Appendix 2

Lagoon Invertebrates Final Report and Monitoring Recommendations

Final Report 2008

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Table of Contents

Summary

Field surveys undertaken between 2006 and 2009 have been compiled to provide an extensive baseline of the distribution and abundance of rock lobster species from the Muiron Islands in the north to Turtles sanctuary in the south. The abundance of lobsters of all species were low, however there were regions that held significantly higher abundances of lobsters. The geographic regions and habitats types in which lobsters were found varied with lobster species. The Western Rock Lobster *Panulirus cygnus* was most abundant in the southern area of the marine park, where high abundances were found in coastal reef areas, especially shoreline reefs in Batemans Bay formed of eroded beach rock. Other species such as *P. versicolor* and *P. ornatus* were also more common on coastal attached reefs rather than offshore reefs, however these species were most abundant in the north. The centre of *P. cygnus* distribution was around Batemans Bay, where the Dugong Sanctuary zone has been in existence since 1990. In Batemans Bay, the density of *P. cygnus* was two orders of magnitude higher in the sanctuary zone than in adjacent areas, however the mean size inside the Sanctuary was significantly smaller than outside it. At Northwest Cape the Lighthouse Sanctuary zone had significantly higher numbers of *P. versicolor* than adjacent areas outside it but given the large size of most of these animals, it is unlikely that this is an effect of the recent rezoning which took place in 2006. The strong influence of habitat on lobster abundance and population structure makes it imperative that monitoring of newly created Sanctuary zones is continued in order to provide the before/after comparisons that are required in order to conclusively assess the effectiveness of zoning for protecting lobster populations. Ongoing monitoring, specifically targeting suitable habitats within a select group of newly declared sanctuaries, is required in order to determine the degree to which lobsters populations will respond positively to protection by sanctuary zones.

Introduction

Background

The *Ningaloo Marine Park (State Waters) Plan 1989* was designated A-Class in 1990. A review of the Management Plan began in 2000; this resulted in a revised Management Plan being approved by the Minister in January 2005. Changes in the current Management Plan include extending the Marine Park southwards to incorporate the full extent of the reef, increasing the number and extent of Sanctuary Zones, introducing Special Purpose Benthic Protection and shore-based line fishing zones. The purpose of this project is to provide an assessment of whether there are any direct effects on benthic invertebrate populations resulting from fishing activities in the Park.

Need

The Ningaloo Marine Park is a Multiple-Use Marine Park with several different types of management zoning. The zonings are intended to achieve a wide range of goals, but particularly to preserve biodiversity and ecological values within the park. In practical terms the main impact of zoning on human usage has been to restrict levels of commercial and recreational fishing within the park. While there was a limited commercial fishery (with essentially one major fisher) for lobsters (mainly *Panulirus cygnus*) through the 1960s and early 1970s, the commercial fishery ceased in the mid 1970s. Since then there has been only recreational take of lobsters.

The re-zoning of Ningaloo Marine Park has been achieved at substantial financial and emotional cost, consequently it is essential that CALM and other state agencies assess the response of reef communities to zoning in order to evaluate the effectiveness of these measures for biodiversity management across the various zones. In terms of ecological theory as well as observations from other parts of the world, there have been concerns that fishing can directly lead to depletion of targeted species. In areas where no-take sanctuary zones exist, these effects are seen as increased density and size of targeted species in sanctuary zones.

Scientific Background

Studies of rock lobster populations in other parts of the world have shown, using no-take marine protected areas (MPAs), that there can be significant changes to population structure but also to total biomass inside these areas relative to fished areas (Kelly *et al.* 2000, Edgar and Barrett 1999, Lafferty and Kushner 2000, Goni *et al*. 2001, Acosta 2002, Rowe 2002). However such changes are not observed universally, possibly because some MPAs lack suitable habitat (Mayfield *et al* 2000) or where populations are highly mobile relative to the size of unfished areas (McGarvey 2003).

Small areas of Western Australian coastal waters are protected by a range of spatial fishing closures that offer varying levels of protection from fishing. While some level of population recovery should be expected in areas closed to fishing due to a reduction in fishing mortality, there are also reasons why this may not necessarily occur. For example *Panulirus cygnus* is a migratory species, moving into deeper water at the age of around 4 years (Chubb *et al*. 1999), and most of the spatial closures within its range are located in relatively shallow inshore waters that include coastal reef systems. Since *P. cygnus* also reaches legal size at around 4+ years, it may be that there is little if any detectable effect of fishing on shallow water populations. A study of *P. cygnus* at Rottnest Island in 2004-2005 showed significant levels of population build up in the comparatively small (145m ha) Kingston Reef marine sanctuary established in 1986 (Babcock et al. 2007) suggesting that lobster populations in sanctuary areas at Ningaloo, which are of a similar age, may show some positive effects of zoning.

The corollary of the response of marine reserves or sanctuary areas to protection from fishing is the inference that the status of populations outside them reflect the effects of fishing. This inference carries the same caveats referred to above in terms of the suitability of the protected areas for the species in question, but clearly fishing, both commercial and recreational (Shears et al. 2006), has had significant effects on the biomass and population structure of lobster populations in the majority of coastal areas which are open to fishing. In the context of the Ningaloo Reef Marine Park, no-take areas can provide important insights into the effectiveness of overall management practices on populations and species of interest, including rock lobsters.

A commercial fishery for rock lobsters, mainly the western rock lobster *Panulirus. cygnus* existed at Ningaloo for approximately 30 years between the early 1960s and the late 1980s, at which time the sole remaining licence holder ceased operations citing a decrease in the number of lobsters caught over the previous fifteen years. Mainly due to deteriorating weather conditions (Mack 2003). Other Ningaloo locals in the region have attributed the decline in numbers (by 70-80%) to fishing by the commercial licence holder (Halkyard 2005). No fisheries catch records for rock lobster are available specifically for the Ningaloo Region during that time. Since then an active recreational fishery has been conducted (Mack 2003, Halkyard 2005) under the regulations that apply throughout Western Australia; a closed season from July 1 through November 14, minimum size limit of 76 mm carapace length (CL), and in the Ningaloo area a personal limit of 4 lobsters of 8 per boat. Female lobsters of any species carrying larvae may not be taken, and for Western Rock Lobster there is a maximum size limit of 105 mm CL for females, plus a ban on taking females in reproductive condition (setose or tarspot).

Anecdotal reports from recreational fishers (Halkyard 2005) as well as from the commercial fishery (Mack 2003) suggest that the current abundances of rock lobsters of all species are far lower than they were in the 1960s and even up to the 1980s. This is supported by the low numbers of rock lobsters estimated to be taken from the region by recreational fishers. In a boat ramp survey of the region in1998-1999 it was estimated that the total annual catch of rock lobsters from Ningaloo was only 536 ±307 lobsters (Sumner 2002). This suggests a dramatic reduction in the abundance of rock lobsters over the decades since lobster fishing began in the region.

Objectives

The objectives of the surveys described in this report were to provide a robust quantitative assessment of whether evidence exists for recovery of rock lobster populations in sanctuary zones of the Ningaloo Marine Park as a result of protection from fishing. These data will make it possible not only to assess whether the zoning of sanctuary areas has produced positive conservation results, but also to evaluate the status of lobster populations in the park overall. As such the project has direct relevance to the following outputs from WAMSI Node 3.2 outputs:

1. Measures of the effectiveness of previously established sanctuary zones for protecting exploited subtidal fish and invertebrate populations (data reports, scientific papers, inputs to models)

Methods

CSIRO Broad scale surveys

A series of surveys conducted in 2006 and 2007 were undertaken principally to assess fish populations in the Ningaloo Marine Park, however any lobsters encountered during this survey were also counted, providing a broad picture of distribution and allowing later surveys (May 2007 to April 2008)to be targeted more efficiently. Survey sites in the Ningaloo Marine Park were selected from among coastal areas stretching from of Gnaraloo in the south to the Muiron Islands in the north. Potential sites were initially identified from a series of digital spatial data sets including geo-referenced aerial photograph mosaics, benthic habitat maps, and marine park zonings for both new and old plans. The marine park zoning data were loaded into a GIS (Arc View 3.3), where the old and new plans were overlaid to generate an entire coverage including pre-existing zone boundaries and the recent extensions to the pre-existing zones.

To facilitate accurate distance measurement, all GIS layers were initially projected to UTM (Zone 49) coordinates. A 200m grid from was then overlaid across the study area from Gnaraloo to the Muiron Islands, from which potential sites were selected randomly. Specifically, sites were chosen by generating a single random point within each 200m grid cell using the Sample 3.03 extension for ArcView 3.3. The aerial photographs were overlaid with the combined zoning and habitat data, and the point coverage from the 200m grid. From this, a selection of sites was chosen from the randomly generated points.

Sites from among the randomly generated points were then selected such that the effects of several factors could be tested. These factors included location of management zone, age of management zone, and habitat. Within each management zone, samples were stratified by habitat; outer reef slope, reef flat, and lagoon, passage, coastal reef.

Sampling around each no-take zone was spatially structured to make it possible to pick up any gradients in abundance that might have developed relative to park zoning. We used a cluster of sites inside and outside each zoning treatment to avoid constructing a "paired" type design. Reconnaissance of the reef prior to the project suggested there was a high degree of spatial variation at scales of 100-1000m that could potentially be confounded with treatment effects. Therefore within any pre-existing sanctuary zone, sites would be placed within the centre of the zone as well as near the boundaries (except the seaward boundary). Outside each sanctuary zone an equivalent spatial structure was established, with sites that were adjacent to the boundary (< 0.5km), as well as other sites that were distant from the boundary (>1km). The Maud zone was an exception because there is no similar fringing reef present immediately to the north of the Maud Sanctuary zone. Within each of these strata, sites were also stratified with respect to reef habitats, to include outer reef slope, reef flat and lagoon, passage and coastal reef sites. A further aspect accommodated by the design was the fact that newly expanded zones included pre-existing zones, so the establishment of sites had to be sufficient to be able to assess the effects of pre-existing zones as well as to lay the basis for detection of trends than may develop in new zones over time (Fig. 1). Sites selected based on these criteria were then projected into geographic co-ordinates (WGS 84) and downloaded to a GPS unit.

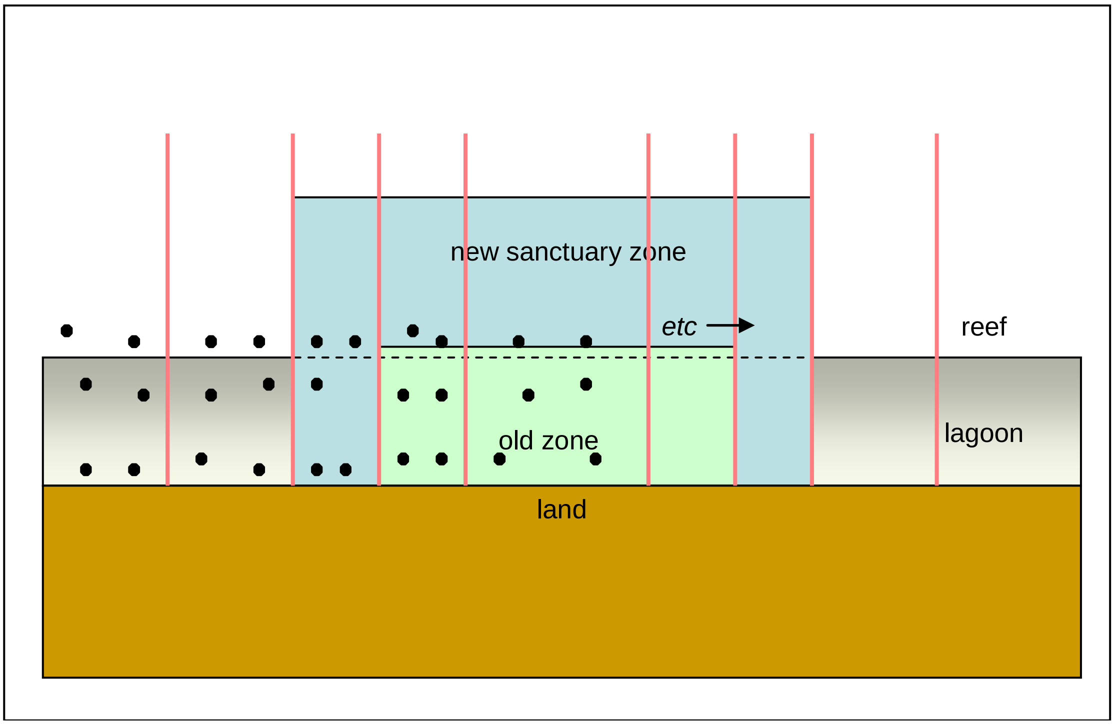

Figure 1. Diagram of sampling design to achieve representation of large scale habitat types, historical variation in zoning and potential gradients in effects on fish and lobster populations.

CSIRO Field Sampling

Fish and Lobster within the Ningaloo Marine Park were sampled using underwater visual census (UVC). Survey sites were located in the field using a hand-held GPS unit; at each site a single SCUBA diver swimming along a 100m x 10m belt transect, identifying, counting, and estimating the total length of fishes observed within the transect.

Transect length was measured by the diver using a modified Chainman©. This device measures distance by paying out biodegradable 0.3mm cotton twine and displaying the length of twine on a counter easily viewed by the diver. On reaching the seabed, the diver wraps a coil of twine around a solid structure then begins the 100m transect. Upon reaching the end of a transect, the twine is wrapped around a structure, broken off, then left on the benthos to biodegrade within a few days. This method greatly increases the efficiency of the transect method since a line does not need to be laid or retrieved as would be necessary using the traditional tape measure approach.

Where possible, fish and lobsters observed on any transect were identified to species level. In order to minimize inter-observer variation in fish identification, photographic species identification guides for both fish and lobsters were produced and divers trained to identify fishes from the families of interest prior to the commencement of field work. In addition, divers were trained underwater and length estimates could be calibrated by first estimating the carapace length of any lobsters and then catching and measuring them (Babcock et al. 2007). Further details of fish sampling are available in a separate report (Babcock et al. 2008).

In addition to surveying fishes and spiny lobsters, each diver characterized the benthic habitat by estimating percent cover of sessile life forms (e.g. coral, algae) and substratum classes (e.g. sand, rubble, boulders), and the cover of live versus dead coral (English et al. 1997). Other information recorded by the SCUBA diver included the depth, visibility, and the compass bearing of the direction swum. A snorkel diver would follow the SCUBA diver and record the percentage cover of the various coral growth forms (branching, tabulate, digitate, massive, encrusting, sub-massive), and the species composition of algae and sea grasses. To complement this habitat data, the snorkel diver also took multiple photographs of the benthos along the length of each transect.

Operationally, the sampling involved deploying two divers, one to complete the transect (SCUBA or snorkel depending on depth) and one to record habitat data (snorkel). This was generally done without anchoring the vessel and each 100m transect took approximately 30 minutes to complete. Since only a single transect was conducted at each site, transects represented a replicate in a given zone–habitat strata. Working in this way using two teams on separate inflatable boats, it was possible to complete up to 40 transects per day. This regime, whilst lacking resolution at the site scale, maximized the resolution of sampling at the larger scale of most interest to the objectives of this study, and allowed collection of density and size data for fishes over a broad area of the Ningaloo Marine Park.

CSIRO Targeted lobster 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 100 × 5 m 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.

AIMS Targeted lobster surveys

Species identification and quantification of rock lobster were undertaken at locations from Lighthouse SZ in the north to Turtle SZ in the south (Table 1). Sampling of the NMP areas was designed in a hierarchical structure to enable analyses at different spatial levels of organization. Site selection was largely predetermined with the aim to balance four 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, and 4) logistical field constraints. In total, 265 transects encompassing 47 sites at 15 separate locations were surveyed (71 in May; 48 in July; 146 in September [Table 1]). 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. 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.

Analysis

Data presented here is an amalgamation of both AIMS and CSIRO lobster data in order to provide as comprehensive an overview as possible.

Data were broadly stratified by management zone, habitat and region for analyses, with habitats being defined as reef slope, reef flat, and lagoon. Because the new zoning provisions were either not in existence or were relatively recent at the time of the surveys, management zones were classified as either no-take (inside pre-existing sanctuary zones established in 1987) or open (outside pre-existing sanctuary zones) Zoning, Habitat and Region were treated as fixed effects (e.g. Willis et al. 2003b).

Lobster densities were generally too low to permit useful multivariate analysis. Broad scale trends in distribution were therefore examined by graphical comparisons in the first instance. Univariate analyses were used to further analyse the data where species were present in sufficient numbers. These analyses used log linear analyses (GENMOD procedure in SAS) using an over-dispersed Poisson distribution since the count data generally did not (and are not expected to) conform to normal distributions. Estimates of statistical power for Poisson distributed data were performed using the methods of Willis et al. (2003a). We used multiple-regression of lobster counts against a number of key habitat variables in order to try to reduce the inherent variability in the data. Variables used in the regression were depth, latitude, longitude, and percent cover of sand, rubble, boulders, consolidated rubble, bommies, pavement, live hard coral , in situ dead hard coral, algae and seagrass.

Results

General distribution and abundance

A combined total of 1206 transects are incorporated in this study of the distribution and abundance of lobsters in the Ningaloo Marine Park (Table 1). Nine hundred and six of the transects were part of a broad scale study of fish distribution but also recorded lobster species abundance (Fig. 2). Three hundred of these transects specifically targeted lobster habitats and regions thought to be most important for lobster populations (Fig. 3).

Targeted lobster surveys in 2007 and 2008 were concentrated in coastal reef habitats based on trends seen in the 2006-07 surveys. Regions that appeared to have higher densities of lobsters, particularly Batemans Bay, Lighthouse, Osprey, and Farquhar were also targeted, although all regions were sampled during 2008 with the exception of the Muiron Islands which could not be re-surveyed due to difficulty of access.

Table 1. Distribution of sampling effort among regions and habitats throughout the Ningaloo Marine park from 2006-2009. Data are numbers of sites samples.

REGION	Coastal Reef	Lagoon	Passage	Patch	Reef flat	Reef slope	Grand Total
Batemans	40	63			10	26	139
Bundegi				19	29	46	94
Cloates		4				10	14
Farquhar	9	8			6	18	41
Gnaraloo	13	23			8	58	102
Jurabi	12	1	1		4		18
Lighthouse	16					79	95
Mandu	10	36	2		42	43	133
Mangrove		35			26		61
Maud		33			28	29	90
Muiron		32			4	49	85
Osprey	11	43	33		64	31	182
Pelican	13	29	4		21	48	115
Turtles	8				1		9
Winderabandi	5				8	15	28
Grand Total	137	307	40	19	251	452	1206

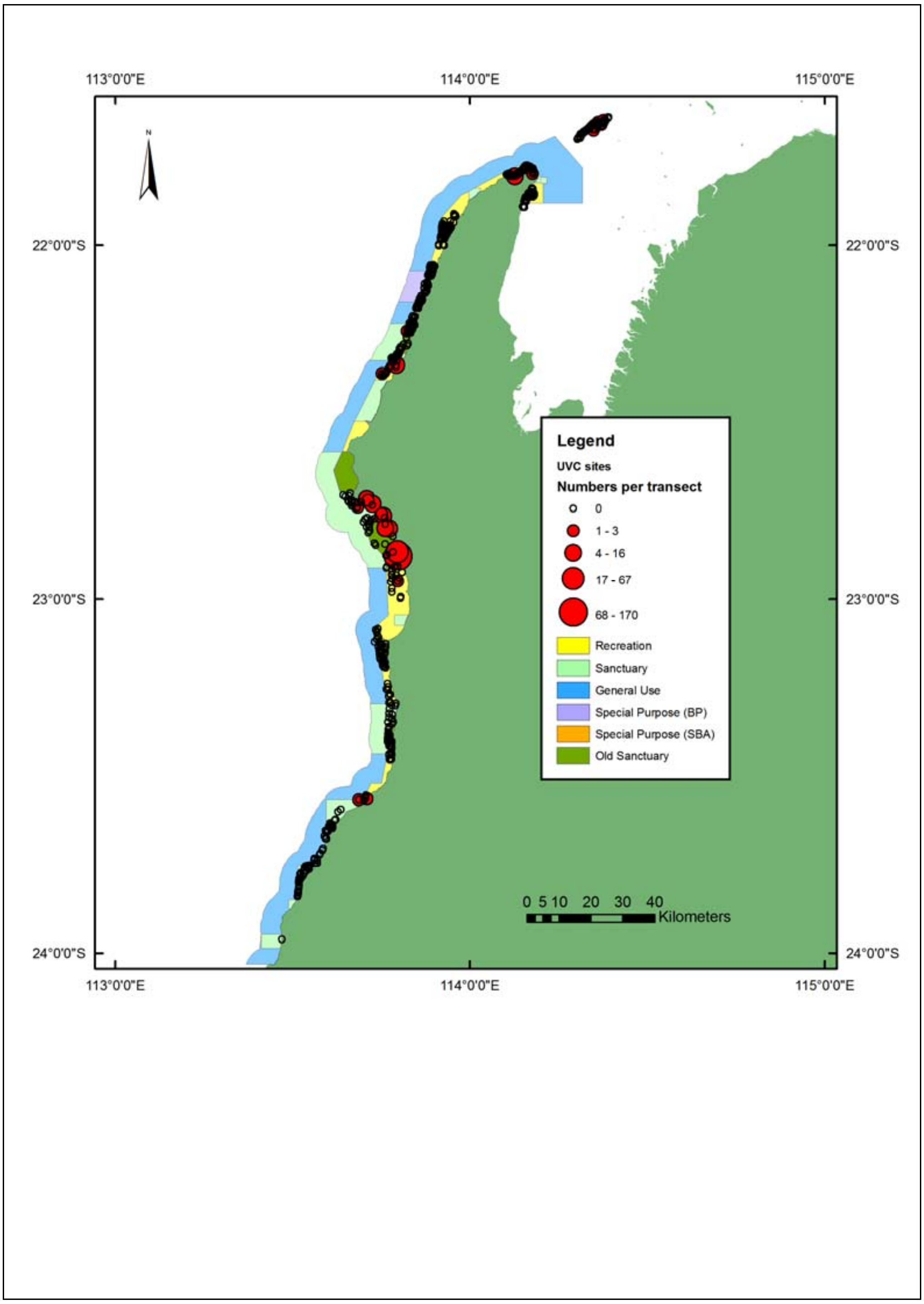

Figure 2. Sampling sites and numbers of lobsters (all species combined) encountered in broad scale surveys of the Ningaloo Marine Park 2006-2007.

Broad scale surveys in 2006 and 2007 determined that there were strong trends in the distribution of lobsters within the Ningaloo Region. Lobsters were far more abundant in the Bateman's Bay Region than in any other area, with a mean density of 33.3.ha^{-1}. The next highest densities were more than an order of magnitude lower at around 1.5 ha^{-1} and in many regions no lobsters were recorded (Fig. 4). Among habitats, densities were similarly skewed towards a single habitat type, coastal reef, where the average density was 139. ha^{-1}. In other habitats densities were more than two orders of magnitude lower, with densities of less than one lobster per hectare. Both of these trends were driven by the occurrence of some sites with extremely high densities on coastal reefs in Batemans Bay (Fig. 2).

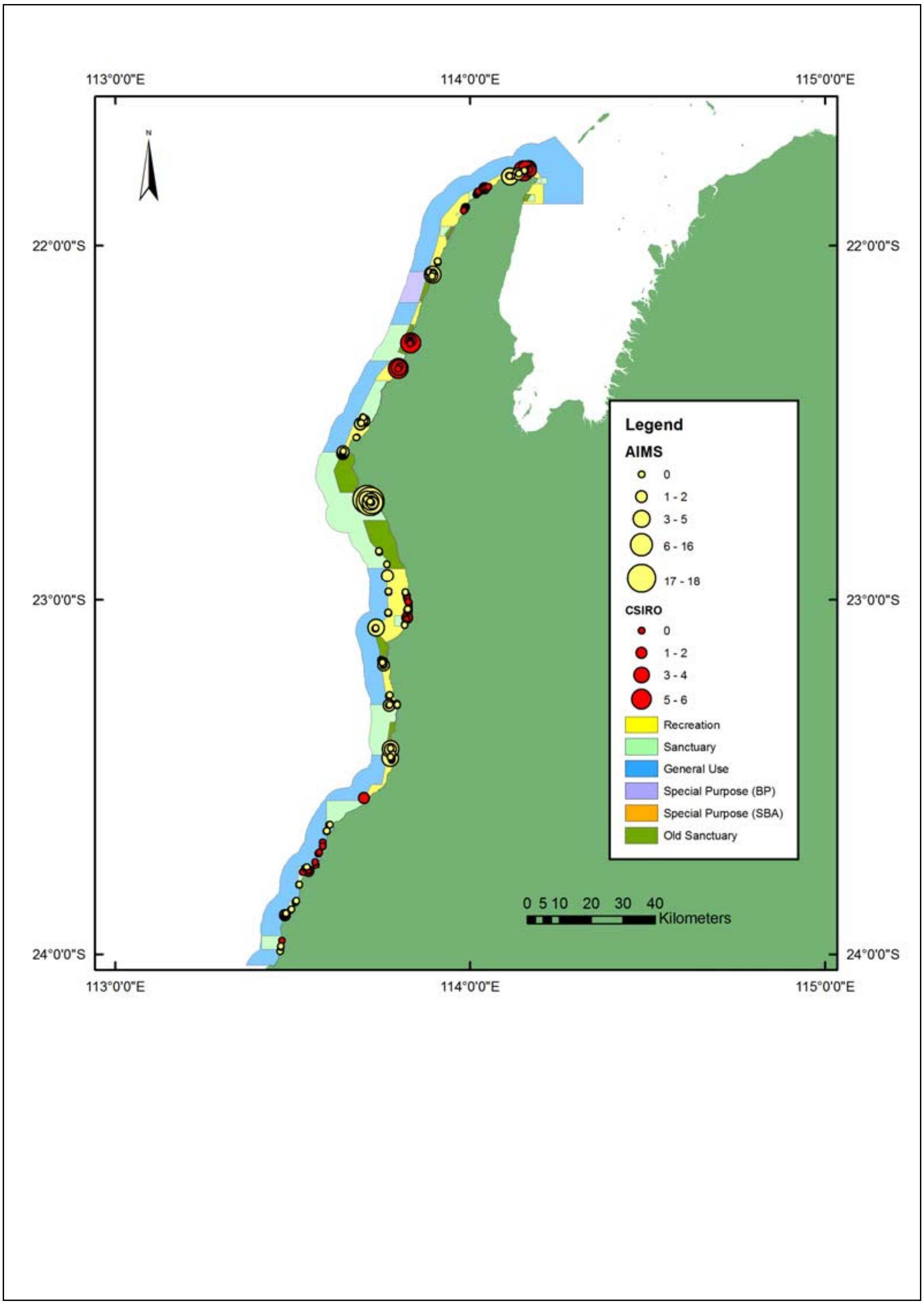

Figure 3. Sampling sites and numbers of lobsters (all species combined) encountered in targeted lobster surveys of the Ningaloo Marine Park 2008-2009.

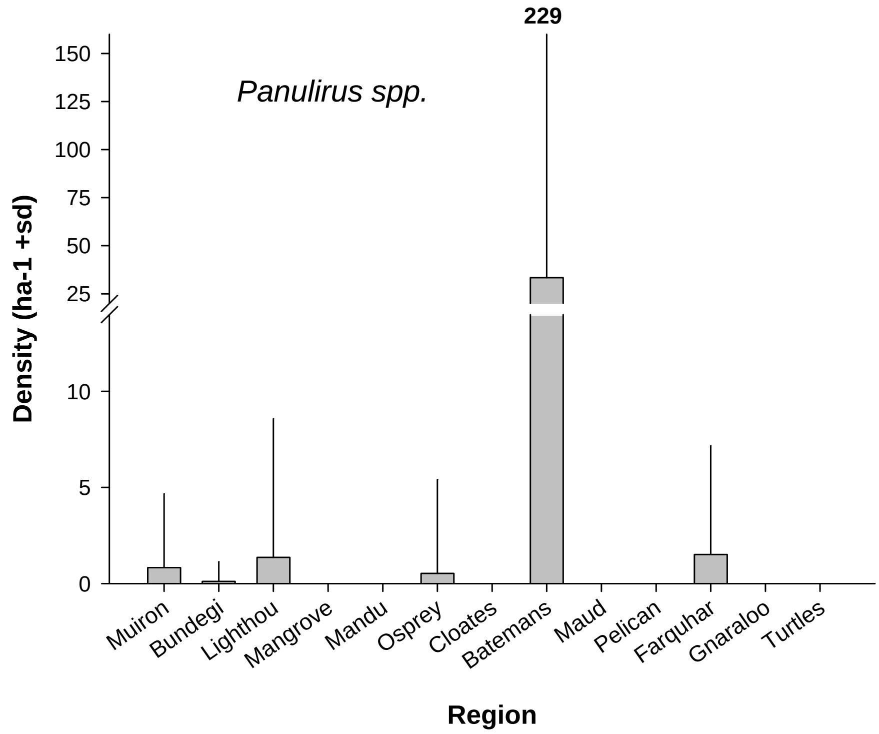

Figure 4. Lobster density across regions of the Ningaloo Marine Park. Data based on targeted lobster surveys 2007-2009.

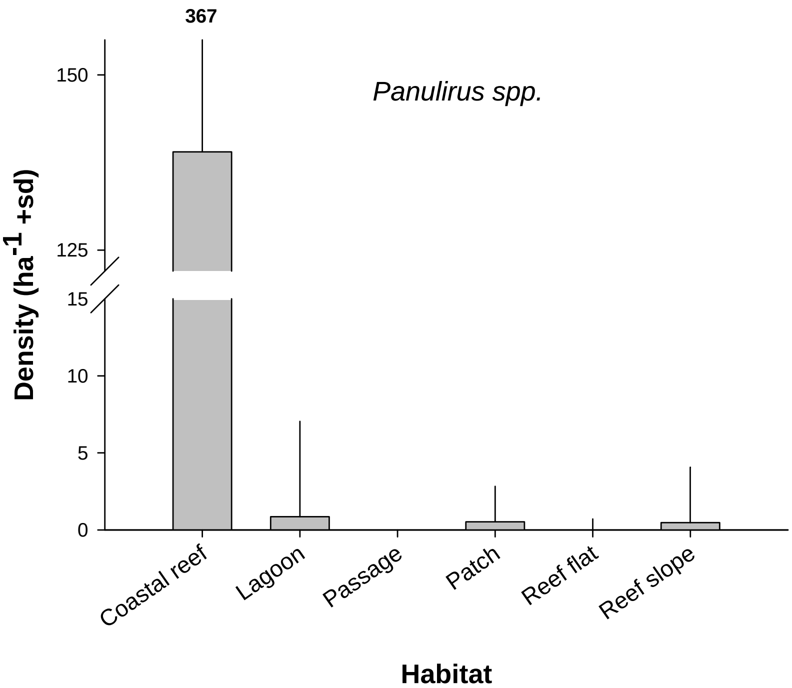

Figure 5. Lobster density across habitats of the Ningaloo Marine Park. Data based on targeted lobster surveys 2007-2009.

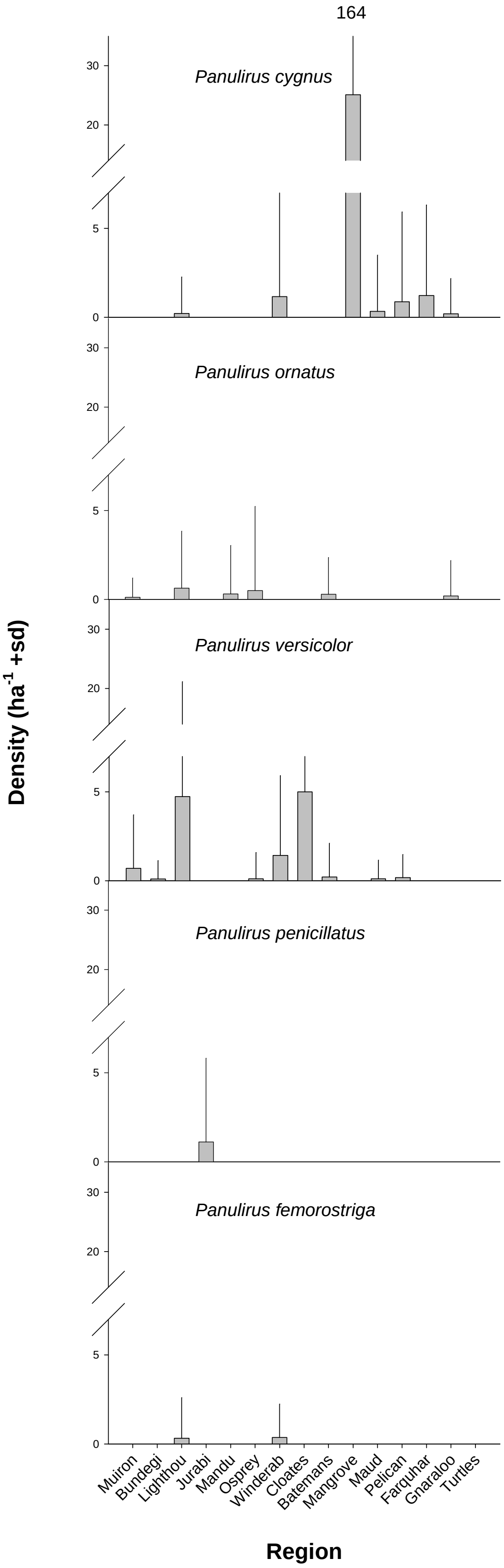

Fig. 6. Variation in density of lobsters across Regions of the Ningaloo Marine Park. Data are based on targeted surveys of lobsters 2007-2009.

The Northwest Cape area (Lighthouse and Jurabi) had intermediate densities of lobsters (Fig. 6), but also the highest diversity of lobsters with all five of the recorded species (*Panulirus cygnus, P. ornatus, P. versicolor, P. penicillatus, P. femoristrigata*) found there (Fig. 7). Both density and diversity of lobsters was lower at Mandu and Osprey (Figs. 6 & 8) and only *P. cygnus* and *P. ornatus* were found there. Osprey was the most northerly region where *P. cygnus* were encountered more than as occasional vagrants. Counts of several individuals per transect were not unusual on shoreline coastal reefs in that region (Fig. 8). Surveys in late January 2009 found females of *P. cygnus* either in berry or with tarspots at this time. In the Winderabandi and Cloates regions densities of lobsters were slightly higher and *P. ornatus* was relatively rare while *P. versicolor* was present in higher numbers (Figs. 6 & 9), mainly at reef slope sites at Winderabandi. *Panulirus cygnus* was found in large numbers within Batemans Bay, and mainly on coastal reefs. Particularly high densities of *P. cygnus* were found on some coastal reef sites (Fig. 2) that were essentially shoreline reefs formed from eroded beach rock. These rock formations provided numerous ledges and overhangs. Waters in these areas were notably turbid due to resuspended algal and seagrass (*Posidonia* and *amphibolis*) detritus (similar to coastal sites on more southern parts of the west coast of WA which are in the central range of this species' distribution).

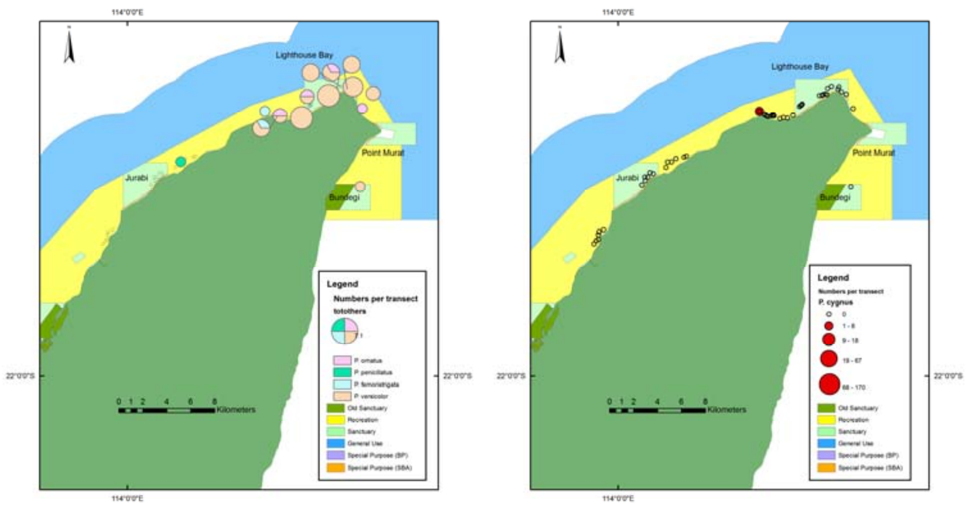

Figure 7. Abundance of lobster species in the Lighthouse and Jurabi regions of Ningaloo Marine Park Data are from 2007-2008.

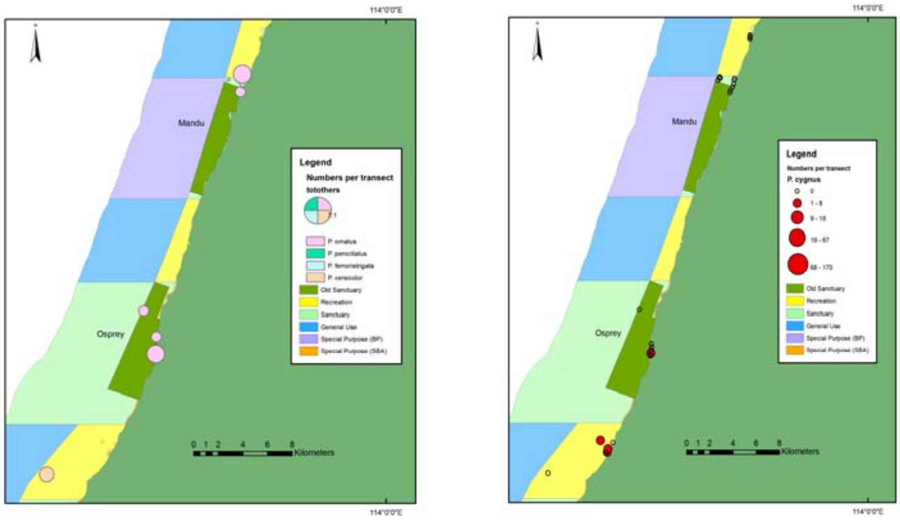

Figure 8. Abundance of lobster species in the Mandu and Osprey regions of Ningaloo Marine Park Data are from 2007-2009.

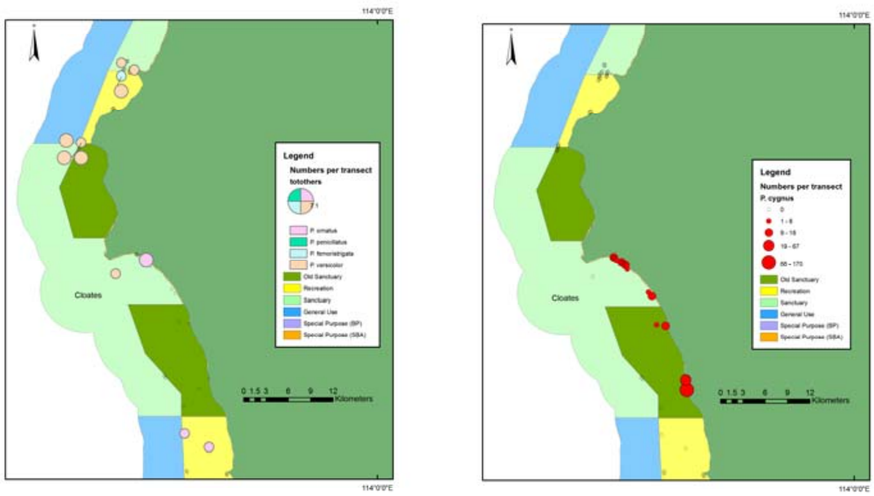

Figure 9. Abundance of lobster species in the Cloates and Batemans Bay regions of Ningaloo Marine Park Data are from 2007-2008.

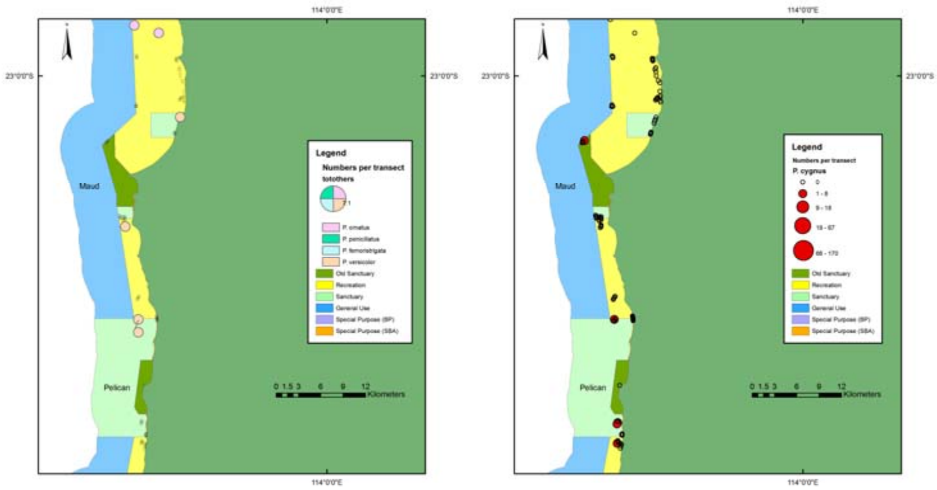

Figure 10. Abundance of lobster species in the Maud and Pelican regions of Ningaloo Marine Park Data are from 2007-2008.

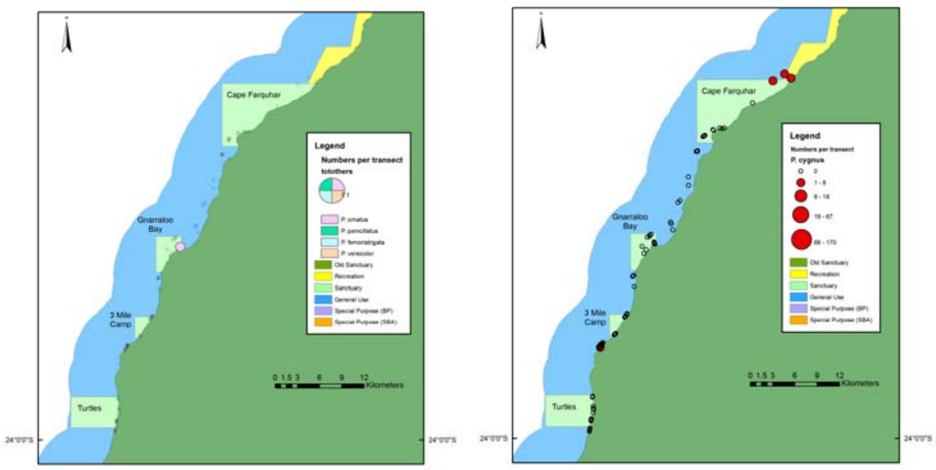

Figure 11. Abundance of lobster species in the Southern Regions of Ningaloo Marine Park Data are from 2007-2008.

Relatively low densities of both *P. cygnus* and *P. versicolor* were found in the Maud and Pelican regions compared to those in Batemans Bay and Winderabandi (Figs. 6 & 10). *Panulirus cygnus* was present consistently at regions from Maud south (Figs. 6, 10, 11) though densities were not particularly high and far lower than those in Batemans Bay. Relatively few *P. ornatus* were recorded in southern areas.

Species abundance and habitat associations

For lobsters in general there was highly significant variation in abundance of lobsters among habitats ($F_{5,1200}$ =107.4, p<0.0001) with most lobster found in coastal reef habitat. Within individual species, *P. versicolor* showed significant variation at the habitat level. ($F_{5,1200}$ =24.68, p<0.0001) and was less common in lagoon, passage and reef flat habitats (Fig. 12). For *P. cygnus* and *P. ornatus* formal analyses were not successful (algorithms did not converge). Visual analysis of data show however that in addition to being by far the most abundant species in the Ningaloo Marine Park *P. cygnus* (Fig. 12) was found most often in the coastal reef habitat, where it was over ten times more abundant than any other species. *Panulirus ornatus* was also more abundant on coastal reefs than in other broad habitats. Both *P. penicillatus* and *P. femoristrigata* were too rare to allow any general statements to be made about their habitat associations.

More detailed (transect scale) habitat associations were explored for *P. cygnus, P. versicolor* and *P. ornatus* using multiple regression. While habitat associations were relatively weak, there were significant correlations between the abundance of species and quantitative habitat descriptors (*P. versicolor* R-square 0.0248, p<0.0001; *P. cygnus* R-square 0.035, p<0.0001). *P. cygnus* was positively associated with macroalgae, but negatively correlated with rubble (Table 3). In contrast *P. versicolor* was positively associated with bommies, limestone pavement and latitude (more abundant in the north) but negatively correlated with live coral cover. *Panulirus ornatus* was not correlated with any of the transsect scale environmental variables.

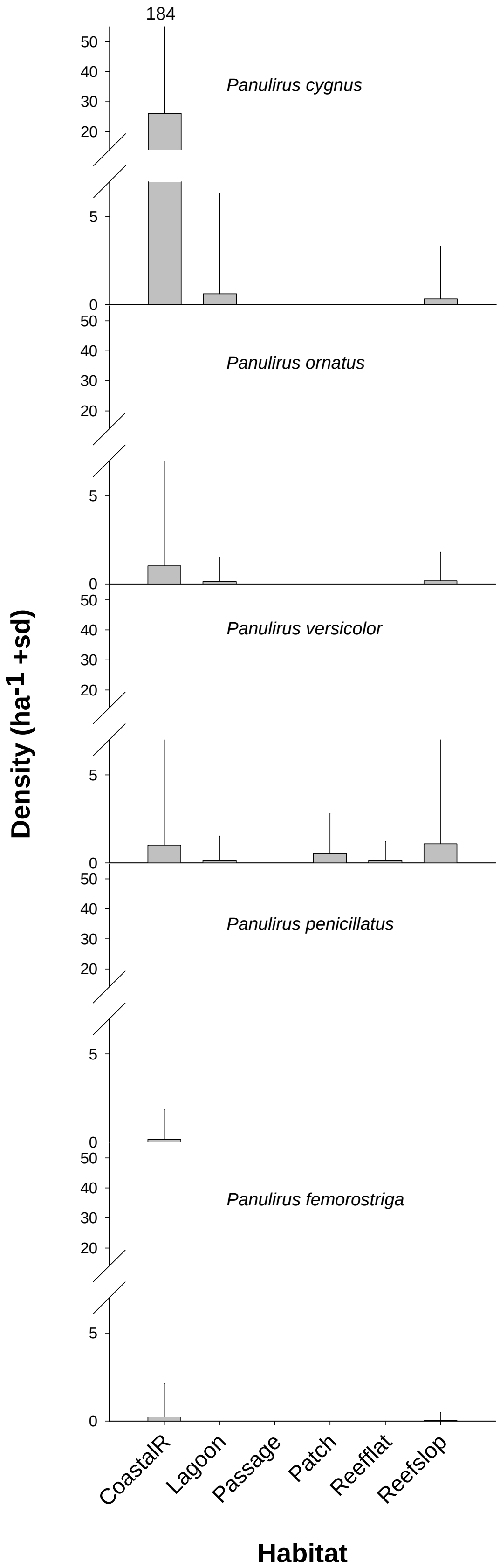

Figure. 12. Variation in habitat distribution of lobster species in the Ningaloo Marine Park.

Table 3. Habitat parameters associated with variation in lobster abundance in the Ningaloo Marine Park. No significant correlations with habitat parameters were found for *P. ornatus*. Numbers of other species *P. penicillatus* and *P. femoristrigata* were too low to analyse. Results from multiple regression with backwards elimination of variables.

Variable	Parameter estimate	SE	F value	p
Panulirus cygnus				
Rubble	-0.21	0.091	5.45	0.0197
Algae	0.388	0.072	29.44	<0.0001
Panulirus versicolor				
Bommies	0.073	0.0143	26.4	0.0001
Pavement	0.009	0.0051	3.16	0.0759
Coral	-0.0137	0.0079	3.01	0.0831
Latitude	0.848	0.218	15.19	0.0001

Marine Park zoning and lobster distribution

Because of the relatively low densities of lobsters present in most regions, as well as differences in the distribution of lobsters among regions, it was not possible to test for overall differences between fished and unfished areas among regions (algorithms did not converge). However for a subset of regions some tests were possible for some species. Populations of *P. cygnus* inside and outside the Dugong (Batemans Bay) sanctuaries (established 1989) were compared, while at Lighthouse regions, populations of *P. versicolor* and *P. ornatus* (Lighthouse only) inside and outside newly created sanctuary zones (est. 2006) were compared with adjacent populations in recreation zones or other areas where recreational fishing is allowed.

There were highly significant differences in the density of *P. cygnus* populations between old sanctuary zones and recreation zones at Batemans Bay, with approximately 33 times greater density inside the sanctuary zone. Differences among habitats were also highly significant, with higher densities in coastal reef habitats, but there was not a significant interaction effect (Table 4, Fig 13). Despite the highly overdispersed nature of the data, the Statistical Power of the performed test was >0.99, primarily due to the large effect size.

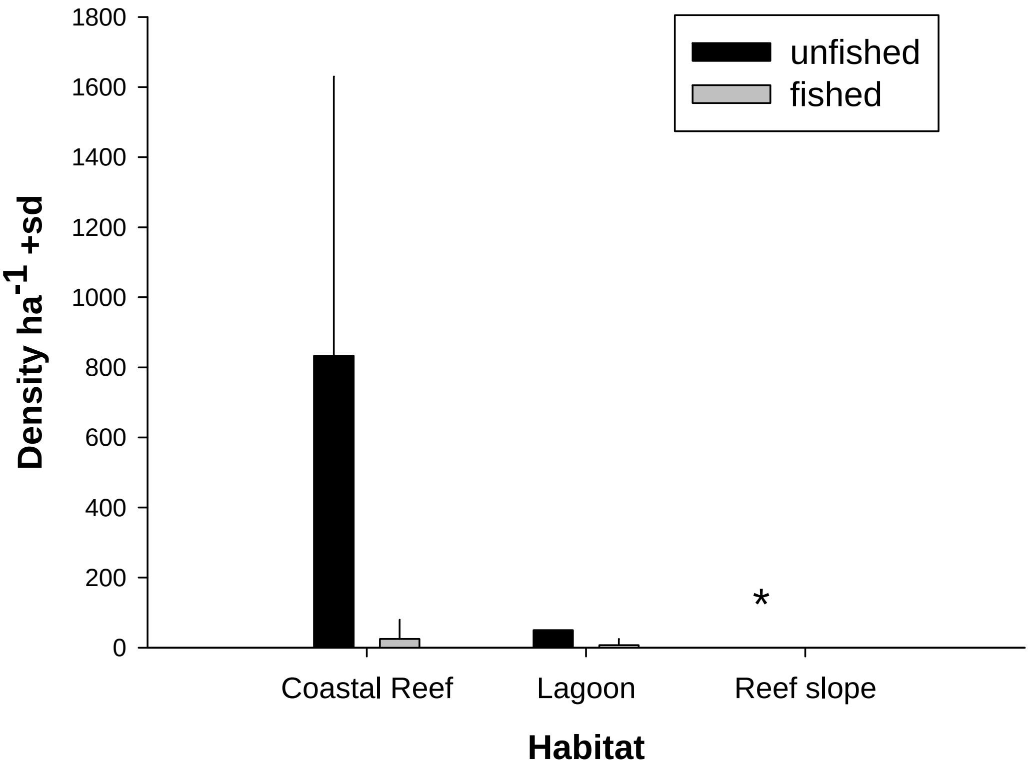

Figure 13. Density of *P. cygnus* in fished and unfished areas of Batemans Bay, 2007-2008. *; not sampled.

Table 4. Density *P. cygnus* at Batemans Bay. Zoning and Habitat were treated as fixed factors in a log linear analysis of density (SAS Proc Genmod).

Source	Num DF	Den DF	F Value	p
Zoning	1	58	5.14	**0.0272**
Habitat	2	58	8.73	**0.0005**
Zoning * Habitat	1	58	0.83	0.3660

At the Lighthouse Region densities of *P. versicolor* were greater inside the sanctuary zone than in the adjacent recreation zones but they did not vary with habitat (Table 5

Fig 14). In contrast, densities of *P. ornatus* did not differ across different zoning types but did vary among habitats being more common on reef slopes and absent from coastal shoreline reefs (Fig. 14). In both cases the power of the performed tests were >0.9, providing a high level of confidence in the results.

Extrapolation of results to produce estimates of sample size required to detect any future changes in population density relies on the assumption that the statistical distribution of the data remains the same as the population changes, an assumption that may well not hold true. However, if we use the *P. ornatus* population at Lighthouse Bay, where there was no difference across sanctuary zone border, as an example we can estimate that approximately 77 samples within each zone would be required to detect a fourfold increase in density. This equates to the cumulative samples from approximately 5 years of monitoring at the same intensity as reported here.

Table 5. Density *P. ornatus* and *P. versicolor* at the Lighthouse Region. Zoning and Habitat were treated as fixed factors in a log linear analysis of density (SAS Proc Genmod).

Source	Num DF	Den DF	F Value	p
P. ornatus				
Zoning	1	28	0.04	0.8469
Habitat	2	28	13.41	**0.0010**
Zoning * Habitat	1	28	0.00	1.000
P. versicolor				
Zoning	1	28	5.44	**0.0271**
Habitat	2	28	2.31	0.1399
Zoning * Habitat	1	28	0.13	0.7250

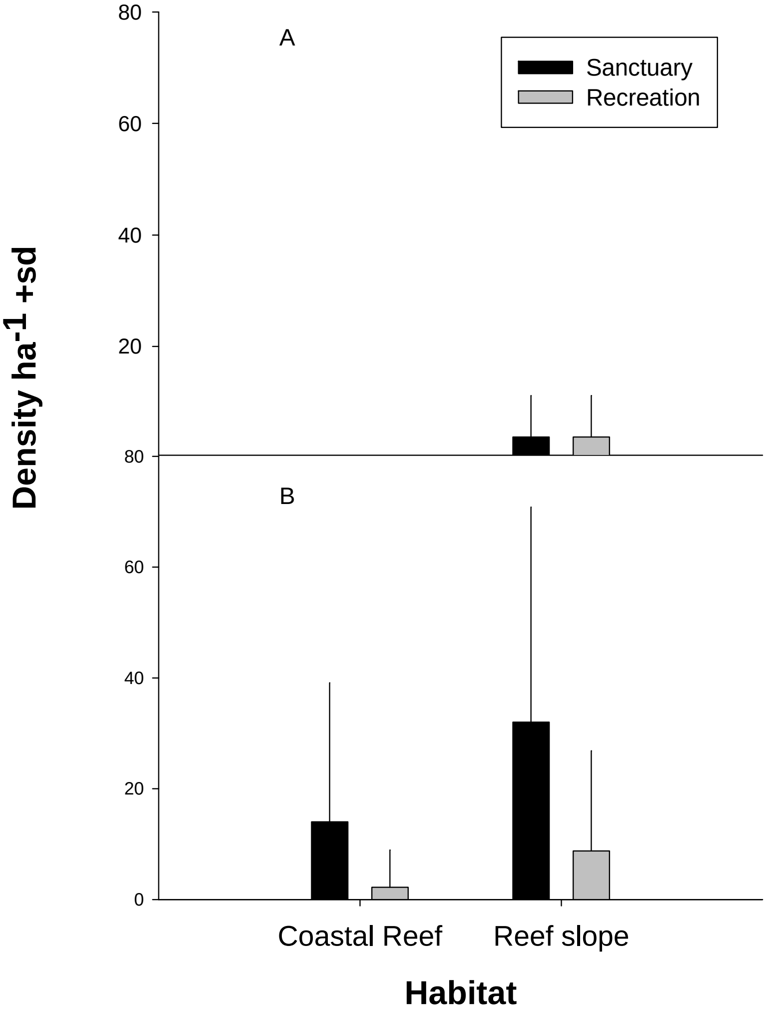

Figure 14. Density of lobsters in fished and unfished areas of the Lighthouse Region, 2007-2008. A. *Panulirus ornatus*, B. *Panulirus versicolor*.

Population size structures

Average sizes of individual *P. cygnus* was significantly different between fished and unfished areas at Batemans Bay. Surprisingly, mean size was significantly larger ($F_{1,574}$ = 57.36, p<0.0001) in the fished area (74.1 +/- 14.1 mm CL) than in the adjacent old sanctuary areas (61.8 +/- 12.1 mm CL). Size structures of *P. cygnus* populations at Batemans Bay also differed markedly between fished and unfished areas (Fig. 15). Even though lobster densities were lower outside the old sanctuary zone, large individuals were more common, and individuals up to estimated carapace lengths of 110 mm were observed there, while the largest *P. cygnus* seen in the unfished area was 95 mm CL. Small lobsters were another even more important factor attributing to the mean size difference, with small lobsters (<45 mm CL) much more common in the old sanctuary zone.

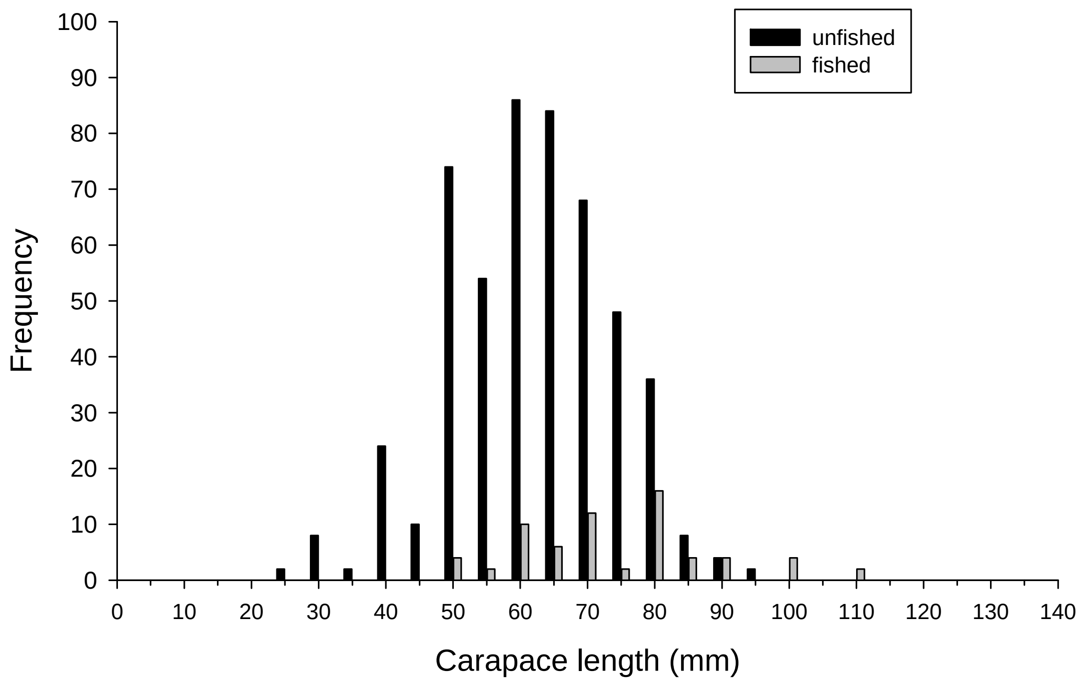

Figure 15. Population size frequency distribution for *P. cygnus* in fished and unfished areas of Batemans Bay.

Sizes of *P. ornatus* and *P. versicolor* were, on average, substantially larger than those of *P. cygnus*. The mean size of *P. ornatus* was 99.8 +/-35.7 s.d. and of *P. versicolor* 95.6 +/- 24 s.d. While sample sizes of both of these species were very low, even when data were pooled across all sites and years, the population structures were similar to those of the more abundant *P. cygnus* and small individuals (< 30mm CL) of both *P. ornatus* and *P. versicolor* were recorded.

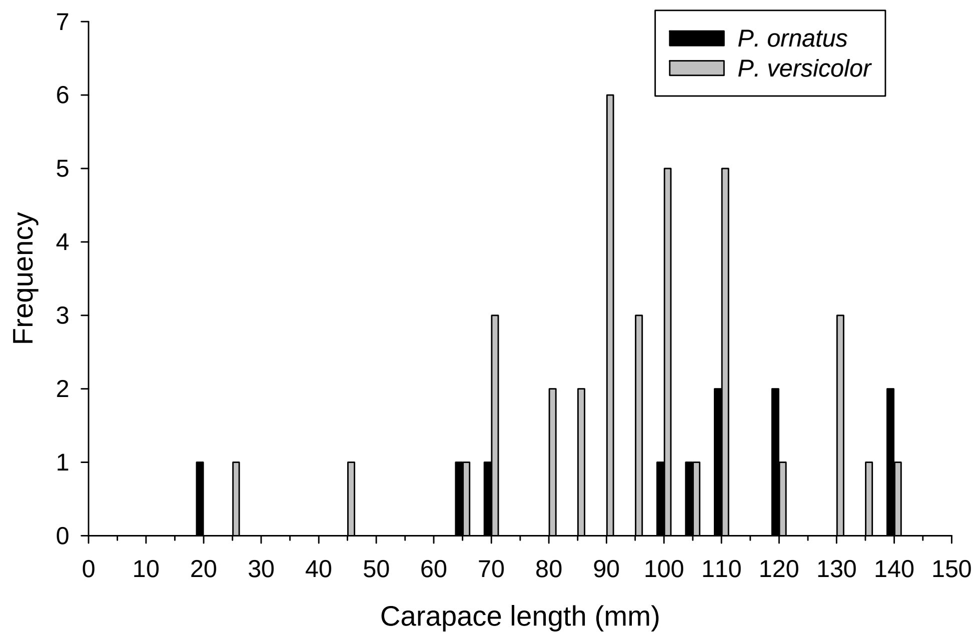

Figure 16. Population structures of *P. ornatus* and *P. versicolor* in the Ningaloo Marine Park.

Discussion

General habitat trends

For all lobsters, the presence of suitable habitat for shelter is a key habitat pre-requisite. Surprisingly, habitats characterised by tabular *Acropora* held relatively low densities of lobster of any species. Larger scale habitat characteristics were a more important determinant of lobster habitat suitability, with most lobsters found in nearshore reef habitats, particularly nearshore coastal reefs of eroded beach rock which provide excellent shelter. Such nearshore habitats are common in Bateman's Bay for example, where the highest numbers of lobsters recorded in this survey were found. Nearshore coastal reefs are not exclusive to this area however, and are well developed in areas along the length of the Ningaloo Region, from the Capes Range section to Cape Farquhar. Historical anecdotal reports also indicate that these shallow nearshore habitats held the highest abundances of lobsters (Halkyard 2005).

Larger scale trends were also apparent, with the Western Rock Lobster *P. cygnus,* characteristic of southern areas, and absent or relatively rare in northern areas of the region (Muirons to Bundegi and Mandu). Tropical species were more common in the northern areas, particularly around Northwest Cape in the Lighthouse Bay Region. Reef morphology in the Lighthouse bay area differs in important respects to that found along the rest of the Capes Range section of the park, with biogenic fringing reefs absent or much less prominent than further south, and limestone pavement and other eroded limestone features forming a much more prominent component of the substratum.

Zoning related trends

Western Rock Lobster

There were significant differences between sanctuary zones and fished areas in density and population structure of *P. cygnus.* These results are similar to the majority of other published studies of rock lobster populations in no-take marine protected areas which have shown increases in one or more of these parameters (e.g. Babcock et al. 2007, Goni *et al*. 2001, Kelly *et al.* 2000). Due to generally low numbers of *P. cygnus* throughout the region it was only possible to convincingly address the question of zoning-related trends in lobster density in the Batemans Bay region, nevertheless we believe that reduced fishing mortality within the sanctuary is the most likely explanation for the higher numbers of lobster in the former Dugong Sanctuary zone (established 1989). Because of the lack of data from prior to the sanctuary's creation, it is not clear whether this is due to the zoning of the area, or to its relative isolation. Therefore any assumption about the effectiveness of the zoning for protection lobsters in Batemans bay must be applied cautiously (c.f. Willis *et al*. 2003a). If the pattern is caused by fishing as we suggest, it implies that recreational fishing has very strong effects on lobster populations at Ningaloo, since there is no commercial fishing within the Ningaloo Region. Continued observations of the trends in lobster populations in the newly established areas of no-take marine sanctuary in the Jane's Bay section of Batemans Bay are required in order to confirm this conclusion.

Differences in population size-structure between sanctuary and fished areas suggest further caution is warranted in ascribing the differences in density to the effects of protection within the sanctuary zone. Both modal and mean size were smaller for lobsters inside the sanctuary zone than for those inside it, the opposite trend to that expected if fishing alone were the main explanation for the observed differences in abundance. While it is therefore possible that the differences in abundance are in part driven by differences in recruitment between the two areas, the magnitude of the difference in density (more than 33 times more lobsters in the sanctuary zone) is so great that it is unlikely that it could be the result of recruitment alone. Differences in size could also be the result of density-dependent growth limitation of dense aggregations within the sanctuary area. Though little is known of density dependent processes in adult *P. cygnus*, they are thought to be important for puerulus and early juvenile *P. cygnus* in southern and central parts of its range (Phillips et al. 2003) The level of difference between fished and unfished areas was very similar to that observed in the Kingston Reef Sanctuary zone at Rottnest Island (34 times).

A further similarity between the lobster populations at Batemans Bay and Rottnest Island is the fact that there were significant populations of lobsters in shallow water. While the majority of *P. cygnus* in any given cohort are expected to move from shallow coastal areas to deeper waters (≥ 30 m, Chubb *et al*. 1999) as they reach maturity, the substantial numbers of large mature lobsters in unfished shallow waters at both Rottnest (Babcock et al. 2007) and Batemans Bay suggest that these individuals can and do accumulate in shallow habitats given the opportunity. If, as we argue, gradients in lobster abundance, biomass and egg production are a result of fishing, then the potential impact of fishing on shallow water lobster populations may be much greater than has been assumed (e.g. IRC Environment 2003).

Tropical Rock Lobsters

Panulirus ornatus and *P. versicolor* were the most abundant tropical rock lobster species recorded. The Lighthouse Bay region held the highest densities recorded for each of these species. Although neither were present at Lighthouse Bay in numbers that compared with those of *P. cygnus* in the Dugong Sanctuary at Batemans Bay, the density of *P. versicolor* at Lighthouse Bay was similar to the density of *P. cygnus* in fished areas of Batemans Bay. Since Lighthouse Bay was until recently zoned as a recreational area where fishing is allowed, there should be potential for it to show strong signs of recovery over the next several years. The time required for a measurable increase in lobster population density in the sanctuary zone is likely to be in the order of several years. Based on studies of multiple reserves in New Zealand, recovery rates of southern rock lobster populations have been estimated as in the order of between 5 and 11% per year (Kelly et al. 2000). Other studies of this species have shown that ten-fold increases in biomass have occurred over a period of 5 years (Edgar and Barrett 1999).

The results for *P. versicolor*, which showed that there are currently significantly higher densities of lobsters in the newly created sanctuary zone than outside it, provide a demonstration of the importance of ensuring that monitoring of no-take zones includes the collection of comprehensive baseline data before new zonings come into effect. Without such data, we may incorrectly interpret stochastic or habitat related differences in density to the effects of zoning (Edgar et al 2004).

Historical trends

> "One day I was off Jane's Bay and there was a bit of a swell – I couldn't launch my dinghy for a start off. So I swam through the breakers and got behind the reef and it was fantastic – I filled up a bag in about ten minutes. I swam back and took that in and went back – two bags, and with the third bag… and when I say a full bag I mean about eighty pounds of crayfish."
>
> - Nick Farinaccio talking to Peter Mack, 2003.

Assuming Farinaccio's lobster were legal sized (77mm), and that a lobster of this size weighs approximately 413 g, 80 pounds of lobster (= 36,287.389 grams), would result in an estimate of approximately 87 lobsters per bag. If we assume that he took approximately one hour to fill the three bags, this would be a catch of over 250 lobsters caught by hand in one hour. By comparison the most lobsters counted on one transect (100x10 m) in this study was 170 *P. cygnus* on a similar coastal reef in the central part of Batemans Bay at least 15 km south of Jane's Bay. It took at least one hour to complete the count and estimate the size of lobsters on this transect. The greatest number of lobsters we recorded on a single transect in Jane's Bay was five. By contrast anecdotal reports from the early 1980's suggest that at that time a large aggregation of lobsters at Jane's bay was considered to be ten lobsters per ledge (Halkyard 2005). The accounts above are a sample of similar reports related by independent sources recorded in Halkyard (2005). Published sources were also cited by Halkyard, including a survey by CSIRO who reported 68 exuvia of *Panulirus versicolor* on the beaches of South Muiron Island (Department of Fisheries 1950). The total numbers of this species encountered at the Muiron islands over two years of surveys was six individuals, on 85 transects.

Based on these admittedly indirect sources of inference, as well as the direct comparison of fished and unfished areas, it appears that the abundance of the most common lobster species *(P. cygnus, P. ornatus and P. versicolor*) are conservatively now at less than 10% of the levels that were present before active commercial or recreational fishing began in around the 1960s. As such they are likely to be lower than the level required for sustainable egg production. For example the Western Rock Lobster Fishery is managed to keep the level of spawning stock biomass at more than 22 % of its estimated unfished original level (Hall and Chubb 2001 Fletcher et al. 2005). Based on the current models of the state of the *P. cygnus* fishery, it is estimated that egg production of the stock is around 22% of unfished levels (Hall and Chubb 2001), However it is estimated that the levels of egg production have dropped as low as 15% of unfished levels in the early 1990s (Walters 1993). The fact that since 2006 the recruitment of Western Rock Lobster has fallen to unprecedented low levels (http://www.fish.wa.gov.au/docs/pub/PuerulusSettlement/index.php?0405), raises the question of whether *P. cygnus* populations have been fished down to the level where spawning biomass is insufficient to sustain recruitment. While the possibility that physical environmental factors are responsible for all or part of this failure, no clear oceanographic or climatic causes have yet been identified. The difference between fished and unfished levels of density (and biomass and egg production) at Ningaloo and at areas such as the Kingston Reef Sanctuary at Rottnest Island, suggests that egg production may be as much as an order of magnitude lower than the target level of 22% of unfished levels.

Monitoring recommendations

- The level of uncertainty around the effectiveness of marine sanctuary areas for rock lobster populations is sufficiently high that the continued monitoring of rock lobster populations should be continued as a matter of some priority. The data set provided by this study provided powerful tests of variation in abundance (Power >0.9) and will allow us to determine whether densities change over time in newly established sanctuary areas, a critical inferential test that could not be addressed based on previously established zones. We can expect detectable effects of protection to occur within 5 years, and since re-zoning in the park was implemented in 2006 we should be planning these surveys for the near future 2010/11.

- A subset of areas that hold relatively high levels of rock lobsters should be targeted, particularly the Batemans Bay area (up to Norwegian Bay) for *Panulirus cygnus*, and the lighthouse Bay – Jurabbi region for tropical species *P. ornatus* and *P versicolo*r.

- The methods used should employ simple methodologies such as scuba surveys of established sites using transect methodology rather than methods that do not allow density estimates to be made directly (e.g. timed swims). The surveys should also include estimates of lobster size, sex, and reproductive status in order to provide stronger basis for interpreting any trends may relate to zoning and fisheries provisions (e.g. legal size).

- Nearshore and coastal reef habitats should be targeted as these held the highest numbers of lobsters in this survey and were also characterised as the habitats with most lobsters in historical reports. Locating sites within lobster habitat will simplify comparisons and increase statistical power.

- Survey methodology and survey design should be consistent with those used in other Marine Parks to enable stock-level inferences to be made at larger scales. There are published methodologies for underwater visual census of lobsters used for surveys of marine parks in other parts of Western Australia. Surveys at Ningaloo should adopt a methodology similar to the one employed in this study and this should ideally be employed throughout the state as part of a coordinated DEC lobster monitoring program. This is particularly true where lobster species are widespread and occur across both tropical and temperate zones.

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