the 39 transects where lobsters were actually present, lobster abundance decreased where access to the sites was greatest (i.e. many access points to a site) (Table 2). Secondly, sites where lobsters were found had the following geographic characteristics; 1) access points in close proximity, 2) were close to a road centreline, and 3) were close to a known place name. In summary, there was a high level of accessibility in areas where lobsters were found in any abundance.

Table 2: Results of the two-stage zero-inflated generalized linear model indicating; a) for sites where lobsters were found (n=39), abundance was significantly correlated to all variables, and b) lobster presence/absence was not related to any of the observed variables.

A) Lobster abundance model (n=39)

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	2.03E+00	2.44E-01	8.33	< 2e-16	***
nearest road	-4.69E-04	6.17E-05	-7.595	3.08E-14	***
access density	-9.83E+00	2.69E+00	-3.66	0.000252	***
nearest access point	4.40E-04	8.21E-05	5.361	8.28E-08	***
nearest place name	-1.05E-04	4.21E-05	4.982	7.10E-07	***

B) Zero-inflation presence/absence model (n=265)

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	1.49E+00	1.52E-01	9.821	<2e-16	***
nearest road	-2.17E-04	2.12E-04	-1.019	0.308	
access density	-3.37E-01	5.54E+00	-0.061	0.952	
nearest access point	1.55E-04	2.95E-04	0.525	0.6	
nearest place name	8.12E-05	1.36E-04	0.381	0.84	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Historical comparisons

Documented exploitation of Ningaloo lobster species since 1933 (Halkyard 2005) indicated abundant populations there in the past. A commercial licence was granted to Nick Farinaccio and his team of divers in the 1960's with qualitative evidence suggesting rapidly declining numbers in the late 1970's and early 1980's. Particularly during the earlier years, estimated catches of approximately 100 kgs / day were commonplace in areas of approximately 1 km^2 (see appendix B) with up to 340 kg taken in 2.5 hours over 100m of reef on at least one occasion (Mack 2003). This equates to 3.3 commercially-sized lobsters for every metre of reef in optimal habitat. Commercial operations would take place in a 6-month period from March-August and only within the calmer lagoonal waters within 6 km from Waroora Station to Cape Farquhar. Assuming the average weight of lobsters at the time (approx 1 kg / individual), a 2 x 2 man team and a 6 day working week, the potential numbers of individuals taken over a single year is a conservative 27,600 (100 individuals x 138 days x 2 teams of workers). Although these estimates are qualitative in nature, the various reports corroborate well with each other. Comparisons with published studies on lobster species suggest mean densities of this magnitude are not uncommon (Joll & Phillips 1984; Zieglar et al. 2002).

3.4 Discussion

General, habitat and geographical trends

The condition of the current lobster population at Ningaloo can only be described as very poor when compared with past historical data and other comparative reef systems. Although the strength of our analyses were hobbled by the lack of lobsters and subsequent number of zeros in the data set, four general trends were obvious. Firstly, Central Cloates is an area of high importance for the remaining Western Rock Lobster stocks of the marine park. Secondly, there is a general decline in tropical lobster numbers (*P. versicolor* and *P. ornatus*) as you travel southwards along the Park. Thirdly, there is a high degree of variation among locations of even quite similar habitat composition which probably best demonstrates the patchy nature of their distribution. Fourthly, it appears that (at least) older sanctuary zones hold statistically higher densities and they may be conserving the remaining lobster populations at Ningaloo.

Mean densities at Central Cloates are an order of magnitude higher than those at nearly all other locations with nearly half of all lobsters counted found in 12 of 265 transects. The Central Cloates location is in the middle of the largest sanctuary zone the Ningaloo Marine Park (NMP) currently has and, in contrast to many other areas of the Park, this study's sampling sites at Jane's Bay have been protected since 1989. Additional factors may contribute to reduced pressure in this location. The area is quite remote, with access strictly controlled by Ningaloo Station caretakers. Campers at Jane's Bay are largely made up of long term camping retirees (the so-called Grey Nomads) and these visitors may spend less than average time in the water. Habitat characteristics are also optimal for Western Rock Lobsters with many limestone ledges available within algal- and seagrass-dominated areas. Finally, the bay area just south of Point Cloates (Jane's Bay) has some interesting oceanographic characteristics that may enhance or facilitate retention of juveniles and/or larval recruitment processes for lobster species. A substantial eddy slewed off from the southward flowing Leeuwin Current circulates substantial amounts of water eastward in an anti-clockwise direction and into the northward flowing Ningaloo Current (Taylor & Pierce 1999). Exactly what this means in relation to adult stocks is currently unknown but the interesting oceanography may be a contributing factor in Western Rock Lobster Densities at Jane's Bay. Taken together, these conditions provide the best possible combinations for Western Rock Lobster populations. Because of these rare set of characteristics, Central Cloates currently provides the most sensitive indication of future trends in the NMP's Western Rock Lobster population and ongoing protection and monitoring of this area is paramount to detecting increases or decreases of this iconic Western Australian species. Future monitoring to incorporate not only abundance and densities, but expansion of their distributions and any increases in species diversity is recommended.

The abundance of the two tropical lobster species declines rapidly from north to south, however, this trend is somewhat similar to that of the Central Cloates Western Rock Lobster population in that isolated pockets of higher densities exist in and around North West Cape (*P. versicolor* mostly), and to a lesser extent Mandu and Osprey Sanctuaries (*P. ornatus* mostly). An area with high visitor access, North West Cape and, in particular, the Lighthouse Sanctuary Zone area contains habitat that is topographically complex and contains plenty of sheltered sites for lobsters. The area also hosts a number of well serviced dive sites and policing of this area by the local dive industry would help ensure compliance of this new sanctuary zone. The outer reef slopes at Mandu and Osprey Sanctuaries are also topographically rugged areas and appear to be current hotspots for *P. ornatus*. The general habitat structure and types of visitors in the southern section (14 Mile Beach to Red Bluff) change remarkably from that of the central and northern sections. Visitors in the southern section of the NMP are generally watermen and women that visit the Park for the sole purpose of getting into the water (e.g. surfers and spear-fishermen). From Waroora Station south to Red Bluff the lagoon quickly disappears and divers have direct access to topographically complex habitat from the shoreline to reef slope. Although speculative, the accessibility of this general aquatic area to these visitors may be a contributing factor to the current densities found in the southern section of the NMP.

It is clear that the distribution of lobsters is extremely patchy at all spatial scales examined and that this is most likely a combination of optimal habitat availability being patchy, and past and present fishing activities. For example, a single transect at Central Cloates yielded 17 individuals, 13 of which were found under a single ledge 5m long (see Fig. 4a) and 226 of the 265 transects yielded no lobsters at all. Localized pockets where habitat variables appear to be ideal and the locations remote tended to support the highest densities. Comparisons with other reef systems indicate that the carrying capacity of unexploited Western Rock lobsters is typically 60-150 / km^2 for juveniles (Joll & Phillips 1984) and 70 / km^2 for adult densities (Babcock et al. 2007) in other Western Australian locations. In comparison, the NMP population averaged one individual / km^2 for all four species combined. It must be noted that the random sampling design necessary to quantify patterns across all of the NMP will always result in low overall densities in any organism that has strong clumped patterns of distribution. No doubt, selective effort in areas of optimal conditions would have provided higher densities (e.g. density patterns at Cloates) but not a realistic view of the NMP.

Although low numbers restricted the potency of our analyses, habitat associations for species are nonetheless strong. As any lobster fisher worth his salt will tell you, lobsters require as a minimum hard substratum for shelter and this is best provided by overhanging coral and / or rock ledges. As such, habitat is a critically important consideration in effectively managing the lobster populations at Ningaloo. Our results suggest that, in combination with some degree of shelter, the Western Rock Lobsters (*P. cygnus*) tended to be found in lagoonal seagrass areas; *P. ornatus* equally in lagoon and outer slope locations in combination with live hard and dead coral; and *P. versicolor* on outer slopes where live hard and soft coral cover features quite strongly. Considering these are the three most abundant species found in the Park, the diversity of habitat preferences indicates that effective management of NMP lobster populations needs to encompass the protection of all of the above habitat types to effectively conserve these animals.

Trends among Management and Reef zones

Sanctuary zones held significantly higher mean densities of lobsters than non-Sanctuary zones even with the exclusion of Central Cloates inner lagoon data. Although we can take heart from this, results pointing to the effectiveness of these no-take zones need to be interpreted with caution in relation to lobsters. Sanctuary zones are often chosen based on the context of "maximum habitat heterogeneity" (i.e. areas of maximal topography) because this is typically where numbers of species and individuals are highest (but see Mayfield et al. 2005). Because of this, these high relief areas also provide the most shelter per unit area, a serious consideration for lobster survival and hence observed patterns of distribution. In addition to this, sanctuary zones are often placed in the more remote and least visited areas of marine parks as these are the least politically sensitive areas. Nevertheless, sanctuary zones have proved effective in protecting lobster populations in other locations (see Babcock et al. 2007; Rowe 2002; Kelly et al. 2000).

For reef zones, outer slope reef zones held higher mean abundances than inner lagoonal zones although this was not statistically significant. Possible reasons to explain this pattern include; 1) the lower intensity of past and present fishing activity in these exposed and comparatively deeper, more remote areas, 2) the presence of the tropical lobster *P. versicolor* to these areas, 3) increased topographic complexity of outer slope sites, and 4) the increased water movement found on the outer reef.

Trends in relation to visitor access

For the 39 out of 265 transects where lobsters were actually found, abundance tended to decrease with increasing levels of visitor access. The outcome of this analysis needs to be interpreted very cautiously for a number of reasons (see Materials & Methods above). However, what this analysis suggests is that the remaining lobster population in and around major areas of activity remains at higher risk of further declines from recreational fishers/divers. Or to put it another way, lobster abundances around areas of high visitor access would have been greater in the absence of fishing. How many more lobsters would there actually be in these high access areas in the absence of fishing is the real (unanswerable) question. Do these areas represent prime lobster real estate and many are being taken by the recreational fishing community, or are they having a negligible effect on the population overall?

Conclusion

It seems clear that the current lobster numbers at the NMP are a shadow of their former self and the potential carrying capacity. A highly profitable fishery existed here for more than a decade before becoming uneconomical. Since then, the rapid increases in visitors, many of whom are accomplished fishers, may have suppressed the already dwindling population to the point that increases in population size are unlikely under current regulations that allow extraction. Under this scenario and given the life history of lobster species, increases in population size may take at least a similar amount of time to increase in abundances that is quantitatively detectable with any increase heavily reliant on compliance. Detection of increases in lobster numbers should manifest themselves in density increases, territory expansions and a recolonisation of other areas which currently do not appear to support a lobster population.

B. Octopus

3.5 Introduction

Octopus are exclusively marine organisms that are found in all the world's oceans and environments (Norman 2000). Existing in tropical to polar waters, octopus are without exception carnivorous benthic predators that have a long and successful evolutionary history and, as both predator and prey, form an intricate part of ecosystem food webs (refs). Octopus have been very successful colonisers of coral reefs and have evolved very successful techniques to avoid predation and hunt down a large range of available prey (refs). On Ningaloo Reef, octopus are readily sought after for use as bait in the recreational fishery. This is not only because they make attractive bait for pelagic and reef fishes, but because of their excellent retention on bait hooks. As such, they are readily fished from the inter-tidal shores of Ningaloo using small hand spears. However, there is currently no information on their numbers, patterns of distribution or their vulnerability to exploitation. This is somewhat worrying considering their intricate links within coral reef ecosystems as both predator and prey for a wide range of organisms and the fact that there is currently no regulations or protection of Ningaloo octopus populations.

Although octopus taxonomy is somewhat in need of revision with many new species still being discovered, images were taken of the octopus species on Ningaloo reefs and sent to one of Australia's leading experts, Dr Jayson Semmens at the University of Tasmania. Semmens indicated that the common Ningaloo species is *Octopus cyanea*, a widely distributed Indo-West-Pacific tropical octopus that can grow to 80cm and is found on coral reef systems from Hawaii to East Africa (Norman 2000). *O. cyanea* is often harvested by artisanal and subsistence fishers in developing countries because of its apparent abundance, large size, diurnal habits and shallow water distribution (Norman 2000, Guard & Mgaya 2002). The species is readily recognizable by the paired ocelli found on its trunk just above the arm bases and the broad black horizontal stripes on the rear sides of each arm (Norman 1991). The species feeds on a range of foods readily found on tropical reefs including crustaceans (particularly xanthid crabs), bi-valves, gastropods and fish (Forsythe & Hanlon 1997). In turn, tropical octopus have been found to constitute a significant proportion of the diets of some sharks, seals and reef fishes (Tricas et al. 1981; van Heukelem 1983; Goodman-Lowe et al. 1999; White et al. 2004; Taylor & Bennett 2008). This involvement in reef food chains as both a predator and prey species indicates a tight and intricate association in coral reef food webs and it is unclear whether they are under pressure from the harvesting that takes place at Ningaloo Reef.

In addition to *O. cyanea*, two other octopus species have been sighted at Ningaloo Reef, although only a single specimen of the first and two individuals of the second species were sighted and photographed (Fig. 11a-c). The first (unidentified) species was photographed on open sand in approximately 5m of water in the Coral Bay area by Frazer McGregor from the Coral Bay Research Station (Fig. 11c); the second was photographed on inter-tidal reef flats around the 13 Mile Beach / Waroora Station area by the author and is identified in Norman (2000) as *Hapalochlaena* sp. I; better known as one of six Blue-ringed Octopus species found in the Indo-Pacific area.

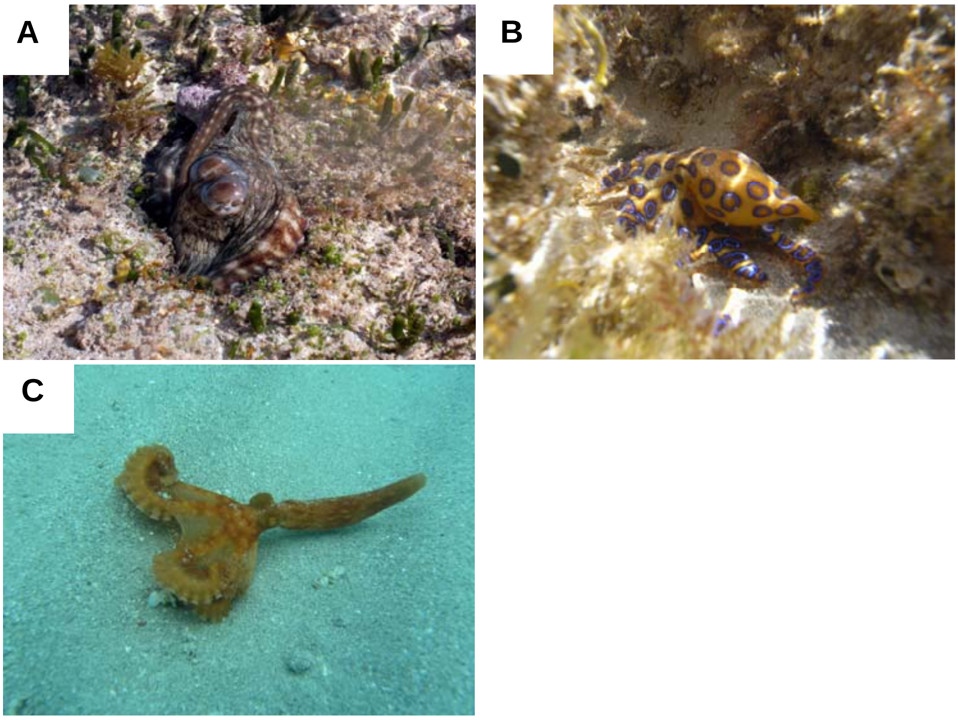

Figure 11a-e: Octopus species of Ningaloo Reef; a) *Octopus cyanea* – by far the most common species of octopus found at Ningaloo Reef, b) *Hapalochlaena* sp. 1 – one of six species of Blue-ringed octopus found in Australia, and c) an unknown species found swimming across the lagoon near Coral Bay (image supplied by Frazer McGregor).

3.6 Materials & Methods

Pilot study

A pilot study was undertaken to determine the best possible method for sampling the octopi of the NMP. Three methods were assessed; traps (passive and attractant models), night lights and underwater/inter-tidal visual transects. In addition to these quantitative methods, opportunistic semi-structured interviews with local residents were undertaken on an opportunistic basis, providing some qualitative data.

Three different octopus trap types, developed for commercial use by the Fremantle Octopus Company were trialed; LCD, cement and PVC types (Fig. 12a-c).

Figure 12a-c: Octopus trap types deployed during pilot study; a) LCD, cement and PVC trap designs, b) LCD trap configuration. Note the two traps outside have trap doors shut, the middle one has its LCD light flashing and c) the LCD light used in the trap which flashes every 5 secs.

A suitable reef site where octopus were confirmed to be present was found to deploy the traps. In total, 3 sets of 3 LCD, 20 cement and 40 PVC traps were randomly deployed over a continuous inner reef providing a total of 69 traps in all (Fig. 13a-c). Setting, deployment and retrieval of traps followed the same techniques as those used by professional octopus fishermen as determined by a previous field trip undertaken on a commercial octopus boat.

Figure 13a-c: a) Representative image of the reef type where octopus traps were deployed, b) octopus hiding in natural hole on target reef, and c) cement and PVC traps attached to long-line on seabed.

All traps were deployed on the 8th July 2008 and retrieved on the 17th July 2008 providing a soak time of 10 days. Cement and PVC traps were attached to a long-line using shark clips at 5m-7m intervals (see Fig. 13c). LCD traps are cradled within a steel frame in groups of three and were deployed on the same reef as PVC and cement traps. Video and still photographs were taken immediately following deployment to ensure correct setting of traps before being left undisturbed until retrieval. Retrieval of traps took place at roughly the same speed as that observed on commercial octopus boats. Following retrieval, traps were redeployed at another continuous reef site where octopus were confirmed present and left until the 5th September (51 days). This provided two very different soak times (10 & 51 days) allowing future comparison.

Two more methods were assessed for their potential to accurately assess the octopus population of the NMP. Firstly, lights (torches and red and green Cylum Glow Sticks®) were placed and left underwater for 30 minutes at a known octopus site (North West Cape) 10cm above the substrate as a possible night-time attractant. Together, these provided 3 different light colours (white, red and green) with each illuminating an area of roughly 1.5m in diameter and able to be seen at a distance of at least 500m by a human eye. Secondly, shallow (< 2m) and deepwater (> 2m) transect surveys were undertaken on SCUBA (> 5m depth) and snorkel (2-5m) and inter-tidal (<2m) surveys were done using viewfinders where the tide covered the reef and visual at lower tides (Fig. 14a-d). Transect size for SCUBA/snorkel surveys were 5 x 100m and conducted in conjunction with lobster surveys. Transect width for inter-tidal surveys were determined by the reef worker comfortably sweeping the viewfinder across the substrate. Distances were calculated using hand-held GPS. Two x 50m transects were determined to provide the best coverage of sites using this technique and inter-tidal habitats were chosen by driving the length of Ningaloo and sampling when suitable habitat was found (i.e. hard reef substrata) (Fig. 15a-d). Full details of all sites surveyed and their geographic locations are provided in appendix C.

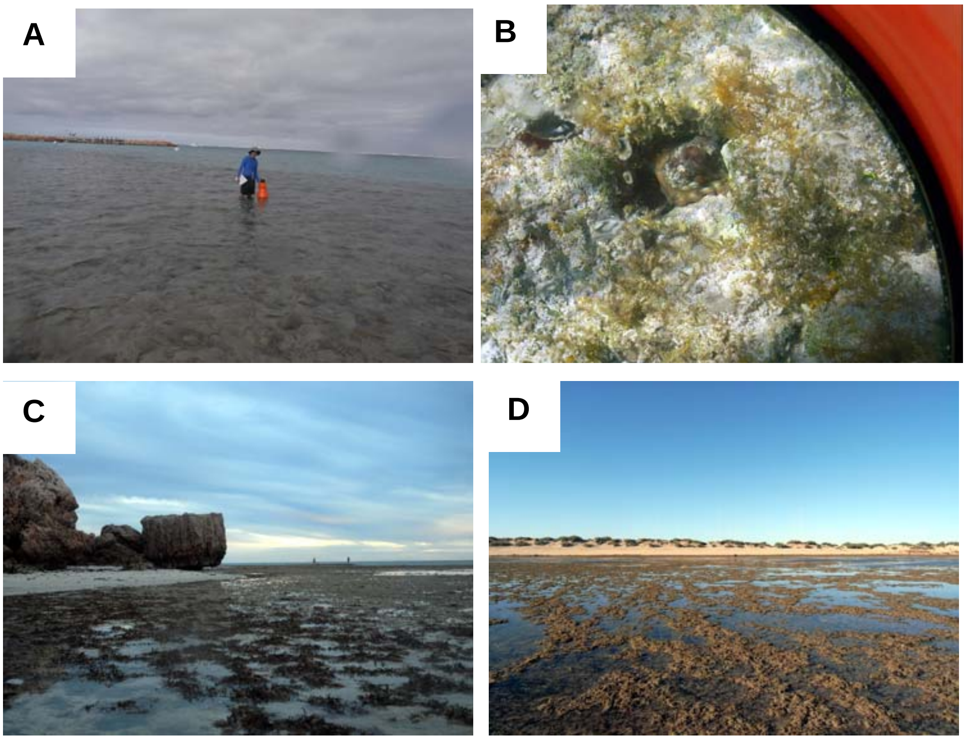

Figure 14a-d: Octopus transect surveys at a) mid to high tide using viewfinders, b) *Octopus cyanea* seen through viewfinder, and low tide examples of the reef flats at sites near, c) 14 Mile Beach in the central section of the park, and d) site near Mildura Wreck in the northern section of the Ningaloo Marine Park

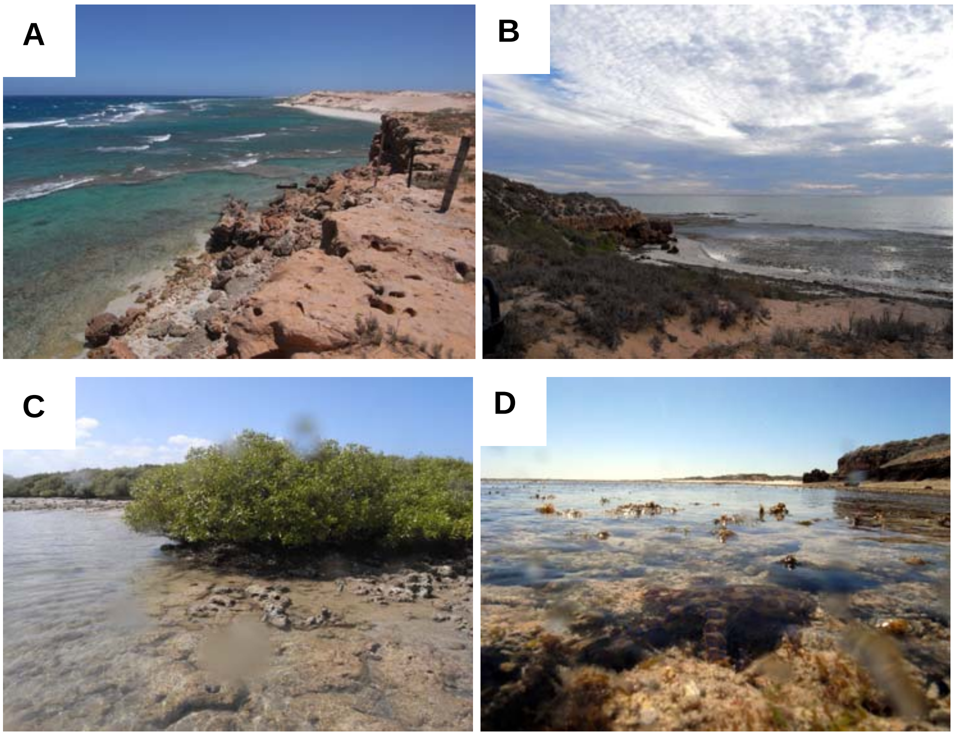

Figure 15a-d: Examples of habitats surveyed during octopus surveys, a) Warroora Station northern border area at mid-tide, b) Turtle Rock near 14 Mile Beach at low tide, c) Mangrove Bay area at low tide, and d) Pelican Point at mid tide with Blue-ringed octopus in foreground

Exploratory analysis & statistical design

Statistical comparisons in mean octopus numbers were impossible even for non-parametric techniques due to the nature of the data (so few octopus in transects). However, the following exploratory figures based on mean densities were generated for both sub- and inter-tidal transects to identify areas of the marine park that contain octopus; 1) the northern, central and southern sections of the NMP, 2) the 15 (sub-tidal) and 10 (inter-tidal) locations. In addition, octopus densities between sub- and inter-tidal transects are also presented. However, exploratory figures for sanctuary and recreational zones were not because many of these sanctuary zones are zoned “special purpose” where beach fishing is permitted. Although spearing in these special purpose fishing areas is illegal, this is a preferred method adopted by recreational fisherman searching for octopus bait. Indeed, members of the public were often seen during the course of this study searching for octopus with gidgees (Fig. 16a-b). This was particularly apparent on low tides in the area known as “Occy Beach” by locals (reef flat at Mildura Wreck near Exmouth) and 14 Mile Beach campsite (near Warroora Station).

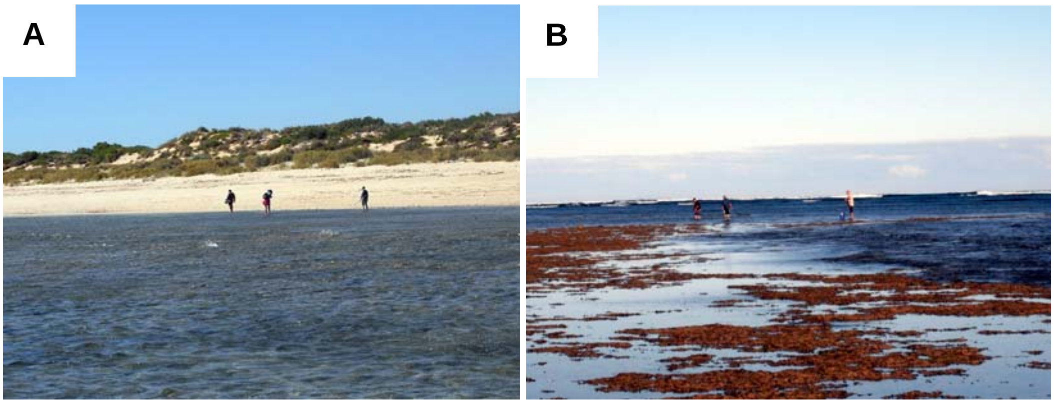

Figure 16a-b: Recreational bait fishermen fishing for octopus with gidgees at Lighthouse Sanctuary Zone (near Mildura Wreck) in a) July and b) December. The area is designated a “special purpose (shore-based fishing) zone”. Fishing is allowed but spearing is illegal

3.7 Results

No octopus were captured in any of the three trap types deployed over either 10 or 51 day soak times despite the obvious presence of octopus in the deployment areas (see Fig. 13b). Although a very successful technique for *Octopus tetricus* in and around the temperate waters of Perth, the complete absence of octopus in Ningaloo traps can probably be accounted for by the fact that there are adequate natural shelter holes on Ningaloo Reefs and / or the ecology of *O. cyanea*. The traps deployed over the temperate waters off Perth are laid over sea-grass beds on sand, a homogenous habitat which offers comparatively little natural shelter or dens. In comparison, the reefs of Ningaloo offer a more heterogeneous habitat with many (up to 8m-2) natural shelter holes within the reef matrix that could easily be occupied by octopus.

Attractant lights (both torches and Cylum Glow Sticks®) at night time were also unsuccessful in enticing octopus to the lit area, however, transects on SCUBA (> 5m), snorkel (2-5m) and using a viewfinder (< 2m) proved more successful in locating octopus. Nonetheless, octopus are notoriously difficult to see even under the best of conditions due to their cryptic colouration and behaviour. Where sighted outside their dens, octopus were generally quite apparent, often out in the open or outside their dens on reef pavement. These individuals rarely attempted to move, instead remaining motionless and blending in with their environment (Fig. 17). However, there is no way to know how many are missed on these surveys when they are deep in their dens. Nonetheless, relative measures of these animals are possible for different sites enabling identification of areas of high density. In addition, this project has stimulated a further study started in June 2009 by a UWA Honours student (Jade Herwig). This work, currently underway, will provide valuable insights into the vulnerability of Ningaloo *O. cyanea* populations based on their life history characteristics.

Figure 17: Demonstration of the camouflage abilities of *Octopus cyanea* on the reef flats at Ningaloo.

In total, 15 octopus individuals were seen over a total area of 132 km^2 (13.5ha) for the sub-tidal SCUBA and snorkel transects and 13 octopus over a total area of 1.45 km^2 (1.48ha) for the inter-tidal view-finder transects. This provides means of 1.86 octopus km^2 overall with means of 0.11 km^2 for sub-tidal and 8.9 km^2 for inter-tidal areas. The other observation of note is the large standard errors associated with all the figures indicating the extremely patchy nature of octopus distribution at all relevant spatial scales in the NMP (Figs. 18a-b & 19a-b).

Sub-tidal surveys

Sub-tidal surveys were very depauperate overall, however they seemed to show a higher degree of consistency in densities both between sections (Fig. 17a) and locations (Fig. 17a) than inter-tidal surveys. The Southern section followed by the Northern and Central sections of the NMP held the highest densities but these were still very low in comparison to inter-tidal areas. Sub-tidal locations showed the South Pelican and Turquoise Bay areas to have the highest densities with Winderabandi, South Cloates, Bateman Bay, South Maud, Cape Farquhar and Gnaraloo recording zeros for all transects.

Inter-tidal surveys

Overall, the inter-tidal surveys contained higher numbers than did the sub-tidal (Fig. 18a-b & 19a-b). The Northern section clearly had the highest density of octopus followed by the Southern section. There were no octopus found in the Central section. Even though the Northern section held the highest densities, these were still a paltry 1.2 individual's km^{-2}. For the inter-tidal locations, North-West Cape, the most extreme northerly point surveyed during the study held the highest densities by far with more than two individuals km^{-2} followed by the most extreme southerly location, Turtle. The only other location where octopus were present was Jurabi in the Northern section of the NMP.

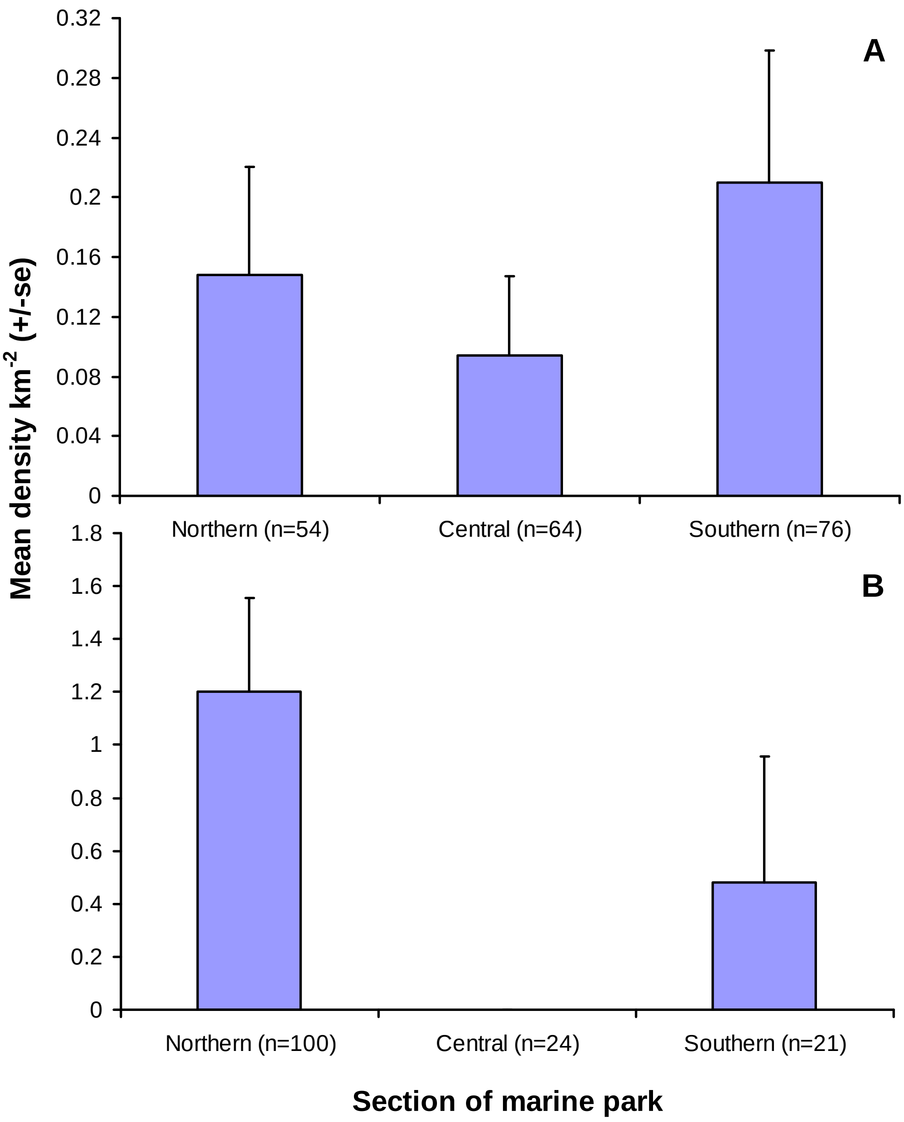

Figure 18a-b: Comparison of mean densities in km^{-2} (+/-se) of octopus between the three sections of the NMP for A) sub-tidal, and B) inter-tidal areas. Note the different values on the y-axes. Inter-tidal areas (B) generally had 3-7 times more octopus than did sub-tidal areas with the exception of the central section where there were no octopus present. N values equate to the number of 5 x 100m sub-tidal (A) and 2 x 50m inter-tidal transects (B).

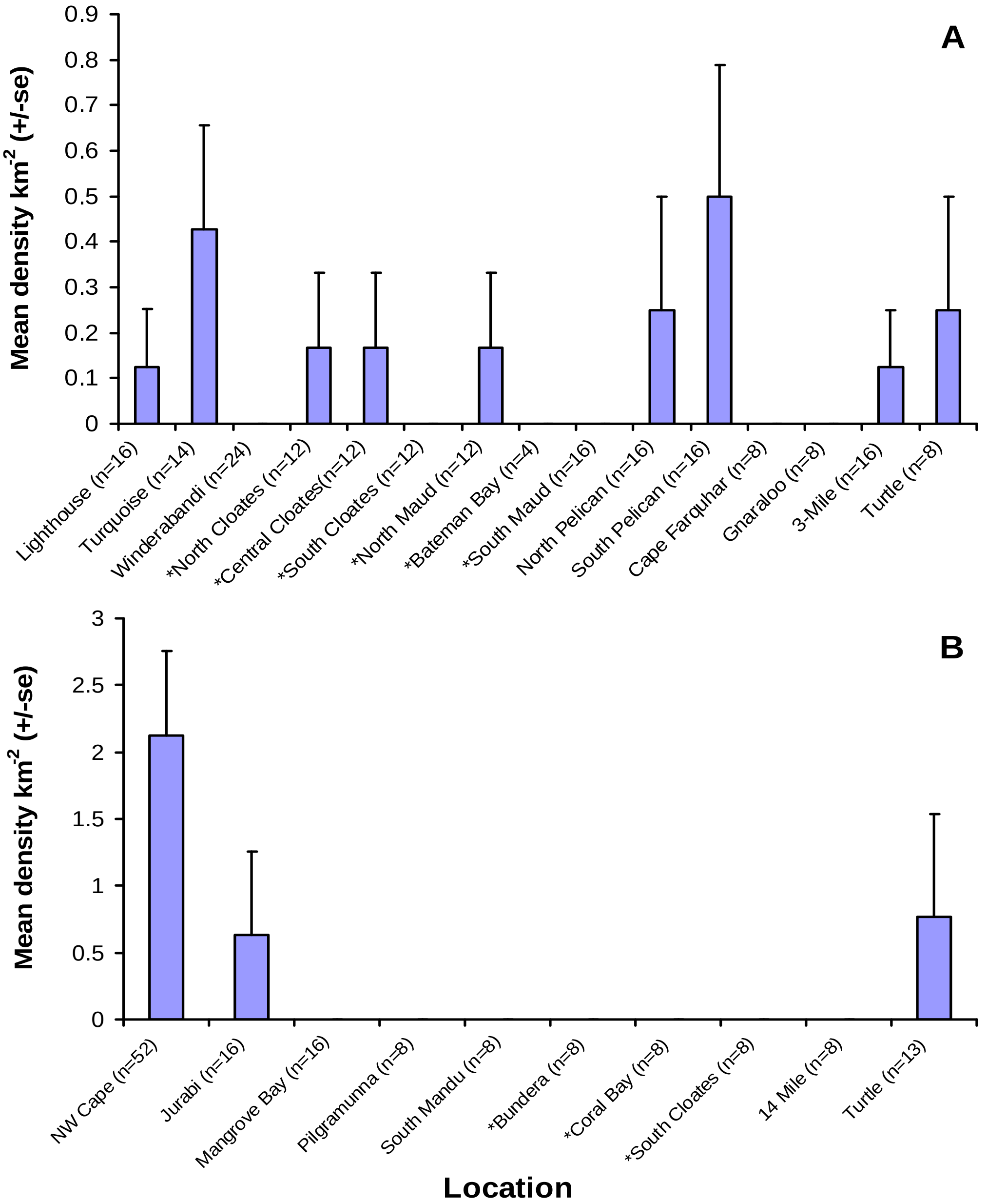

Figure 19a-b: Comparison of mean densities km^{-2} (+/-se) of octopus between the various locations surveyed in the NMP for A) sub-tidal, and B) inter-tidal areas. Note the different values on the y-axes. N values equate to the number of 5 x 100m sub-tidal (A) and 2 x 50m inter-tidal transects (B). Locations are ordered from north to south (left to right) with those that fall into the central section denoted with an asterisk, north and south sections in regular font.

3.8 Discussion

The most striking picture to emerge is the degree of patchiness in the densities of octopus at all the spatial scales examined. Possible causes to explain this include a number of causative and non-exclusive factors; 1) octopus are particularly cryptic animals that are also often deep inside their dens and many were missed on the surveys, 2) there is a unique and refined set of habitat parameters that are essential to octopus habitation and these are only found in a few areas of the NMP, 3) *Octopus cyanea* are a merobenthic species (i.e. spend a significant amount of their larval development in the open sea as opposed to holobenthic octopus species without a pelagic larval phase) indicating that patterns of recruitment may be highly variable over space and time, and 4) recreational fishing for octopus has had a significant influence on patterns of distribution.

It is interesting that inter-tidal areas appear much patchier than sub-tidal areas where octopus fishing would be non-existent. Even though the lower number of replicates at most inter-tidal sites and smaller transect sizes may account for some of this discrepancy, it seems plausible that recreational fishing of octopus may be having a significant impact on patterns of distribution and densities. We do not know if suitable habitat and dens are a limiting factor determining the densities of these animals at the various locations. Certainly, not all holes in the reef were occupied. Locations were stratified by habitat type but this is a gross measure to standardize data gathering at various sites. There may be more fine-scale differences in habitats that play an important role in patterns of distribution and abundance. Again, like the lobsters, selective effort would have produced higher densities but not provided a realistic stock assessment of octopus densities throughout the marine park. Although habitat data was gathered in tandem with transects, the lack of useful density data precludes any analyses using habitat as a correlate. Den availability, size and whether they still retain water at low spring tides are all important considerations for octopus, as is food availability at each of the various sampling sites. One way of assessing whether suitable habitat is a limiting factor would be to gather information on the recolonisation of octopus dens following the removal of residents. Another would be to study rates of replenishment via life history studies focusing on age at first maturity, timing of reproduction and recruitment, speed of growth and rates of natural mortality. What we can say from this limited data is that their patchy nature and limited occurrence overall suggests that they are probably quite vulnerable to episodes of localised short-term extinction and the lack of life history information provides a high degree of uncertainty over their sustainability as a recreational bait fishery at Ningaloo.

The carrying capacity of *O. cyanea* on the reefs of Ningaloo is difficult to estimate, because without management protection of the species the possible densities that protected habitat could sustain cannot be determined. Not having an unexploited "natural" population at any site where there are decent numbers severely hinders a lot of research on the species. Natural patterns of distribution, densities, sex ratios, age at maturity, rates of mortality and seasonal patterns of recruitment are all compromised with a fished population, making it difficult to define their natural rhythmic patterns of abundance for the NMP. Studies elsewhere have shown that *O. cyanea* is abundant enough to support artisanal and subsistence fishing in parts of Africa (Guard & Mgaya 2002), Asia (Norman & Sweeney 1997; Norman 2000), the Hawaiian (van Heukelem 1973) and Pacific Islands (Norman 2000). Based on the surveys, the current numbers at Ningaloo would not support even a small artisanal fishery, an indication that densities are much lower at Ningaloo than in other tropical reef areas. However, whether this is a natural attribute of the NMP or one caused by recreational fishing is impossible to tell without access to an unexploited population. Although the significance of *O. cyanea* to the NMP can be defined by their value to recreational fishers, we also know that cephalopods form an important part of many marine foodwebs by virtue of their role as both predator and prey (Clarke 1996, Cherel & Hobson 2005). Ecologically, their value and significance to the Ningaloo system can therefore also be viewed by the number and closeness of their links to other reef organisms, their intrinsic rate of increase over time (i.e. energy brought onto the reef measured as reproduction and growth) and their population densities.

Anecdotal accounts from reliable witnesses around the 14-Mile Beach area south of Coral Bay indicate that recent past fishing of octopus has taken place on a semi-professional basis. This area has quite a few somewhat remote inter-tidal reef flats and is recreationally fished for octopus by campers for bait. The accounts are of systematic harvesting of these remote reef flats at spring low tides. Reportedly, up to twelve large foam broccoli boxes full of octopus have been taken on more than one occasion from these reefs. Considering how well octopus bodies pack down, these are significant numbers. The persons apparently responsible for this harvesting are "Polish Carnarvon vegetable growers" and the harvesting is reputed to take place a couple of times per year. Other (personal) observations include recreational fishers taking up to six individuals per fishing episode and the repeated spearing (using a gidgee) of octopus who have retreated deep into their dens. Extraction of the individual is rarely successful at this stage, the octopus preferring to tenaciously cling to the den walls and be repeatedly stabbed rather than come out. This situation is obviously unethical and unsatisfactory to marine park managers and the majority of the public.

3.9 General Conclusions & Future Directions (octopus & lobsters)

Both lobsters and octopus are extremely vulnerable to human impacts by virtue of their predictable habitat requirements, clumped patterns of distribution, and relative ease of capture. There is little doubt that past human activities have played an important part in the devastating decline of lobsters, and there is strong evidence to suggest that octopus populations are also under threat from the same source. We also know that both these taxonomic groups play important roles in reef ecosystems by virtue of their tight and diverse links within food webs (Clarke 1996, Shears & Babcock 2002, Cherel & Hobson 2005, Langlois et al. 2005, Salomon et al. 2008) and that they are highly valued as an ecosystem asset by the Australian public for many different reasons. Finally, there is little doubt that lobster and octopus will come under increasing pressure in line with projected increases in visitation rates if no additional management action is taken.

Perhaps the three (scientific) components most in need of addressing for these two taxonomic groups are; 1) an investigation into the source of larval input for the NMP lobster population, 2) research on the life cycle of *Octopus cyanea* alongside indications of their carrying capacity per unit area and role in the Ningaloo ecosystem, and 3) a continued monitoring presence of both groups at selected sites using sensitive indicators such as increases in distribution, inter-annual fluctuations and increases in densities at critical sites. By understanding these biological and ecological processes, the viability of resurrecting present day numbers to their former glory could be more appropriately assessed.

Key management questions

The following are summary point form answers to questions identified by the Department of Environment and Conservation as being important to the management of the Ningaloo Marine Park;

1) **What is the species diversity of invertebrates at representative habitats in the NMP?**

Five lobster species and three octopus species were found in the NMP. In order of abundance these are;

a) Lobsters - Western Rock Lobster (*Panulirus cygnus*), Painted Lobster (*P. versicolor*), Painted Cray (*P. ornatus*), and two species of Spiny Lobsters (*P. femoristriga* & *P. penicillatus*).

b) Octopus - Day octopus (*Octopus cyanea*), Blue-ringed octopus (*Hapalochlaena*), and another unknown or undescribed species.

2) **What is the relative abundance of these species and how do they compare with the "natural" abundance of these species on comparable reefs?**

a) Lobsters – Compare very poorly with other comparable reef systems. For example, densities of the Western Rock Lobster at other Western Australian locations are between 60-150 individuals km-2 for juveniles (Joll & Phillips 1984). At Ningaloo they are 70 individuals km-2 (Babcock et al. 2007).

b) Octopus – Unknown although it appears that poorly is the answer. For example, the Day Octopus *O. cyanea*, supports artisanal as well as subsistence fishing in many other tropical reef areas around the world. The Ningaloo population would be unable to do this even for a small handful of people.

3) **How does the abundance of these species change over a gradient of historical and human pressure?**

a) Historical (lobsters) - devastating declines in numbers since the 1960's – 1970's according to anecdotal evidence from numerous sources which include academic transcripts, discussions with long-time locals and formal interviews with commercial fishermen (see appendix B). Unknown for octopus (no historical data or anecdotal evidence available).

b) Human pressure (lobsters) - Analyses suggest that continuing human pressure (measured as degree of accessibility using four quantified proxies) is affecting remaining numbers of lobsters. However, trends are based on 39 of 265 transects where lobsters were present so should be interpreted with caution.

4) Are current fishing regulations appropriate?

No, based on the status of populations and lack of detailed scientific information, the current regulations are currently inadequate to protect both taxonomic groups.

5) What should management targets be?

Management could target the repopulation of lobster numbers, perhaps to a level approaching historical estimates, and a better understanding of the vulnerability of octopus populations as their core aims in relation to these two taxonomic groups. Recommendations based on project results include;

a) Lobsters - complete cessation of all fishing for lobsters in the NMP until numbers rebound to an adequate (to be determined) level.

b) Octopus - complete cessation of fishing, and rigorous enforcement, at a number of critical inter-tidal sites so that some natural populations exist. In tandem with life history studies, this is critical in order to make a proper assessment of their population dynamics and vulnerability to anthropogenic pressure.

6) What species should be monitored regarding these species?

a) Lobsters - Western Rock Lobster. Once abundant at Ningaloo, *P. cygnus* populations appear to be critically in danger of disappearing altogether. However, there are a couple of areas in the Ningaloo Marine Park where a small population exists. In sharp contrast to the tropical lobsters, this species tends to aggregate, allowing rapid assessments of population or distribution increases in key critical areas of the marine park.

b) Octopus - Day Octopus. Essentially fished everywhere they are found at Ningaloo from easily accessed inter-tidal areas, the status of Ningaloo's *O. cyanea* populations is unknown. Literature suggests that natural abundances of this species is substantially higher on other tropical reefs than that found in the Ningaloo Marine Park.

Each of these management objectives is discussed in detail within the body of the report. Key findings are summarized in the executive summary above.

3.10 Acknowledgements

We would like to thank Frazer McGregor and Mike van Keulen from the Coral Bay Research Station; Phil Kendrick, Jane and Billie Lefroy from Ningaloo Station; Leonie, Murray, Martin and Muriel McDiven and Christine Hennessey from Warroora Station; Andy and Tracey from 14 Mile Beach Camp and the staff at Gnaraloo Station for their generosity of knowledge, hospitality and friendship. The team at the DEC regional office in Exmouth and Ben Fitzpatrick from UWA for their local knowledge of the waters at Ningaloo. Len

Annabel and Leonie McDiven for their insights into Nick Faranaccio's commercial cray fishing operation.

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4. Communication and outputs

4.1 Communication achievements

WAMSI media liaison officer Sue McKenna ran a press release for the commencement of this project to coincide with the beginning of the field trip. As a result, live radio interviews on local ABC radio stations were conducted in early July 2008 along with a written piece in the Carnarvon local paper the *Northern Guardian*.

In addition, a summary of the field trip's objectives was posted on the Ningaloo Research Program website at;
http://www.ningaloo.org.au/www/en/NingalooResearchProgram/Field-Survey-Calendar/Field-Program-2008.html

4.1.1 Students supported

Herwig Jade (Hons project) The life history and ecology of Octopus cyanea at Ningaloo Reef, Western Australia

4.1.2 Theses and dissertations

Herwig J – Honours thesis expected June 2010 – The life history and ecology of Octopus cyanea at Ningaloo Reef, Western Australia (for full proposal see appendix A)

4.1.3 Publications

Nil (see below)

4.1.4 Planned publications

Depczynski M, Heyward A, Radford B, O'Leary R, Babcock R, Thomson D, Haywood M – Status of lobster populations versus carrying capacity forecasts for Ningaloo Reef, WA

4.1.5 Presentations

An oral presentation at the AIMS/CSIRO seminar in December 2008 and one at the Ningaloo Symposium in May 2009 presented findings of this project in Exmouth.

4.2 Project outputs

- Annual Field Report (August 2008) – Stock assessment of target invertebrates at Ningaloo reef – August 2008
- Final Report (October 2009) - Stock assessment of target invertebrates at Ningaloo Reef WAMSI Node 3 Project 1 (WAMSI project reference no. 3.1.3)
- Accessibility survey (.shp file)
- Density measure of accessibility (.ers file)

4.3 Data management

The final data sets are available as either excel spread sheets or ESRI shapes files. An AIM manages these data sets within the AIMS WA Data Repository and can make them available online by request. All WAMSI records from the AIMS MEST are harvested by IVEC and made available online. AIMS has created the following MEST metadata statement for this sub-project.

MEST Metadata Title: Crayfish and Octopus Surveys, Ningaloo Reef, Western Australia (WAMSI Node 3 Project 3.1.3)
Metadata standard: Australian Marine Community Profile of ISO 19115:2005/19139
Metadata version: 1.3-19139

For the complete copy of the metadata information see appendix D.

5. Appendices

Appendix A: Hons proposal by Jade Herwig.

Honours research proposal on the life history features and ecology of *Octopus cyanea* in relation to their role in the Ningaloo Reef ecosystem.

SCIE7472: FNAS Research Preparation

THESIS PROPOSAL

The life history and ecology of *Octopus cyanea* at Ningaloo, Western Australia.

2009/2010

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CONTENTS

1. ABSTRACT

Life history attributes are key elements required in understanding how an organism survives and the role it plays within a given ecosystem, and these attributes include: age, growth, mortality, reproductive output and the density and distribution of individuals within a population. Ageing octopus had proved difficult as they have very plastic growth and show variation in size-at-age relationships, and as a result of this, there are no accurate age estimates done on natural populations of *Octopus cyanea*. This makes it hard to estimate certain aspects of their life history. A new technique based on growth increments in the stylet opens up new opportunities for ageing wild octopus. Aided by this technique, I propose to examine life history attributes and population structure of *O. cyanea* to uncover important baseline data that can be used for effective management of the species. This data will be examined in the context of: what is the ecological role and vulnerability of this species within the Ningaloo Reef ecosystem?

2. INTRODUCTION

Effective conservation requires baseline biological and ecological data in order to understand how particular ecosystems operate and enable educated decisions to be made for future management of the species. Octopus comprise a significant part of the ecosystem as they play the role of both predators and prey on the coral reefs. Octopus are known to consume other invertebrates (bivalves, gastropods, crabs) and some fish (Forsythe & Hanlon (1997, Aguado Gimenez & Garcia Garcia 2002) and they themselves have been found as the diet for seals, sharks and other predatory fish (Tricas et al 1981, Goodman-Lowe et al 1999, White et al 2004, Taylor & Bennett 2008). In addition to this, information is needed on basic life history aspects to more fully appreciate their role within coral reef systems. This study is important because not only will it provide base line data on some aspects of *Octopus cyanea*, it will also build on other studies to produce a more holistic view on the biology of this octopus and on the ecology of *O. cyanea* populations at Ningaloo.

Understanding the life histories and trophic biology of organisms is an essential prerequisite to defining their ecological role within an ecosystem. One major aspect in the study of life histories is the understanding of life spans and the distribution of ages within a population. Age estimations are important as they can be used to estimate growth, mortality, age at maturity and infer reproductive productivity (Leporati et al 2008b) and this, coupled with information on their diets and patterns of distribution, assists the researcher in determining the role that the cephalopod species plays within the ecosystem.

The majority of cephalopods are considered to 'grow fast, breed once and die' (Houlihan et al 1990). They are also extremely variable in their size-at-age and they are considered to have non-asymptotic growth (Moltschaniwskyj 2004, Semmens et al 2004). Age estimation in cephalopods has been a difficult area to investigate, in the absence of laboratory-raised animals, because of the rapid growth patterns as well as plasticity in growth that renders size-at-age methods inaccurate (Semmens et al 2004). Alongside this, there is also a distinct lack of life history studies on natural populations of octopus species.

Most octopus species contain two chitinous-like structures that are considered to be reduced internal shells, the stylets (Bizikoz 2004). Very recently it has been found that the microstructure of the stylet contains rings that allow an age estimate to be calculated for both aquaria and wild individuals (Sousa Reis & Fernandes 2002, Semmens et al 2004, Doubleday et al 2006). Although stylet increment analysis has proved to be accurate in ageing temperate species (Doubleday et al 2006), its potential in ageing tropical species has yet to be determined. The development of this technique is particularly important in the study of wild populations as it allows age estimates to be determined in the absence of a known hatching date and without studies of growth in controlled laboratory conditions.

O. cyanea is a tropical cephalopod that is found at Ningaloo, Western Australia as well as other tropical areas around the world (Norman 2000). Although studies have looked at various biological aspects of this octopus, such as life cycle, physiology and behaviour, there are no accurate age estimates for the species. Van Heukelem (1973) studied the life history of *O. cyanea* and tried to determine the ages of the individuals using weight-based methods. Using 4 separate octopus that had been followed for 90 days (providing known weights-at-age) he compared the weights of other individual octopus to those weights of the 4 separate octopus to determine the age of the individuals. Due to the variability in weights of octopus at different ages, this does not necessarily provide an accurate estimate of age.

Therefore, the purpose of this study is to look at the population structure and life history attributes of *O. cyanea* in the context of understanding: what is the ecological role of this species within the Ningaloo Reef ecosystem?

With this is mind the specific aims of this project are to:

1) Investigate the life history characteristics of *O. cyanea* using stylet increment analysis to determine estimates of age, growth and rates of mortality,
2) Examine the reproductive status of the populations by determining mean age at first maturity and natural sex ratios of *O. cyanea* using gonad histology,
3) Examine how the Ningaloo Reef populations are distributed through space and time on the intertidal reef flats,
4) Examine the strength and nature of the trophic links of *O. cyanea* within the Ningaloo Reef system.

Addressing these aims will provide important base line data that can help determine the structure of the octopus populations within our study sites. This will provide a realistic ecological evaluation of the role and significance of *O. cyanea* within the tropical reefs areas and provide an understanding of their vulnerability within the Ningaloo Reef system.

3. LITERATURE REVIEW

3.1 Life History

Studying an organism’s life history provides the groundwork for understanding how that organism survives and grows within its given environment, as natural selection will favour those life history characteristics that maximise the rate of increase for the species (Roff 2002). Life history characteristics include birth rate, death rate and the age composition of the population (Cole 1954) as well as timing of maturity, survival rates, population densities and distributions. Life history studies can be used in a generic sense to predict relationships across species such as those between size and longevity, mortality, growth rate, timing of maturity and lifetime reproductive output (Depczynski & Bellwood 2006). The relationship between body size and longevity states that; generally, larger organisms tend to have slower rates of growth and lower levels of mortality corresponding with longer life spans (Calder 1984, Roff 1992, Depczynski & Bellwood 2006).

Theoretical generalisations of life history include the *r* and *K* strategists. The *r* strategists include organisms with early maturity and high reproductive output (Duellman 1989) and organisms such as these typically live in constantly changing or unstable environments. *K* strategists are those that tend to grow slower, mature later, and have much lower reproductive outputs. *K* strategists are found in more competitive environments and invest more in fewer offspring as they have a greater chance of survival to adulthood. *r* strategists are found in less competitive environments than *K* strategists as those life history characteristics that they possess allow populations to grow rapidly within unstable environments due to their high rates of reproduction. 'Although life-history theory has shifted away, somewhat, from a focus on *r* and *K* selection, the themes of density-dependent regulation, resource availability and environmental fluctuations...are potentially important in any natural system' (Reznik et al 2002).

By examining different life history characteristics such as age structure, growth rate, timing of maturity, reproductive output, mortality rate and size, as well as looking at relationships across species such as the relationships between body size and longevity, a life history type for the species can be inferred. This, coupled with theory of *r* and *K* life histories and the fact that the type of life history an organism exhibits reflects the environment in which they live (Pierce et al 2008), means that from life history characteristics you can infer some idea of the pressures that the species may be under, as well as how they may function within a given ecosystem.

Life history can be seen as the baseline data for any organism. Without it, the functioning of the species remains a mystery. How an organism lives within a given environment is important in understanding how they survive and knowledge of this helps make more educated decisions for future management. This baseline data can be used to infer a role for the organism and may provide information on how vulnerable it is, or could be, under increased pressures. This is particularly important for intertidal cephalopods that face increased pressures in areas of unregulated fishing. It can only be well managed with a good understanding of life history.

3.2 Cephalopod life history

The class Cephalopoda includes the two existing subclasses including Nautiloidea with an external shell (includes the nautilus) and Coleoidea (which includes the cuttlefish, octopus and squids) in which they have an internal or absent shell. 'Cephalopods are an ancient molluscan class notable for their active lifestyle and well-developed senses' (Wood & O'Dor 2000). Their generalised life cycle characteristics include many *r* strategist features such as short life spans with high growth rates, early reproduction (Boyle & Boletzky 1996) and non-overlapping generations (Pierce et al 2008). And with the exception of the Nautiloids, most cephalopods are generally semelparous breeders. The majority of cephalopods (with the exceptions of some deep-water species) live for short periods of time (about 1-2 years (Boyle & Rodhouse 2005)) and life history theory would predict fast growth rates and high levels of mortality.

Octopus species differ in the number of eggs produced and the stage at which the young hatch. Holobenthic species produce 100's of eggs with a benthic dispersal of hatchlings, whereas merobenthic species produce 100,000's of eggs with a pelagic larval phase (Narvarte et al 2006, Leporati et al 2008a).

The type of life history strategy that an organism exhibits reflects the environment in which they live (Pierce et al 2008). Variations in life histories between different octopus species demonstrate this well. For example Daly & Peck (2000) demonstrated that the generalised striking characteristic of rapid growth in cephalopods did not apply to the polar octopus, *Pareledone charcoti*. They found an averaged 0.11% increase in body mass per day for their recorded *P. charcoti* as opposed to 2.0-4.65% increase in body mass for a range of other octopus species (Forsythe & Van Heukelem 1987, Daly & Peck 2000).

Typically, life history studies on octopus have involved examination under aquaria conditions using either captured live animals or raised young (for examples see Table 1). These types of studies are very important for some aspects of life history and have uncovered, for example, important information on; reproduction, incubation period, position of embryos within egg sacs, developmental stages, number of eggs produced (Tranter & Augustine 1973), effect of temperature on food consumption (and/or growth) (Mangold & Boletzky 1973, Van Heukelem 1973, Joll 1977, Aguado Gimenez & Garcia Garcia 2002, Andre et al 2008) and embryonic development (Mangold & Boletzky 1973). They also provide estimates of age at maturity, death and longevity of the species.

Table 1. Some studies looking specifically at life history of octopus in aquaria.

Author and Year	Species Studied	Life History Aspects Studied
Dew (1959)	*Octopus cyaneus* & *Hapalochlaena maculosa*	Brooding behaviour, egg morphology, incubation period, development of hatchlings, hatchling behaviour
Mangold & Boletzky (1973)	*Octopus vulgaris*	Weight at maturity, reproduction, spawning temperatures, growth in early benthic stage, growth as estimated by weight from regular catches
Tranter & Augustine (1973)	*Hapalochlaena maculosa*	Incubation period, embryonic development, brooding behaviour, position of embryo in egg sac, chromatophore development, longevity
Van Heukelem (1973)	*Octopus cyanea*	Brooding behaviour, egg morphology, hatching time, growth
Overath & Boletzky (1974)	*Hapalochlaena lunulata*	Brooding behaviour, position of embryo in egg sac, embryonic development
Joll (1977)	*Octopus tetricus*	Growth with varying levels of food supply
Aguado Gimenez & Garcia Garcia (2002)	*Octopus vulgaris*	Growth with different diets
Andre et al (2008)	*Octopus pallidus*	Relationships between temperature, feeding and food conversion in juveniles

We know a reasonable amount about various life cycle aspects of different octopus species; however, natural growth is one aspect that is hard to determine under laboratory conditions. This is due to the unnatural physical environments that the octopus are exposed to, and the lack of accurate estimates of age. The past research has had to focus strongly on aquaria based studies because there was no accurate way to age and observe growth in wild octopus. As a result of this, there is a lack of study on growth and age in natural populations. Growth is an important life history parameter and understanding growth is pivotal to understanding an animal's life history. Therefore, accurate estimates of growth in natural populations are required.

3.2.1 Growth of Cephalopods

'Many cephalopods grow throughout their lifetime and critically this means that they lack an asymptotic phase of growth, when, for a substantial part of their lifetime, growth slows and body size increases minimally' (Moltschaniwskyj 2004). Forsythe & Van Heukelem (1987) found that there were differences in growth rates of individuals even amongst siblings that were raised under identical conditions in aquaria. Other studies have highlighted the importance of food and temperature on growth (for example; Wells & Wells 1970, Van Heukelem 1973, Leporati et al 2008b), and others have found that these factors did not limit growth and that octopus seemed to grow substantially with little or no food intake (Andre et al 2008). Differences in growth were also found depending on food quality, size, gender, stage of maturity and level of activity (Forsythe & Van Heukelem 1987, Andre et al 2008). Joll (1977) found that despite the normal variations in weight between octopus of the same age, weights of individuals is further affected by feeding history, and where food is variable, weight should not be used as an indicator of age. In addition, a study on the role of hatchling size and its effects on size-at-age found that small differences in early growth were amplified in later life (Pecl et al 2004). All of these point to the well documented generalised characteristic of octopus that they have rapid non-asymptotic growth with high levels of individual variability (Semmens et al 2004) and as a result of this there is extreme variability in size-at-age (Pecl et al 2004).

To determine rates of growth, mortality, expected productivity and overall population structure, accurate age estimates are required (Leporati et al 2008b). The age of an octopus has traditionally been observed by raising the animal from the egg stage. This is an accurate method because you know exactly how many days have passed since hatching, however, applying this to adult specimens with no known hatching-date will not work. Also raising animals in aquaria does not simulate natural conditions. It has been found that laboratory-reared cephalopods show growth curves with two-phases whereas wild animals show single growth curves (non-asymptotic) (Moltschaniwskyj 2004).

3.3 Growth and age estimation methods

It is difficult to accurately age wild populations and observing growth in aquaria has been seen to deviate from growth in the wild (Moltschaniwskyj 2004). For these reasons, studies have uncovered a variety of other methods that can determine the growth and/or age of any individual in natural growth situations.

Modal Progression Analysis is a commonly used method in octopus growth studies that uses field-based length-frequency data looking at the growth on a population level by following cohorts through time (Semmens et al 2004). It is used commonly in fisheries assessments (e.g. *Octopus mimus*, Cortez et al 1999) due to its low cost, however, for this you need a strong size/age relationship and the lack of this combined with a generally short life span (<2 years) for most octopus species (Boyle & Rodhouse 2005), discourages the use of this method (Semmens et al 2004, Leporati et al 2008b). Another growth estimate method includes 'mark-recapture' studies that require the tagging of juveniles (e.g. *Octopus vulgaris* Domain et al 2000). However, this can be problematic due to the difficulty in traditional tag retention for octopus and in recapturing the tagged animals.

The problem with both of the above methods is that you cannot get an age estimate for the individual octopus. One potential technique for determining the age of individual octopus is the quantification of the metabolic waste product lipofuscin, which accumulates in nervous tissue. This product is proportional to physiological age and may thus be able to be used as estimates for chronological age (Semmens et al 2004). It has been used in *O. vulgaris* (Sobrino & Real 2003), however it is yet to be validated.

3.3.1 Stylet Increment Analysis

Stylet increment analysis is an exciting new technique that allows an accurate age estimate to be calculated from the microstructure of an octopus stylet. It does not involve weight or length measurements or known hatching-dates, it overcomes the variability and plasticity of individuals and can be used on wild populations. The technique has been validated from young raised in aquaria (Doubleday et al 2006) which showed irrefutable evidence that the rings counted are laid down daily in the temperate species *Octopus pallidus*, hence providing a robust method to age octopus.

'Octopus stylets, which are thought to represent a highly reduced internal shell, consist of a pair of small widely separated chitinous-like rods embedded within the mantle musculature' (Bizikoz 2004, Doubleday et al 2006). The stylets can be removed whole by dissection and once mounted in thermo-plastic cement, they can then be ground down to a fine translucent section. Under a light microscope the daily rings can be observed and counted. Previous studies using this technique have been able to identify not only daily rings but also the embryonic nucleus (hatch mark) (see Fig 1).

Validation of this technique was done on *O. pallidus* by Doubleday et al 2006. To validate it, known-age laboratory-raised specimens were used and for each month for a period of 4 months, 12 individuals were randomly selected for stylet analysis. Other validation techniques have involved injecting stains (or immersing the animal into solution) to mark certain rings and then performing stylet increment analysis after a set period of time. Similar validation techniques have been used on fish otoliths (Siegfried & Weinstein 1989). Stains previously used for this on *Octopus maorum* consist of: Oxytetracycline, Alizarin complexone and Ba isotope (unpublished data, Pers com; Jayson Semmens 2009) of which none have been successful to date.

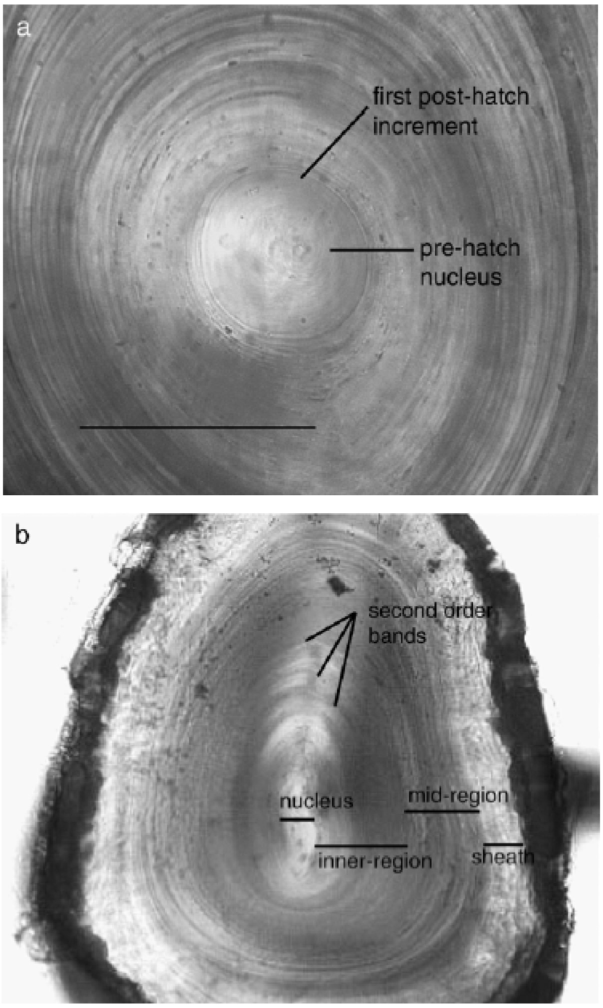

Figure 1: The microstructure of a stylet of *Octopus pallidus* (transverse section) showing a) the embryonic nucleus and the position of the first post-hatching daily ring, b) the stylet showing the nucleus and the outer sheath (dark area) of the mounted stylet (taken from Doubleday et al 2006).

3.4 Octopus cyanea

Octopus cyanea was first described by Gray, in 1849, from two preserved specimens in the British Museum of Natural History collection (Gray 1849, Norman 1991). It is a medium sized tropical cephalopod that inhabits the reefs off Ningaloo in Western Australia, as well as many other tropical areas around the world (Norman 2000). Commonly known as the ‘Day Octopus’, it is diurnally active and is associated with clear tropical waters and coral reefs (Norman 2000). *O. cyanea* is a merobenthic octopus which means it has a bi-partite life cycle and produces many small eggs which hatch into a pelagic larval stage before settling onto the benthos where it remains for the rest of its life (Wells & Wells 1970).

O. cyanea is characterised by two distinctive ocelli present on the body (just above the arm crown), dark bars or stripes on the ventral arms surfaces and small cream to pale blue spots on the dorsal arm surfaces (Norman 1991). The species exhibits an enormous capacity to change its body colour and colours vary from deep reds to dark browns, mottled patterns and through to pale grey or almost white in colour. Individuals have been reported to grow up to 1m in length and 6kg in weight (Norman 2000). There is no obvious marked sexual dimorphism in this species (Norman 1991) and males (as in most octopus) can only be identified externally by a tiny ligula (small cup-like feature) on their third right arm (hectocotylised arm) and a number of enlarged suckers, on mature males, on the second and third arms. These hectocotylised arms are used by the males to transfer sperm to the females during courting.

3.5 Studies on O. cyanea

Considering its wide- spread tropical distribution on the reefs all over the world, *O. cyanea* has not been well studied in the past. Van Heukelem's (1966) unpublished Master's thesis is the earliest available documented study on the species. Since then, there have been a number of (mainly biological) studies that have looked at various aspects of this species including its general lifestyle, physiology and some aspects of its behaviour (studies specifically on *O. cyanea* are summarised in Table 2 below). Studies on their life history parameters have been lacking and those that have previously looked at age and growth used either weight and length relationships or estimates of age from their size by relating it to other 'aged' species or individuals (Van Heukelem 1973, Van Heukelem 1976, Guard & Mgaya 2002). In addition, none of these studies have looked at Ningaloo Reef populations.

Table 2. Summary of journal articles looking specifically on *O. cyanea*. Listed in chronological order.

Author and Year	Title	Study Focus
Van Heukelem (1966)	Some aspects of the ecology and ethology of *Octopus cyanea* Gray. Masters Thesis.	Ecology and behaviour
Maginniss & Wells (1969)	The oxygen consumption of *Octopus cyanea*	Regulation of oxygen uptake over a range of different oxygen levels
Yarnall (1969)	Aspects of the behaviour of *Octopus cyanea* Gray	'Den-ing' and hunting behaviour in aquaria
Wells & Wells (1970)	Observations on the feeding, growth rate and habits of the newly settled *Octopus cyanea*	Behaviour of the post-planktonic hatchlings
Van Heukelem (1973)	Growth and life span of *Octopus cyanea* (Mollusa: Cephalopoda)	Life history and comparisons on growth between captive and branded wild animals
Van Heukelem (1976)	Growth, bioenergetics and life-span of *Octopus cyanea* and *Octopus maya.* PhD dissertation	Growth, life span, energy budgets and effects of temperature and food on growth
Norman (1991)	*Octopus cyanea* Gray, 1849 (Mollusca: Cephalopoda) in Australian waters: description, distribution and taxonomy	Physical description, distribution in Australia and taxonomy
Papini & Bitterman (1991)	Appetitive conditioning in *Octopus cyanea*	The effects of food reinforcement on repeated responses of the octopus to a stimulus
Forsythe & Hanlon (1997)	Foraging and associated behaviour by *Octopus cyanea* Gray 1849 on a coral atoll, French Polynesia	Foraging distance, behaviour and diet
Guard & Mgaya (2002)	The artisanal fishery for *Octopus cyanea* Gray in Tanzania	Some life history aspects (e.g. sex ratios and size at maturity) in response to artisanal fisheries management
Mather & Mather (2004)	Apparent movement in a visual display: the 'passing cloud' of *Octopus cyanea* (Mollusca: Cephalopoda)	Changes in skin colour and why they may do it
Hanlon & Forsythe (2008)	Sexual cannibalism by *Octopus cyanea* on a Pacific coral reef	Mating behaviour
O. cyaneus*		
LeSouef & Allan (1933)	Habits of the Sydney octopus (*Octopus cyaneus*) in captivity	Behaviour in captivity
LeSouef & Allan (1937)	Breeding habits of a female octopus	Behaviour whilst brooding
Dew (1959)	Some observations on the development of two Australian octopuses	Development after hatching

*The few studies done on *O. cyaneus* in Sydney, Australia (Dew 1959, LeSouef & Allan 1933, 1937) are considered to probably be of a different species than the tropical *O. cyanea* (Norman 1991).

3.6 Diet and predation

'Cephalopods play key roles in marine environments both as predators and as food of top predators...' (Clarke 1996, Cherel & Hobson 2005) and knowing their trophic position in the food chain helps add to the picture of what their role is within the ecosystem.

Examining diets has sometimes been done by stomach content analysis, however this has been considered to be sometimes inappropriate in the study of cephalopod diet. The small diameter of the oesophagus which runs through the brain means that hard parts (e.g. fish skeletons and mollusc shells), which are commonly used in diet analysis, are rejected. Rejection of these hard parts by the cephalopods could create bias in the estimation of diet from stomach content, with 'softer' prey showing up as a more dominant food supply (Rodhouse & Nigmatullin 1996).

Fortunately, we do have a good idea of the diet of *O. cyanea* from Forsythe & Hanlon (1997). In their paper on the foraging behaviour of *O. cyanea* they looked at the prey species from the remains dropped by the octopus during foraging periods. They estimated that the diet of *O. cyanea* seemed to primarily consist of; bivalve and gastropod molluscs and xanthid crabs. This is quite common prey for many octopus species and they have also been found to eat, to a lesser extent, fish (Aguado Gimenez & Garcia Garcia 2002). Some studies have tried to estimate prey species by the remains around the dens of the octopus. However, some species of octopus (for example *O. vulgaris*) have been found to consume food away from their dens (Smale & Buchan 1981), and thus the remains around the den may not be representative of the spectra of their diet. Isotope analysis has also been suggested, however, since prey items are closely related phylogenetically, the degree of separation of ingested items is likely to be at a very gross level (i.e. phyla/sub- phyla only).

We also know that octopus and other cephalopods make up a substantial part of the diets of many predatory fish, seals and whales. In other tropical areas, sharks and seals have both been found to eat octopus, and seal's specifically have been found to eat *O. cyanea* (Tricas et al 1981, Goodman-Lowe et al 1999, White et al 2004, Taylor

& Bennett 2008). Moray eels are also considered to be one of the major predators of *O. cyanea* (Van Heukelem 1983).

3.7 Maturity

Maturity is important in the study of life histories as it provides an insight into the patterns of growth, social environments (e.g. sex ratios), potential reproductive output of individuals, rate of mortality and re-distribution of energy from growth into reproduction. Female octopus die after their eggs hatch (with the exception of some being kept alive in aquaria (Mangold & Boletzky 1973)) and thus they have non-overlapping generations and are considered to be semelparous breeders.

Overall, there is not a lot known about sexual maturation in octopus. In short, octopus appear to 'grow fast, breed once and die' (Houlihan et al 1990). And although females die after brooding, males do not seem to appear to outlive the females (Van Heukelem 1973). Due to the lack of accurate age estimates, maturity for octopus is typically calibrated against weight or size of the specimens (e.g. Smale & Buchan 1981, Van Heukelem 1973). However, due to the plasticity in octopus growth, weight alone does not really provide a reliable measure of age at maturity. For example, Guard & Mgaya 2002 found the smallest *O. cyanea* female at one site weighed only 600g at maturity but 80% of mature females weighed over 2500g. Weight at maturity has been calculated for *O. cyanea* but as is quoted in Mangold & Boletzky 1973, '...the strong individual differences in growth rate and in attaining sexual maturity in relation to size (weight)...makes it impossible to establish a rigid model of the life history...'. Weight at maturity may not be as useful as knowing age at maturity due to the variation in size between individuals.

Examining the maturity of females, especially in octopus who only brood once, is important in areas where the animals are fished. Guard & Mgaya (2002) found in their study, on the artisanal fishery of *O. cyanea* in Tanzania, that the dominance of females in the catch and the fact that they tend to be more obvious to fishers (due to den habits whilst brooding) may suggest that mature females are more prone to capture. If we assume equal or male biased sex ratios within the populations, if too many females are taken at one time, it may severely impact the recruitment and population levels of the next generation and could be detrimental to the survival of a species in an area of unregulated fishing.

3.8 Lack of study on some octopus species

The majority of octopus studies to date, especially those looking at populations, have focused on those species that are important for commercial fishing (Hartwick et al 1984, Pierce et al 2008). This is because of the methods of catching the animals (as a by-product of fishing (Boyle & Boletzky 1996)) and also the interest in knowledge of the species being exploited. Those of no commercial interest (usually the tropical and deep water species) tend to be, not only less well studied, but often only studied as the result of indirect observations, for example; predator stomach analysis (Pierce et al 2008). There is no commercial fishery of *O. cyanea* in Australia (Norman 1991), however, in other areas like some of the Hawaiian Islands (Van Heukelem 1973), areas in the Philippines (Norman & Sweeney 1997) and Tanzania in Africa (Guard & Mgaya 2002) it is important as an artisanal fishery. It is also sold frequently at fish markets throughout the central and southern tropical Pacific and in countries such as Fiji, Tonga, Solomon Islands, New Caledonia and Papua New Guinea (Norman 2000). In some areas of Ningaloo, *O. cyanea* is taken off the reefs as a recreationally fished species (Pers obsv).

3.9 Significance and conclusion

From past research we know that the majority of octopus species appear to exhibit *r* strategist life history characteristics where they grow fast, mature early and are semelparous breeders. And from aquaria based studies we have a good insight into the life cycle of a number of octopus species. It has been noted that wild animals seem to exhibit a different type of growth curve to laboratory raised animals whereas wild ones appear to grow continuously throughout their life. What is lacking to date is accurate estimates of growth and age of wild populations. Stylet increment analysis provides a robust method to examine growth and age in natural populations, which has not been possible in the past.

The lack of study on natural populations is even more profound for species like *O. cyanea* which is not a commercially fished species. *O. cyanea* is an ecosystem component and its importance and vulnerability is yet to be validated.

For an understanding of the role of *O. cyanea* within the coral reef system, basic life history characteristics must be understood, and to determine growth, recruitment, productivity and population structure, accurate age estimates are essential (Leporati et al 2008b). Looking at the age and maturity of octopus as well as the trophic interactions and the distribution of individuals within the populations, this study proposes to gather baseline data that can be used for the effective management of the species as well as providing information to help determine the significance and vulnerability of *O. cyanea* within this coral reef system.

4. METHODS

4.1 Study Site

The purpose of this study is to examine natural populations of *O. cyanea* in order to further our understanding of: what is the ecological role of this species within the Ningaloo Reef ecosystem? To answer this question we are looking at 4 main life history areas: 1) age and growth, 2) reproductive biology, 3) population distribution and density, 4) diet and trophic interactions.

The Ningaloo Marine Park ranges from Bundegi Reef in the north to Amherst Point in the south covering an area of 5070km^2 and consisting of the largest fringing coral reef in Australia. The intertidal reef areas are full of natural holes that provide areas for octopus to live (dens).

To look at the populations of *O. cyanea* we will be collecting samples from several different beach/reefs in two main areas (see Fig 2). The first area is about 10km north of the Exmouth town centre and we will be collecting from the beach known as Mildura Wreck. The second area is about 30km south of Coral Bay and here there are several different beaches that we will sample from; North Turtle, Turtle Rock and Pelican Point (moving southwards from Coral Bay). Previous collections by the

Australian Institute for Marine Science (AIMS) occurred from three beaches: Mildura Wreck, North Turtle and Pelican Point. In order to have a good representative number from each site octopus will also be taken from these areas in subsequent field trips as well as from the new area, Turtle Rock.

Octopus will be collected from these sites as we know that they are present here. All these sites have reef that is exposed on low tides with holes that octopus like to occupy, and this will allow us to be able to be collect them from these areas.

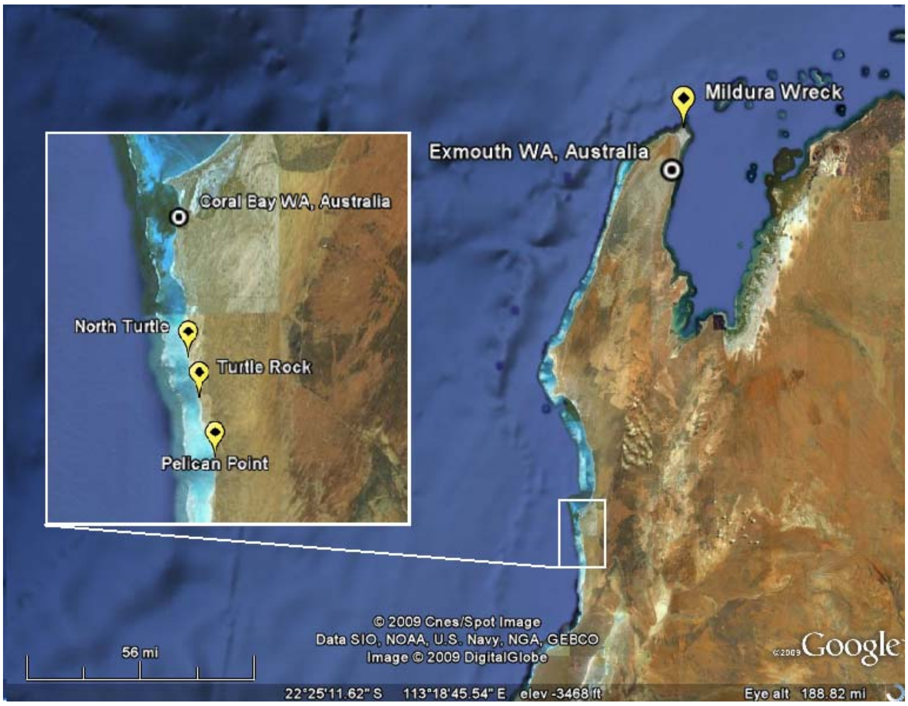

Figure 2: The 4 main collection areas of *O. cyanea* at Ningaloo (Balloons= Collection areas, Circles= Major towns).

4.1.1 Collection of *O. cyanea*

Octopus will be collected opportunistically by walking over the reef during spring low tides and will be found within their dens during daylight hours. They will be removed from their den by sprinkling a small amount of Copper Sulphate in the entrance, which causes them to leave the hole, and then they will be caught and sacrificed upon exiting. Octopus will be stored in plastic bags full of seawater whilst at the beach and will then be put into a fridge as processing occurs immediately following each collecting session. Each den location will be recorded on hand-held GPS. Occurrence will then be mapped to provide patterns of distribution and densities.

Ideally, about 100 specimens are required in order to have a representative number of individuals for growth trajectory analysis (Pers com, J Semmens 2009) and to allow for errors in the processing of the stylets. Due to the difficult nature of stylet increment analysis with the stylets becoming unreadable after a short period of time, it was suggested that about 20% more than required should account for this problem (Pers com, Zoe Doubleday 2009).

Specimens will be collected every 2 months for a period of 6 months at each of the different sites to gain a wide range of sizes and therefore a robust representative sample of the different populations. This adds both spatial and temporal components to the study and further ensures that a limited number of individuals are taken from each site.

4.1.2 Processing of Specimens

Each specimen that is collected will be taken back for immediate processing at the end of each day to ensure specimen integrity. Measurements will be performed on; mantle width, dorsal mantle length, ventral mantle length as well as the total weight of each octopus. Each animal will also be sexed externally by looking the 3rd right arm (hectocotylised arm) in which the presence of a ligula denotes a male (see Fig 3). However, due to the fact that some octopus may have missing or re-grown arms, this will also be confirmed by histological sectioning of the gonads (see *Reproductive Biology)*. Both left and right stylets will be removed (by cutting through the ventral mantle flap and cutting under the large muscle which sits just under the gill attachment) labelled and dated and preserved in a 70% ethanol solution. After processing, each specimen will be placed in a plastic clipseal bag with holes in it and then immersed in a solution of 5% Formalin: 95% Freshwater. Each specimen is labelled and dated before storing.

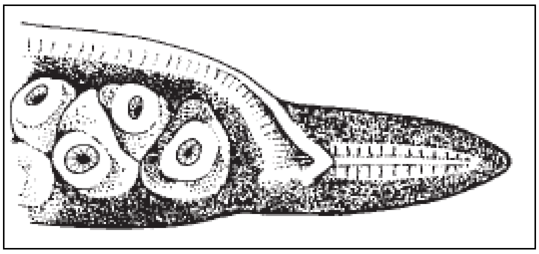

Figure 3: The tip of the hectocotylised arm showing the ligula in male octopus (taken from Norman 2000).

4.2 Age and growth

The ageing technique follows that of Doubleday et al (2006) using stylet increment analysis. Transverse sections are cut from the post-rostral zone of the stylet (see Fig 4) and are mounted in thermo-plastic cement (Crystalbond^{TM} 509-1) that is set onto a glass slide with the cut section facing upwards. The Crystalbond will be cooled slightly before mounting the stylet as excessive heat renders the microstructure of the stylet unreadable by causing it to darken. Once the transverse section is mounted and the Crystalbond has hardened (due to cooling) it is then ground down to a thin and polished translucent section that enables the microstructure to be seen. This is done by moving from coarse to finer grades of sandpaper to lapping film whilst keeping the section continuously wet: 1200 grit wet-and-dry sandpaper to 12µm, 9µm and 5µm lapping film. Once the mounted section is thin enough to see the rings, digital photos will be taken immediately to ensure the clearest picture possible (Doubleday et al 2006, Leporati et al 2008b).

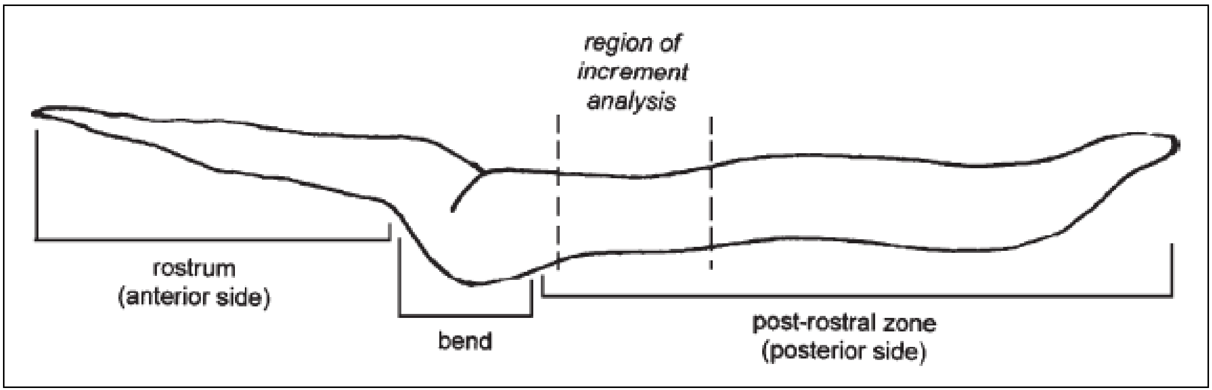

Figure 4: The morphology of a typical *Octopus pallidus* stylet (taken from Doubleday et al 2006).

Counts of the concentric rings will be performed at least twice at different times on the images taken from the stylets and in random order to avoid bias in results.

This technique has been validated on *O. pallidus* which is a holobenthic species (no pelagic larval phase). *O. cyanea* is a merobenthic octopus which means that raising the young in aquaria is notoriously difficult (Villanueva et al 2002). The difficulty in raising merobenthic species under laboratory conditions coupled with the failure of a range of marking stains precludes validation of *O. cyanea* within the scope of this study. However, given the 1-2 year life cycles of octopus species in general (Boyle & Rodhouse 2005), we can realistically expect that the rings laid down in the stylets of *O. cyanea* are daily rather than yearly rings.

4.3 Reproductive biology

The octopus collected will be sexed externally (see *PROCESSING OF SPECIMENS*) and this will be confirmed by histological analysis of the gonads. Histological sections coupled with the age of each individual will provide us with an estimate of age at maturity. This will provide an idea of the sex ratios of the populations and the size and age of the animals at maturity.

4.4 Population distribution and density

In order to see the distribution and densities of octopus at the various study sites, replicated 8x30m grid transects will be run at two distances from the shoreline. These transects will be run every 2 months for a period of 6 months to provide an understanding of the temporal dynamics of the populations. The different study sites will be sorted by habitat to ensure comparability amongst them. Within the transects the presence of any octopus will be recorded using hand-held GPS in order to generate distribution maps of octopus in the intertidal area. These octopus will also be removed as in '*COLLECTION OF O.CYANEA*' for processing to provide information on the distribution of ages and sexes within the population. This method will provide information to aid in the understanding of the spatial distribution of *O. cyanea* within the study sites of Ningaloo.

4.5 Diet and trophic interactions

Quadrats (0.5m x 0.5m) will be randomly laid out in the grid transects done at each site. Within each quadrat we will be looking to quantify known prey species (Forsythe and Hanlon 1997). This data will give an indication of the densities of prey species available.

Literature will be examined to find evidence of the predator species of *O. cyanea*. This, combined with the data on prey densities, will provide an indication of the trophic links involving this octopus and will provide further insight into the role of *O. cyanea* in this tropical coral reef system.

4.6 Data analysis

The two main data analyses will be creating growth trajectories for the populations and comparing distribution and density of octopus between sites.

Growth trajectories will be plotted on graphs with age against size. Different plots will be done comparing age against the 4 measured size factors: weight, mantle width, dorsal mantle length and ventral mantle length. Different growth curves will also be fitted to find the best fit and thus the curve that best fits the growth of wild *O. cyanea* at Ningaloo.

To compare the distribution and density of octopus between sites, Analysis of Variance will be performed. This will take into account replicates at each site and will be done looking not only between sites but also comparing sites from North and Central Ningaloo.

Density of octopus will be extrapolated (from the data taken from the transects) across the intertidal areas at each of the study sites. This will provide an idea of the number of octopus per square metre within the different populations.

4.7 Special topic

Octopus are considered to be highly visual and tactile hunters and they are said to typically find food by groping about in and on the substrate with their arms (Chase & Wells 1986). However, there are other sensors that could play a more important role, for example chemosensory receptors, at sensing objects in their environment. It is known that octopus have chemosensory cells/receptors that enable them to sense and respond to different organic chemicals in the water (Chase & Wells 1986, Lee 1992) and the presence of these cells in the suckers has been noted by Graziadei (1962, 1964).

The aim of this project is to see whether sensory cells are more numerous in the suckers at the tips of the arm as compared to those at the base of arm, and to look at the number of sensory cells in regrowing arms as compared to grown arms.

This will be examined by taking histological sections of suckers (tips of arms, base of arms, tips of regrowing arms and base of regrowing arms) and comparing the numbers between the 4 different regions. This project will build on work done in 1962 and 1964 by Graziadei, which claimed a concentration of ciliated sensory cells in the suckers of *Octopus vulgaris*, and hypothesises that numbers of sensory cells will be greatest at the tips of the arms on both grown and regrowing arms.

5. TIMETABLE

	SCIE7472			SCIE 7479	SCIE7480					SCIE7474,5,6,7,8						
WEEK BEGINNING	Proposal Draft	Seminar	Proposal	Book Review	Research	Analysis	Committee Pres.	Seminar	Report	Field Trips	Lab Work	Research	Analysis	Seminar	Thesis Draft	Thesis
20/07/2009																
27/07/2009																
03/08/2009																
10/08/2009																
17/08/2009																
24/08/2009																
31/08/2009																
07/09/2009	7/9															
14/09/2009		TBA														
21/09/2009			25/9													
28/09/2009																
05/10/2009																
12/10/2009																
19/10/2009				19/10												
26/10/2009																
02/10/2009																
09/11/2009																
16/11/2009																
23/11/2009																
30/11/2009									30/11							
07/12/2009																
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28/12/2009																
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29/03/2010																
05/04/2010																
12/04/2010																
19/04/2010																
26/04/2010																
03/05/2010																
10/05/2010															13/5	
17/05/2010																
24/05/2010														27/5		
31/05/2010																
07/06/2010																7/6

6. BUDGET

ITEM	COST PER UNIT	UNIT	NUMBER OF UNITS	TOTAL COST	COST COVERED BY
Field Trips					
Car Hire	$0.55	Per km + $5 per day	7000km + 22 days	$3960.00	AIMS
Fuel	$20.00	Per 100 km	70	$1400.00	AIMS
Food and Accommodation	$150.00	Per person	8	$1200.00	AIMS
Equipment Consumables					
Slides	$5.00	Per 50 slides	400	$40.00	AIMS
Slide Boxes	$31.92	Per box	4	$127.68	AIMS
Ethanol	$10.00	Per litre	100	$1000.00	AIMS
Sandpaper	$3.00	Per sheet	10	$30.00	AIMS
Lapping Film	$0.95	Per sheet	60	$57.00	AIMS
Vials	$0.50	Per vial	100	$50.00	AIMS
20L Drums	$15.00	Per drum	12	$180.00	AIMS
Formalin	$15.00	Per litre	10	$150.00	AIMS
Nets	$4.00	Per item	4	$16.00	Honours account
Plastic Bags	$0.15	Per bag	200	$30.00	AIMS
Buckets	$2.95	Per item	2	$5.90	Honours account
Other					
4WD training course	$100.00	Per course	1	$100.00	Honours account
PAWES course	$50.00	Per course	1	$50.00	Honours account
Histology	$2.50	Per sample	150	$375.00	Honours account
Printing costs	-	-	-	$100.00	Honours account
			TOTAL COST	$8871.58	
			Total Cost Honours Account	$646.90	

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Appendix B: Interview

Interview conducted on 11 December 2008 between Martial Depczynski (interviewer) and Len Annabel (interviewee) at Cervantes Caravan Park, WA.

Interviewer: Martial Depczynski AIMS
Interviewee: Len Annabel ex-Commercial Cray Fisher from Ningaloo Reef

MD: When did you commercially fish for crays at Ningaloo Len?

LA: In 1974, the season of 74.

MD: That was over summer? Or the winter months?

LA: Over the winter months.

MD: Everyday?

LA: Everyday. Sometimes there would be a six foot shore break we couldn't go but most of the time we'd get through somehow.

MD: On a boat?

LA: On tinnies, we had two fourteen foot tinnies, we had a forty main outboard with the six auxiliary. We used hookah and we had about four hundred feet of air-hose. There was two per boat; one would go down with the gaff and a sac for the crays. The other would just keep nudging up to keep a loop. You wouldn't anchor because if you did you would always be at the end of the line. So, you would search an area and if there was nothing there, you would surface, signal the guy on the boat by just waving the gaff. He would drive past; you would hold the air-hose, just cruising to go to another likely spot. You would grab the gaff and just go down. Then again, you would just nudge up and back.

MD: So were you on the outside or the inside of the reef?

LA: Inside.

MD: Yes, the inside OK…I was going to say…On the outside it gets pretty big out there sometimes but I guess as you go further South there is no lagoon…So you start working on the outside further South?

LA: We started off at Cape Farquhar but most of the time we would try to get as far as we could on a calm day and sometimes just below Nick's Camp we would get about fifty kilos of crays just snorkelling or diving off there.

MD: So you were fishing for the commercial operator Nick…

LA: Farinaccio

MD: Yes, an Italian. Do you know how long he was fishing for crays for at the end of the day? Because I think he started sometime in the sixties of something…

LA: Yeah, and I went back in 1994 and he had just sold, or the licence went back to the CALM.

MD: So, do you know if he was fishing right up to 1994 or if he stoped a little bit in the 80'. Did he? When the numbers dropped a bit or…

LA: As far as I know he was going most of the time, I don't… He had a heart attack when I first met him and that's why he employed four divers. Originally it was just him and his cook, Graham. Graham came from Perth. And when we went up there, Graham was still employed. He was only there a month and his wife had a baby so we had a change over of people who did the cooking. Cooked the crays that is and…

MD: So you guys would just camp out on the beach each night?

LA: Under the stars…

MD: Under the stars, and eat crayfish and drink beer…

LA: I ate one crayfish in the whole time I was there.

MD: Really?

LA: Out of the thousands we caught…

MD: Do you just don't like eating them?

LA: Well I didn't, no. I just loved catching them.

MD: Ok. Were they mostly painted or mostly reds?

LA: I think we only got two or three painted the whole time we were there. They were all reds.

MD: Right up and down in the lagoon, and just in the weedy area and stuff.

LA: Oh they were just everywhere. It was unbelievable.

MD: We will grab a map a bit later on. I'll tell you first where we, sort of, found some reds and everything and you can tell me where else you found some reds. To try and get a bit of an idea on whether the distribution has expanded or actually decreased, and that sort of information. Because that is important information I think. Did you ever try pots at all?

LA: No. We used a bit of inch copper pipe about a metre long, a big fish hook, filed the barb off it, crimped it in the end of the pipe, opened up the angle of the hook. When we got them we had to get it under the crays belly to make them stand up just hook them under their rib-cage and just gently pull them out. We weren't allowed to mark them.

MD: Yeah, damage them…sure…

LA: And then, in the bag. Once the bag went to the surface; the guy in the boat would empty them out, gauge them and actually over the side for…

MD:…for the ones that were under…

LA: And keep another bag for the keepers.

MD: And he'd put them strait on ice or just leave them alive in the…

LA: Live in the boat because we would only be out for two hours so they wouldn't start to deteriorate.

MD: Sites, we will talk about the sites in a minute. So never any potting…
How many guys did you have in you team in 74?

LA: Four. There was two Maori boys and another Aussie mate of mine John. We were travelling round Australia together. Kim and Greg the Maori boys. And we all had different jobs. My mate was a refrigeration mechanic so he was able to maintain the truck which would constantly break down and the trailer.

MD: You had a four-wheel drive truck that was following your refrigerated truck…

LA: No, just a normal, like big ice cream delivery truck and a six by four trailer with a refrigeration unit…

MD: And running that strait off a generator or something?

LA: Yes.

MD: So never cooking the Cray, they were all fresh…

LA: No, they were cooked. We have a forty foot process van that had a door at each end. And we used to have drowning tanks, a boiler to cook them in, and then there's a washing tank to wash them. We used to make up the boxes out of tomato case bands, and banana slacks along the sides, line it with plastic. When they cooled down we would pack to crays, box it at the other end of the caravan and into the back of the refrigerated truck.

MD: So drown them; basically kill them so they don't pull their legs off. Cook them, cool them down put them into refrigeration and pack them ready for the market.

LA: That's right.

MD: Sounds like a pretty efficient operation. So you would go out each morning or something and try to get the mornings in…

LA: Each morning, at about eight 'O'clock you'd be leaving the beach. And you'd have to be back on the beach by eleven, at the latest.

MD: To get them cooked and processed and that sort of thing. Did you know if Nick had a larger team or a smaller team in the past?

LA: In the past, from what I gathered, it was just he and Graham.

MD: For years and years, every year…

LA: Before I went there he had another guy. I was in New Zealand and at a dive club showing movies about it. And the guy there said he actually worked for Nick the year before so he must've had the odd guy to help.

MD: To help him out… It would be pretty hard operation to try and do it on your own I imagine.

LA: That's right, pretty lonely life out there.

MD: Even now, it's still quite remote out there.
So, always on hookah and sometime on snorkel as well. I guess you went by yourself on snorkel.

LA: On snorkel just off the beach.

MD: Just free diving off the beach and stuff.

LA: Most of the time we got them it was only in about six feet to about fifteen feet. Right in around the bommie, the ledges. You didn't have to go deep at all.

MD: I guess you learned to hold you breathe for a long time.

LA: Well I used to be able to free dive. The deepest I have done is ninety feet, sixty feet, that was in Piccaninny pond in the caves in South Australia. A guy got his anchor stuck at Waroora Station at sixty feet and I free dived and freed it for him.

MD: Can you still do it?

LA: Probably thirty-forty feet. But diving every day, I used to practice as kid. Dad had a pool about eight foot six deep. I'd go down, load myself up with rocks and see how long I could stay down for. I had to do a free ascent abalone diving in Tassy. I got tangled in the kelp, in the bull kelp pulled the regulator out and I couldn't find it. I had to ditch it all and go up a hundred feet.

MD: And that was all right? You didn't…

LA: No, I just had to make sure I let the air out. So your lungs don't explode. My mates were trying to buddy breath but I felt like I had a lung full of water. I could breath in, I'd chock. I just had to make sure I kept under the bubbles and release as I went up.

MD: Did you get you gear back?

LA: Oh, yes. We just pulled up the hose again that was a hookah outfit. We had a thousand feet of air-hose each on that boat. There were three of us and straight off the shore, about twenty metres off the shore it would be a hundred feet deep, out of Port Harper.

MD: I guess you had to make a decision pretty quick. Now, I can't find my reg. I can either spend time looking for it and hope that I really find it or I can just go. So it would have been a split decision… Obviously a good decision because you are here today!
So you stayed fishing...I know I asked you this question before Len, but… How long did you fish for? Two or three hours at a time in the mornings?

LA: each of us would spend an hour below then you'd go up and the other chap would have a turn.

MD: So you would switch in pairs…

LA: Yeah

MD: And then what? The other guy was working.
How many days each week did you work?

LA: If the weather was fine you would just work everyday.

MD: You would just work the weather basically. And is that why you sort of worked, the season was from March till September? Or over the winter months? Or?

LA: Yes.

MD: Because over summer it starts screaming in there…
The commercial fishing licence; Nick had one from the Department of Fisheries I take it. He would have been the only operator that you know of? For the crays?

LA: No, there were two I was told. Nick had from Perth to Darwin territory. And then there was someone else from Perth to South Australia. I couldn't tell you who that operator was. Never met anyone or…

MD: They were diving as well those guys or potting?

LA: I don't know, I just thought they were divers as well. But you couldn't tell you who they were.

MD: I think you got the better end of the two, the warmer end.

LA: It was freezing there.

MD: It gets really cold, the lagoon is really cold. Its a few degrees…its very strange because normally you get a lagoon and the lagoon is much warmer than the outside slope. But at Ningaloo, because the land gets so cold and the water are so shallow in the lagoon…in winter.

LA: That current coming through, it was freezing. Diving in Tassy in the winter for the abalone, we needed these really thick wetsuits and hoods and everything. Well you needed the same here. I'm used to just having short sleeves and short wetsuit pants diving off Queensland…

MD: I know what you mean, it does get cold. I was quit surprised how cold it actually gets here because it's pretty much on the same sort of latitude as Rocky. So you'd think it would stay pretty warm but it does get cold out. I was pretty surprised…

LA: That's right…

MD: And when you're in the water for a long time, I guess…

LA: When you're not moving far or fast, using much energy to keep warm…

MD: That's true…
So, you've explained how you went about the operation. Just went out in the morning when the weather was good. And you're on hookah…Can you just explain the operation a little bit?

LA: We had our different jobs. My mate John was the refrigeration mechanic. Greg and Kim, they had been abalone divers from Esperance and New Zealand. They used to service the outboards. I would go and get the fresh water to do all the cooking and washing of the Crays. From the wind mill each day I'd fill up a big tank on the back of the four wheel drive and we'd pump that across. Graham, it was his responsibility to cook the crayfish and we would all get in and help clean them and box them up, make the boxes. Once that was done…

MD: Knock off…did you go surfing?

LA: I wasn't a surfer. One day I went to go spear fishing. I went down the beach; I forgot they didn't empty the water tank. First time I'd driven the four wheel drive on the beach and down she went and got bogged. Couldn't get down, I'm digging away…got hot as it could be. Went to jump in to have a swim and all of a sudden all these mullet came leaping out of the water. The next wave there's five sharks beached and there is another school of them rounding up the fish.

MD: Did you a see a lot of sharks in that lagoon when you were diving?

LA: Never saw any on the bottom but they were above me. On top, my mate, when I'd come up, he'd say "did you see the sharks today?". I'd say "what sharks?' and he'd say "look over there". And you could see the dorsal fin. They'd been playing with the hookah hose. And they'd just cruise past…
One day, the other guys' boat broke down so they would make some money while Greg was fixing the outboard and Kim came with us. So there was two in the boat, I'd go spear fishing. Came up and fillet the fish and dolphins are beside the boat so I'm throwing the remains to the dolphins. And after a while, my mate came screaming out at the end of the boat. And I said "what's wrong with you?", "didn't you see the hammer-head down there?". He said he had him pinned under the boat for about twenty minutes, he couldn't move. Every time he got out from under this ledge he'd have a go at him.

MD: And you were free diving down there…

LA: And sometimes, Nick would set up a bait by the beach and you had a couple of old engine blocks and a slab of concrete tied together and a float and a big hook. You'd have a small shark about six feet on it. And then we'd come back, the whole lot would be towed away…

MD: So what do you reckon that was?

LA: Tigers. Yeah, Nick hated tiger sharks.

MD: Just because they were a bit of a risk or something… Did you see many Tigers?

LA: I didn't see any there…

MD: I saw one in September, had to get the boys out of the water. And it was coming straight for them too. It was only about twelve foot long or something; it was a flat calm day, glass surface. Below the surface like that. It's the only one I've actually seen there. But like you, I mean, when you've got your head down, you're doing stuff, you just don't see anything and it's probably just as well.

LA: There's a lot of wobbies (wobbigongs) in under the ledge, and we had little bang stick, with a little shot gun shell in it. Of course all the crays would be there and you'd be getting in…and all of a sudden he'd be in behind, get disturbed, come out and have a snap…So you'd power head the wobby to get the rest of crays. From that vibration, you'd find the other ledges around had them in as well and all of a sudden two or three others would come in right in front of your face. Snapping at the Cray legs and things like that…

MD: Probably wasn't actually worth doing the first one….

LA: They would try to grab the bag.

MD: So what sort of bags were they? Like onion bags?

LA: Yeah, big sacs about the seize of the mail sack. One guy, one day, had a big Potato Cod actually snuck up between he's legs…

MD: Did you get it back?

LA: Yeah, power heading the thing to get it back. But we had another Kiwi when Graham went back to see his wife. Another friend of Nick's was a Pakaha Kiwi which is a name for a white Kiwi. He came out on the boat sometimes, had he'd be a nut. While you're down there under the ledges, he'd grab you and shake you on the back of the head or on the leg…

MD: Just playing games…

LA: Yes. So one day I saw and I gaffed him and I said "don't do that again". It's scary enough there.

MD: I know, when you're under the water all day long out there… So was the water a pretty wild frontier back then? It's wild enough now but back then it would have been… Did you see many people there? How many did you see in a week for example, on average? Where you guys were working…

LA: Probably two…

MD: Coming thru the camp or out on the water?

LA: No, out on the water. Well some people used to come and camp to fish, they'd come up from Perth with the big ice chilly bins and in three days it would be shocka-block.

MD: Full of fillets.

LA: They'd mainly get Spangled Emperor and stuff…

MD: Where they after crays as well?

LA: No, no one knew about the crays; they just came fishing and filled it in no time.

MD: How did you manage to keep the crays secret if they were fishing near where you guys were, near the camp?

LA: Even now no one knows there's crays there. They all think it's only painted crays, not the reds.

MD: I hate to tell, Len, but now there are no crays there. There are very very few crays. We got, we ran five by five hundred metre transects and we did half of them on the outer slope, looking for Painteds and there is an other one there, Versicolor, thats the species name. And then we were doing the lagoon. So we did half and half, a couple of hundred and CSIRO did a couple of hundred and we got between; it's probably roughly a hundred and fifty odd crays. So half a kilometre square per transect and we ran lost and lots of them…

Things have changed, except for a couple little spots. Im sure you know where they are but we'll talk about them later, I'm sure you know where most of them are.
Where did Nick sell his crays? And who did he sell them to?

LA: He took the small trailer when that was full around to Coral Bay. They had a pub there. It's also different, Coral Bay has been wrecked. The beautiful staghorn coral and everything was right off the foreshore, now you have to go out onto the reef to see it all.

MD: Boats anchoring up in there…

LA: And the pub in Exmouth, the pub in Carnarvon….

MD: So there wasn't another middle man that sort of, proper market he would sell them, or…

LA: No, the big truck would go to Freo, then to Perth to the export market, but the sort of damaged ones, he must've had a contract to supply the local pubs as well.

MD: Ok, so a pretty big operation.

LA: Yeah… unfortunately…
After the big truck went to Perth, the little trailer was full and packed up, generator and all that packed up. We couldn't get any cool room space in Carnarvon. We phoned up everywhere. It turned out this guy who had a kangaroo store said he had space…well he had space. We took the crays down there, put them in. And when we finally got the truck back went down to pick them up we had to throw them away because the smell of the kangaroo meat went thru it all. Lost a lot of money there…

MD: How much were they getting for the crays? Back then; this is 1974…

LA: I am not sure. We were on percentage.

MD: So your wages were…

LA: Divided up. The divers got fifty-five percent of each cray they took. The cook got fifteen percent and Nick got thirty-five percent. Sometime I'd be on, back in 74 two hundred dollars a day.

MD: That would have been pretty good money back then…

LA: Yes. For basically a couple hours a day on a boat. Again, I would split mine with my mate. Some days he might make fifty bucks a day. Other days I might make fifty. And we would split it up…

MD: So you would always work with your mate?

LA: Yes.

MD: Not with the other two?

LA: Yes.

MD: Nick was one of the other two, was he?

LA: No, he didn't dive because he had a heart attack and couldn't dive. So he was still making good money.

MD: He was always at the camp, was he?

LA: No, he was based in Fremantle where he lived because he was still having check ups with the doctor and never got the OK. He only came up two or three time during the season. When we left, he wanted us to stay on for the next year and we said "no, we have things to do…". He brought a shotgun out and he was going to shoot us; he didn't want us to go.

MD: Shooting you wouldn't have helped you work the next season, would it…

LA: He was such a wild character.

MD: Was he an older fellow?

LA: Probably ten years older than what I was at the time.

MA: So, accent, Italian…Sicilian guy or…?

LA: I'm not sure of his real background…so we got out of there quick.

MA: And never went back…

LA: No.

MA: Because there must have been a lot of guys work for him over the years.

LA: I imagine so.

MA: Fairly sure he started this operation in the late sixties and it sort of finished up in the early eighties, I think. That's fifteen to twenty years of operation. And because I got hold of this thesis, it was a social science thesis. It was on the turtle fishery and the cray fishery that was there back then. I was reading through a couple of the interviews and they said, in the interview, somebody was saying: when was the operation stopped and they were thinking it was in the early eighties.
Do you know if Nick is still alive?

LA: He died. He lived as a hermit out at Nick's Camp.

MD: till the end of his days…

LA: And with his agreement with CALM he couldn't sell the licence to anybody. He could hand it in to his family but no one in the family wanted to go and live out there. They all had established jobs, well off.
Nick fell out with all the family and just became a hermit and lived on echidnas and goannas, snakes and stuff like that. And Leonie, the new station manager used to go down and see how he was and cook him a stew, take some food down.

MD: So this is well into his older days and he just perished there. That's why the call it Nick's camp…Which is just North of Warra station is that right?

LA: South.

MD: I've seen the camp but I have never actually been into that camp. Can you launch a boat off that camp really easy?

LA: We used to go out in the lagoon from the beach. Launching the boat was an exercise…you'd have to have it teed up, the four of you, couple of boat rollers. You'd all get the first boat ready to launch, then you'd get the second one. Launch the first boat, two guys would get in, off they go. Get thru the waves. Second boat do the same in between the breakers.
Coming back, one guy from each boat would jump out, swim to shore. You'd get the four wheel drive, reverse it up as close as you could with a long rope and a big hook to hook onto the bow rail and you'd have a couple of boat rollers ready. They would ride the surf in, as soon as they hit the sand boat roller under, the guy would jump out and drive up before the next wave. If you hesitated you'd get swamped, be half full of water.
Had to be so quick…

MD: Can be pretty dangerous.
You never actually put those boats on a trailer. You would just keep them on the beach for the overnight and then just turn them round and push them back in the water. And these were five metre tinnies with a forty on the back or something.
Because you need something with a bit of grump to get out of the way there.

LA: That's right.

MD: We nearly got swamped in September.

LA: Having a six auxiliary was so, when your actually diving if you just kept idling and nudging up with the bigger outboard it would oil up and then we'd have trouble fouled plugs when you wanted to get going…

MD: You couldn't.

LA: No.

MD: You would have the auxiliary going?

LA: The whole time we'd just nudge up and down, up and down…to make sure there was slack in the hose.

MD: How big a section you would actually work, Len? Throughout the whole season, I mean how many kilometres do you reckon North and South you guys went? You were on one reef and then there was no point going back to that reef. You just worked on the next one, the next one. As the season went on you had to go further and further away or?

LA: Well the furtherest we went was Cape Farquhar and probably five or six kilometres north of the lagoon campsite. From right in close to out where the reef dropped off.

MD: Would go up as far north as Tantabiddi or anything like that?

LA: No

MD: You'd just work around Nick's, from Farquhar to five or six kilometre north of the camp.
How come you came all the way down to Farquhar but didn't go north?

LA: Because there is more down there. More further south than north, and bigger. The idea was, in the good weather get down there and do as much as we could around that area because you couldn't get there in rough weather.

MD: You would drive the boats all the way down there? How long would that take you to go down there from Nick's Camp?

LA: About an hour.

MD: In the lagoon, not around the outside…

LA: Yes, in the lagoon.

MD: Strait through on a high tide. Just power through there.
You'd work the back lagoon every time. And how did you keep tabs on what reef you'd already worked and which ones you hadn't.

LA: I just got to know.
And you soon realise when you jumped over the side when there was nothing there…

MD: That's true, yes.

LA: You just see the feelers coming out everywhere.

MD: Would that happen very often, when you'd jump over the side and there's crays?

LA: Everywhere

MD: Crays everywhere?

LA: Yes.
That's why I thought, after Nick gave the licence back to CALM and I went back ten years later you'd think there would be heaps…

MD: I think that what's maybe happened, I'm not sure, it's just a theory…I think Nicks operation took part of the population and got it down to a certain level here and then some of the recreational people have probably (because people do recreationally fish for crays here all the time, maybe they didn't back then but they certainly do now), and they fish them down here to the point where the adult population is not actually enough to start an increase going. So there has been this bottom level, this bottom line of crayfish and it's just not enough to increase the population. So maybe they need to leave it alone for a while completely and just ban it for awhile. Until we can see the levels…but that's not my decision, we just provide them with the science. This is just my opinion.

LA: With what we were taking how would it recover…you know…
Sad.

MD: It is sad, but if you don't have that information before hand, you'd expect the population to go back up again. And you were only taking the proper sized ones. So you would expect the young ones to carry on.
What was the ratio between, when you guys were diving between legal sized one and illegal sized ones? Was it fifty-fifty?

LA: Probably more eighty, eighty, eighty five percent keepers. Very few you put back.

MD: And what's the biggest cray you reckon you got?

LA: Probably a kilo and a half.

MD: Which is a cray that size…probably, what, eighty centimetres?

LA: Most of them around the same size, a lot of them had big bodies and small tails. Compared to diving in New Zealand getting the crays there…they were just big all over, being in cold water…

MD: That's interesting. So they probably grew a lot quicker at Ningaloo but they didn't put on the meat.

LA: Because they reckon, when I was out on the cray boats I talked to the guys at Lancelin, they had these pots there for research, to catch the floating larvae. They were saying a majority of their eggs end up in Tassy or New Zealand.

MD: Something must going on at Ningaloo because the fact that the population hasn't increased over the years considering that there is not that much fishing going on there means that maybe Ningaloo Reef itself gets seeded by Ningaloo Reef rather than somewhere else like somewhere up North or down South. The other thing that might be happening is, for the reds, it's pretty much the northern boundary for them. So maybe the larvae from the reds were actually going south but there was nothing from the South going north. That might something that is going on at Ningaloo.

LA: Well, it makes sense or here it's passing up and down to restock but up there that's the limit.

MD: They can't get anything from up north… unless it's getting something from south. That's very interesting actually. I'll have to think about that one, there is something there, there really is. Im trying to work out why there hasn't been an increase. Because I have to say, you would expect them to increase…
I have all ready asked you: you had nearly all reds, there weren't really many painteds.
We did find some Painted in September and July, but they were on the outside slope. And you know, there's one there and then, not another one for miles and then another one and then another one sort of thing…
What was your average catch for the day? Like a reasonable day, how many kilos between you and your mate? One of 2 teams?

LA: Probably over a hundred-odd kilos.

MD: So that's eighty to a hundred crays sort of thing.
LA: Yes

MD: So a couple of hundred kilos each day on average…
Do you remember what you best take was?

LA: No. Because everyday was basically the same. The only day you didn't like was when you couldn't get out.

MD: Sure. Did that happen very often?

LA: Sometimes. Two days in a week would be unusual. Most of the time you got out every day.

MD: And the main factor was just the swell…

LA: Once you got past, the boat out, it was flat as a tack. It's just that short break…

MD: I haven't actually been to Nick's Camp but there's just this big short break at Nick's Camp, is there, coming in…?

LA: Whether it's just the season, the waves, the tides. It probably has a big thing to do with it too. The high tides, get more surge…

MD: Was there a time in that six month period, you basically worked March to September…is that roughly right?

LA: Yes

MD: Was there a time were there were more crays or that you noticed that maybe they were disappearing, marching off somewhere, or do you think they just stayed put all year?

LA: They just seemed to stay put. They didn't…like normally crays will march round but they were right in all the time. That's why you didn't have to venture over the edge.

MD: Ok…and go looking for them and stuff.
Basically on top of each other… I think they aree weed eaters as well, the Reds…they like the weed.

LA: Yes, and a lot of the ledges and that would have the weed around and once you got down into it, you'd just see feelers and legs. They had nowhere to go. You were just going around these rocks and…

MD: …picking them up….

LA: you just moved around trying not to be seen…move to the next one and they wouldn't seem to try to get away…

MD: Easy to catch aren't they…It's no wonder they sort of vulnerable. They are really…they don't move. Once you know what sort of habitat to look in, you jump in the water and you go, they will be there! You can go there and you can always guarantee they're going to be there.

LA: In certain type of… Rock Cod would be around that sort of reef, near the ledges. When you saw them you knew there'd be crays.

MD: They seem to live together quit a bit.

LA: And sometimes you would have to watch in the ledges for the cobbler.

MD: Ah, the black ones.

LA: It's a stone fish over here…sure they call them cobbler or something. Yeah, it was a stone fish and before you'd put your hand in you'd always just give a good look because they'd be there…

MD: I guess, if they were there all the time there wasn't anything that you noticed where you'd catch more, you'd catch less. Did you notice places where there was maybe more weed or less current. What were the features of the habitat that made you think, when you jumped in water, "this is going to be a good spot"?

LA: As you say, the weed and a lot of ledges. And sometimes you go to isolated middle bommie and it would have a big ledge all the way around…as you were going down you could just see the feelers sticking out.

MD: And nobody in Exmouth or anything was asking you guys where you were getting all your cays?

LA: We never saw anybody there, no need to talk to.

MD: You must've kept it pretty quiet…

LA: We just went to town, now and again go in, sell the crays, have a night at the pub and stuff. Sleep in the panel van and drive back because you want to work the next day.

MD: I guess you were only putting a few crays in the Exmouth pubs and in the Carnarvon pubs, nobody would actually realise that he's actually getting quite a few…. Because most of them were going down to Fremantle and being sold, who knows, all over the place. Overseas maybe for all we know. Because the Italians are pretty shrewd. My first boss on the trawlers was an Italian guy and he was a very very shrewd man, excellent fisherman. Very smart guy he was. He used to be a shark fisherman in Bass Strait.

LA: He also wanted us to stay after the season to stay on and do fishing and shark fishing.

MD: So did he have guys doing that stuff as well?

LA: I don't know. He put it to my mate and I but I wanted to head up to Darwin. We didn't do it. He tempted us with a trip. "If you do that, I'll take you out diving on the Abrolhos Islands for a week" ….tempting but no. It was time to move I think…

MD: Sure…especially after being in the water everyday for six months or so…I wouldn't mind staying dry for a little while.

LA: That was our life. We were doing a dive trip around Australia. We'd dive Mount Gambier, the sink holes for two weeks. Dive Tassy, abalone diving and worked on a fruit orchard and then we used to do night dives to get crays and sell them for... We would just dive mad.

MD: I've heard the before actually…getting crays and…yes, ok…and then selling them off for vegetables and stuff like that. Why to people dive for crays at night? Because I know some people do…

LA: It was sort of the only time we had; we were working abalone diving…

MD: I thought there must have been an advantage to diving at night for crays or something…

LA: Well, you could gaff a lot of fish because they were stunned by the light.

MD: There is this text book that I have seen. I think its just a fish book, and it's got a picture of this guy. He's got a light on his helmet and he's got this Long Tom embedded in his eye all the way down to the Long Tom's eye. He lost his eye. So it's probably.
And speared right thru there…Have you ever heard of this?

LA: No.

MD: A torch on his head a Long Tom just saw the light and went straight for it. Straight through his mask, it didn't kill him, embedded in his eye. It's just a little photo in a book but it's a nasty looking photo. They have chopped the Long Tom off and it's about that thick and it's just stuck in his eye. Lucky he didn't die. Anyway…
We've talk about whether there were other commercial cray operators working in Ningaloo.
I've just read something about somebody, Yomanis or something…Stan, Stanovich…does that ring a bell at all…?

LA: No

MD: No. That might've been a different time. No…
I've asked you whether….
You only worked one season, so seeing cray numbers decline over your time working there isn't really a question you would have an answer for.
Have you heard anything about crayfish up there? Do you know anyone who goes up there who's said that they're still catching crays up there?

LA: No. Like I told Andy… I used to have an on-site van here, and I said you ought to go up there. Of course we'd bring our craying gear and I said try your pots out there. And he had a run-in with Bruce who had been the former caretaker. He said you can't cray with pots here, it's illegal. He said he would find out. So he went to the fisheries and found out you can put pots in there. These guys had been telling everyone (he'd worked there for about eight years), that they weren't allowed to pot…

MD: Not worth potting there now…that's straight out the front of 14-Mile. Ok

LA: It was thirty knots the other week. I said "hey Andy what's this?" I got a phone call someone wants me to go referee for you…become an Aussie citizen …how can we do that, you've killed both our emblems…. You've killed both a kangaroo and an emu

MD: Did he kill an emu too did he?

LA: Going to Exmouth one day…

MD: I heard about this kangaroo. He told me…I spoke to him last Wednesday or something and he said this kangaroo was coming and just hit the back of his bike and just thru him off his bike…He had a couple of cracked ribs and everything…but he was getting around all right.

LA: I'll just swap my batteries (Len has a video recording the interview)

MD: Yes no worries

LA: I was stirring him up and I said "what other damage happened?" and he said "Aw, I got a cut above his eye and he had to go to Exmouth hospital" I said "Yes, I've been there for stitches in the leg from diving off the jetty there, on the wreckage underneath…"

MD: Off the pier there…

LA: Yes, the jetty there, diving…

MD: You didn't get held up as you got out of the water? It's pretty restricted…

LA: I'd payed to go on the…to do it…so they just thought I was trying to attract sharks for the camera…I said "well why is that?", I was cut to the bone from barnacles under the jetty…

MD: Anything for a good shot, Len, anything for a good shot…that's what we say when we get cut up…We do it for science…

LA: The stuff I've done…

MD: Yeah, right, you must have some damn good photos.
Is there anything you want to add Len about the cray fishing, anything you think I haven't covered, that might be important…what the agenda is for me, as in the reporting of the population down there…

LA: Possibly if you can get a study of the currents to see what may float back up north, mainly the current, when you are diving you're sort of flowing south…

MD: Yes, in the lagoon

LA: There might not be any way for them to restock. All the larvae might be heading south. So eventually it will just die out.

MD: Eventually, I guess it will; which would be a pretty sad thing because we don't really know exactly what job they perform in the ecosystem. So whether they perform a really important job or, if they disappear something else can take their place and still do the job that the crayfish were once doing.
I guess the larger crays…I don't know how many years old they would have been but if Nick was going there year after year to the same reefs; I imagine they were fairly new each time, fairly new crays each time. He would go every single year, wouldn't he?

LA: Yes

MD: Not every two years or anything like that…

LA: No, he'd be there.

MD: What would Nick do the rest of the year, do you know?

LA: Don't know

MD: I was just wondering if he was making enough money for the whole year round or if ….

LA: He would've!

MD: He would've, but knowing Italians he would've been busy doing something else…

LA: He had a house in Perth or Fremantle, that's where we met him; at the end he ended up living a hermits life in a bit of a shanky at his campsite. Fell out with all the family, no one wanted him…

MD: He must've really loved that place. It must've been pretty dear to his heart for him to live there and go up there.

LA: Oh I love it. It's the best free campsite in Australia. I've told people from New Zealand, divers I've met. I used to go to the dive club and show them photos and introduce so many people to go and camp at 14-mile and stuff.

MD: That's a nice camp "14-Mile". That's a very nice camp, I really like that one.

LA: So important, you try to keep it as a campsite, not lose it. Leoni is doing a great job up there.

MD: Leoni, Andy and Tracy are doing an awesome job. There is not a scrap of rubbish around; all the paths are well kept. They keep everything really really good. I think they are doing a fantastic job, a good model for camps right up and down Ningaloo Reef.

LA: That's right, I went to Gnarloo Station and that has gone to eco-camping…

MD: It's a bit of a mess

LA: Yes, we went there four years ago and they started developing the chalets or whatever they call them. Then the builder ran away with the money.

MD: Was that a Japanese mob that put money into that…?

LA: That's right

MD: I don't quite know the full story about that yeah, there's like thirty of them. We stayed there last week, for a couple of nights because you can go in to Gnarloo Bay and launch the boat off Gnarloo Bay. So it's not too bad to work from. But it's always blowing its guts out, dust everywhere coming off the dunes…

LA: They finished the chalets?

MD: No. There are chalets that you can stay in. Some are completed…

LA: There is only twelve started, they got them so fast, so many walls and roof up. And then he asked for another million. The Japs sent out the million and he took off.

MD: They never found him?

LA: I don't think so.

MD: Shit!

LA: I was prepared to say "Ok, how about I work two or three days, help building these things. Live here for free and go diving".

MD: Well, that may well be a possibility because even though they haven't finished them there are, like there was an electrician there the other day. So there are people actually working on the station. But I think, compared to what it used to be, it's very very low key now. Instead of having fifty blokes working there and having them done, there's like a couple of blokes or a handful of blokes just doing a little bit.

LA: I saw a thing about the grey nomads and they showed a bite about it. The Irish chap taken over now. Has he bought it off the Japanese or?

MD: I don't know. I think there's a guy named Paul…

LA: I'm not sure

MD: There's different people there all the time I think. I know there is somebody there with an Irish accent and there is a woman there with an Irish accent so she might be his wife or something… And then there is guy in that tool shed named Ferrel…he lives up to his name…nice block though, he got us out of trouble in June, flat battery and stuff. He was pretty good. And lo and behold we were reading a surfing magazine and his name was in the surfing magazine. Not surf, because somebody had illegally camped and he goes out at night looking for illegal campers…

Now, we are doing crays but we're also doing octopus. Did you have anything to do; do you know anything about octopus up there? Did you ever catch any or see any, or?

LA: The only octopus, is when I was up there maybe a couple of months ago. There was lots on the shelves; probably four weeks periods guy were bragging how they had fifty kilos of occy…and walking around, I got one for bait while I was there. Other guys are going out, getting four an afternoon. And you can see, again, it will just get wiped out. You walk on the reef; everyone's out there looking for them.

MD: So the reefs you're talking about they're the ones just north of 14-Mile or just south of 14-Mile base?

LA: Both. There's one north of Turtle Head going along the coast there. You used to walk out each day and see two or three. And after six weeks you wouldn't see any. And just south of where the marker just after the sanctuary zone, down below that, guys were getting thirty, forty kilos in an afternoon. At the end there is none there either.

MD: So this was this year?

LA: This year yes. And people were going out getting squid. I don't know if there is limits on squid. The former caretaker was getting up to forty a day everyday…

MD: Jigging them was he?

LA: Yeah, in his tinnie. How's the place gonna survive if everyone's raping it like that?

MD: It is a bit of a problem actually because once again, little like the crayfish, there is only so many places you can go and actually really get them when they don't actually move very much. So those reefs you are talking about we went there last week and we couldn't find any octopus on them. But Andy was telling us about a guy who comes up from Carnarvon, one of the vegetable growers from Carnarvon, a Polish guy goes up there and takes ten-twelve large foam containers and then just disappears with them basically. He must just take them home and marinate them or something. Apparently he swaps vegetable with somebody so he was able to go and fish them or something. That's what Andy was saying to me anyway.

Occasionally, you guys would take one octopus just for a fish or something like that. Bu they weren't worth anything back then…

LA: No.

MD: I remember, because even when I was fishing in the eighties we were getting a buck a kilo for squid and octopus, we'd get nothing for them. So it wasn't worth keeping them. That's it mate. We can have a look at a couple of charts if you are happy with that. I'll tell you where we found our crays and you can tell me where you used to find your crays if that's Ok? That's up to you though Len, if you want to fill us in on your secrets or not.

There is Coral Bay, you guys were further south. You didn't work any of this area at all.

LA: No
How did it go up there, did you find any?

MD: Up here, we had for the octopus, we get octopus up here. Specially near the Mildura wreck so this reef here. The locals actually call it "Occy Beach". And you know its spattered around here, there's the odd one. I think we only got twenty-five or something. On the whole coast about a hundred and fifty…different transects that we ran. Not a lot of octopus.

LA: I never saw any. I spent a month diving, about fourteen years ago…where is Mesa camp?

MD: It should be, there's Jurabi Point so Milyering must be…there's Mangrove Bay, so Milyering must be up here. The National Park must start here somewhere. So Mesa Camp is somewhere just here I think.

LA: So I dived most of that reef every day for a month and never saw one octopus. Not one cray.

MD: When was that?

LA: Fourteen years ago.

MD: Fourteen years ago…and no crays at all either.

LA: No, nothing there.
So you guys found a certain spot, here, they stop?

MD: But that was our best spot by far…in this area…which is great because this is sanctuary zone, from here to here. That's the biggest sanctuary zone. People tend not to go there. And the grey nomads, bless them, they keep a real good eye…even we went surveying them and I look up and on the sand dunes there is this guy with pair a binoculars watching what we were doing; which is great. Because there is a place called Crayfish Reef, here, and they are all Reds in there. But there is nowhere near the numbers or the size you used to catch at. And then, you know, there is the odd on the outside. We were doing the inside and we were doing the outside. The outside you'd get a few painteds and stuff. Over there is absolutely nothing. Not octopus or anything around Bundegi area…
Lets get a map that's a bit further south for you.

LA: So the good area for the crays was in this area

MD: Well there are some crays there but its completely no-take area now, what they call a sanctuary zone. They are the last few remaining ones. You might want to be a little careful who you show the video to, that's all Len. Just in case they go and pilfer them. Because if there is not many left…it is really happening. You don't have to worry you don't even eat them…
Cloates area, that the whaling station, Norwegian Bay. Did you go to the whaling station?

LA: No

MD: That's pretty interesting getting up in there.

LA: How do you get into there?

MD: You go to Ningaloo Station. You ask, you just let them know that you're there. It's a great place to actually stop. There's a little camp in here somewhere. There's the old lighthouse which is just a magnificent site. The view from there is like two-hundred and seventy degrees over the ocean and you've got all the back, sheep area and everything. And they're quite nice people there. It's just different station. But anyway, up round the corner here is this bay here. It's called Norwegian Bay, and the reason they call it Norwegian Bay is because all the Norwegians used to come and they set up a whaling station here. And you can see all the old winches, rusting away on the beach, there's whale bones everywhere, big ribs, vertebrae on the beach. That sort of thing…and they picked that because there is a nice big channel going right thru here. You could get a thirty-sixty metre vessel thru. It's sort of three-four fanthoms thru there; quit a nice area through there. The beach itself isn't great but that's interesting to go and have a look.

LA: All the whaling gear and stuff's still there?

MD: Yeah, the old boilers. They are rusting away and sort of everywhere but can certainly get to them in a four-wheel-drive. You might to leave you caravan behind for the sand dunes but…
You basically go to the old lighthouse area and they've got the Ningaloo Station. Jane Lefroy. That's Jane's Bay that's named after…and you can drive up through the back of the dunes and you have a bit of a walk. There is even a couple of grave sites up in the back here from the Whaling Station. Young blocks, nineteen years of age, they came over from Norway for six months of the year. Back in the thirties or forties or even the fifties, I think it ran for quite a while. So yeah, there's a couple of graves there. But all the equipment's there.
That's Coral Bay, here we are. So you didn't get up that far north.

LA: No.

MD: None of the blkes you were working with had worked for Nick before?

LA: No.

MD: That's a bit of a shame.

LA: No. The Maori boys came up from Esperance. They'd been previously diving for abalone down there.

MD: Again that's Coral Bay, Point Anderson…………..Cloates…Tantabiddi, near Exmouth….The Murions…far north… Occy Beach.
This guy told us there was crays out there but we didn't find any. That's Tantabiddi where the boat ramp is…a few octopus but no crays…

LA: What about Dugongs?

MD: Well I have only seen one. That was right here, Mildura wreck road and there is a surfing beach here.

LA: I have only seen one off Mesa camp. Fishing one day, doing no good fishing so jumped in and had a snorkel and he just came up and sat there for about ten minutes, looking at me. It was unreal.

MD: I don't think there is a lot up here because there's not a lot of seagrass. They need seagrass, and there's just not a lot of it up there. Not the sort that they are probably after… Coral Bay to Point Henderson, yeah…we'll have a look in the computer because I've got much better map on the computer. You'll like this map. I showed Andy this map actually…There isn't much in the way of charts on the south, it's the most remote area…it's a shame Nick's not around anymore…

LA: Yeah, he would've been very interesting to interview…
He never said much about friends…his family must've got fed up of it…

MD: He was never married or stuff like that?

LA: Yeah, he used to not talk about them but Leoni would know about them…

MD: Because an Italian without kids isn't an Italian. I have to be careful what I say there…because my wife is Italian…
I'll show you this map, this is the sort of map that we have now for Ningaloo…all just aerials…pretty cool stuff.
This is the Exmouth area, we can actually zoom in here…the resolution is pretty good these days…whole of Ningaloo…this'll give an idea of the places we sampled…all the little dots…Cloates, Pelican….
You were just out here weren't you?

LA: South.

MD: Cape Farquhar, and the border there…sanctuary zone. We did some sampling here, that's Cape Farquhar there… I'm not really sure where your camp is. That's Alison Point, does that ring a bell?

LA: No

MD: That's just at the front of Waroorra Station

LA: South of the station

MD: Do you know how many kilometres?

LA: Probably about five…
Is that the lagoon?
We were just near the lagoon.
It was just north of the lagoon because we used to drive down to the lagoon and to the boats.

MD: In there…Ok

The camp must be that one there…

LA: It was up on the cliff, all rocks.

MD: So that might be it then…
And you used to go as far as Cape Farquhar…

LA; Yeah, because otherwise it would take too long to get back.

MD: Did Nick designate where you guys should work or…

LA: He just wanted us to work round there and come back.

MD: Fifteen kilometres, that's still a fair way to go in sloppy seas from your camp to the bottom of Farquhar…eight miles or something…
So those reefs aren't really on here I guess, Len. Because your camp is there and Cape Farquhar here. You were working in the back edge, round here…shame we don't have it…technology…

LA: Tea or coffee?

MD: Can I take you to lunch?

END OF INTERVIEW

Appendix C: Lobster and octopus survey locations

Complete list of lobster and octopus survey locations from north to south, reef and management zonation, number of replicate 5 x 100m surveys and GPS coordinates completed at the Ningaloo Marine Park in 2008. AIMS surveys are marked with an * for lobsters and octopus; CSIRO lobster surveys marked with a ^. Note that intertidal surveys for octopus are 2 x 50m surveys and standardized to m^2 for comparative analyses. Intertidal octopus surveys have been placed at the end of each section's list.

Section	*Location*	*Reef zone*	*Management zone*	*No. transects*	*Latitude*	*Longitude*
Northern	Lighthouse*	Inner lagoon	Sanctuary	4	-21.787624	114.156888
Northern	Lighthouse*	Outer slope	Sanctuary	4	-21.795033	114.13835
Northern	Lighthouse*	Inner lagoon	Recreational	4	-21.802622	114.109797
Northern	Lighthouse*	Outer slope	Recreational	4	-21.803167	114.1166
Northern	Lighthouse^		Sanctuary	6	-21.78754	114.1715
Northern	Jurabi^		Sanctuary	6	-21.85562	114.01769
Northern	Jurabi^		Recreational	12	-21.88956	113.98899
Northern	Turquoise*	Inner lagoon	Sanctuary	6	-22.07407	113.896771
Northern	Turquoise*	Outer slope	Sanctuary	4	-22.075454	113.883842
Northern	Turquoise*	Inner lagoon	Recreational	4	-22.04572	113.908582
Northern	Osprey^		Sanctuary	6	-22.3395	113.80252
Northern	Osprey^		Recreational	1	-22.3395	113.80252
Northern	Winderabandi*	Inner lagoon	Sanctuary	4	-22.492051	113.701991
Northern	Winderabandi*	Outer slope	Sanctuary	2 x 4	-22.483517 & -22.495057	113.697483 & 113.693746
Northern	Winderabandi*	Inner lagoon	Recreational	4	-22.495975	113.700564
Northern	Winderabandi*	Outer slope	Recreational	2 x 4	-22.50275 & -22.498598	113.690483 & 113.691856
Northern	North West Cape*	Inter-tidal	Sanctuary	52	-21.78462	114.16453
Northern	Jurabi*	Inter-tidal	Sanctuary	8	-21.84749	114.02818
Northern	Jurabi*	Inter-tidal	Recreational	8	-21.84805	114.03018
Northern	Mangrove Bay*	Inter-tidal	Sanctuary	16	-21.96202	113.93922
Northern	Mandu South*	Inter-tidal	Sanctuary	8	-22.14598	113.86929
Northern	Pilgramunna*	Inter-tidal	Recreational	8	-22.19321	113.85518
Northern	Bundera*	Inter-tidal	Sanctuary	8	-22.49303	113.72567
			Total transects	193		

Section	*Location*	*Reef zone*	*Management zone*	*No. transects*	*Latitude*	*Longitude*
Central	North Cloates*	Inner lagoon	Recreational	4	-22.54042	113.681802
Central	North Cloates*	Outer slope	Sanctuary	4	-22.588147	113.640416
Central	North Cloates*	Outer slope	Recreational	4	-22.582833	113.642087
Central	Central Cloates*	Inner lagoon	Sanctuary	3 x 4	-22.721801 & -22.725846 & -22.717036	113.717985 & 113.724044 & 113.710481
Central	South Cloates*	Outer slope	Sanctuary	4	-22.898552	113.765581
Central	South Cloates*	Outer slope	Recreational	4	-22.931583	113.767033
Central	South Cloates*	Inner lagoon	Recreational	4	-22.981599	113.81846
Central	Bateman^		Recreational	14	-23.02391	113.82724
Central	Bateman^		Sanctuary	4	-23.049883	113.822517
Central	North Maud/ Bateman*	Inner lagoon	Recreational	4	-23.029167	113.821617
Central	North Maud*	Outer slope	Recreational	4	-23.03715	113.7699
Central	Bateman*	Inner lagoon	Sanctuary	4	-23.068098	113.816296
Central	North Maud*	Outer slope	Sanctuary	4	-23.081237	113.732624
Central	South Maud*	Inner lagoon	Sanctuary	4	-23.170667	113.7558
Central	South Maud*	Outer slope	Sanctuary	4	-23.172708	113.750233
Central	South Maud*	Inner lagoon	Recreational	4	-23.173332	113.755875
Central	South Maud*	Outer slope	Recreational	4	-23.183917	113.754833
Central	South Cloates'	Inter-tidal	Recreational	8	-22.91128	113.81655
Central	Coral Bay'	Inter-tidal	Sanctuary	8	-23.15479	113.76753
Central	14 Mile Beach'	Inter-tidal	Recreational	8	-23.15407	113.46979
			Total transects	110		
Southern	North Pelican*	Outer slope	Recreational	4	-23.27106	113.770482
Southern	North Pelican*	Inner lagoon	Recreational	4	-23.293957	113.794469
Southern	North Pelican*	Outer slope	Sanctuary	4	-23.297208	113.77055
Southern	North Pelican*	Inner lagoon	Sanctuary	4	-23.294494	113.79434
Southern	South Pelican*	Outer slope	Sanctuary	4	-23.422033	113.775033
Southern	South Pelican*	Inner lagoon	Sanctuary	4	-23.435609	113.781509
Southern	South Pelican*	Outer slope	Recreational	4	-23.445598	113.775301
Southern	South Pelican*	Inner lagoon	Recreational	4	-23.451421	113.779164
Southern	Cape Farquhar*	Outer slope	Sanctuary	4	-23.37958	113.36296
Southern	Cape Farquhar*	Outer slope	Recreational	4	-23.652016	113.594462
Southern	Gnaraloo*	Outer slope	Sanctuary	4	-23.755967	113.535

Section	Location	Reef zone	Management zone	No. transects	Latitude	Longitude
Southern	Gnaraloo*	Outer slope	Recreational	4	-23.803533	113.5175
Southern	Gnaraloo^		Sanctuary	6	-23.764533	113.544583
Southern	Gnaraloo^		Recreational	4	-23.68276	113.58476
Southern	3-Mile*	Outer slope	Recreational	4	-23.849916	113.50997
Southern	3-Mile*	Outer slope	Sanctuary	4	-23.853073	113.50766
Southern	3-Mile*	Inner lagoon	Sanctuary	4	-23.874477	113.495178
Southern	3-Mile*	Inner lagoon	Recreational	4	-23.885584	113.479119
Southern	3-Mile^		Recreational	7	-23.890883	113.477017
Southern	Turtle*	Inner	Sanctuary	4	-23.977833	113.466983
Southern	Turtle*	Inner	Recreational	4	-23.987517	113.46565
Southern	Turtle1*	Inter-tidal	Sanctuary	8	-23.96761	113.47038
Southern	Turtle2*	Inter-tidal	Sanctuary	8	-24.00071	113.46127
			Total transects	105		
			Grand Total	408		

Appendix D: AIMS MEST Metadata input.

Crayfish and Octopus Surveys, Ningaloo Reef, Western Australia (WAMSI Node 3 Project 3.1.3)

Data Identification

Title	Crayfish and Octopus Surveys, Ningaloo Reef, Western Australia (WAMSI Node 3 Project 3.1.3)

Date

Date	2008-05-01
Date type	**creation**: date identifies when the resource was brought into existence
Data Summary	Surveys along the coast of Ningaloo Reef on targeted invertebrate communities (crayfish and octopus) in relation to patterns of human usage.

Point of contact

Organisation name	Australian Institute of Marine Science
Position name	Data Manager, AIMS Data Centre

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Online resource

OnLine resource	http://www.aims.gov.au/adc
Hours of service	0800 to 1640 UTC+10: Monday to Friday
Role	**pointOfContact**: party who can be contacted for acquiring knowledge about or acquisition of the resource

Descriptive keywords Biological Classification | Animals/Invertebrates | Molluscs , Cephalopods , Biological Classification | Animals/Invertebrates | Arthropods , Crustaceans , Crayfish octopi panulirus western red painted lobster (Type: theme).

Language English

Character set **utf8**: 8-bit variable size UCS Transfer Format, based on ISO/IEC 10646

Topic category

Topic category code oceans

Topic category

Topic category code biota

Extent

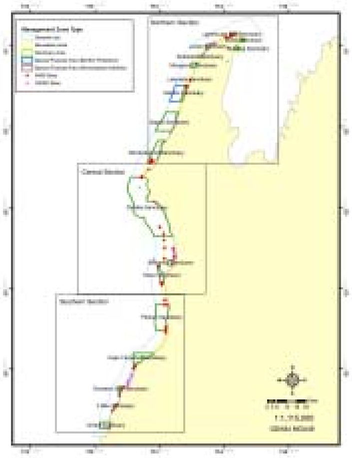
Description Seasonal Snapshot entire length of Ningaloo Reef

Geographic element

Geographic bounding box

North bound latitude
-21.47

West bound longitude
112.99



East bound longitude
114.16

South bound latitude
-23.76

Temporal element

Temporal Extent (MCP)

Extent

Begin date 2008-05-01T16:06:00

Temporal Currency **mostRecent**: resource currency is most recent

Temporal Aggregation **none**: aggregation unit is none

Vertical element

Vertical extent

Minimum value 0

Maximum value	30

Metadata Info

File identifier	e8f43d2f-3417-42b1-a015-b7d4b1d68755
Language	English
Character set	**utf8**: 8-bit variable size UCS Transfer Format, based on ISO/IEC 10646
Hierarchy level	**dataset**: information applies to the dataset

Contact

Organisation name	Australian Institute of Marine Science
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Online resource

OnLine resource	http://www.aims.gov.au/adc
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Date stamp	2008-10-16
Revision Date	2009-10-16T11:17:33