Western Rock Lobster Ecology – The State of Knowledge Marine Stewardship Council Principle 2: Maintenance of Ecosystem

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Western Rock Lobster Ecology – The State of Knowledge

Marine Stewardship Council
Principle 2: Maintenance of Ecosystem

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Contents

1.0 Background to the Western Rock Lobster Managed Fishery

1.1 Biology and Distribution

1.1.1 Distribution

The western rock lobster *Panulirus cygnus* (George 1962) is found in temperate waters off the west coast of Western Australia where juveniles populate shallow inshore reefs (< 40 m depth) and adults (> 80 mm Carapace Length) populate deep-water offshore habitats (> 40 m depth) including coral reefs at the Abrolhos Islands. Its area of distribution is the continental shelf on the west coast of Western Australia, with greater abundances off the mid-west coast (Geraldton – Perth) than the northern and southern parts of the west coast (Figure 1.1).

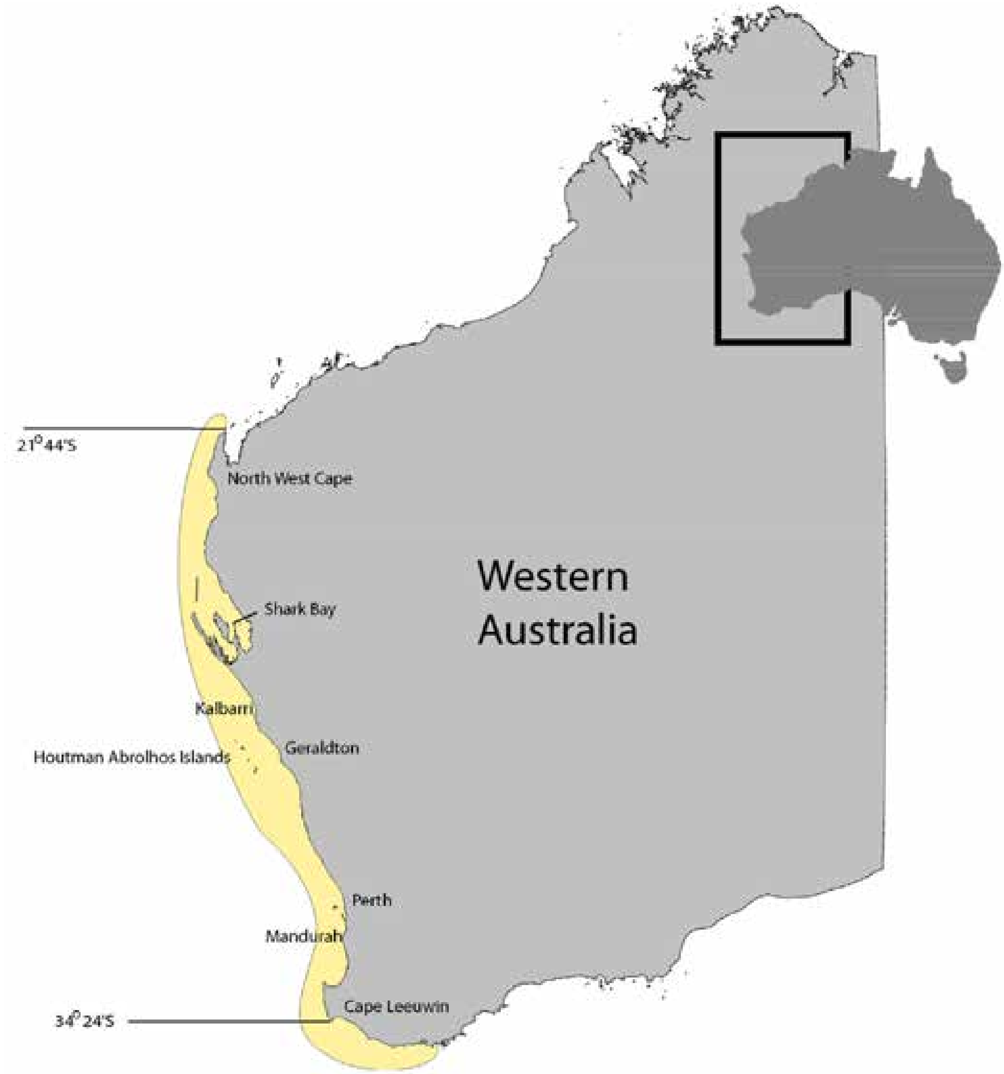

Figure 1.1. Distribution of the western rock lobster (*Panulirus cygnus)* along the Western Australian coastline.

The east coast of the Indian Ocean, which skirts around the Western Australian coast line, is dominated by the warm, southward-flowing, tropical water of the Leeuwin current. In contrast, the Capes current runs inshore of the Leeuwin current and when pushed by strong south-westerly winds during the summer months, it causes cool, high-salinity water to flow northwards along the coast. Thus, the western rock lobster experiences a large annual temperature range across its distribution from around 27°C at North West Cape in February to 16 °C near Cape Leeuwin in August.

1.1.2 Life History

The western rock lobster typically lives for 10 to 15 years and weighs less than 3 kg. The mating system involves the male attaching a package of sperm called a tarspot to the female's sternum. At spawning, the female releases eggs from small pores at the base of the third pair of walking legs. When the female scratches the tarspot, sperm is released and the eggs are fertilised as they are swept backwards and become attached to the sticky setae on the pleopods. After successful external fertilisation, the female lobster will carry and care for the egg brood attached to her abdomen for a period of 5-8 weeks. The number of eggs produced by a particular female during a spawning period depends on the size of the individual (Chubb 1991). Hence, larger females produce more eggs per unit of size than smaller females, with large females capable of producing up to a million eggs (Morgan 1972), and have a greater likelihood of spawning twice in a season (Melville-Smith and de Lestang 2006).

Upon hatching, the tiny larvae called phyllosoma spend 9-11 months as plankton in the water column driven by ocean currents. After several moults, the phyllosoma larvae moult into the free-living puerulus stage and swim towards the coast to settle among seagrass beds and algal meadows (Figure 1.2). The settlement of pueruli occurs throughout the year, with peaks from late-winter to mid-summer, although the rate of settlement of pueruli can vary greatly from year to year and is largely driven by environmental factors (Caputi *et al.* 2000). For example, when the Leeuwin current is flowing strongly, the settlement of puerulus is high and a higher proportion of the larval lobsters return to the coast. The effects of climate change on puerulus settlement, lobster catchability, movement and moulting patterns are currently being monitored (Caputi, *unpub. data*).

After they moult into the juvenile stage, *P. cygnus* are more prevalent on inshore reefs where they spend the next 3-4 years feeding and growing. When they reach a size of 80 mm carapace length (CL), many lobsters undergo a synchronised moult event. These lobsters are known as 'whites', as their new shell is paler than their normal bright red colour. The 'white' phase of a rock lobster's life coincides with its migratory phase, when lobsters leave the coastal reefs and make a mass migration across sandy habitats to their deep-water, offshore breeding grounds. When the 'whites' reach the offshore breeding grounds, they undergo another synchronised moult back to their normal red shell colour and remain in the deep-water habitats. Another significant migration is the movement of lobsters from the Abrolhos Islands to Big Bank, an offshore area near Kalbarri. The dynamics of the 'whites' and Big Bank migrations (e.g. cause, speed, direction, and magnitude) and whether these vary between years remains unknown (de Lestang *et al*. 2009).

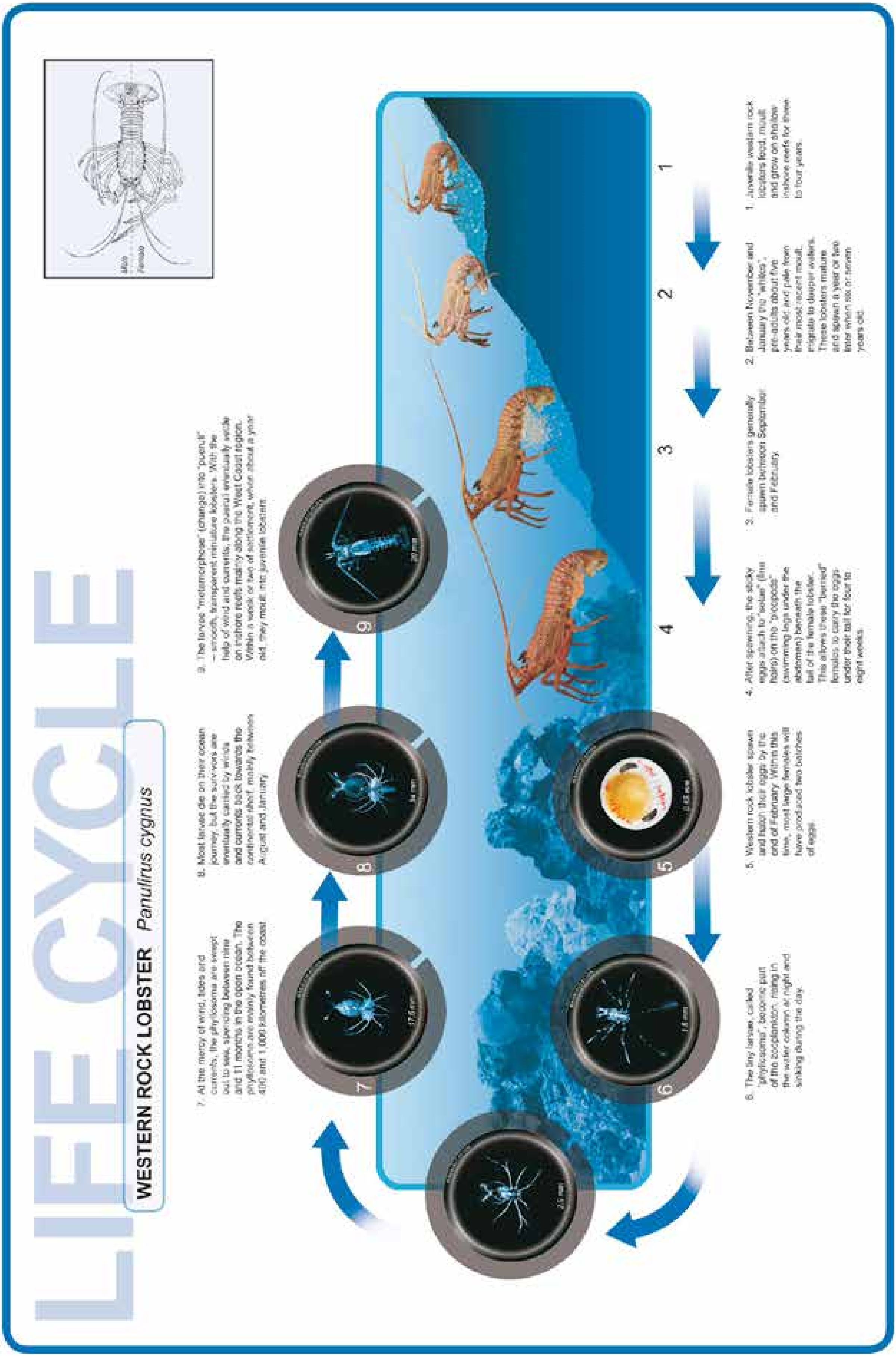

Figure 1.2. Life history of *Panulirus cygnus* (Source: Department of Fisheries 2011).

1.1.3 Biology

Factors such as temperature, photoperiod, oxygen availability, diet, density, limb damage and size at sexual maturity can all influence the growth rate of *P. cygnus* (Chittleborough 1975). There is considerable spatial variation in the reproductive biology and growth of male and female western rock lobsters throughout the fishery. In the cold-water southern areas of its distribution, lobsters become mature at about 6-7 years or around 90 mm carapace length (CL). In the warmer northern waters near Kalbarri and the Abrolhos Islands, they mature at smaller sizes, usually at about 70 mm CL (Melville-Smith and de Lestang 2006). The growth rate of western rock lobsters is faster in warmer waters towards the northern end of the fishery than in the south (de Lestang *et al*. 2009) and has been attributed to increased moult frequency rather than larger moult increments (Chittleborough 1975).

The western rock lobster is an opportunistic omnivore, feeding on a wide range of food items from coralline algae to molluscs and crustaceans (Joll and Phillips 1984; Edgar 1990a). The diet and feeding strategies of juvenile rock lobsters vary greatly between seasons and habitats and is reflective of the abundance and size distribution of the available benthic macrofauna (Edgar 1990a). The diet of adult lobsters in deep-water habitats is primarily carnivorous and consists of crabs, amphipods and isopods, and is supplemented by bait from lobster pots and discards from fishing boats (Waddington *et al.* 2008; Waddington and Meeuwig 2009). There is no evidence that lobster size (65-120 mm CL) or sex affects the lobster's diet or trophic position in deep-water ecosystems (Waddington *et al*. 2008). As juveniles, *P. cygnus* are eaten by a number of fish species, while at large sizes they are one of a number of prey items for octopus and a variety of larger finfish. There are no predators that rely on western rock lobsters as their only prey item (Waddington *et al.* 2008).

1.2 Management of the West Coast Rock Lobster Managed Fishery

The commercial West Coast Rock Lobster Managed Fishery (WCRLF) operates from shallow inshore regions to the edge of the continental shelf. Historically, the primary management methods were input controls with limits on the number of licensees and the total number of pots that could operate in the fishery; however, in 2009/10 the fishery switched from input controls to a Total Allowable Commercial Catch (TACC)*. The western rock lobster is also a popular recreational species. Around 45 000 recreational rock lobster licences are issued annually, and approximately 80 % of them are used. Most of the recreational fishing is focused around Perth and Geraldton. Several restrictions apply to the recreational capture of lobsters including the number of pots-per-licence, pot design, bag limits, and allowable fishing areas and periods. More recently, the West Coast Rock Lobster Managed Fishery has undergone the Integrated Fisheries Management (IFM) process, and the Total Allowable Catch allocated as 95 % to the commercial sector, 5 % to the recreational sector and one tonne to customary fishers (IFAAC 2007; de Lestang *et al.* 2010b).

The commercial fishery is managed in three zones: south of latitude 30°S (Zone C), north of latitude 30°S (Zone B) and a third offshore zone (Zone A) around the Abrolhos Islands (Figure 1.3). Effort is evenly split between the southern and northern zones through the implementation of management controls aimed at addressing zone-specific issues. These issues include different maximum size restrictions and seasonal opening and closing dates. The only allowable method

* See http://www.fish.wa.gov.au/docs/sof/2009/index.php?00 for further information

of capture is the use of baited pots made of wood slates or cane material fitted with escape gaps (for undersized lobsters and bycatch). After an overnight soak period, the pots are retrieved with the captured lobsters of legal size and appropriate reproductive status (e.g. not berried) placed into holding tanks and returned to on-shore processing plants, where the majority are prepared for live shipments.

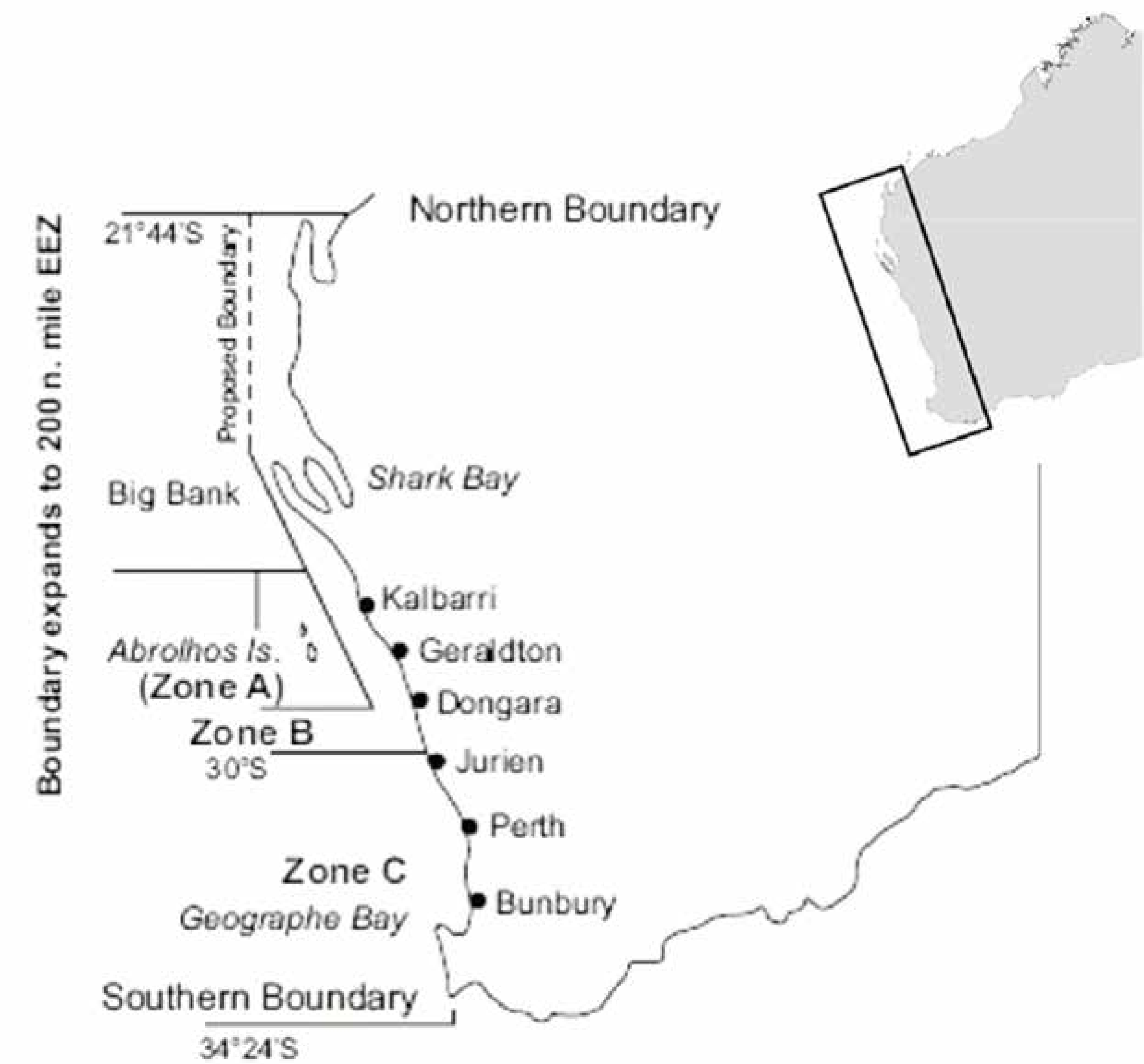

Figure 1.3. West Coast Rock Lobster Managed Fishery Management Zones

The commercial minimum legal size for rock lobsters is 77 mm CL from 15 November to 31 January and 76 mm CL from 1 February to 30 June. Retaining setose (breeding) lobsters is prohibited to optimize egg production levels. At the start of the fishing season in November, fishers target red lobsters from inshore coastal reefs. When these lobsters moult and the run of the 'whites' begins, most of the commercial fishers follow the migration offshore. Catch rates increase during this period as fishers target larger-sized lobsters; however, paler-coloured lobsters fetch a lower market price than red-coloured ones (Wade *et al.* 2008). Due to the staggered moulting periods, catch rates rise and fall across the fishery and then decline from the deep-water regions as the fishing season closes at the end of June.

1.3 Marine Stewardship Council Certification (MSC)

The Marine Stewardship Council (MSC)* is a globally recognised non-profit organisation dedicated to promoting sustainable and economically viable fisheries while maintaining the biodiversity, productivity and ecological processes of the marine environment. Their mission statement being: "*To safeguard the world's seafood supply by promoting the best environmental choice*". The MSC certification process involves independent third-party assessment of a fishery based on evaluations made against a set of MSC principles and criteria that describe what aspects need to be present in a fishery to indicate it is are moving toward sustainable management.

In 2000, the West Coast Rock Lobster Managed Fishery became the first fishery to receive MSC certification on the basis of demonstrating the sustainability of its fishing and management operations. To achieve this, the WCRLF was assessed by an international group of experts that included Dr Chet Chaffee (Scientific Certification Systems Inc. [SCS]), Dr Tony Smith (CSIRO), Dr Trevor Ward (University of Queensland) and Dr Bruce Phillips (Curtin University). The assessment team assigned numerical scores between 0 and 100 to each of the performance indicators aided by "scoring guideposts" describing what constitutes an ideal fishery (score = 100), what constitutes passable performance for an indicator (score =80), and the minimum performance required for an indicator (score = 60). Scores and weights were then combined to get overall scores for each of the three MSC Principles, which are:

> **Principle 1**: *A fishery must be conducted in a manner that does not lead to over-fishing or depletion of the exploited populations and, for those populations that are depleted, the fishery must be conducted in a manner that demonstrably leads to their recovery.*
>
> **Principle 2**: *Fishing operations should allow for the maintenance of the structure, productivity, function and diversity of the ecosystem (including habitat and associated dependent and ecologically related species) on which the fishery depends.*
>
> **Principle 3:** *The fishery is subject to an effective management system that respects local, national and international laws and standards and incorporates institutional and operational frameworks that require use of the resource to be responsible and sustainable.*

The WCRLF was recertified in December 2006 on the grounds it continued to meet the standards of the MSC, while intermediate surveillance audits of the fishery ensure ongoing conditional requirements are being addressed to MSC guidelines.

Stemming from the evaluations and conditions relating to Principle 2 was an urgent need to improve the general understanding of the ecological impacts of fishing by the WCRLF. The current document provides an overview of the completed and ongoing research projects, workshops and review documents that feed back to specific conditions raised by the MSC assessment team.

In 2011, the MSC outlined a new risk-based framework in the document "Marine Stewardship Council Fisheries Assessment Methodology and Guidance to Certification Bodies Including Default Assessment Tree and Risk-based Framework". The chapters of the present document will follow Section 7, Principle 2, Subsection 7.8 of the framework.

* http://www.msc.org

1.4 Ecological Risk Assessment

For a fisheries agency, 'risk' is the chance of something affecting the agency's performance against the objectives laid out in their relevant legislation (Fletcher 2002). One of the key requirements of the MSC certification process was to conduct a formal ecological risk assessment (ERA) of the West Coast Rock Lobster Managed Fishery.

ERA workshops for the fishery were conducted in February 2001 and February 2005 to provide a register of the potential ecological risks that may arise from activities carried out by the fishery and to identify management strategies to control risk where necessary. Invited stakeholders identified general ecosystem effects of fishing issues and ranked them by the seriousness of the hazard to ensure an appropriate level of management actions. The Risk Assessment Methodology developed by Fletcher (2002; 2005) was used to determine the priority of identified issues and the appropriate level of response or level of consequence. From the combination of consequence and likelihood, an overall level of risk was generated, ranging from negligible to severe. The risk ranking then assisted in deciding whether an issue required specific management action or not. The complete listing of the issues (hazards) identified from the 2001 and 2005 ERA workshops are provided in Table 1 and Table 2 of the Appendix. Potential management responses ranged from continuing fundamental ecological studies, through increased monitoring, to explicit management prescriptions (Anonymous 2005).

The 2006 MSC re-certification process considered the 2005 ERA workshop outcomes to be inadequate in meeting the MSC 80 standard for assessing the ecological risks of this fishery. Major weaknesses of the 2005 ERA identified by the assessment team included, "the failure to implement a robust and peer-reviewed scientific ERA, the lack of a precautionary approach to gaps in knowledge, and the lack of involvement of a relevant range of ecological expertise and stakeholders, and the failure to provide the ERA with relevant and available data/knowledge pertinent to assessing the risks of the fishery" (Anonymous 2006). This resulted in an improved ERA in 2007, where the ecological hazards identified in the 2005 ERA were re-assessed using the 'Ecological Risk Assessment for Effects of Fishing' (ERAEF) methodology developed jointly by CSIRO Marine and Atmospheric Research and the Australian Fisheries Management Authority (AFMA) (Hobday *et al*. 2003). The ERAEF methodology provides a hierarchical framework for a comprehensive assessment of the ecological risks arising from fishing, with impacts assessed against five ecological components: (1) target species; (2) by-product and bycatch species; (3) threatened, endangered and protected (TEP) species; (4) habitats; and (5) (ecological) communities. ERAEF also provides an explicit approach to uncertainty in the assessment of ecological risks from fishing.

From the 37 hazards that were assessed from the 2005 ERA, 27 hazards received a risk ranking of moderate or higher. These issues were subsequently assigned to an ERAEF Level 2 analysis (equivalent to moderate- or high-risk assessment). However, as Level 2 ERAEF methodology only deals with those issues that address potential ecological threats from fishing activity and does not consider hazards associated with threats external to the fishing activities, only 15 potential hazards were eligible for Level 2 ERAEF analysis (see Table 3 of the Appendix). Of these 15 hazards, only four hazards were ranked as moderate-risk (see Table 4 of the Appendix) and the rest were classified as low- or negligible risk under existing management controls. Additional risk treatment on these four hazards further reduced the risk ranking of some of the hazards (see Table 5 of the Appendix).

Two hazards that retained a moderate-risk ranking were the deep-water communities of the central west coast and the Kallbarri-Big Bank regions, which had the potential for changes in the relative abundance of species from fishing activities. In response to these risks, different research institutions and individuals conducted a range of research projects that focused on deep-water habitat characteristics and the ecology of deep-water lobster habitats. A core component of this report summarises the activities of these research projects to date.

1.5 Environmental Management Strategy

The Environmental Management Strategy (EMS) was developed to provide objectives, targets and management actions to deal with hazards identified as risks from the ERA process. The first EMS covered the period July 2002 to July 2006 and the second is for the period July 2010 to June 2015 (Brown and How 2010).

1.6 Ecological Effects of Fishing Scientific Reference Group

The Ecological Effects of Fishing Scientific Reference Group (EcoSRG or SRG) was established in 2003 as a sub-committee for the Rock Lobster Industry Advisory Committee (RLIAC). The EcoSRG provides advice on the effects of fishing on the ecosystem, to ensure the western rock lobster resource is managed in a manner that is consistent with the national principles of Ecologically Sustainable Development (ESD) and ecosystem-based fisheries management (EBFM).

The initial overall assessment by the EcoSRG stated, "There is a paucity of data from the deep-water such that, the SRG was not able to determine the impact on the ecosystem of removing lobsters from deep-water habitats and that this should be a priority focus for research" (Anonymous 2008). The EcoSRG considered identifying and quantifying ecosystem patterns to be the important first step for all forms of ecosystem research. This would allow for objective evaluations of any observed gradients due to different lobster densities or between fished and unfished areas. To achieve this, the EcoSRG produced a strategic research framework as a basis for more detailed and focused research proposals that would address the ecosystem effects of rock lobster fishing activities. These research projects were essentially asked to test the null hypothesis that: *Removal of western rock lobsters on a scale experienced in Western Australia does not have a significant or irreversible effect on the ecosystem*. Thus an operational plan of research was developed incorporating the following four key focus areas: (1) habitat mapping of areas utilised by *P. cygnus*; (2) size structure and density of lobsters across their distribution; (3) trophic dynamics of lobsters; and (4) lobster behaviour and interactions (Brown 2009).

The research plan was further developed in the FRDC project 2004/049: *The effects of western rock lobster fishing on the deep-water ecosystem off the west coast of Western Australia* that commenced in July 2004 (Bellchambers 2010). During 2005, the operational research plan was further amended, but its final endorsement was delayed. In 2007, the EcoSRG reviewed the draft research plan in light of the key outcomes from the completed FRDC project, as well as all rock lobster related projects in both shallow-water and deep-water habitats of the State (Anonymous 2008). Arising from the 2007 workshop findings was the need to develop a new FRDC project. This new project would further highlight any ecological impacts due to the removal of legal-sized lobsters by the fishery using fished and unfished area comparisons. Discussions concentrated on the selection of sites and methodologies to be undertaken, along with the development of a conceptual model to help identify the ecosystem parameters that needed to be monitored as part of the project. The FRDC project 2008/013: *Assessing the ecological impact of the West Coast Rock Lobster Managed Fishery in fished and unfished area* commenced in January 2009.

The 2007 workshop was the last meeting of the EcoSRG and with the dissolving of RLIAC in 2010, the EcoSRG was also officially dissolved. In order to maintain independent advice on the ecosystem effects of fishing, a newly formed expertise based body, the Effects of Fishing Advisory Group (EFAG), was formed in November 2010*.

* see http://www.fish.wa.gov.au/docs/op/op091/fop91.pdf for more details

2.0 Retained species

Rock lobster fishers are permitted to retain all species of rock lobsters (not just *Panulirus cygnus*) caught in pots. Fishers can also retain deep sea crabs in accordance with the West Coast Rock Lobster Management Plan Amendment (No.11) 2010 (Section 5A(1) of the Plan) and octopus. An exemption has been granted by the Minister for Fisheries, pursuant to Section 7 of the Fish Resources Management Act (1994), to permit the retention of demersal scalefish taken as bycatch in pots for personal consumption only (i.e. not for commercial purposes). This exemption replaced the previous exemption issued for the 2009/10 fishing season and will expire on 31 August 2011. The current scalefish arrangement is temporary and will not necessarily be renewed in subsequent seasons.*

Octopus is generally caught in rock lobster pots in shallow water (< 40 m). A catch rate of 0.03 octopus per pot lift was recorded in the 2008/09 voluntary research log book data. This was 25 % above the average of 0.024 per pot lift over the historical range (1985/86 to 2003/04). This catch rate translates to an estimated 120 337 octopus caught in all regions of the fishery during 2008/09. Estimated octopus catches for zones A, B and C were 16 562, 49 087 and 54 688, respectively. The catch rate of octopus (incidental landings) is an indicator for the fishery, and at 0.03 octopus per pot lift, 2008/09 catch levels achieved the performance measure of being within 10 % of the historical range (0.013-0.033 octopus per pot lift) (de Lestang *et al.* 2010b).

The predicted 2008/09 catch for the WCRLF, forecast from puerulus settlement 3-4 years previously, was 9 250 t; however, due to additional management changes that were introduced in response to poor puerulus settlement in previous years, the catch landed by the WCRLF for the 2008/09 season was just 7 593 t. This was 31.0 % lower than the long-term average catch (1981/82 to 2006/07) of 11 005 t and 14.9 % lower than the previous season's 8 920 t. In 2008/09, the catches in zones A, B and C were 1 339, 2 588 and 3 667 t, respectively, with zone A down 30.6 %, zone B down 14.9 % and zone C down 7.8 % compared to previous fishing seasons (de Lestang *et al.* 2010b).

* For relevant legislation see http://www.fish.wa.gov.au/docs/pub/LegislationHow/gateway.php?0006

3.0 Bycatch

3.1 Bycatch

Fishery-independent monitoring on commercial vessels records the catch rates of fish and invertebrate bycatch species caught during normal rock lobster fishing operations. Approximately 17 084 fish and invertebrates other than rock lobster and octopus were captured during the most recent fishing season, 2009/10, of which most were released. This is a marked reduction from previous years, i.e. 41 904 in 2008/2009 and 67 165 in 2006/2007, and reflects the substantial reduction in fishing effort throughout the fishery.

Table 3.1 provides the rank (R), catch rate and estimated total numbers of finfish, elasmobranch and invertebrate species recorded as bycatch during catch monitoring undertaken during the 2006/2007 and 2009/2010 seasons. Particular emphasis was placed on identifying bycatch species during an intensive, but localized study during the 2006/2007 season, resulting in a more comprehensive list. The reduced effort (pot lifts) in the fishery over previous years is reflected in the lower bycatch total for the most recent season. Note that the same species rank in the top three for both seasons.

Various demersal finfish rank in the bycatch, including break sea cod *Epinephelides armatus* and baldchin groper *Choerodon rubescens* (Table 3.1). However, the total number retained is small due to the recreational limits discussed above. Likewise, Port Jackson and wobbegong sharks, which are the second and third ranked bycatch taxa, are not retained and typically survive release. Other small fish, i.e. various wrasses (Labridae), are also released as they are not permitted to be retained as bait.

Few invertebrates other than western rock lobsters and octopus are caught during normal fishing operations. Hermit crabs (Paguroidea) may be caught, but are released if they do not escape as the pot is retrieved. Depending on the habitats and depths fished, small numbers of slipper lobsters (Scyllaridae) and champagne crabs *Hypothalassia acerba* may be caught at certain times. Fishers are permitted to keep up to 12 deep sea crabs for personal consumption, although few have been caught in recent years (Table 3.1).

3.2 Bait

Western rock lobster fishing is conducted using baited pots. Most of the bait species used by the WCRLF come from managed fisheries, although the management status for a few species is unclear (Table 3.2). The most common bait for the 2009/10 fishing season was blue mackerel from New Zealand (1 432 t), which is a managed fishery. The amount of bait used has decreased in recent years, and in 2009/10 was 4 576 t (Table 3.3).

Table 3.1. Rank (R), catch rate and estimated total numbers of finfish, elasmobranch and invertebrate species recorded as bycatch from catch monitoring during the 2006/2007 and 2009/2010 seasons.

	2006/2007 Season			2009/2010 Season		
Bycatch species	**R**	**Catch/ 1000 Pot Lifts**	**Estimated Total (whole fishery)**	**R**	**Catch/ 1000 Pot Lifts**	**Estimated Total (whole fishery)**
Break Sea Cod (Epinephelides armatus)	1	2.09	17 396	1	2.64	5 813
Wobbegong shark (Orectolobus spp.)	3	1.69	14 014	2	2.15	4 745
Port Jackson Shark (Heterodontus portusjacksoni)	2	1.92	15 947	3	0.70	1 542
Baldchin Groper (Choerodon rubescens)	11	0.58	4 832	4	0.48	1 068
Wrasse (Labridae)	9	0.7	5 799	5	0.32	712
Parrotfish (*Scarus* spp)				5	0.32	712
Leatherjacket (Monocanthidae)	12	0.52	4 349	7	0.27	593
Western Wirrah (Acanthistius serratus)	17	0.12	966	8	0.22	475
Cuttlefish (Sepia sp.)	5	0.93	7 732	9	0.11	237
Sweetlips Emperor (Lethrinus miniatus)	8	0.76	6 282	9	0.11	237
Leopard Wirrah (Acanthistius pardalotus)	9	0.7	5 799	9	0.11	237
Black-banded Seaperch (Hypoplectrodes nigrorubrum)	21	0.06	483	9	0.11	237
Dhufish (Glaucosoma hebraicum)	14	0.17	1 450	13	0.05	119
Gurnard (Chelidonichthys sp.)	14	0.17	1 450	13	0.05	119
Unknown fish	14	0.17	1 450	13	0.05	119
Spangled Emperor (Lethrinus nebulosus)	21	0.06	483	13	0.05	119
Eel (Muraenidae)	4	1.4	11 598			
Chinaman Cod (Epinephelus rivulatus)	6	0.81	6 765			
Scorpion Fish (Scorpaenidae)	6	0.81	6 765			
Pink Snapper (Pagrus auratus)	13	0.23	1 933			
Hermit Crab (Paguroidea)	17	0.12	966			
Skipjack Trevally (Psuedocaranx dentex)	17	0.12	966			
Western Foxfish (Bodianus frenchii)	17	0.12	966			
Blackspot Pigfish (Bodianus vulpinus)	21	0.06	483			
Blue-barred Parrotfish (Scarus ghobban)	21	0.06	483			
Boxfish (Ostraciidae)	21	0.06	483			
Bullseye (Pempheris sp.)	21	0.06	483			
Cobbler Carpetshark (Orectolobus tentaculatus)	21	0.06	483			
Flathead (Platycephalidae)	21	0.06	483			
Footballer Sweep (Neatypus obliquus)	21	0.06	483			
Harlequin Fish (Othos dentex)	21	0.06	483			
Lined Dottyback (Labracinus lineatus)	21	0.06	483			
NW Blowfish (Lagocephalus scleratus)	21	0.06	483			
Queen Snapper (Nemadactylus valenciennesi)	21	0.06	483			
Scalyfin (Parma muccullochi)	21	0.06	483			
Silver Spot (Threpterius maculosus)	21	0.06	483			
Urchin (Echinoidea)	21	0.06	483			
Total			**67 165**			**17 084**

Table 3.2. Identity, origin and amount of bait supplied to the Western Rock Lobster Fishery during the 2009/2010 fishing season.

Bait	Species	Tonnes	Usage	Origin	Managed	Source
Hoki	*Macruronus novaezelandiae*	171.59	Heads	New Zealand	Yes	http://fs.fish.govt.nz/Page.aspx?pk=7&tk=153&sc=HOK
Alfonsino	*Beryx* spp	27.84	Heads	New Zealand	Yes	http://fs.fish.govt.nz/Page.aspx?pk=7&tk=153&sc=BYX
Blue Mackerel	*Scomber australasicus*	198.38	Heads	New Zealand	Yes	http://fs.fish.govt.nz/Page.aspx?pk=7&tk=100&sc=EMA
Blue Mackerel	*Scomber australasicus*	1432.03	Whole	New Zealand	Yes	http://fs.fish.govt.nz/Page.aspx?pk=7&tk=100&sc=EMA
Blue Mackerel	*Scomber australasicus*	26.55	Whole	Taiwan	unclear	http://www.worldfishing.net/features101/new-horizons/taiwan
Cardinal	*Epigonus telescopus*	69.56	Heads	New Zealand	Yes	http://fs.fish.govt.nz/Page.aspx?pk=7&tk=153&sc=CDL
Kahawai	*Arripis* spp	134.97	Whole	New Zealand	Yes	http://fs.fish.govt.nz/Page.aspx?pk=7&tk=153&sc=KAH
Kahawai	*Arripis* spp	1.70	Heads	New Zealand	Yes	http://fs.fish.govt.nz/Page.aspx?pk=7&tk=153&sc=KAH
Orange Roughy	*Hoplostethus atlanticus*	728.87	Heads	New Zealand	Yes	http://fs.fish.govt.nz/Page.aspx?pk=5&tk=1&fpid=15
Orange Roughy	*Hoplostethus atlanticus*	73.43	Heads	Mauritius	unclear	
Tuna	*Thunnus* spp.	42.06	Heads	Thailand	unclear	http://www.fao.org/fishery/countrysector/FI-CP_TH/en
Tuna	*Thunnus* spp.	45.74	Heads	Indonesia	unclear	http://www.fao.org/fishery/countrysector/FI-CP_ID/en
Sanmar	*Cololabis saira ??*	15.18	Whole	Taiwan	unclear	http://www.worldfishing.net/features101/new-horizons/taiwan
NS Herring	*Clupea harengus*	58.64	Whole	Holland	Yes	http://ec.europa.eu/fisheries/marine_species/wild_species/herring/index_en.htm
NS Herring	*Clupea harengus*	182.57	Whole	USA	Yes	http://www.asmfc.org/
Jack Mackerel	*Trachurus* spp	32.48	Whole	New Zealand	Yes	http://fs.fish.govt.nz/Page.aspx?pk=5&tk=1&fpid=50
Menhaden	*Brevoortia tyrannus*	679.72	Whole	USA	Yes	http://www.asmfc.org/
	Total Imported	**3921.30**				
Hoki	*Macruronus novaezelandiae*	7.43	Heads	Tas	Yes	http://www.afma.gov.au/managing-our-fisheries/fisheries-a-to-z-index/southern-and-eastern-scalefish-and-shark-fishery/
Hoki	*Macruronus novaezelandiae*	7.43	Heads	Tas	Yes	http://www.afma.gov.au/managing-our-fisheries/fisheries-a-to-z-index/southern-and-eastern-scalefish-and-shark-fishery/
Alfonsino	*Beryx* spp	10.88	Heads	Tas	Yes	http://www.afma.gov.au/managing-our-fisheries/fisheries-a-to-z-index/southern-and-eastern-scalefish-and-shark-fishery/
Blue Mackerel	*Scomber australasicus*	326.56	Whole	SA	Yes	http://www.afma.gov.au/managing-our-fisheries/fisheries-a-to-z-index/small-pelagic-fishery/
Orange Roughy	*Hoplostethus atlanticus*	44.40	Heads	Tas	Yes	http://www.afma.gov.au/managing-our-fisheries/fisheries-a-to-z-index/southern-and-eastern-scalefish-and-shark-fishery/
Pig fat		61.00		WA	N/A	
Sardines	*Sardinops sagax*	19.10	Whole	WA	Yes	http://www.fish.wa.gov.au/docs/sof/2009/index.php?0706
A. Salmon	*Arripis truttaceus*	80.82	Heads	WA	Yes	http://www.fish.wa.gov.au/docs/sof/2009/index.php?0706
A. Salmon	*Arripis truttaceus*	12.42	Heads	SA	Yes	http://www.fish.wa.gov.au/docs/sof/2009/index.php?0706
A. Salmon	*Arripis truttaceus*	66.00	Cutlets	WA	Yes	http://www.fish.wa.gov.au/docs/sof/2009/index.php?0706
A. Salmon	*Arripis truttaceus*	0.02	Whole	WA	Yes	http://www.fish.wa.gov.au/docs/sof/2009/index.php?0706
Kangaroo		9.56		WA	N/A	
A Herring	*Arripis georgianus*	14.92	Whole	WA	Yes	http://www.fish.wa.gov.au/docs/sof/2009/index.php?0706
Other		1.18		WA		
	Total Local	**654.29**		**WA**		

Table 3.3. Effort, total catch and total amount of bait used by the Western Rock Lobster Fishery between the 2007/2008 and 2009/2010 fishing seasons. The conversion rate indicates the amount of bait used (kg) to catch one kg of lobsters.

Season	Pot lifts (million)	Catch (t)	Bait (t)	Conversion
2007/2008	7.8	8926	10127	1.1
2008/2009	4.8	7595	10904	1.4
2009/2010	2.2	5899	4576	0.8

4.0 Endangered Threatened and Protected Species

All interactions between the WCRLF and endangered, threatened, and protected (ETP) species need to be recorded on a Catch and Disposal Record (see Figure 2 of the Appendix).

4.1 Dusky whaler sharks

All whaler sharks (Family Carcharhinidae), including the dusky whaler shark *Carcharhinus obscurus* are “Totally protected Fish in the South Coast and West Coast regions” (Fish Resources Management Regulations 1995, Schedule 2, Part 2, Division 2). However, regulations also provide “Defences for offence against Section 46 or 47” meaning that whaler sharks, other than dusky whaler sharks with an interdorsal fin length over 70 cm, can be landed by authorised fisheries “Where the fish the subject of an offence is a totally protected whaler shark other than a dusky shark, it is a defence that the fish was taken by a person acting under a managed fishery licence granted in respect of a managed fishery the management plan for which specifically allows for the taking of sharks or rays” (Fish Resource Management Regulations 1995, reg. 11 [5] [*]).

McAuley *et al*. (2004; 2005) assessed the stocks of the dusky whaler shark and found that catch rates of this species increased from the 1970s to 1980s, before falling in the early 1990s, with approximately 45 % of the catch being neonates. The dusky whaler shark received a moderate risk classification in the 2007 ERA (Stoklosa 2007), due to their high age at maturity and low fecundity, as females reach maturity at about 30 years of age and give birth to small numbers of offspring every second or third year (mean no. female offspring = 2.0 yr^{-1}; McAuley *et al*. 2007). Thus, there is potential for declines in stock recruitment as a result of even modest exposure of adult sharks to commercial (e.g. bait bands, demersal gillnets, various line fishing methods) or illegal fishing activities. McAuley *et al*. (2007) found that one to two percent annual mortality rate from fishing activities, applied to dusky whaler sharks over ten years of age, makes the species vulnerable to decline in Western Australia. This mortality rate represents a small number of mature adult animals.

A Level 2 PSA analysis was undertaken subsequent to the ERA workshop to gain a better understanding of the threat of bait bands to the dusky whaler shark. Susceptibility to bait entanglement by dusky whaler sharks was assessed with respect to:

1. ‘Availability’, or the overlap of the western rock lobster fishery with the spatial distribution of the Western Australian population of the dusky whaler shark;
2. The ‘encounterability’ of the species with bait bands—that is, the likelihood that individuals will encounter bait bands within the area of their geographic range;
3. The ‘selectivity’ of bait bands to entangle dusky whaler sharks based on the size of bait bands with respect to the size of individuals encountering bait bands; and
4. The likelihood of post-entanglement mortality.

The susceptibility analysis focused on the Western Australian population only. This population is highly migratory, but limited in range to the western coastal region of Australia at depths up

* Regulation 11 inserted in Gazette 10 Nov 2006 p. 4704-5; amended in Gazette 13 Feb 2009 p. 298; 2 Nov 2011 p. 4620.

to 200 m near the edge of the continental shelf (nominally Esperance to Cape Leveque). The analysis did not incorporate potential impact to dusky whaler shark stocks from exploitation by other fisheries, such as commercial long lining and demersal gillnetting. The interaction of bait bands with *C. obscurus* can be attributed to a number of fisheries that utilise bait bands aboard vessels, not solely the western rock lobster fishery. In light of the susceptibility of the dusky whaler populations to mortality associated with discarded bait bands from the western rock lobster fishery, Stoklosa (2007) made three recommendations:

5. That no further risk assessment of bait band entrapment hazards to the bycatch species *C. obscurus* is recommended in the short term.
6. That alternatives to bait bands, to avoid the use of materials that can entangle *C. obscurus* and other bycatch species, should be investigated as a matter of improving environmental management of the western rock lobster fishery. If the bait band hazard is eliminated, no other specific actions would need to be taken by the western rock lobster fishery to avoid impacts to this species.
7. That if bait bands continue to be taken to sea by the western rock lobster fishery, on-going stock assessments of *C. obscurus* should consider the threat of mortality due to bait band interactions and investigate methods for collecting data to monitor any increased mortality with a high level of confidence.

The management objective was to eliminate the use of bait bands in the western rock lobster fishery. It was noted in the 2007 ERA Workshop that about one percent of all bait bands loaded onto fishing vessels are lost at sea, and it's estimated that less than ten percent of those are in an 'uncut' condition, still forming a ring that could entrap animals. These figures predict that about 1 000 uncut bait bands are lost at sea each year. It is not known whether the western rock lobster fishery is the source of the bait bands, although the fishery is implicated as the biggest user of the bands. It is unknown how many dusky whalers interact with bait bands or what percentage survives interaction. Mortality of dusky whalers from bait band entanglement has not been reported by the fishing industry in the last couple of years, but it is not certain whether this is from a decline in the reporting rate or a reduction in the number of entanglements. A Bait Band Code of Conduct currently exists.

The Minister for Fisheries announced prohibition on the use of plastic bait bands on "active" fishing boats in the western rock lobster fishery from the start of the 2010/11 season (15 November 2010), and was later extended to all active fishing boats in Western Australia. New legislation is currently being drafted, however, due to consultation requirements with the other sectors of the fishing industry that are now included in the ban, it will not be finalised in time for the commencement of the 2010/11 season, but will be implemented prior to the 2011/12 rock lobster season. This is in line with the second part of Recommendation 4 from the 2007 ERA (Stoklosa 2007) and eliminates the need for any specific actions regarding dusky whalers.

4.2 Sea lions and SLEDS

4.2.1 Background

Previously, interactions between the WCRLF and the Australian sea lion *Neophoca cinerea* resulted in the accidental drowning of a small number of sea lion pups in rock lobster pots, as the pups attempted to retrieve bait or rock lobsters from the pots (de Lestang *et al*. 2010b). Incidents were restricted to shallow waters (< 20 m) and to areas within 30 km of the mainland sea lion breeding colonies along the mid-west coast. Sea lion interaction with pots was therefore identified as a moderate risk in the initial 2001 ERA (IRC Environment 2009). A sea lion scientific reference group (SL SRG) was formed and research conducted into possible mitigation of the risk. In order to eliminate further drowning of sea lions, a sea lion exclusion device (SLED) was developed, with mandatory introduction to areas of "potential sea lion interaction" in November 2006. All pots in waters less than 20 m within approximately 30 km of the three breeding colonies, i.e. just north of Freshwater Point to just south of Wedge Island, were fitted with approved SLEDs. Approved SLED designs include an internal rigid structure, directly under the pot neck and an external design across the top of the pot. Both internal and external structures ensure that the diagonal distance from the SLED to the neck of the pot is not greater than 132 mm. Monitoring of commercial pots in the SLED zone in 2007/08 and 2008/09 showed that over 95 % of pots checked had an approved SLED. Furthermore, video trials have indicated that this device does stop sea lion pups from entering lobsters pots and drowning. After the introduction of SLEDs into the central west coast area during the 2006/07 seasons, the risk of sea lion interactions with pots was reduced from moderate to low in the 2007 ERA (Stoklosa 2007).

The performance measure for the fishery is that there are no increases in the rate of capture of sea lions. The historical level of interactions between the fishery and sea lions is just over three sea lions per season, and during the 2008/09 season, no sea lion captures were reported. The fishery has therefore met this performance measure (de Lestang *et al.* 2010b).

4.2.2 Sea Lions at the Houtman Abrolhos Islands

Interactions between sea lion pups and lobster pots have also been recorded at the Houtman Abrolhos Islands (Abrolhos) (Brown and How 2010). Previous research had not detected any interactions; however, during the 2007/08 season a dead sea lion pup, which a post-mortem revealed had drowned, was found on the Department of Fisheries jetty. Although the reason for the mortality was inconclusive, research has shown that sea lion pups do interact with lobster pots at the Abrolhos. Given the small size of the sea lion population in the area, even a small additional mortality due to interactions with lobster pots (1-3 pups per 12-18 months) could severely compromise the viability of the population.

Risk areas for interactions at the Abrolhos have been identified as being in waters of 0-20 m depth around the Easter and Pelsaert (Southern) Groups, which are areas of sea lion pup distribution and frequent foraging by both juvenile and female sea lions (see Figure 3a and 3b of the Appendix). It was therefore recommended by the SL SRG that there be a voluntary implementation of SLEDs in these risk areas for the 2010 zone A season, and that SLEDs be made mandatory in the risk areas for the 2011 season.

The Minister for Fisheries has now approved the drafting of legislation that requires the use of SLEDs on commercial and recreational lobster pots in the two risk areas at the Abrolhos (Figures 3a and 3b of the Appendix) following recommendation from the SL SRG and in consultation with the Western Rock Lobster Council (WRLC), the WA Fishing Industry Council (WAFIC) and the Recfishwest. One of the conditions from the Marine Stewardship Council (MSC) reaccredidation is that "The implementation of SLEDs into the risk areas of the fishery at the Abrolhos Islands is required for the 2011 zone A fishing season". The new legislation is expected to be in place by the commencement of the 2010/11 Abrolhos season on 15 March 2011. Further information about the SLED management package is available at http://www.fish.wa.gov.au/docs/pub/SeaLionExclusionDevices/index.php.

4.3 Turtles

Interaction between turtles and the rock lobster fishery by entanglement with lobster pot ropes or boat strikes, was identified as a moderate risk in the 2001 ERA (IRC Environment 2009). Information presented at the 2005 ERA (Burgman 2005) from voluntary surveys of lobster fishers from 1999/2000 - 2001/02 seasons highlighted 34 interactions, with 5 mortalities over the three seasons (Table 4.1).

Table 4.1. Interactions and mortalities of seas turtles from three years of annual bycatch surveys (Burgman 2005).

Season	Interactions	Mortalities
1999/2000	12	1
2000/2001	17	3
2001/2002	5	1

The assessment of the expert groups, while considering the consequence of further impacts as severe or major, decided that given the decline in sea turtle populations the likelihood of extra mortalities associated with the fishery was very unlikely. This resulted in a reclassification of this risk as low.

Turtle deaths as a direct result of interaction with the lobster fishery are very rare. Of the 6 turtle species that occur in the waters of the western rock lobster fishery, only the entanglement of leatherback turtles (*Dermochelys coriacea*) was concluded to be above a negligible risk, and this was still rated as a low risk. Given the significant reductions in fishing effort and hence, pot ropes in the water, the current risk is now probably even lower (de Lestang *et al*. 2010b).

The performance measure for the fishery is that there is no increase in interactions with turtles. In 2008/09, no leatherback turtles were reported to have been entangled in lobster fishing gear (de Lestang *et al*. 2010b). This incident rate is below the historical range of between two and five entanglements per season over the preceding five seasons, and the fishery has therefore met this performance standard.

4.4 Cetaceans

There are occasional reports of a whale becoming entangled in pot ropes (de Lestang *et al*. 2010b). The humpback whale is the predominant species that interacts with the WCRLF, during its northward migration to the North West Shelf breeding grounds from June to August. However, as the lobster fishery operates from November to June the interaction period is quite limited. Due to the increasing humpback whale population, increased interactions were considered likely in the future; however, the large reduction in effort levels within the fishery means that this increase may no longer eventuate.

Interactions between whales and the lobster fishery are reported by the industry to the Department of Environment and Conservation (DEC) and a specialist team is used to disentangle the animal. The industry has developed a code of practice to minimise the interaction with whales in conjunction with DEC and SeaNet. The environmental management strategy adopted for the WCRLF requires monitoring of, and attempts to, minimise accidental interaction with whales wherever possible.

The performance measure for the fishery is that there is no increase in the rate of interactions/entanglements with whales and dolphins. Over the recorded history (1989-2008), commercial lobster fishing has resulted in zero to four whale/dolphin interactions per season (de Lestang *et al*. 2010b). One whale entanglement was recorded during the 2008/09 lobster season, with the whale successfully disentangled; therefore, the fishery met this performance measure (de Lestang *et al.* 2010b).

While the ecological impacts of whale entanglements are considered a low risk, the 2005 ERA also assessed the social impacts of whale entanglement (Burgman 2005). This was rated as a high risk due to the possible (L4) or occasional (L5) likelihood of major political or social problems associated with regular pot entanglements of whales. However, using the new ERAEF methodology, the social impacts of whale entanglement were unable to be assessed, and the ecological risk of whale entanglement was adjusted from low to negligible in 2007 (Stoklosa 2007).

5.0 Understanding Habitat Structure

5.1 Background

Performance indicator 2.1.1.1 of the MSC states, "The nature and distribution of habitats relevant to the fishing operations is known". The initial MSC assessment in 2001 found limited information on habitats relevant to the WCRLF, such as the Abrolhos Islands and specific inshore areas, and information was generally lacking elsewhere, especially the deep-water regions. As a result, habitat mapping across the extent of the WCRLF using an agreed classification system was made a condition of re-certification (Condition 2.1.1.1).

The EcoSRG identified habitat mapping relating to western rock lobster fishing grounds as one of its focus areas of research to address the following questions:

- What habitats do lobsters use?
- Is there a pattern in the habitat type that is related to lobster density and/or size structure?

The action plan to address these issues included:

- Produce a broad scale habitat map
- Review existing benthic habitat and seabed data for the shelf waters between Mandurah and Kalbarri
- Conduct broad large-scale rapid assessment protocols in waters between Mandurah and Kalbarri to determine areas of interest.
- Choose a minimum of three representative transects with replicates at each location
- Conduct detailed habitat mapping of chosen sites that includes
    - Acoustic survey of hard structure and associated ground truthing of epifauna and infauna 'habitat' using video techniques
    - Limited grab sampling to later determine infaunal composition and sediment type

A significant portion of Western Australian marine habitat within the fishing grounds of western rock lobster has been mapped to describe both the physical substratum and the biological communities (Figure 5.1).

This is largely a result of different government agencies and private sectors undertaking habitat-mapping exercises in relation to coastal development projects and marine reserve planning initiatives. The information available spans several decades and has been collected using different methodologies (due to technological advances) and at different spatial scales (Table 5.2). Despite these inconsistencies, habitat classification categories are similar across the regions, providing a comprehensive overview of the benthic habitats associated with *P. cygnus*. The rest of this section describes benthic habitat information between Kalbarri and Cape Leeuwin, as well as key offshore regions such as Big Bank, Abrolhos Islands and Rottnest Island.

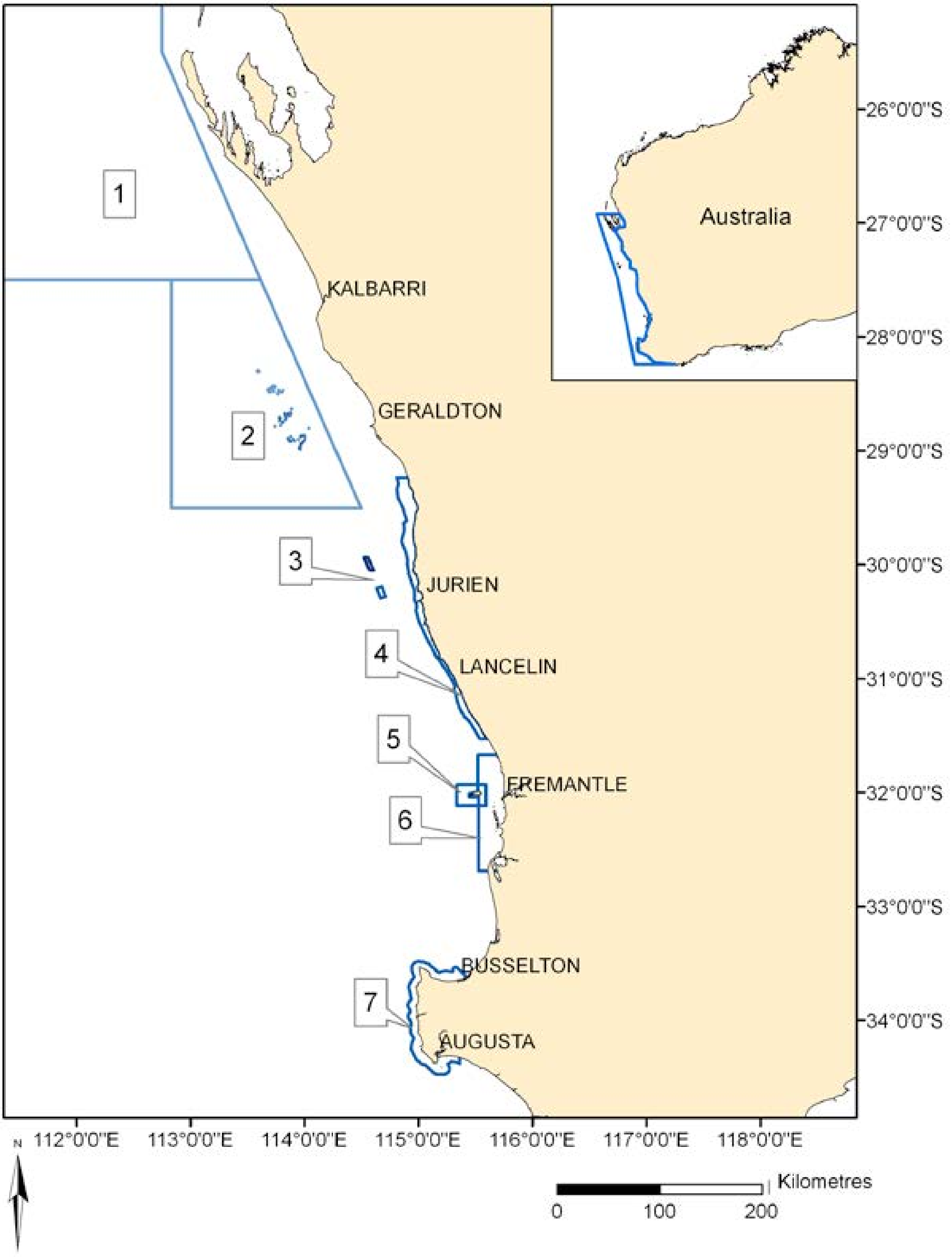

Figure 5.1. Extent of Western Rock Lobster Fishery where habitat mapping is available. Numbers on map correspond to further details in Table 5.2.

5.2 Kalbarri to Dongara

The northern range of the West Coast Rock Lobster Managed Fishery (Onslow to Kalbarri) represents less than 1 % of the total fishing effort (with the exception of Big Bank) and has not been included in this report.

5.2.1 Big Bank

The Big Bank region lies to the north of the Abrolhos Islands near the edge of the continental shelf in depths of up to 200 m. Two habitat types are associated with the fishing grounds, reef bottom (44-92 m) and barren featureless sea floor (70-120 m) (Chubb *et al*. 1994). A resident population of lobsters, comprised of breeding males and females as well as some non-breeders, inhabit the shallower banks. The remainder of the population are recently moulted migratory lobsters. High and variable catch rates of *P. cygnus* in this region suggest that suitable habitat is available, however, fine-scale habitat data is lacking.

5.2.2 Kalbarri

Marine habitat information from Kalbarri to Geraldton is very limited for both the inshore and offshore regions. The Kalbarri Blue Holes Fish Habitat Protection Area (FHPA), located immediately to the west of the town of Kalbarri, includes part of a near-shore limestone reef system, which stretches intermittently from Red Bluff in the south to the Murchison River Mouth in the north.

As part of the planning process in April 2002, the Australian Marine Conservation Society WA (AMCSWA) conducted dive surveys over two days using SCUBA and snorkel (Department of Fisheries 2004). A combination of video footage, quadrat sampling and sample collections were used to document information on substrate and biota. These surveys found the habitat within 400 m of the shoreline to consist of inter-tidal and sub-tidal reef platforms, featuring irregular shaped depressions (1-2.5 m) with sandy bottom, commonly referred to as the Blue Holes. The majority of the reef lagoons were characterised by broken and undulating limestone outcrops and sandstone outcrops with occasional patches of seagrass and algae. Beyond the reef platforms, the offshore area was characterised by gently undulating limestone substrate with moderately-dense algal cover, with small depressions and outcrops. The topography of the reef slope contained rock ledges, rides and depression/runnel (2-3 m)/trenches, eventually becoming sandy at 17-18 m depths. Commercial fishing for the western rock lobster takes place off the outer edge of the inter-tidal reef platform (in a minimum depth of 4 m). In total, 200 species of marine flora and fauna were identified including 10 sponges, 11 coral, 71 fish, 7 algae and 4 seagrass species.

5.2.3 Oakajee

Construction of a deep-water port near Oakajee (approximately 20 km north of Geraldton) is set to commence in late-2010. To assess the environmental impact on the adjacent coastal waters, a study of the habitat types was undertaken by George (1993). Six habitat types and associated biotic assemblages were identified:

- Inter-tidal beach sands
- Nearshore sand sheets (< 2-3 m) colonised by seagrasses
- Nearshore limestone pavements (3-6 m) occurring sporadically and supporting a small range of encrusting algae, grazing molluscs and echinoderms

- Dissected limestone platforms with discontinuous thin sand veneer occurring from 3-6 m depth and providing the main source of shelter for sponges, corals and lobster in the caves and gutters
- Offshore featureless limestone pavements covering most of the seafloor from 6 m to 16 m and supporting diverse algal and seagrass assemblages with mobile fauna including rock lobsters, grazing gastropods and fish
- Offshore sand sheets occurring from a depth of 13 m and becoming larger and deeper with increasing depth. The 'white' phase lobsters are fished as they migrate across this area.

5.2.4 Geraldton

The Geraldton Port Authority commissioned marine seafloor and habitat surveys of the nearshore and coastal regions of Geraldton Harbour, Point Moore and Georgia (an area 18 km south of Geraldton) to identify potential sites for port development. Aerial photographs were used to identify key habitat types and areas, which were then ground truthed using towed video transects, diver based surveys and divers using a manta board (Monaghan Rooke and Robinson 1993; 1994).

The following habitats were identified at all three sites:

- Sandy beaches – extending to a depth of 1.5-2.0 m
- Intertidal limestone pavement – covered by intermittent veneer sand and a range of algae and seagrass species
- Low reef – A block of broken limestone occurring across the inner shelf area. The vertical edges and undercuts were colonised by encrusting sponges, ascidians and corals and in October were heavily stocked with rock lobsters.
- Seagrass meadows – occurring extensively in the shallow and deeper sand areas
- Shallow limestone reef – forming the floor of most of the inshore platform and colonised by algae, seagrass and patches of kelp
- High reef – occurring along the outer edge of the inshore shelf and in large patches across the inshore shelf. This habitat consisted of dissected and undercut limestone with vertical walls, caves and large gullies. Upper surface and slopes were colonised by kelp with an understorey of encrusting and coralline red algae. The vertical walls, underhanging surfaces and caves were colonised by a diverse range of encrusting fauna such as sponges and ascidians. The habitat provided refuge for a range of reef fish and rock lobsters, which were not abundant in the outer line of high reef, but were abundant in the high reef patches further inshore.
- Deep sand seafloor – occurring where the limestone pavement was overlain by thick sheets of sand and was absent of algae, seagrass or any fauna. This habitat could be mobile.
- Deep limestone pavement – (15-25 m) forming much of the deep offshore seafloor and was colonised by patches of red algal species. Closer inshore, the limestone pavement was more exposed and colonised more densely by algae and seagrass.

5.3 The Abrolhos Islands

5.3.1 Shallow-water habitats

The Houtman Abrolhos Islands (Abrolhos) are a complex of 122 low-lying islands and reefs located approximately 60 km west of Geraldton on the edge of the continental shelf. There are three major island groups: North Island-Wallabi Group, Easter Group and Pelsaert (Southern) Group, separated by the Middle and Zeewijk Channels, respectively. The Abrolhos marine fauna is unique in that its reef communities are dominated by species of tropical origin, in addition to algae and seagrasses that are predominately of temperate origin. Commercial fishing activity around the islands is largely by the West Coast Rock Lobster Managed Fishery (Zone A), as well as by the Abrolhos Islands and Mid-West Trawl Fishery and some wetline fishing (Webster *et al*. 2002).

Extensive habitat mapping of the shallow-water regions of the Abrolhos has been undertaken since the 1980s. Habitat mapping by Hatcher *et al*. (1988) is the earliest and involved a 5-stage process: (1) preparing orthophotomosaics (aerial photos) of each reef group overlaid with depth contours, (2) designing a classification of ecological units, (3) identifying ecological units on the photomosaics and tracing them onto draft maps, (4) ground truthing ambiguous units by submarine inspection and (5) preparing final ecological base maps from the corrected draft maps (Figure 5.2). The resulting twelve geomorphological classes were:

- Exposed reef slope – compacted and grooved ancient reef limestone down to 40 m, supporting rich, high biomass communities of algae and seagrasses
- Submerged limestone platform – reefs overlayed thinly with sand and rubble, containing a low biomass of meso-algae, sponges and some corals and supporting a high abundance of rock lobsters
- Emergent limestone platform – reef crests that are exposed at low tide, containing dense turfs of fleshy and calcareous algae and encrusting invertebrates
- Dissected limestone platforms – channels cut into the reef platform by strong unidirectional water currents and usually dominated by mixed coral and macro-algal communities
- Back reefs – an area of transition to lagoons, occurring behind reef crests on reef perimeters. These reefs are dominated by meso- and macro-algal communities and isolated colonies of massive corals.
- Mobile sediment sheets – occurring in areas of high water movement and only supporting isolated patches of seagrasses
- Isolated patch reefs – surrounded by sand, ranging in size and generally consisting of a mixture of coral and macro-algae assemblages
- Static sediments – found mostly in deep lagoon basins containing rich infaunal communities
- Drowned doline field – limestone platforms interspersed with deep pot holes (dolines) and characterised by high coral cover
- Complex karst platform – shallow limestone platform with a veneer of sediments, rubble, coralline and meso-algae, including shallow dolines

- Storm rubble field – the top of sheltered reefs, terminating in a narrow reef flat leading to the foreshore and characterised by detached and broken corals with algal coating and sessile invertebrates
- Sheltered reef slope – emerging from exposed reefs, these reef slopes are protected from heavy wave action with corals and brown algae near the surface followed by branching coral and high-density coral communities near the base of the slopes.

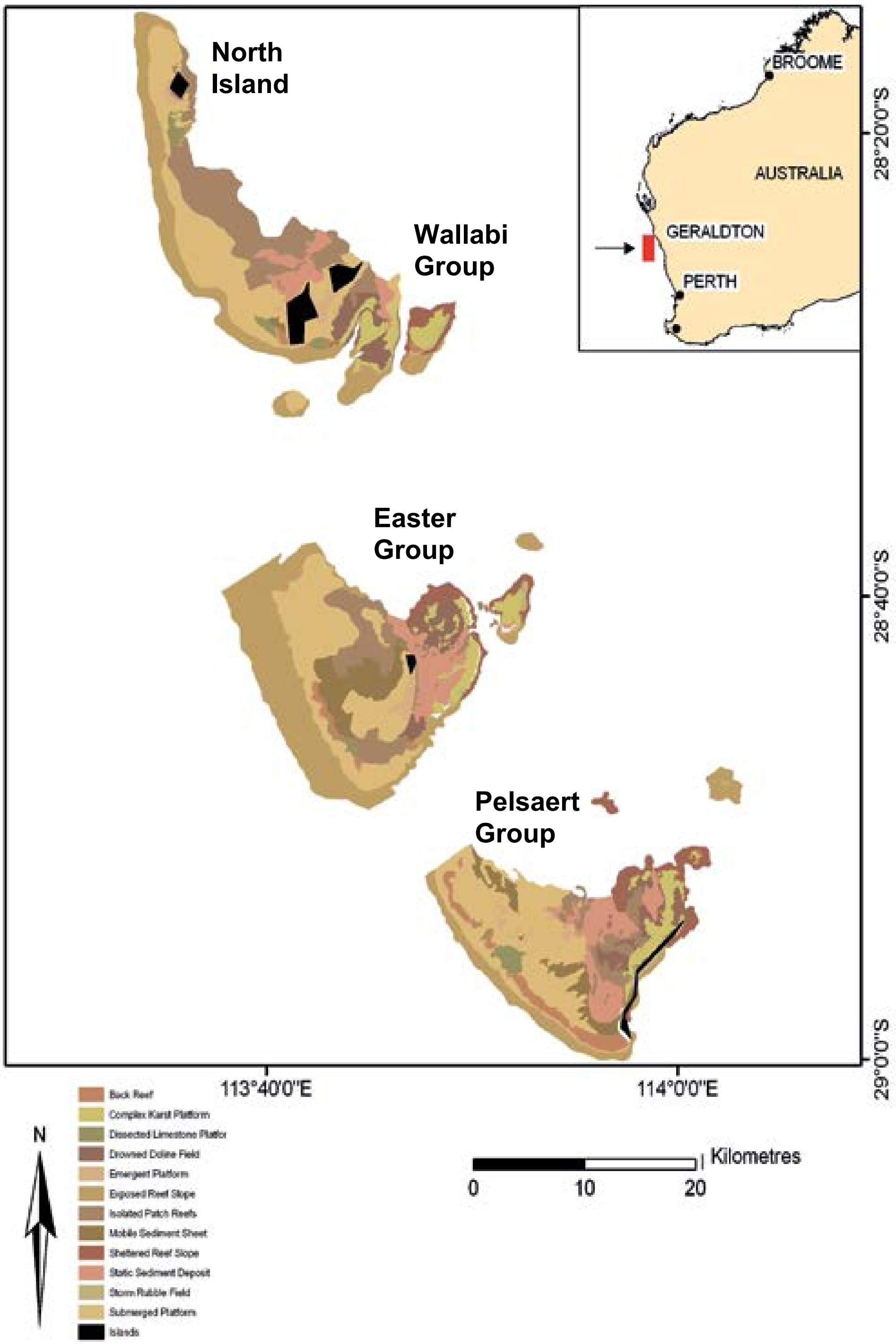

Figure 5.2. Geomorphologic units mapped at North Island-Wallabi Group, Easter Group and Pelsaert (Southern) Group (Source: Hatcher *et al*. 1988).

Habitat mapping of the Abrolhos was undertaken by Marine Science Associates (1995) on behalf of the Abrolhos Islands Consultative Council (AICC) as part of the development of an Abrolhos Island Planning Strategy. Satellite imagery (LANDSAT images collected in 1989) was used to classify habitats for depth, slope and cover type (i.e. plant, coral, sand, pavement), followed by ground truthing of selected areas. To produce a manageable distribution of habitat classes, original data was reduced to a 50 m pixel size and smoothed. This resulted in eight habitat classifications:

- Dry land, drying flat and very shallow (< 0.5 m) sand
- Sand (1-3 m), bare or up to 30 % broken rocks, corals or small patches of algae
- Habitat greater than 3 m
- Plant cover (1-3 m), including shallow pavement and reef tops with turf algae or kelps, seagrass beds and macro-algae beds
- Plant cover greater than 3 m
- Shallow coral communities (1-3 m)
- Coral or mixed coral and plant habitat greater than 3 m
- Water, no discernible bottom signal, usually > 10 m.

In 1994, the Department of Fisheries also collected benthic habitat information in areas of the Abrolhos that were impacted by the scallop trawling and rock lobster potting activities (Dibden and Joll 1998). The habitat survey involved a total of 31 towed video transects. The camera was towed approximately 50 cm from the bottom and provided video images that were coded for the different bottom types, as well as their position. Habitat types included:

- Flat sand – substrate consisting of sand, silt or occasionally harder bottom with patches of sparse sponge, coral, seagrass or algal growth.
- Garden – hard substrate with a thin sand layer and usually covered by sponges, soft and hard corals, seagrasses and algae and abundant in fish and invertebrate fauna.
- Algae/marine plants – substrate of sand or hard bottom and covered in marine plants.
- Reef – hard substrate of branching and hard coral communities and or algae.

Habitats that would be most suitable in providing shelter and food sources for rock lobsters were reef habitats, although rock lobsters also utilise sandy habitats during their migration phase and while foraging between reef patches.

Webster *et al*. (2002) conducted additional ground truthing of the geomorphological units identified by Hatcher *et al*. (1988) to identify a range of human use activities (e.g. fishing gear, anchor damage, divers) and natural factors, such as storm damage, that could potentially physically impact the marine habitats at the Abrolhos (Figure 5.3). A number of west-east transects covering most of the geomorphological units in each island group were surveyed using video equipment. Lobster fishing effort data was collected through interviews, aerial surveys and commercial logbook information to determine which habitats were impacted by lobster potting. The sensitivity of the different geomorphological units to physical damage and fishing effort levels are given in Table 5.1.

The study found both spatial and temporal differences in the fishing intensity across all habitat types. Pot deployment comprised between 45 % and 65 % of the fishing effort on submerged platforms and exposed reefs at depths < 20 m in each island group. In the Wallabi/North Island and Easter Group, isolated patch reefs were also important fishing grounds. Approximately 9.2 % of the high sensitivity habitat had the potential to be impacted by pot deployment.

Figure 5.3. Examples of the geomorphological classes identified by Webster *et al*. (2002) for shallow-water (0-20 m) habitats of the Houtman Abrolhos Islands.

Table 5.1. Geomorphological classes and their corresponding sensitivity index and percentage of fishing effort (pot lifts) (averaged over five seasons 1995/96 – 1999/00) in shallow-water habitats (0-20 m) of the Houtman Abrolhos Islands.

Geomorphological Classes	Sensitivity	Total Fishing Effort
Exposed reef slope	Moderate	16.7
Submerged limestone platform	Moderate	39.2
Emergent limestone platform	Low	2.0
Dissected limestone platform	High	3.3
Back reef	Moderate	2.7
Mobile sediment sheet	Low	4.2
Isolated patch reefs	High	16.9
Static sediment deposit	Low	2.8
Drowned doline fields	High	3.0
Complex karst platform	High	3.6
Storm rubble field	Low	0.7
Sheltered reef slope	High	4.8

In response to tourist development in the Abrolhos, benthic habitat mapping of the area around Long Island (part of the Wallabi Group) was undertaken in 2005 (Oceanica 2006). The distribution of habitats was determined at a coarse scale using bathymetry information, digital charts and aerial images. The digital images were then ground truthed by snorkel surveys, which recorded habitat type and biota. Fine scale habitat data and boundaries were collected using a chart plotter and underwater viewer. Sand habitat surrounding Long Island comprised of deep, sheltered sand areas and shallow, more exposed areas of sand and coral rubble. Reef structures ranged from dead coral platforms to intertidal reef and sloping reefs covered in coral colonies (Figure 5.4).

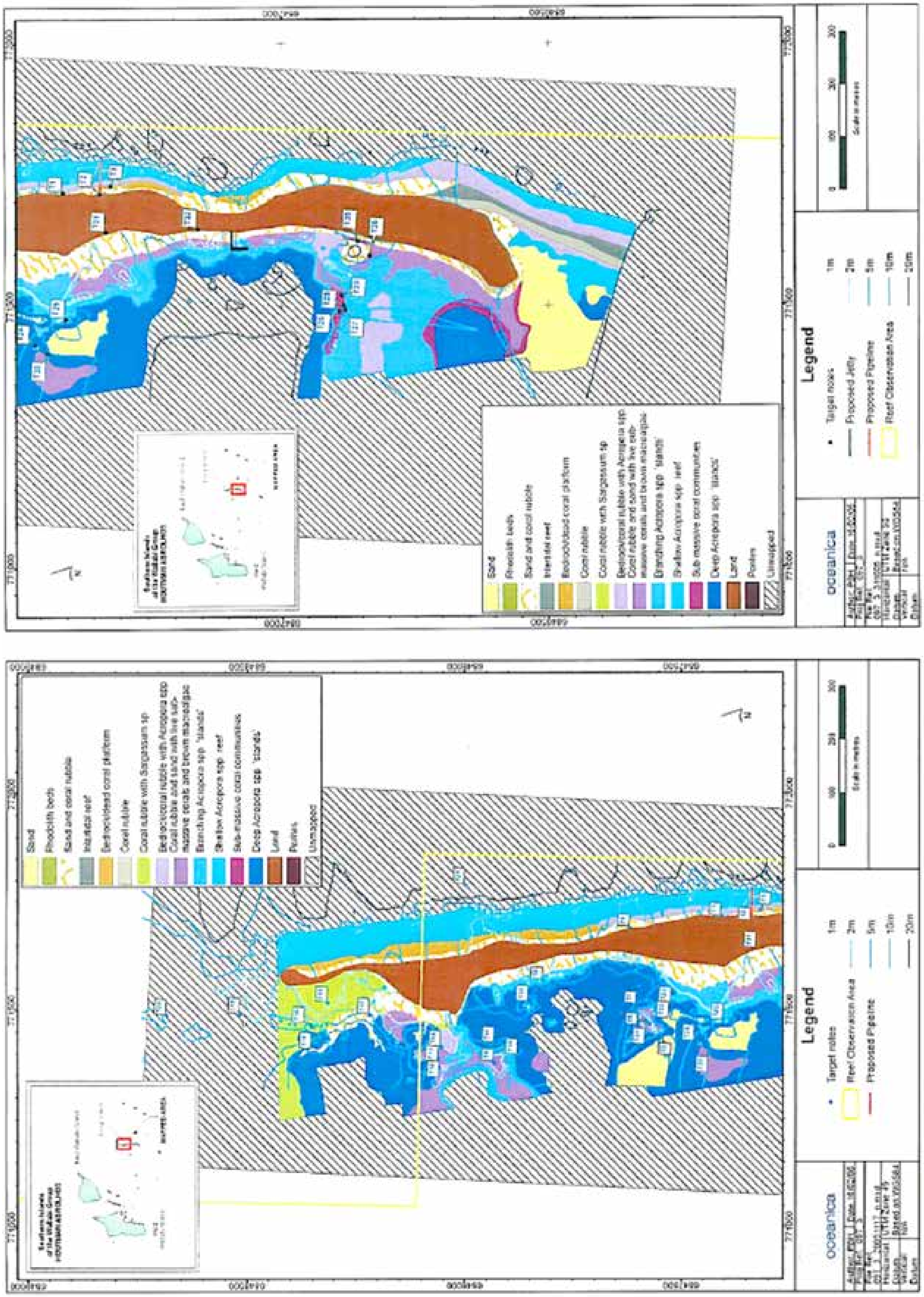

Figure 5.4. Distribution of benthic habitats surrounding the northern (left) and southern (right) portion of Long Island (Source: Oceanica 2006)

5.3.2 Deep-water habitats

The WA Marine Futures project collected baseline habitat information in a number of areas around the state for natural resource management and planning initiatives (Radford *et al*. 2008). The habitat information provides an understanding of the potential for an area to contain certain marine features, as well as estimates of abundance and spatial distribution of the range. The seafloor of nine deep-water (> 10 m) study areas were surveyed with hydroacoustics using a Reson 8101 Multibeam to produce full coverage maps of bathymetry and textural information. Observations of the seafloor were also made using towed video to determine substrate composition, habitat type and associated biota. Where no field observations were available, predictive modelling was used. Additional information on fish biodiversity, fine-scale benthic biota and spatial distribution of key organisms was obtained from Baited Remote Underwater Videos (BRUVs).

As part of this project, habitat maps of two areas of the Abrolhos were produced detailing the physical substrate and the biota. (Figure 5.5). The deep-water habitat at the Pelsaert (Southern) Group was predominantly composed of sand and patchy reefs, while the Easter Group site was mainly reef substrate. Both regions displayed vegetation inter-dispersed with sessile invertebrates.

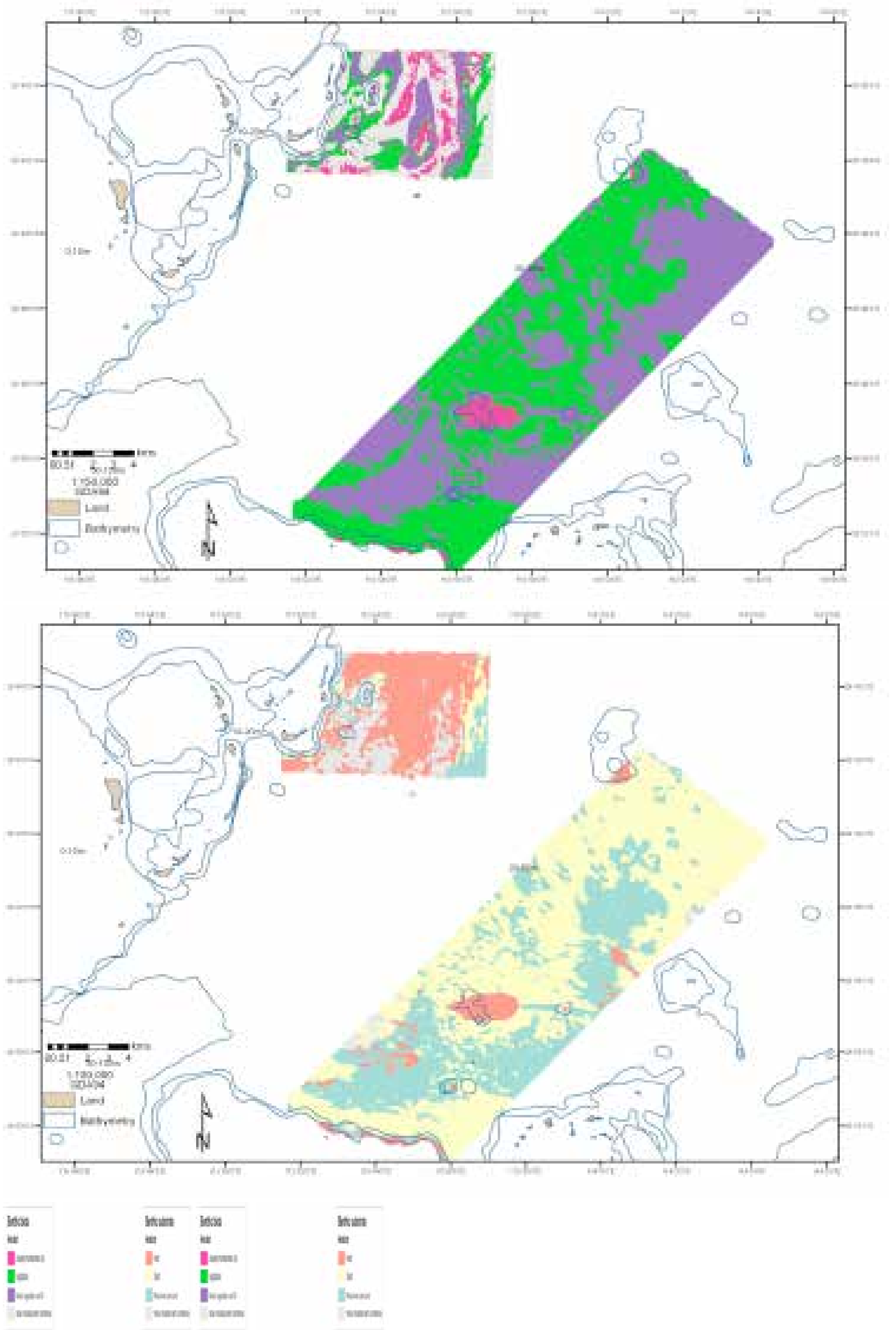

Figure 5.5. Deep-water regions of the Houtman Abrolhos Islands showing the benthic substrate (top) and biota (bottom) habitats modelled (Source: Radford *et al*. 2008).

5.4 Central Coast (Dongara to Guilderton)

5.4.1 Shallow-water habitats

The central coast is comprised of a narrow ribbon of limestone and sand substrates with an extensive chain of offshore reefs. The nearshore environment between offshore reefs and the coast includes a wide range of submarine landforms and marine habitats such as reef, sand and seagrass communities (Figure 5.6). The nearshore zone is comprised of a series of marine basins or lagoon features, separated by ridges of reef and sand banks that are generally < 10 m depth. They support a wide range of seagrass and algal communities that are important for shoreline stability, as well as for commercial and recreational fishing (Department of Planning and Urban Development 1994).

Seagrass species (e.g. *Posidonia* spp. and *Amphibolis* spp.) can be found in patches on sandy seafloor, among mixed communities on rocky pavement and with algal assemblages on reefs. The dominant algal species on reefs in < 10 m depth is *Ecklonia* spp., while in deeper waters it is usually *Sargassum* spp. The distribution of macrophytes, interpreted from satellite imagery, indicated that the most extensive areas of marine vegetation occurred in the most sheltered areas, from Sandy Point to White Point and south of Ledge Point. Between Ledge Point and Wedge Island the nearshore zone is narrow, restricting the extent of the faunal communities.

5.4.2 Jurien Bay

The central coast also includes Jurien Bay Marine Park (established in 2003), which extends from Green Head to Wedge (Figure 5.7). Five major habitat types dominate the Jurien Bay region (Hill 2005):

- Seagrass meadows – important habitat in the more sheltered areas in the lagoonal environments of the park and cover 25 % of the park
- Bare or sparsely vegetated mobile sand
- Shoreline and offshore intertidal reef platforms – range from highly protected to fully exposed. Significant areas of intertidal reef platforms are located between Green Head and North Head and between Cervantes and Wedge.
- Subtidal limestone reefs – (< 20 m) are dominated by large algal species while deeper offshore reef platforms are dominated by red algae. Although small coral communities are relatively common in the Jurien Bay region, there are no coral reefs.
- Reef pavement

The marine park is located in Zone C of the rock lobster fishery. A significant proportion of the fishing fleet operate within the marine park waters, excluding the sanctuary and special purpose (puerulus) zone. The most protected zones within the park include sanctuary zones and scientific reference areas where commercial lobster fishing and shore-based line fishing are allowed but other extractive activities are prohibited.

Baseline surveys of subtidal rock reefs at Jurien Bay were conducted in 1999 and 2000 at 7 to 9 sites within each of the management zone types (general use, sanctuary, and scientific reference) using underwater visual census techniques (Barrett *et al*. 2002). At each site, the abundance and size structure of large fishes; the abundance of cryptic fishes and benthic invertebrates; and percentage cover of macro-algae, corals and other invertebrates were assessed separately along four 50 m transects. Algal, coral and sessile invertebrate coverage was determined from quadrat sampling at 10 m intervals. Subsequent monitoring surveys were undertaken in 2003, 2004, 2006 and 2007 (Edgar *et al*. 2009).

Survey results indicated that the fish assemblage was similar across the three zones for all sampling periods. The most common large mobile invertebrates encountered were molluscs, echinoderms, hermit crabs and rock lobsters. With the exception of rock lobsters (mostly juveniles), which were highly variable between years, all other groups showed stable patterns of abundance across the sites. Rock lobster density was expected to increase in sanctuary zones, but the increase in biomass was not statistically significant. Interestingly, the mean size (CL) of rock lobsters in fished zones was greater than for lobsters in sanctuary zones. The coral cover was five times greater in sanctuary zones than in scientific reference and general use zones. Algal coverage also differed significantly between zones, with the highest cover of foliose red algae and lowest cover of *Sargassum* spp. observed in the sanctuary zones.

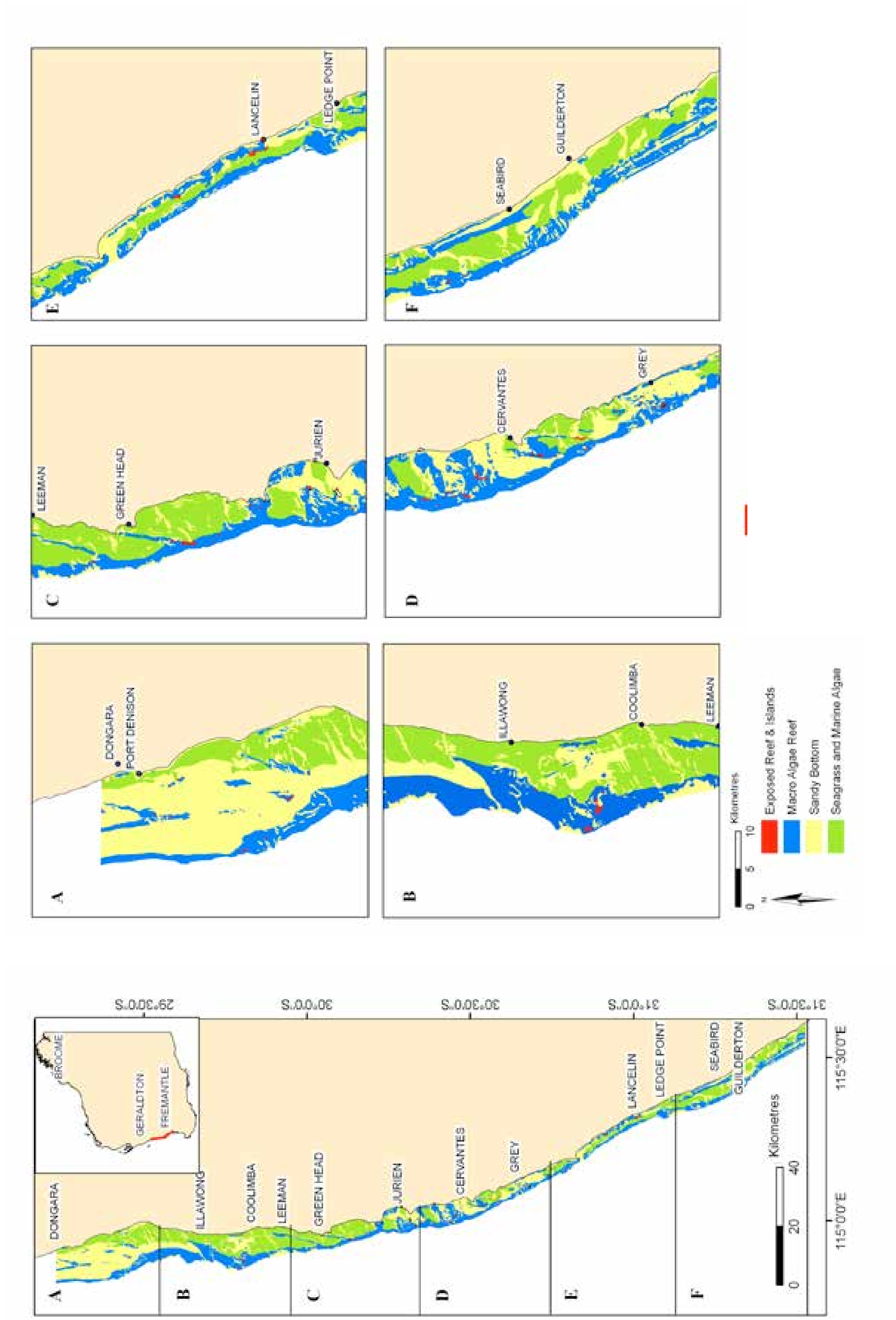

Figure 5.6. Major benthic habitats of the central coast (Source: Department of Planning and Urban Development 1994).

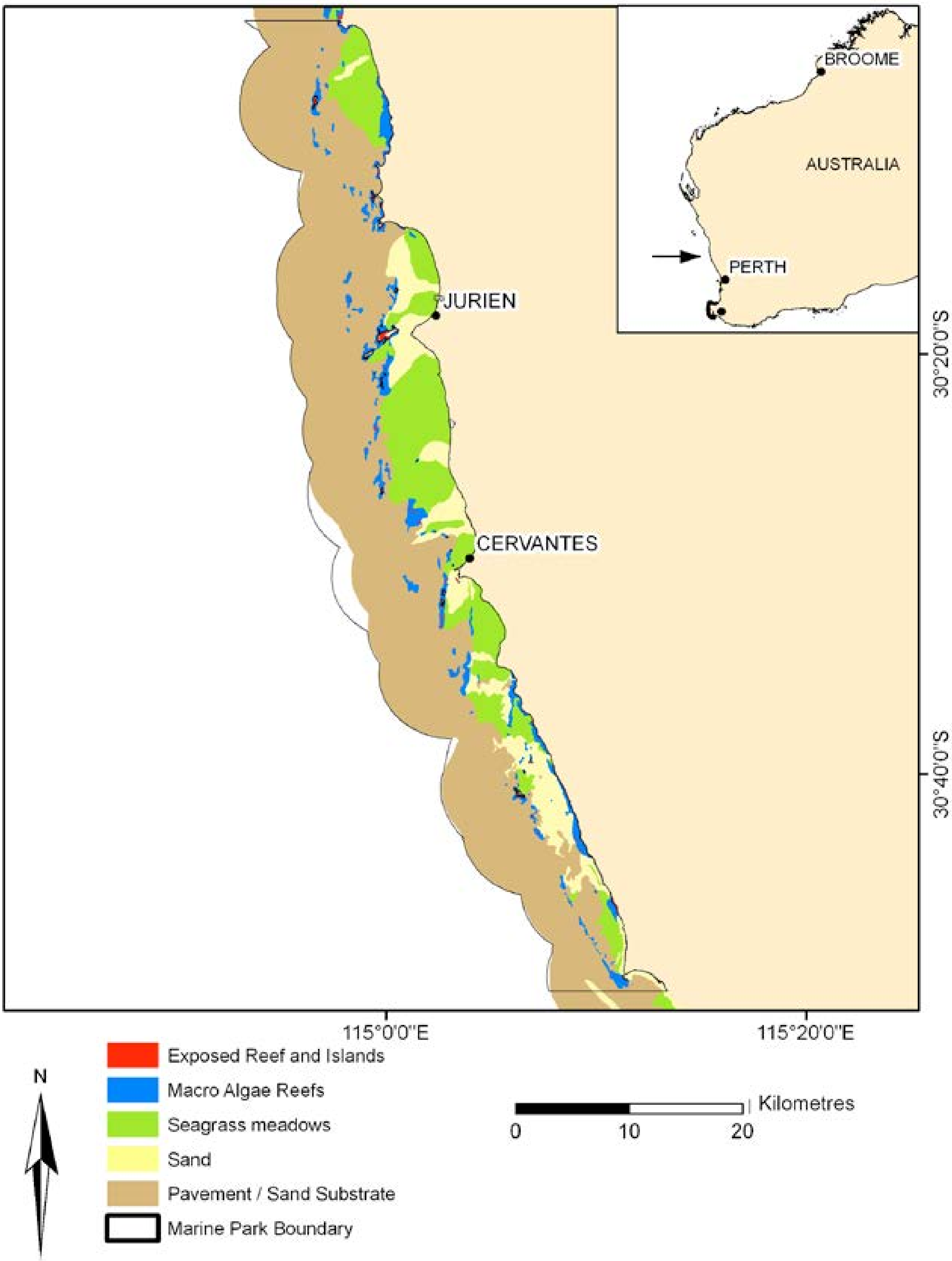

Figure 5.7. Major benthic habitats within Jurien Bay Marine Park (Source: Hill 2005).

5.4.3 Deep-water habitats

The biota of deep-water habitats at Dongara, Lancelin and Jurien were assessed to evaluate the effects of western rock lobster fishing on the deep-water ecosystems along the coast of Western Australia (Bellchambers 2010; Bellchambers *et al*. 2010). Habitat type and biota, in depths from 35 to 75 m, were classified using towed video. Dongara was identified as a sponge-dominated ecosystem, while Lancelin was macro-algae dominated and Jurien Bay was a mixture of sponge and algae. The macro-algae assemblage was dominated by *Ecklonia radiata*, which is likely to be the main source of primary production in the deep-coastal ecosystems. The macro-invertebrate community across the three locations consisted of 20 families and 27 species of sessile invertebrates (excluding sponges). Crabs, polychaetes, and amphipods were also commonly encountered. The invertebrate community composition did not differ between sites within locations but did differ between locations. Results showed higher abundances of decapods (excluding crabs) and hammer oysters at Dongara relative to Lancelin. Higher abundance of crabs and gastropods and lower abundance of amphipods at Jurien Bay, relative to Lancelin, drove the invertebrate faunal differences between these locations. In terms of habitat differences between locations, Dongara is distinctively different from Lancelin and Jurien Bay due to greater coverage of sand, lower cover of mixed assemblage with sponge and no high coverage of *Ecklonia* spp. Jurien Bay had a higher coverage of undifferentiated mixed assemblage, while Lancelin had lower coverage of brown algae than the other two sites.

Two study sites in the Jurien region were also mapped as part of Marine Futures (Radford *et al.* 2008) (Figure 5.8).

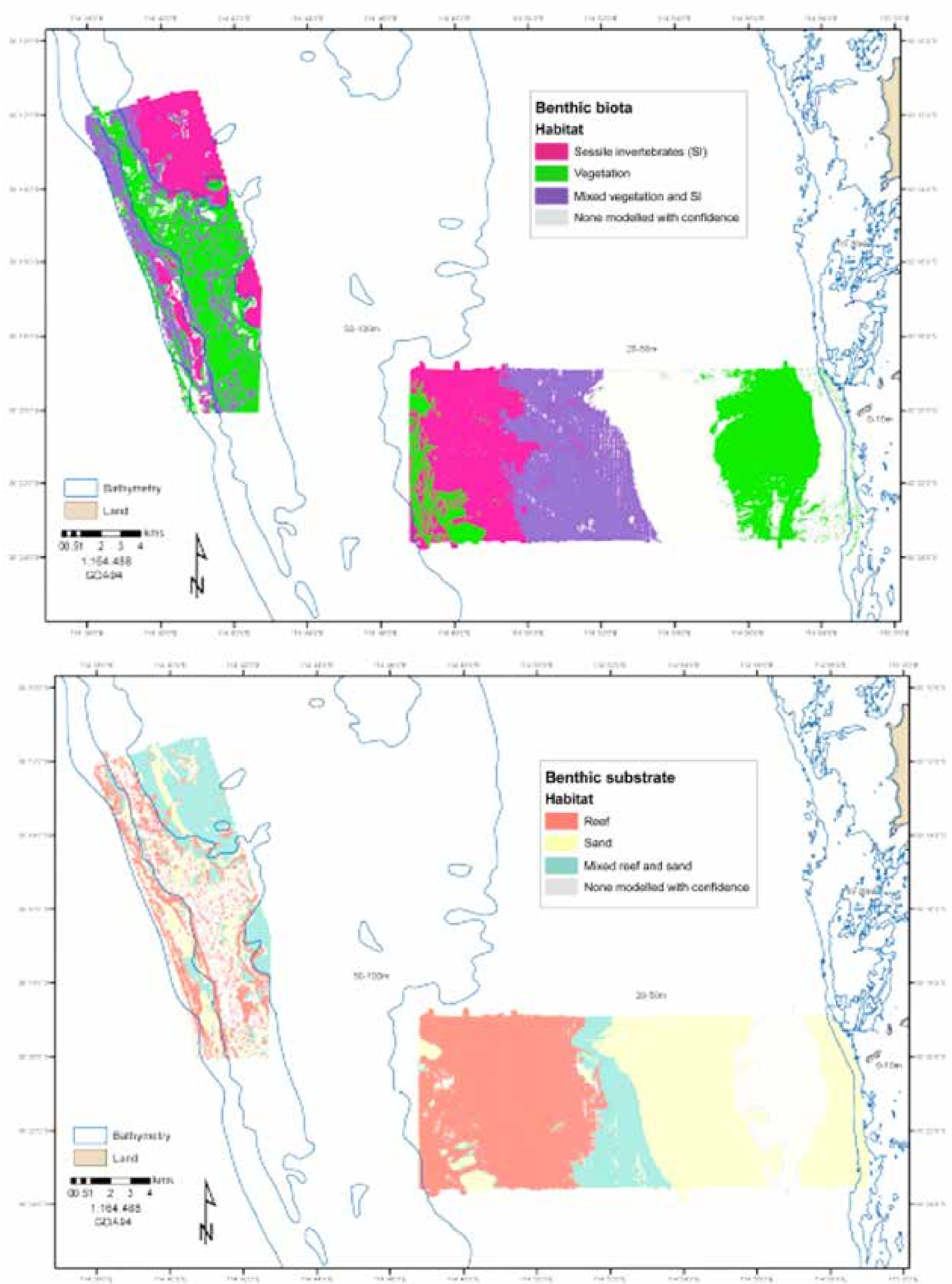

Figure 5.8. Deep-water regions adjacent to Jurien Bay showing the benthic biota (top) and substrate (bottom) habitats modelled (Source: Radford *et al*. 2008).

5.5 Northern Metropolitan Region

5.5.1 Marmion Marine Park

The northern coastal region within the Perth metropolitan zone includes the Marmion Marine Park, which extends from Burn Rocks to Trigg Island. In 1985, the Department of Conservation and Environment conducted a study of Marmion Marine Park in order to characterise and describe the marine environments and communities within the park (Simpson and Ottaway 1987). The study included 63 transects selected from aerial photographs and bathymetric charts. A combination of quadrat sampling at 10 m intervals along a 150 m transect and collections of species along 6 m transects were used to collect data on the total number of species present at each site. The substrate type and water depth was also recorded for each quadrat according to the following classifications:

- High reef – hard substrate (< 2 m)
- Reef – hard irregular (fragmented) substrate (> 2 m)
- Pavement – hard, regular (smooth) predominantly limestone substrate (> 2 m)
- Bare sand – loose, bare sand
- Sandy – consolidated sands

In general, one-third of the areas sampled were bare sand, while the rest consisted of a diverse assemblage of seagrasses, macro-algae and sessile invertebrates. Six broad geomorphological habitat units were identified in total, as shown in Figure 5.9.

The 1992-2002 Management Plan for Marmion Marine Park also included habitat classification from field surveys within the park (Pobar *et al*. 1992). These were described as:

- Lagoon subtidal sandy sea floor - areas of bare sand stabilised by interspersed seagrass meadows
- Lagoon subtidal limestone pavement - occurs in the less sheltered areas of the lagoons with limestone pavement and consolidated sand substrata
- Lagoon intertidal reefs - isolated reef patches occur in the lagoons
- Nearshore reefs and intertidal onshore rock platforms
- Offshore shallow limestone reefs - characterised by marked algal zonation related to depth

Ryan (2008) investigated the effects of wave exposure on temperate reef communities within Marmion Marine Park. Three sanctuary zones within the park were compared, each situated on a separate reef system within the park and receiving different levels of wave exposure. Macro-algae was sampled from each site by divers, who also recorded differences in abundance and size of lobsters in fished and sanctuary zones within the marine park. The study indicated that wave action had an important influence on macro-algae assemblage structure in the Marmion Marine Park. Reef assemblages within the sanctuary zones appeared to be more palatable to grazing by fish and invertebrates than assemblages from the fished zones, which appeared to be more resistant to grazing. The results also showed significantly higher total abundance of lobsters and mean abundance of legal size lobsters in sanctuary zones compared to fished sites. It was suggested that some lobsters may transverse the boundaries of the sanctuaries and enter the fishery, while others show high site fidelity and stay within home ranges for extended periods of time.

5.5.2 Ocean Reef – Mullaloo

An initial assessment of Ocean Reef Marina was undertaken in 1975 to assess its impact on the marine environment, as well as on the rock lobster and abalone fisheries that operated in the vicinity (Meagher and LeProvost 1975). Using dive surveys the inshore zone (within a 3 km radius of the proposed marina) was classified into four zones:

- Broken reef surface - usually covered by algae
- Reef with undercuts and caves - surfaces covered by more diverse range of algae and animals
- Bare sand flats
- Seagrass and algae meadows - occur either on sand or crumbly shallow reef

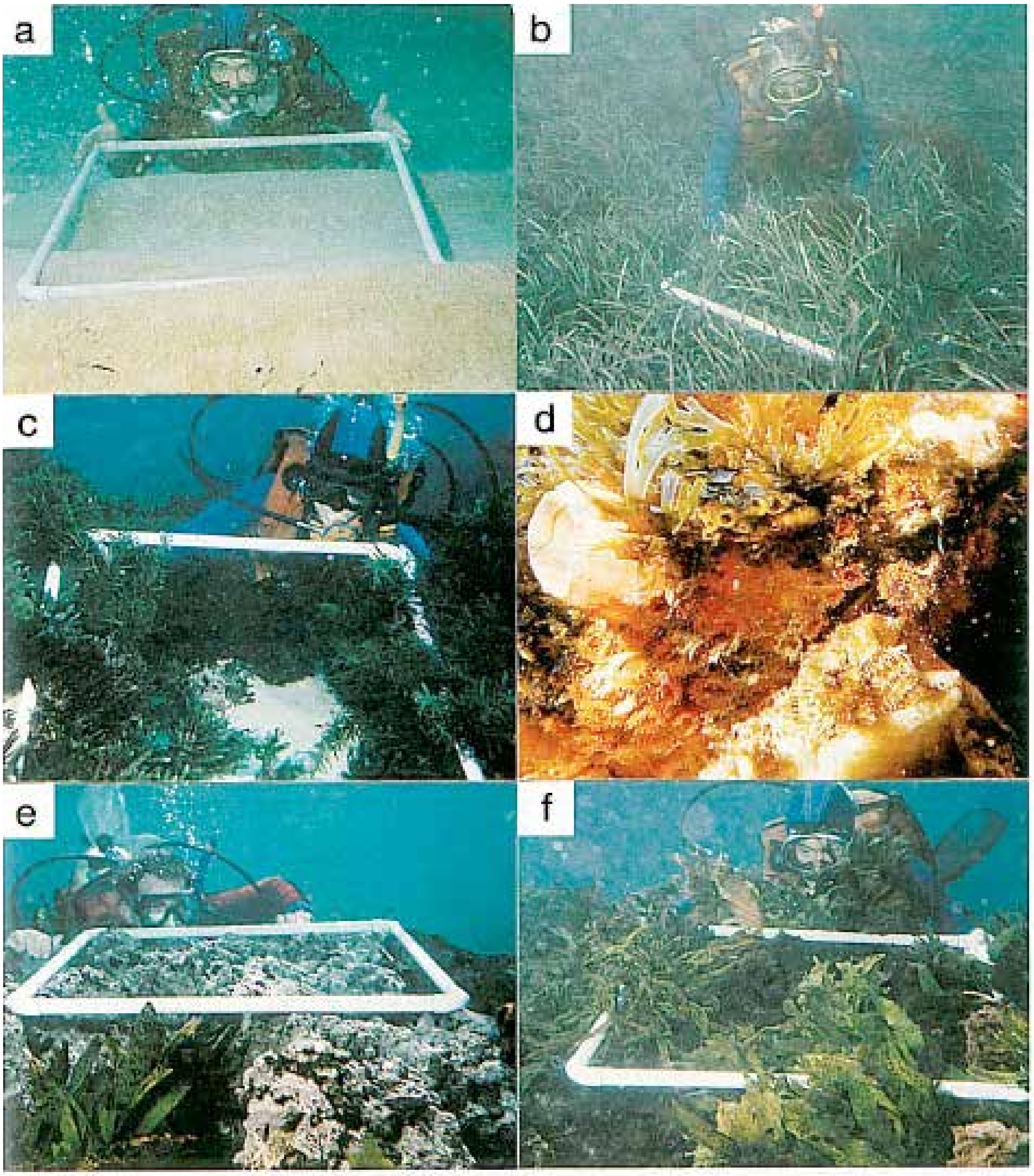

Figure 5.9. Marine habitats identified within Marmion Marine Park: (a) Loose sand ripples, typically devoid of attached fauna; (b) Seagrass meadow; (c) Limestone pavement with attached plants and small patches of sand; (d) Vertical high reef face colonised by seaquirts, anemones and algae; (e) Reef platform with patchy kelp and encrusting red algae; (f) high reef with a canopy of kelp (Source: Simpson and Ottaway 1987).

Rock lobsters were sampled over four days in February, March and April 1975, at two test sites within the assessment zone. Thirty-five baited lobster pots with modified escape gaps were deployed (20 m apart) close to the reefs. The results showed that the habitat at Ocean Reef is not a significant nursery area for juvenile lobsters, which may reflect upon seasonal differences in recruitment, although lobsters > 56 mm were encountered in larger numbers (Meagher and LeProvost 1975).

5.5.3 Sorrento (Hillarys) Boat Harbour

The initial planning phase of the Sorrento Boat Harbour in the mid-1980s included an assessment of the marine environment that was likely to be impacted by construction and increased human activity (Scott *et al*. 1984). The review found the subtidal habitats within 2 km of the boat harbour to include sandy seafloor and limestone pavement/low reef, high reefs and limestone pavement grades from a flat surface covered by a veneer of sand to low reef with pockets of sand in depressions. The main intertidal habitats were comprised of intertidal platforms and sandy beaches. The biotic assemblages identified among these habitats were:

- Intertidal rocky shore assemblage composed of algae, molluscs, crabs, echinoderms and boring infauna on limestone platforms on top of intertidal reefs and patches along the shoreline. A gradient in species composition with vertical height was observed.
- Sandy beach assemblage with infauna in sand, such as isopods, polychaete worms and bivalves, and some fish in the shallow-water along the shoreline.
- Seagrass meadow assemblage occurring on sandy bottom in shallow-water and providing refuge and food for a range of species.
- Sandy seafloor assemblage of subtidal sands found in depressions and basins with no permanent attachment of fauna and some burrowing infauna.
- Kelp assemblage composed of *Ecklonia* and providing habitat for a range of fish and invertebrate species.
- Foliose red algal assemblage occurring on limestone pavements in deeper waters.
- Coralline red algal assemblage limited to soft, crumbling limestone reefs in deeper waters. Some brown algae were also found in this assemblage along with ascidians, sponges and burrowing and boring infauna. Fish and mobile invertebrates were also abundant.
- Sponge-ascidian assemblage found mainly in caves, overhanging platforms and crevices of reefs.
- Nektonic/Planktonic assemblage occurring in the water column.

The Sorrento area also supports high densities of juvenile rock lobsters, due to the extensive availability of preferred habitats, such as reefs and limestone pavement.

5.6 Rottnest Island

5.6.1 Shallow-water habitats

Rottnest Island is situated just outside the 50 m water depth contour of the continental shelf and the seafloor rapidly descends to approximately 4000 m, 30 km west of the island. A reef, which reduces the depth of the water to 10 m, extends between the eastern tip of Rottnest Island and Garden Island. Rottnest Island is managed by the Rottnest Island Authority and classified as an A-Class Reserve, which extends approximately 800 m from the shoreline and is divided into general use, recreational and sanctuary zones (Rottnest Island Authority 2003). The benthic habitats around Rottnest Island have been classified into eight types:

- Sand (20 %) – bare sand, sometimes containing patches of seagrass
- Seagrass (7 %) – dominated by *Amphibolis* spp. and *Posidonia* spp.
- Seagrass (1) (3 %) – occurring in deeper, higher-energy areas and containing *P. ostenfeldii, P. coriacea* and *A. graffithii*
- Seagrass (2) (1 %) – dominated by *P. australis*
- Mixed seagrass and reef (10 %) – (< 10 m depth) consisting of a complex mixture of sandy substrate, seagrass beds growing on rock or sand, and reef outcrops supporting seagrasses, kelp, and short algal turfs
- Reef (45 %) – supporting algal communities dominated by large kelp species such as *Ecklonia* and *Sargassum* and also algal turfs of fine red, brown and green algae
- Intertidal platform (4 %) – regularly exposed at low tides and dominated by algal turfs and *Sargassum*
- Reef wash (9 %) – rocky outcrops close to the surface or on intertidal platforms

The marine fauna around Rottnest Island is a mixture of tropical and temperate species, including some coral communities. Commercial rock lobster fishing occurs within the Reserve but on the outside of the marine park sanctuary zones.

Harvey (2009) developed a hierarchical habitat classification scheme for Rottnest Island. The island was mapped using hyperspectral remote sensing techniques, where the data was corrected for atmospheric effects, sunlight and the influence of the water column. This map provided an improved ecological description of the inshore habitats (< 15 m) at Rottnest. The study revealed that 33.8 % of the benthic habitat was sand substrate and the rest bio-substrate (Figure 5.10). Of the bio-substrate, 40 % was dominated by seagrass, 59 % by macro-algae and the remaining 1 % dominated by coral. Of the macro-algae assemblages, 13.7 % was identified as canopy algae and 86.3 % as algal turf. *Ecklonia* (33 %) and *Sargassum* were the predominant canopy algae, while the main seagrass species were either *Posidonia* or *Amphibolis*.

5.6.2 Deep-water habitats

Habitat mapping by Marine Futures showed high rugosity reefs surrounding the island. The deep-water regions in the eastern portion of the island consisted of deep reefs, while extensive sand beds were found to the west of Rottnest Island (Radford *et al.* 2008) (Figure 5.11).

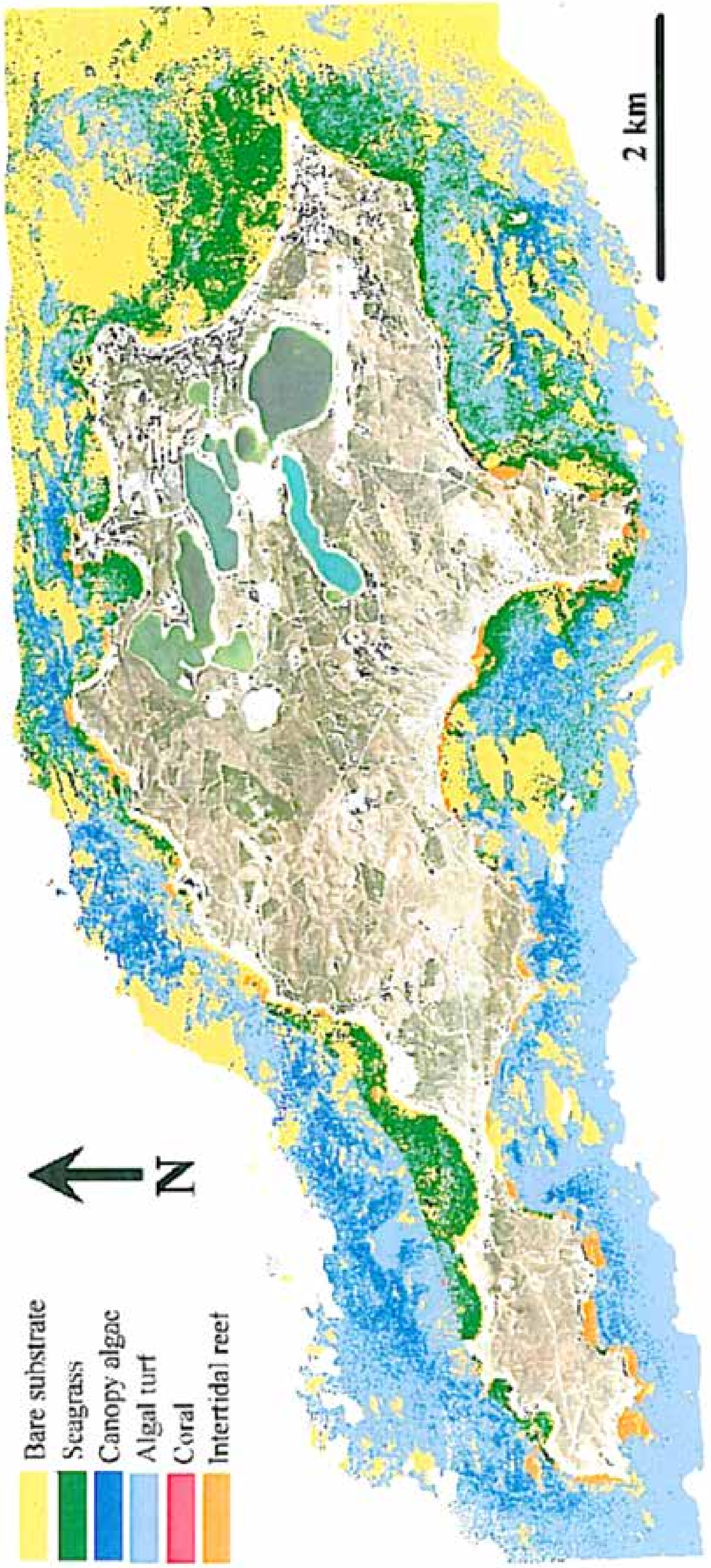

Figure 5.10. Benthic habitat map of Rottnest Island using HyMap flight lines and limited to regions < 15 m water depth (Source: Harvey 2009).

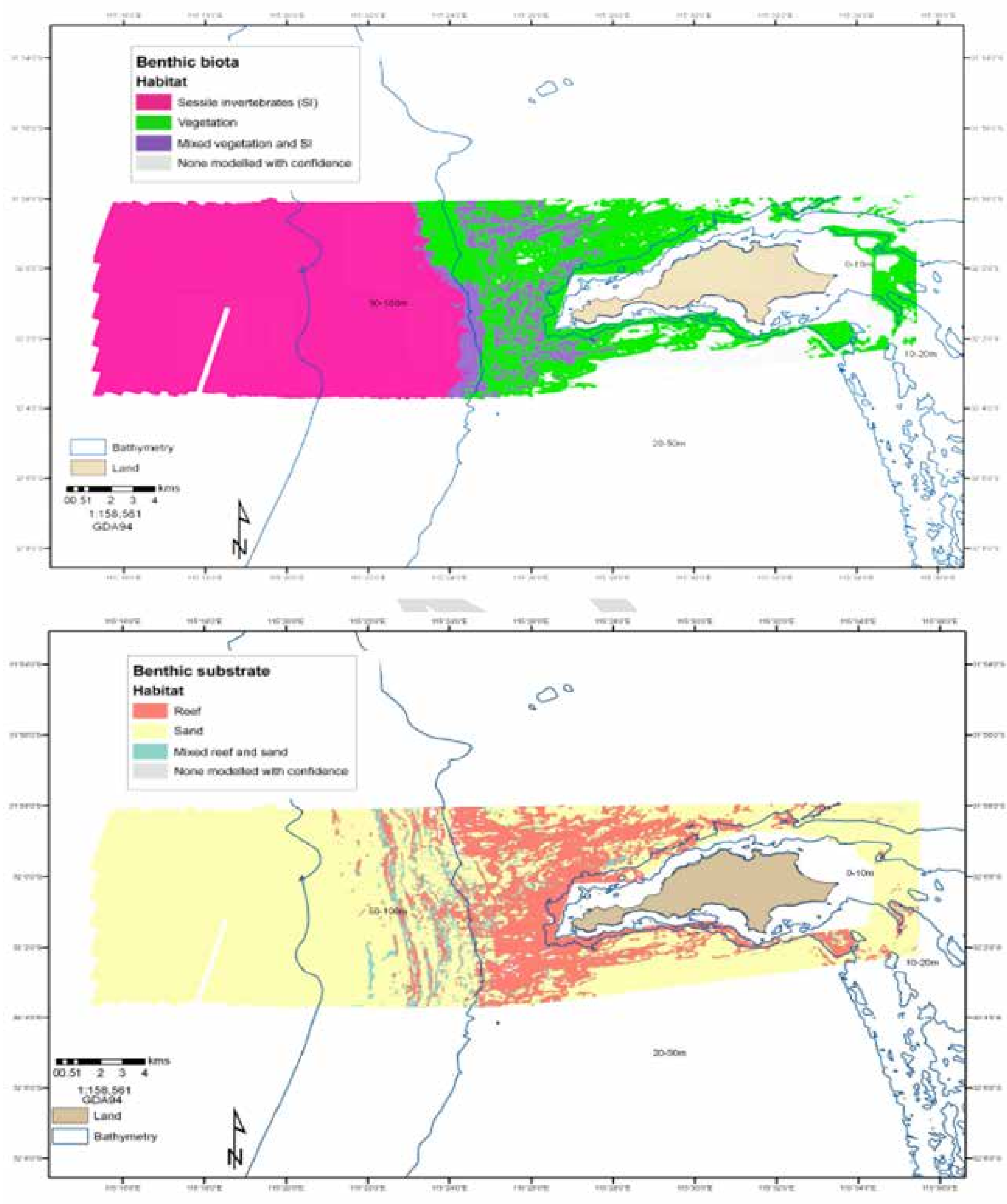

Figure 5.11. Deep-water regions surrounding Rottnest Island showing the benthic biota (top) and substrate (bottom) habitats modelled (Source: Radford *et al*. 2008).

5.7 Southern metropolitan region

5.7.1 Yanchep to Mandurah

In 1993 the major benthic habitats of the southern metropolitan coastal waters (Yanchep to Mandurah) were mapped using a Geoscan airborn multi-spectral scanner (Department of Environmental Protection 1996). The study area was classified into seven benthic habitat types (Figure 5.12):

- Silt (< 10 m) – 10 % of the total area mapped and 60 % of the area in Cockburn Sound.
- Fine sand silt (> 12 m) – represented only 1 % of the total area mapped and 10 % of the area of Owen anchorage where it mainly occurs
- Bare sand with some areas of sparse seagrass (< 10 m) – inshore of the Garden Island Ridge and occurring in approximately 35 % of the total area mapped. Bare sand represented > 60 % of the seafloor, whereas in Cockburn Sound and the Shoalwater Islands Marine Park, it was just over 30 % of the benthic habitat.
- Coarse sand (> 15 m) – dominant benthic habitat and approximately 40 % of the total area mapped
- Seagrass meadows (approximately 12 m) – 5 % of the total area mapped, 20 % of the benthic area in Owen anchorage, 15% in the Shoalwater Islands Marine Park and 5 % in Cockburn Sound
- Subtidal reef – generally occurring offshore as part of the reef chains that make up the Garden Island Ridge and Five Fathom Bank Ridge. Represented approximately 15 % of the benthic habitat in the total area mapped, < 20 % of the area in the Shoalwater Islands Marine Park compared with 10 % for Owen Anchorage and < 1 % for Cockburn Sound.
- Intertidal reef platforms – found onshore but more offshore as fringing island reefs along the Garden Island Ridge. Represented < 1 % of the benthic habitat in the total area mapped, however, they contained a relatively high diversity of biota.

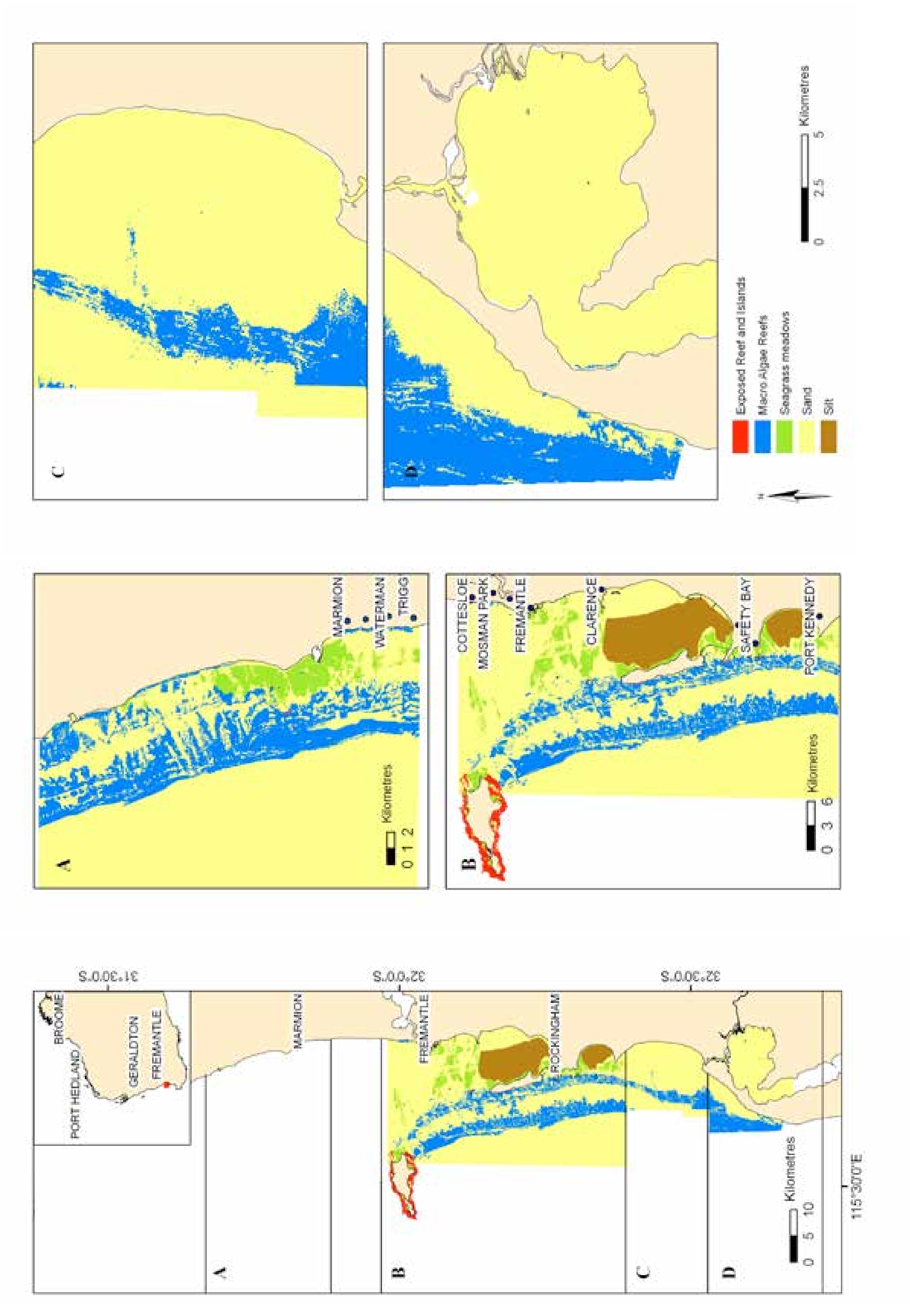

Figure 5.12. Major benthic habitats within the southern metropolitan waters off Perth (Source: Department of Environmental Protection 1996).

5.7.2 Shoalwater Islands Marine Park

The Shoalwater Islands Marine Park extends from Perth to Black Point (Figure 5.13). Subtidal reef and limestone pavements attract a wide range of marine invertebrates, while underwater limestone features, such as caves and pinnacles, harbour a variety of invertebrate assemblages including sponges, gorgonians and other species. Subtidal reefs within and west of the marine park provide settlement sites and nursery grounds for larvae and juvenile western rock lobster. Western rock lobster fishing grounds extend from the nearshore reefs to the shelf break. Within the Shoalwater Islands Marine Park area, lobster fishing is permitted in the general use zone of the park and sometimes inside the special purpose (scientific reference) zone (Department of Environment and Conservation 2006a).

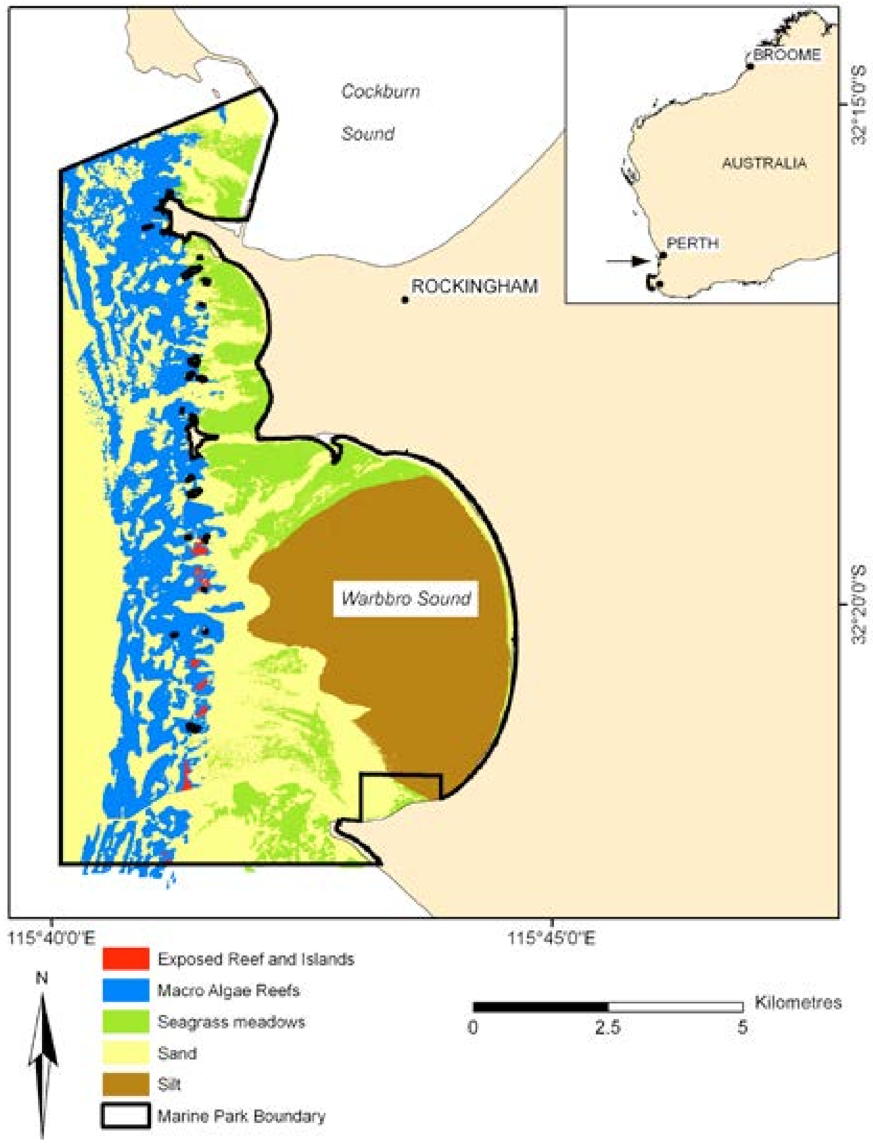

Figure 5.13. Major benthic and shoreline habitats within the Shoalwater Islands Marine Park (Source: Department of Environment and Conservation 2006a).

5.8 Geographe Bay to Cape Leeuwin

5.8.1 Shallow-water habitats

The coastal region from Geographe Bay to Hardy Inlet is a proposed marine park area (Department of Environment and Conservation 2006b) (Figure 5.14). The Geographe Bay seagrass meadows are the most extensive temperate seagrass communities on the west coast of Australia; however, Geographe Bay is dominated by monospecific stands of the narrow-leaf tape-weed *Posidonia sinuosa* that covers approximately 70 % of the Bay. Shoreline reef platforms and offshore intertidal reef communities occur throughout the proposed marine park, comprising approximately 0.5 % of the major marine habitats in the area. Macro-algae are the main primary producers found on the reef systems. Shallow-water reef systems found in < 10 m depth consist of subtidal limestone and granite habitats dominated by macro-algal communities. Patches of shallow limestone reefs occur within the seagrass communities. Deep reef communities (> 10 m depth) include both limestone and granite habitats. Unusual communities of endemic and tropical corals are found among macro-algal reefs, forming bommies and growing on artificial structures. Rock lobster fishing (Zone C) is one of the major commercial fishing activities within the area.

5.8.2 Deep-water habitats

Deep-water regions of Geographe Bay and around Cape Naturaliste were mapped as part of the Marine Futures project (Figures 5.15 & 5.16). The majority of the deep-water area surveyed in Geographe Bay had soft substrate, with reef outcrops in the east, along a narrow ridge running east-west (Four Mile Reef), and patchily distributed in the north east and west. A mixture of reef and sediment cover was widely distributed around the periphery of reef outcrops and was more extensive than reef-only areas. Seagrass was the dominant nearshore vegetation type and the presence of macro-algae increased with water depth. The deep-water region surrounding Cape Naturaliste included reefs close to shore in the north, with isolated patches of lower lying reef further from shore and a large patch as predicted at the outer limit of the southern part of the site. The majority of the area was either sand or reef, surrounded by areas of mixed sand and reef. Macro-algae occurred on exposed reefs and covered a large portion of the mapped area, while a mix of vegetation and sessile invertebrates was largely encountered in the southern-most part of the site (Radford *et al. 2008*)

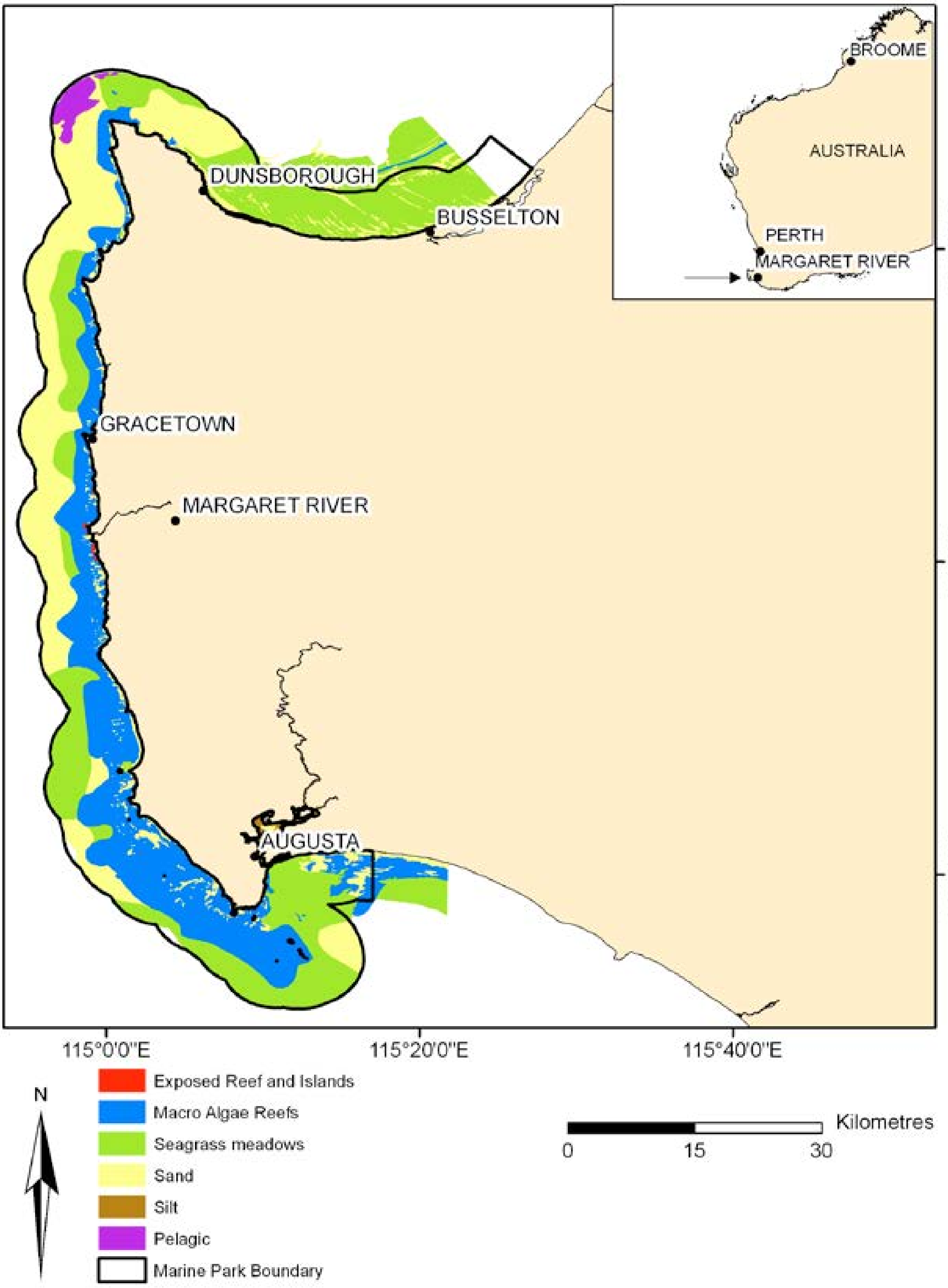

Figure 5.14. Major marine benthic and shoreline habitats within the proposed marine park (Source: Department of Environment and Conservation 2006b).

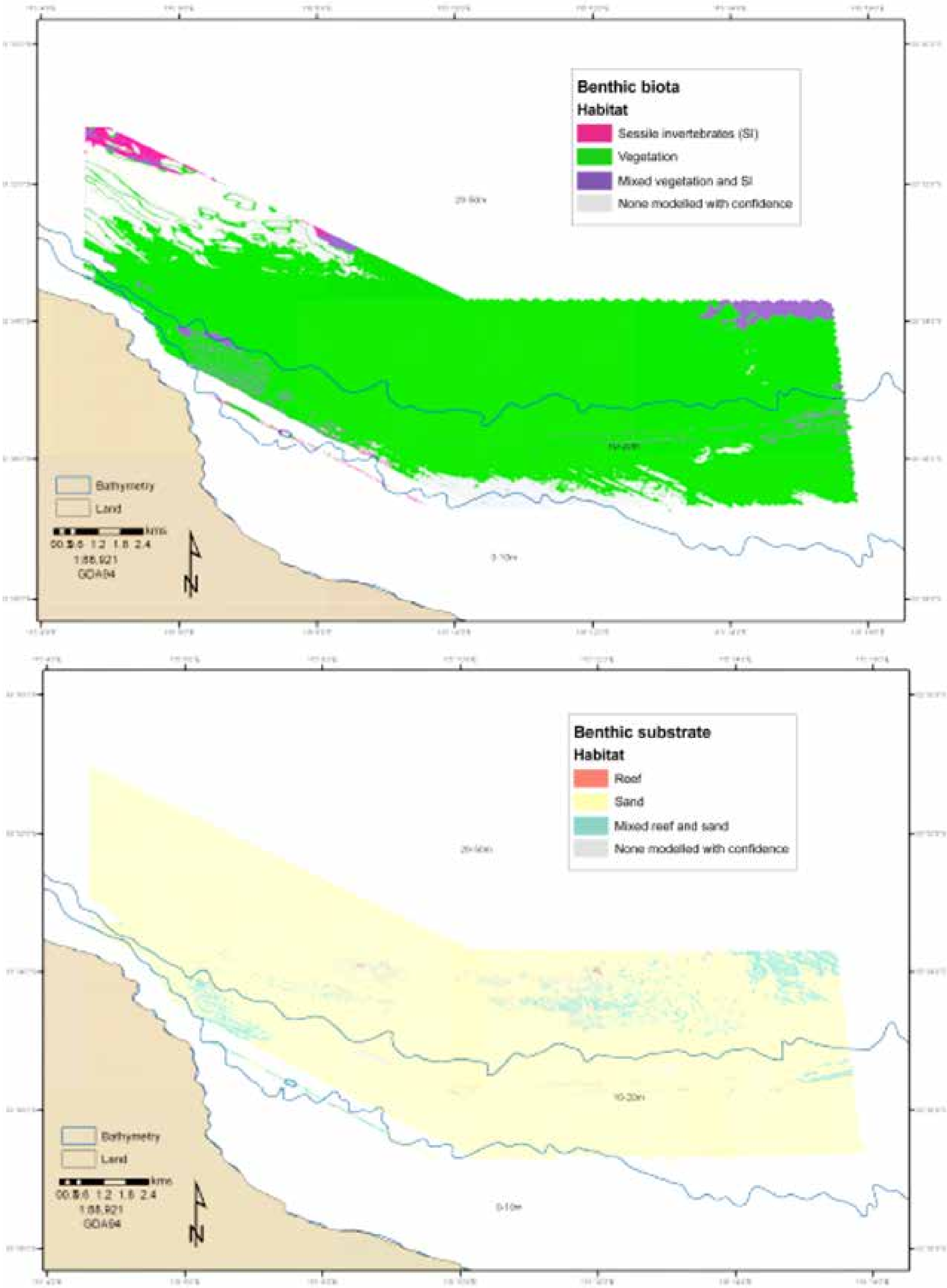

Figure 5.15. Deep-water regions of Geographe Bay showing the benthic biota (top) and substrate (bottom) habitats modelled (Source: Radford *et al*. 2008).

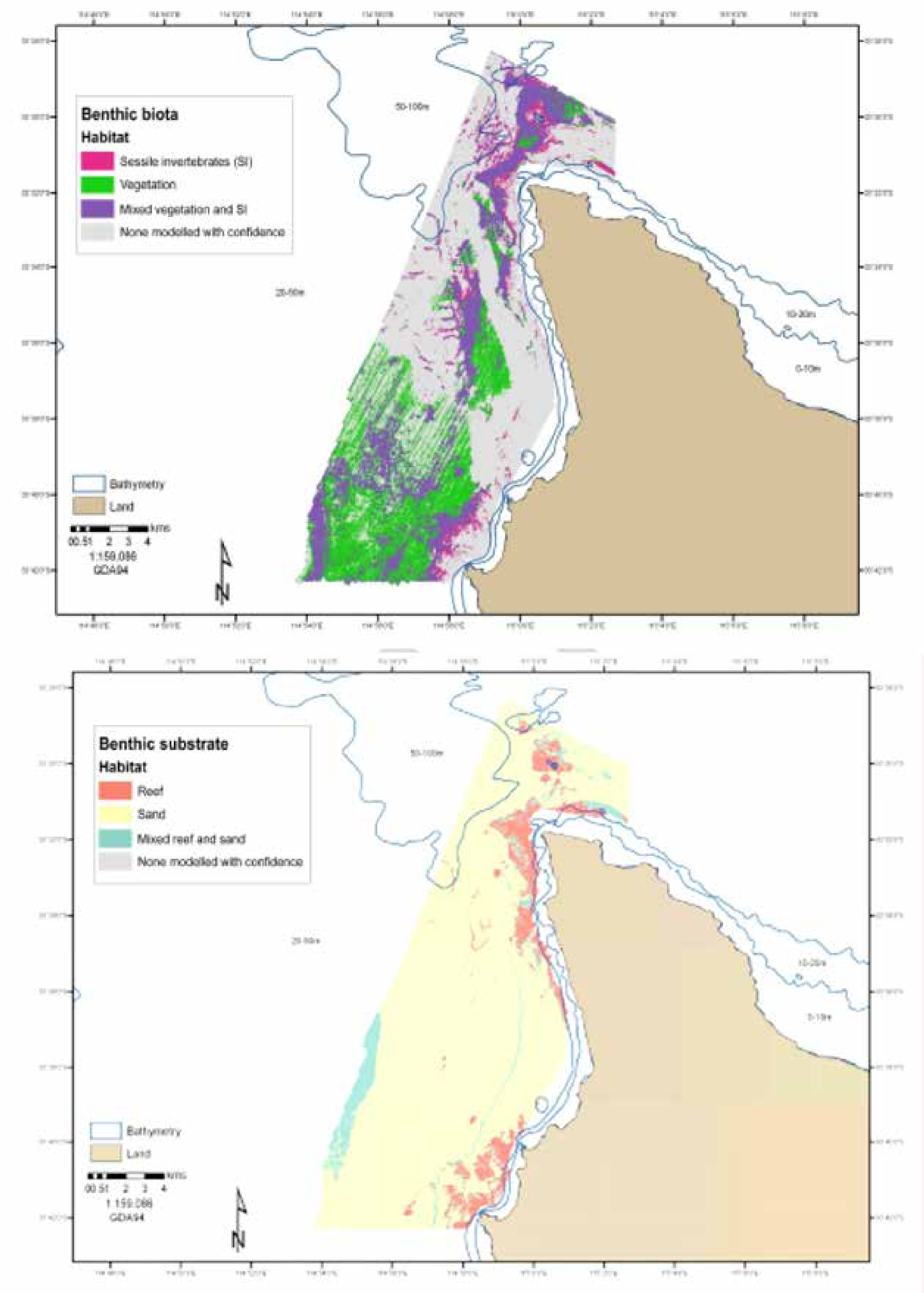

Figure 5.16. Deep-water regions around Cape Naturaliste showing the benthic biota (top) and substrate (bottom) habitats modelled (Source: Radford *et al.* 2008).

5.9 Habitats used by *P. cygnus*

Habitats used by western rock lobsters, and their population structure within these habitats, are largely confined to the limestone reef systems fringing the central coast of Western Australia; reef systems surrounding offshore islands (e.g. Abrolhos); and offshore reef systems in deeper waters (e.g. Big Bank). However, rock lobsters can be found across the continental shelf where they utilise a range of habitats at different stages of their lifecycle:

- Phyllosoma spend up to 12 months in the water column before settling as puerulus onto seagrass and algal meadows found within nearshore habitats. Post-puerulus (< 25 mm CL, 1 + year) usually inhabit small holes in the reef and reef face along algal or seagrass communities, which are used as shelter and a food resource. As the lobsters grow, they move into larger spaces where they begin to share the den habitat of juvenile lobsters in caves and ledges (Fitzpatrick *et al*. 1990).

- Juveniles forage and grow among reef habitats until they become sub-adults. Habitat surveys near Geraldton revealed high densities of sub-adult rock lobsters among high reef areas and low reef areas at Point Moore, and the low reef and high reef blocks at Georgia (Monaghan Rooke and Robinson 1993, 1994) (Figure 5.17). Lobster shelter (caves, crevices and ledges) is most abundant in the dissected pavement habitat that occurs at about 4-6 m depth and is limited on the featureless rock pavement. Other habitats such as sand and limestone pavement with algae and seagrass cover are used by lobsters at night during foraging activities.

- Sub-adults (3-4 years of age) migrate across the deep-water regions of sand and reefs to settle on offshore, deep-water habitats as mature breeding lobsters. The migratory path of 'white' lobsters is generally from the coast to the edge of the continental shelf, but their movement through different habitats is not known. Migratory immature 'whites' are regularly caught on sandy or silty substrates in deeper waters, however, it is unlikely they seek refuge in these habitats due to the lack of shelter and food.

- Breeding females are known to prefer limestone or coral reef habitats throughout their distribution. In the central coastal region, breeding grounds are between 20 to 40 fathoms depth (Chubb *et al*. 1989).

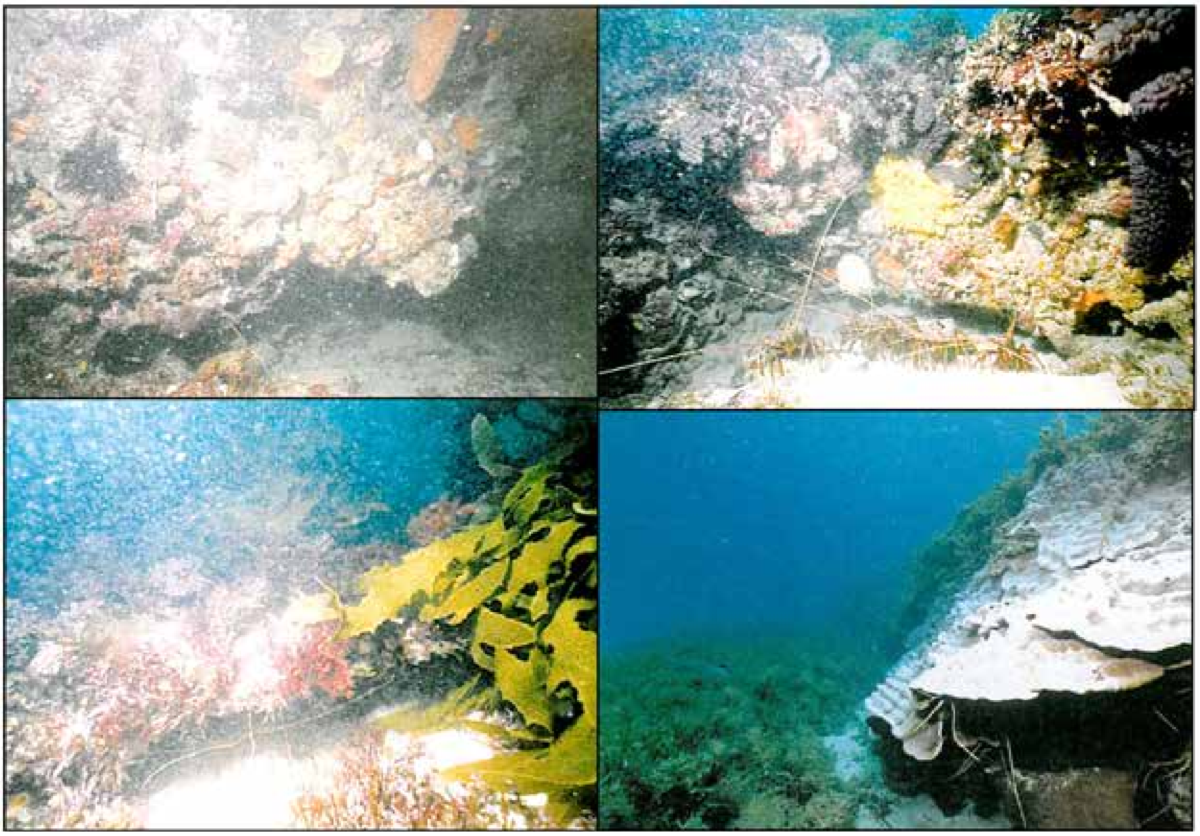

Figure 5.17. Examples of rock lobsters among different habitats (Source: Monaghan Rooke and Robinson 1993, 1994).

Fishery-dependent data is collected through a volunteer logbook programme that provides catch information based on fishing blocks. While this data is useful for stock assessment purposes, it is voluntary and only a portion of the fishery provides information. In addition, as the fishing blocks are large, both latitudinally and longitudinally, the logbook information is only available on a broad spatial scale.* Broadly, the regions between Dongara and Mandurah are known as areas of high effort in the fishery; however, this is likely to change under the new quota management system and as a result of low puerulus settlement in recent years.

Fishery-independent data also currently lacks fine-scale spatial distribution; however, dedicated research surveys do fill some of the knowledge gaps. In 1985-1987, rock lobster fishers were asked to record the exact locations of berried female lobsters captured through potting, in order to determine the extent of breeding grounds across the fishery. Only 28 % of the fishing fleet (220 fishers) participated in the study. The results of the study indicated that the majority of breeding females occurred in the deeper water offshore grounds (20-40 fathoms) of the central coastal region. The shallow-waters along the cliffs north of Kalbarri and the Houtman Abrolhos Islands were also identified as key breeding grounds (Figure 5.18). Inshore reefs and islands in the Jurien-Cervantes and Cape Naturaliste-Cape Leeuwin regions were also considered important, as moderate numbers of berried females were regularly captured in these areas (Chubb *et al.* 1989).

* Refer to Figure 4.11 of the P1-Stock Assessment document

During the 2009/2010 fishing season, fishers participated in a study to determine finer-scale spatial distribution of sub-legal and legal sized lobsters across the fishery (Department of Fisheries, *unpublished data*). Fishers were provided with an additional pot, covered in fine mesh to inhibit the escape of all lobsters, and were asked to record the sex, size and colour of captured lobsters and the GPS location of the pot. The study involved 31 fishers. Data was collected from 2 760 pot lifts resulting in a total of 30 321 lobsters (size range 18-155 mm CL) being recorded (Figure 5.19).

This preliminary study is the first to provide fishery-wide coverage of catch rates of different size lobsters during a single fishing season. The data indicates that small lobsters (< 60 mm CL) were predominantly caught in less than 20 fathoms in the northern part of the fishery (Dongara to Kalbarri) (Figure 5.20).

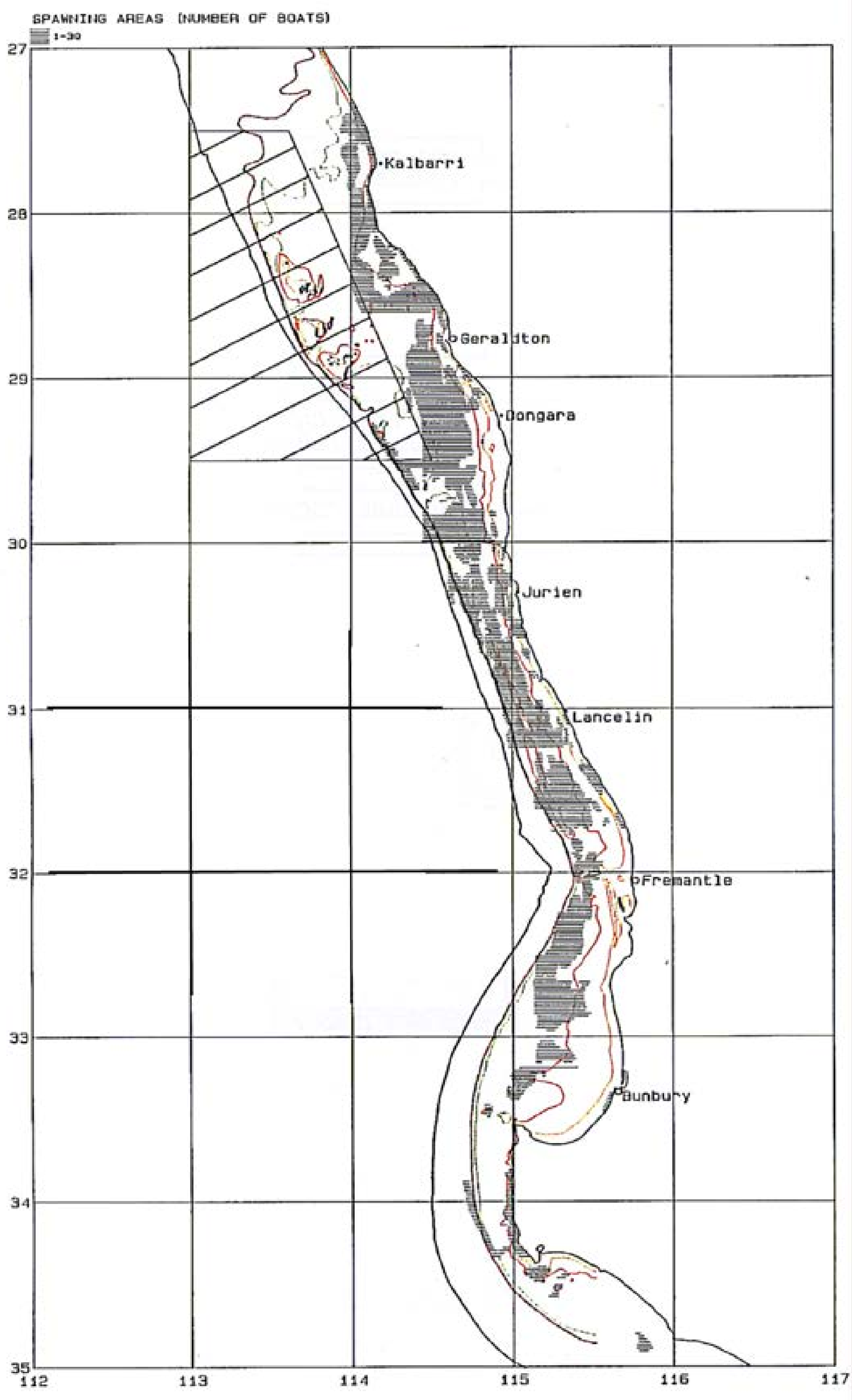

Figure 5.18. Map showing areas (grey shaded) of commercial catches of berried females during the 1985-1987 catch survey. The 10 (yellow), 20 (orange), 30 (green), 40 (red) and 100 (blue) fathom isobaths are shown. Note: This map does not indicate densities of breeding females and little information is known for the Abrolhos Islands zone (Source: Chubb *et al*. 1989).

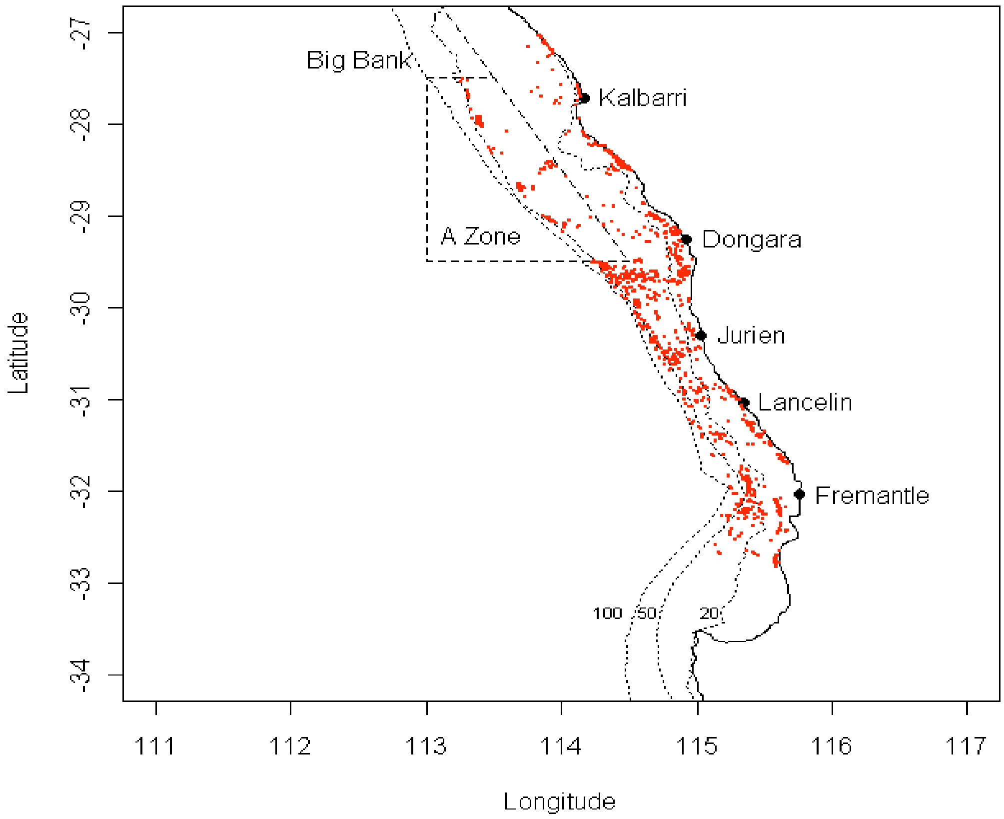

Figure 5.19. Location of data supplied from meshed pot trial (2009/10), with the dotted line representing 20, 50 and 100 fathoms isobaths.

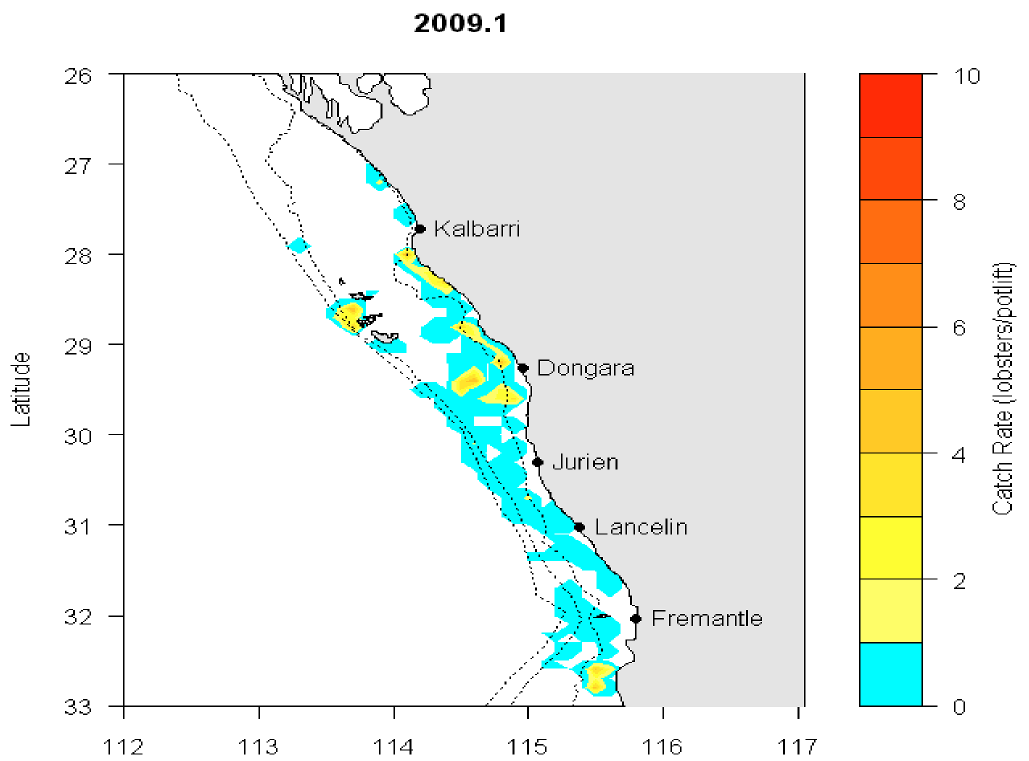

Figure 5.20. Catch rates of lobsters < 60 mm CL sampled during the 2009/10 fishing season in meshed pots.

Table 5.2. Summary of habitat information presented. Map reference numbers refer to broad areas outlined on Figure 5.2.

Year	Study Source/ Publications	Region	Scale	Methodology	Classification System	Map Reference
1994	Department of Fisheries (Chubb *et al.* 1994)	Big Bank	Broad	N/A	N/A	1
2002	Australian Marine Conservation Society WA (Department of Fisheries 2004)	Kalbarri (< 20 m)	Broad	Video surveys Quadrat sampling	Physical substrate Marine flora and fauna	NA
1993	Landcorp (George 1993)	Oakajee (< 20 m) 2 km from shore	Medium	N/A	Integrated biophysical system (6 categories)	NA
1991-1994	Geraldton Port Authority (Monaghan Rooke and Robinson 1993; 1994)	Geraldton (< 30 m)	Medium	Aerial photography Dive surveys	Integrated biophysical system (8 categories)	NA
1988	Abrolhos Islands Task Force (Hatcher *et al.* 1998)	Abrolhos Islands (< 20 m)	Medium/ Fine	Aerial photography Dive surveys	Integrated biophysical system (12 categories)	2
1995	Marine Science Associates (Marine Science Associates 1995)	Abrolhos Islands (< 20 m)	Medium	Satellite imagery Dive surveys	Integrated biophysical system (8 categories)	2
1994, 2001	Department of Fisheries (Dibden and Joll 1998; Webster *et al.* 2002)	Abrolhos Islands (20–100 m)	Broad	Towed video transects	Integrated biophysical system (4 categories)	2
2005	Oceanica (Oceanica 2006)	Abrolhos Islands - Long Island	Broad	Aerial images Snorkel surveys	Integrated biophysical system (15 categories)	2
2010 (Ongoing)	Department of Fisheries	Abrolhos Islands	Fine	ALOS AVNIR imagery Towed and drop cameras	N/A	2

Table 5.2. Continued

Year	Study Source/ Publications	Region	Scale	Methodology	Classification System	Map Reference
2008	Marine Futures (Radford *et al.* 2008)	Abrolhos Islands - Pelsaert & Easter Groups (10–80 m)	Fine	Multibeam Hydroacoustics Towed video transect CART, BRUVs	Benthic substrates (4 categories) Benthic biota (4 categories)	2
1994	Department of Planning and Urban Development (Department of Planning and Urban Development 1994)	Central coast (Dongara to Guilderton) (< 10 m)	Medium	Satellite imagery Dive surveys	Integrated biophysical system (4 categories)	4
2005	Department of Environment and Conservation (Hill 2005)	Jurien Bay Marine Park (< 20 m)	Medium	Satellite imagery Dive surveys	Major biotic assemblages (5 categories)	4
2002	Tasmanian Aquaculture and Fisheries Institute (Barrett *et al.* 2002)	Jurien Bay Marine Park	Fine	Visual census Quadrat sampling	Marine flora and fauna assemblages	4
2009	Tasmanian Aquaculture and Fisheries Institute (Edgar *et al.* 2009)	Jurien Bay Marine Park	Fine	Visual census Quadrat sampling	Marine flora and fauna assemblages	4
2008	Marine Futures (Radford *et al.* 2008)	Jurien Bay (10–80 m)	Fine	Multibeam Hydroacoustics Towed video transect CART, BRUVs	Benthic substrates (4 categories) Benthic biota (4 categories)	3
2010 (Ongoing)	Department of Fisheries	Jurien Bay (10–80 m)	Fine	Multibeam Hydroacoustics Towed video transect CART, BRUVs	N/A	3

Table 5.2. Continued

Year	Study Source/ Publications	Region	Scale	Methodology	Classification System	Map Reference
1987	Department of Environment and Conservation (Simpson and Ottoway 1987)	Marmion Marine Park (< 10 m)	Medium	Aerial photography Quadrat sampling	Integrated biophysical system (6 categories)	6
1992	Department of Environment and Conservation (Pobar *et al.* 1992)	Marmion Marine Park (< 10 m)	Medium	Satellite imagery Dive surveys	Integrated biophysical system (5 categories)	6
2008	University of Western Australia (Ryan 2008)	Marmion Marine Park	Medium	Quadrat sampling	Marine flora and fauna assemblages (% coverage)	6
1975	Meagher and LeProvost Ecologists (Meagher and LeProvost 1975)	Ocean Reef 3 km from shore	Broad	Dive surveys	Integrated biophysical system (4 categories)	6
1984	Western Australian Public Works Department (Scott *et al.* 1984)	Sorrento/Hillarys 2 km from shore	Medium	N/A	Marine flora and fauna assemblages (9 categories)	6
2003	Rottnest Island Authority (Rottnest Island Authority 2003)	Rottnest Island	Medium	N/A	Integrated biophysical system (8 categories)	5
2009	Murdoch University (Harvey 2009)	Rottnest Island (< 15 m)	Fine	Hyperspectral remote sensing techniques	Integrated biophysical system (6 categories)	5
2008	Marine Futures (Radford *et al.* 2008)	Rottnest Island (10-100 m)	Fine	Multibeam Hydroacoustics Towed video transect CART, BRUVs	Benthic substrates (4 categories) Benthic biota (4 categories)	5

Table 5.2. Continued

Year	Study Source/ Publications	Region	Scale	Methodology	Classification System	Map Reference
1996	Department of Environmental Protection (Department of Environmental Protection 1996)	Southern Metropolitan Region (Yanchep to Mandurah)	Medium	Geoscan airborn multi-spectral scanner	Integrated biophysical system (7 categories)	5
2006	Department of Environment and Conservation (Department of Environment and Conservation 2006a)	Shoalwater Islands Marine Park	Medium	N/A	Integrated biophysical system (5 categories)	5
2008	Murdoch University	Swan Marine Region	Fine	Quickbird satellite imagery Drop-camera sampling	Integrated biophysical system (4 categories)	5
2006	Department of Environment and Conservation (Department of Environment and Conservation 2006b)	Geographe Bay to Cape Leeuwin 10 km from shore	Medium	N/A	Integrated biophysical system (6 categories)	6
2008	Marine Futures (Radford *et al.* 2008)	Geographe Bay (10-50 m)	Fine	Multibeam Hydroacoustics Towed video transect CART, BRUVs	Benthic substrates (4 categories) Benthic biota (4 categories)	6
2008	Marine Futures (Radford *et al.* 2008)	Cape Naturaliste (10-100 m)	Fine	Multibeam Hydroacoustics Towed video transect CART, BRUVs	Benthic substrates (4 categories) Benthic biota (4 categories)	6
2007	University of Western Australia	Capes region	Fine	Video surveys Quadrat sampling BRUVs	Marine flora and fauna assemblages (% coverage)	6

6.0 Ecosystem

6.1 Movement and Behaviour

6.1.1 Background

The western rock lobster *Panulirus cygnus* has a complex, spatially segregated life-cycle, where juveniles (1-5 years of age) concentrate on shallow coastal reefs (< 40 m) for 3-4 years before many migrate to deep offshore habitats (> 40 m). The migration occurs between late-November to mid-January each year and is generally referred to as the 'whites' migration, due to the lack of pigmentation of migrating individuals after moulting.

Studies of *P. cygnus* in shallow-water areas have shown that lobsters forage throughout the night in seagrass meadows (in particular, *Amphibolis* or *Heterozostera/Halophila*) surrounding the reef, moving distances of up to 300 m (Jernakoff *et al.* 1987). The animals return to their caves and ledges on, or at the base of, high-relief limestone reefs around dawn. Waddington *et al.* (2005) suggested that unmated females and those carrying early-stage eggs forage more frequently than males and females carrying late-stage eggs, thereby making them more susceptible to capture by the fishery. This is in contrast to the findings of Jernakoff (1987b) that indicate males are more frequent foragers.

Migrations of 10's of km, and as small as 100's of metres, have been recorded in several studies of the western rock lobster (Phillips 1983; Ford *et al.* 1988; Phillips 1990). MacArthur (2009) suggested that offshore migration of an intermediate scale may also occur in shallow coastal waters, which could partly explain the size distribution of western rock lobsters. During the ontogenetic migration from shallow to deep-water habitats, most lobsters move directly offshore, although a large number also make extensive long-shore migrations, generally in a north-westerly direction (Phillips 1983; Cheng and Chubb 1998; Melville-Smith and Cheng 2002). MacArthur *et al.* (2008a) proposed that a high proportion of sub-adult, maturing 'white' phase lobsters may remain resident on some coastal reefs for a period of time instead of migrating offshore. Several researchers have tagged a large number of migrating lobsters, either with internally anchored spaghetti tags (Phillips 1983; Melville-Smith and Cheng 2002) or with acoustic tags (MacArthur *et al.* 2008a; b). Cheng and Chubb (1998) found that individuals tagged in deep-water moved longer distances than lobsters tagged in shallow-water. It is believed that *P. cygnus* move in groups or packs when making their offshore migration to deep-water breeding grounds, possibly due to increased survival benefits. Lobsters are gregarious animals changing their behaviour depending on how many individuals of the same species surround them. Chittleborough (1974) noted that in crowded conditions dominance for food is displayed among juvenile rock lobsters (2-5 years old).

Research shows that certain reef and habitat characteristics influence variations in density and size structures of western rock lobsters in both shallow and deep-water (MacArthur 2009; Bellchambers *et al.* 2010). Sanctuary (no-take) zones also have the potential to influence lobster densities. Babcock *et al.* (2007) found that densities of legal and sub-legal sized lobsters in shallow-water habitats surrounding Rottnest Island were higher in sanctuary zones than fished zones. A greater number of large, mature lobsters were also found in the sanctuary zones.

See Table 6.1 for a summary of completed and ongoing research regarding the movement and behaviour of rock lobsters.

6.1.2 Movement

6.1.2.1 Shallow-water habitats

Phillips (1983) tagged and released a total of 5 034 juvenile western rock lobsters *P. cygnus* (both males and females) on a shallow coastal reef adjacent to Cliff Head. Tagging was restricted to individuals ≥ 65 mm CL, as this was assumed to be the minimum size of potential immigrants from the reef. The results of the study showed a wide range of lobster movement, with approximately 67 % of animals moving almost directly offshore and a few individuals moving offshore in a north-westerly direction. It was believed that few, if any, lobsters ≥ 65 mm CL would stay in the study area for longer periods or become permanent residents. The maximum rate of offshore movement was recorded at up to 622 m d^{-1} over 37 nautical miles (ca. 68 km) and occurred primarily during November. The observed north-westerly migration by some individuals suggested that these pre-adult lobsters travelled in a circuitous route on their way to offshore spawning grounds, allowing for increased use of food resources in offshore algal meadows and broken reef areas along the coast between Cliff Head and Denison.

Natural foraging patterns of juvenile *P. cygnus* at Seven Mile Beach were investigated by Jernakoff (1987a; b) using electromagnetic tag tracking. Information on the types of ranges, the extent of foraging within a range, the direction of foraging, start and finish times of foraging, speed of movement and foraging habitats was documented. Foraging ranges were found to vary among lobsters, although a few general patterns were evident. Lobsters foraged over either a small circular area or over long straight paths and on a circuitous route. Although lobsters usually lived on one reef, during the period of observation, approximately 50 % of lobsters changed home reefs and used different dens. Results also showed that western rock lobsters responded rapidly to changes in light levels during dawn and dusk, while no relationship was found between changes in activity of lobsters and changes in water currents and diurnal temperature. It was therefore concluded that changes in light levels in natural field situations were a major physical component of start and finishing times of foraging for juvenile lobsters. Foraging activity was constant throughout the night, and lobsters continued to forage until dawn. Male lobsters were found to be more active foragers than females, with both sexes being more active in November, possibly due to seasonal moulting and migration. The rate of movement did not differ much between seasons and sexes; lobsters generally moved at a rate of approximately 1 m min^{-1} while foraging, although some lobsters were observed moving at a speed of up to 18 m min^{-1} over bare sand.

Foraging occurred in two main types of seagrass habitat: *Amphibolis* and *Heterozostera*/*Halophila*. All juvenile lobsters used home dens found on reefs covered by *Amphibolis,* but foraged for longer periods in *Heterozostera*/*Halophila* beds or a mixture between the two. The preference for mixed *Heterozostera/Halophila* beds may be due to easier foraging offered by this particular habitat mixture, as well as an increase of infaunal food items available for juveniles in the range of 55-68 mm CL.

In a related study, Jernakoff *et al.* (1987) tracked western rock lobsters at Seven Mile Beach using an electromagnetic tracking device. A total of 108 lobsters (both male and female), estimated to be four years old with carapace lengths between 55-68 mm, were tagged during the study. The aim was to determine nocturnal foraging distances of rock lobsters and identify variation in movement patterns between sexes, seasons and years. Of the 108 lobsters tagged, only 47 were successfully tracked throughout the duration of the study. Nocturnal foraging distances were found to be variable. Results showed 25 % of foraging distances ranged between 400-800 m, with 95 % of the population moving between 72.5 and 585 m $night^{-1}$ (median distance and the longest distance moved on a single night was 310 m and 803 m, respectively). It was concluded that *P. cygnus* forage over larger distances and larger areas than had previously been suggested (Chittleborough 1974).

Waddington *et al.* (2005) measured movement and food consumption of lobsters at different reproductive states. Animals were collected from Lancelin using baited traps. The study was conducted in a tank environment to estimate foraging activity and thus potential impact on catchability of rock lobsters. Lobsters showed greater movement during the night than during the day. Both the density and the reproductive state of rock lobsters had a significant effect on movement and food consumption. This study found that lobsters kept in tanks at densities of 3-4 individuals showed greater movement and food consumption compared to solitary animals or animals kept at lower densities (1-2 individuals per tank), demonstrating the gregarious nature of lobsters previously observed by Chittleborough (1974).

Mature, unmated, ovigerous females carrying stage-one eggs, showed significantly greater movement and food consumption than females carrying late-stage eggs or males. These females were found to move away from their shelters more frequently than the latter groups, making them more susceptible to capture by the fishery. This is in contrast to the findings of Jernakoff (1987b) that showed males forage more frequently than females. It is possible that exogenous factors, such as moon phase or temperature, may have affected lobster movement in the study, as these factors could not be controlled within the tank. When compared with observed wild fishery data, similar catchability effects, caused by the same variations in movement and food consumption, for females of different reproductive states were observed.

MacArthur *et al.* (2008a) acoustically tagged 34 rock lobsters between 60-85 mm CL on a shallow coastal reef in south-western Australia.. Tagging and monitoring occurred between November and May in two consecutive years. The proportion of 'white' rock lobsters moving away from the reef and the large-scale movements of 'red' rock lobsters were examined, as well as any behavioural effect of tagging and handling of animals. It was expected that lobsters in the size class 60-80 mm CL would undergo two moults per year (mid-November and between February and April). All lobsters tagged in the study were in intermoult condition.

No significant difference was detected between 'white' and 'red' phase lobsters undertaking large-scale movements, suggesting that colour alone may not be a suitable indicator of long-distance movement. The majority of 4-5 year-old individuals tagged in the study were likely to remain close to the tag site during summer and autumn, regardless of colour. After the migration period (February), 11 of the 22 (50 %) 'white' phase lobsters (63-84 mm CL), which had been tagged over a two-year period in late-November or early-December, were encountered on the inshore reefs. Only three 'whites' (13.6 %) were detected by outer receivers of the inshore array during migration. Only one tagged 'white' phase lobster (4.5 %) moved in the clear offshore direction typically associated with migration movement. This suggests that a high proportion of sub-adult, maturing 'white' phase *P. cygnus* may remain resident on some coastal inshore reefs over a period of time, rather than migrating offshore. It was estimated that 'white' phase lobsters migrating offshore during the study period ranged between 4.5 % and 50 %. One particular individual (78 mm CL) displayed offshore movements similar to 'white' phase lobsters studied by Phillips (1983). The animal travelled in a straight line covering 3.37 km between inshore and offshore reefs and moved at a speed of 560 m day^{-1}. Three 'whites' (67-77 mm CL) displayed nomadic movement patterns that were believed to be the result of handling and/or tagging. These animals moved over *Posidonia* spp. habitat at speeds of 94-146 m h^{-1} ranging 4.5-7 km.

In an associated study, MacArthur *et al.* (2008b) tagged 15 western rock lobsters (69-84.5 mm CL) with acoustic transmitters to determine the scale of nocturnal foraging activities in three common lobster habitats within Jurien Bay Marine Park (seagrass meadows of *Amphibolis* spp. and *Posidonia sinuosa* and macro-algae-dominated pavement). The results indicated that the spatial distribution of nocturnally active western rock lobsters is strongly affected by the location of high-relief shelter reef habitat. Although lobsters travelled over extensive areas, 90 % of lobster activity occurred within 60 m of a high-relief reef at all three sites. Lobster core activity areas were also either overlapping or adjacent to the edge of the high-relief habitats, making it likely that foraging by western rock lobsters is greatest in these areas.

The mean total distance travelled each night at each site was 231.6-443.3 m (similar to findings by Jernakoff *et al.* 1987), whereas the mean distance travelled away from the reef edge was 9.4-19.5 m. Core areas varied in size, shape and position. The number of core areas used by lobsters (50 % utilisation distribution [UD]) and total activity areas (95 % UD) also showed significant variation. Some lobsters used several different nightly core activity areas, whereas others used only one area. The core activity areas averaged 2 556 ± 482 m^2 and total nocturnal activity areas averaged 10 437 ± 2 221 m^2. The distance between core foraging areas for individual lobsters was up to approximately 250 m. The use of *Posidonia sinuosa* and macro-algae-dominated pavement habitat by lobsters in the study indicates that these areas are important foraging habitats, in addition to *Amphibolis* spp. and *Heterozostera*/*Halophila* habitats (Jernakoff 1987a). The results showed no significant effect of carapace length, sex, moon phase, water temperature or swell height on the nocturnal activity area of *P. cygnus*.

Melville-Smith and Beale (2009) tagged migrating and pre-migrating *P. cygnus* with data storage tags over a two-year period at Dongara and Jurien Bay. The aim was to investigate movement patterns of lobsters migrating offshore and to determine their diurnal migration cycle. Only 'whites' between 63.8-76.9 mm CL were tagged, with 135 individuals released with backpack tags. A number of individuals (33 % up to potentially 63 %) identified as pre-migrating animals by their pale 'white' colour failed to migrate. This result was similar to MacArthur *et al.* (2008a), where only 13.6 % of tagged 'white' phase lobsters migrated offshore. The lobsters that did migrate were found to display similar migratory behaviour, migrating only at night at approximately the same time and between 1-94 days. All migrating rock lobsters travelled in either a westerly or northerly direction, depending on where tagging occurred (shallow or deep-water). Migrating speeds of individual lobsters ranged between 0.20-0.68 km h^{-1}, with a mean speed of 0.44 km h^{-1}, or 7.4 m min^{-1}. The daily movement rates were often > 1.8 km day^{-1}. Migrating animals displayed longer activity periods each night, in response to the moon rising at a later hour. As lobsters migrated further into deeper-water, where moonlight was absorbed, animals became active earlier and remained active later in the night. Lobsters did not migrate during daylight.

6.1.2.2 Deep-water habitats

Melville-Smith and Cheng (2002) tagged and released 3 412 migrating 'white' phase western rock lobsters, in the size range 65 mm to 77.9 mm CL, west of Jurien (42-49 m depth) and south-west of Cervantes (92-133 m depth). The majority of lobsters were tagged ashore, where they were kept in holding tanks overnight and released 18-24 hours later within 6 km from where they were captured. A few individuals were tagged at sea and released immediately after capture. Over the three seasons of the study, a higher number of lobsters tagged at sea were recaptured than lobsters tagged ashore.

The results indicated that lobsters tagged ashore travelled over larger distances than those tagged at sea. Tagged lobsters from deep-water at Cervantes (> 90 m depth) also moved larger distances than lobsters captured in intermediate depths at Jurien (43-47 m depth). The resident breeding stock of *P. cygnus* generally occurs at these middle depths (40-90 m). Lobsters tagged ashore in both Cervantes and Jurien moved significantly faster and further than lobsters tagged and released at sea. For both the sites and the two tag-and-release methods, the correlation between angle and speed of movement ranged between 0.25 and 0.42. Lobsters tagged either at sea or ashore in Cervantes, and that had been at large for one season, travelled approximately the same distances as those lobsters at large for two or three seasons. In Jurien, recaptured individuals in the second or third season were found to have travelled over longer distances than lobsters recaptured in the first season. All lobsters, whether released at intermediate depths in Jurien Bay or in deep-water at Cervantes, moved in a northerly to north-westerly direction.

6.1.3 Behaviour

6.1.3.1 Shallow-water habitats

Chittleborough (1974) measured home ranges of juvenile *P. cygnus* at Garden Island over a one-year period. Results showed that juvenile rock lobsters at this site had relatively small home ranges (maximum radius 15 m), and it was suggested that the juveniles may have a restricted home range while resident on these shallow-water nursery grounds. An experiment was also conducted to determine if juvenile rock lobsters display a homing instinct. A total of 199 juveniles, aged 3-5 years, were tagged and released at various distances south and north from their original home site. The juveniles rarely remained on the new sites. Only one of the recaptured lobsters remained on the reef where it was transplanted (400 m south of the home reef), suggesting that rock lobsters do not readily settle when removed from their home reefs and instead disperse rapidly to other areas.

Chittleborough (974) also investigated feeding dominance of juvenile rock lobsters on a crowded reef at Seven Mile Beach. The mean catch per unit effort of 2-year-old *P. cygnus* in screened bait traps was significantly higher (138 individuals/trap-night) than in unscreened bait traps (6.5 individuals/trap-night). Despite the abundance of smaller and younger rock lobsters in the area, dominant displays from larger juveniles prevented smaller ones from entering the traps. It was also noted that the home range of lobsters at the crowded Seven Mile Beach was larger than at Garden Island. The use of mark-recapture methods to estimate population densities of juvenile rock lobsters may underestimate the number of the 2-year-old size class due to feeding dominance among juveniles. These displays of dominance would also most likely increase when the level of food supply decreases.

Konzewitsch (2009) used an *in situ* multi-camera video system in an inshore shallow-water study at Cervantes. The aim was to investigate the effect of the migratory phase on trap behaviour of western rock lobsters. Observations were also made in the laboratory to determine whether the presence of a large lobster in the trap influenced the behaviour and catchability of smaller lobsters outside the trap. Trap behaviour was recorded during both the ‘white’ migratory phase (November – December) and the ‘red’ phase (March).

Both ‘white’ and ‘red’ phase lobsters were found to use escape gaps, with approximately 70 % and 94 % of lobsters that entered the traps escaping through the escape gap, respectively. Agonistic behaviour between lobsters was observed around the trap during the course of the study, generally resulting in the retreat of one individual. Interactions between species other than *P. cygnus*, particularly octopus (*Octopus tetricus*), and the traps also occurred *in situ*.

Octopus were observed consuming bait inside the traps or sheltering in the traps. The presence of an octopus in the trap appeared to have an inhibitory effect on the entry of lobsters to the traps and may affect the catchability of lobsters. Agonistic interactions resulting in the retreat of submissive lobsters from the traps suggested that *P. cygnus* experience trap inhibition possibly due to food competition. Agonistic behaviour between small individuals outside the traps occurred mostly among males, usually over females. Observations in the laboratory showed that smaller lobsters spent longer near a trap containing a large female than a trap containing a large male.

6.1.3.2 Deep-water habitats

No studies on the behaviour of the western rock lobster in deep-water habitats have been undertaken to date.

6.1.4 Size structure and lobster density

6.1.4.1 Shallow-water habitats

Chittleborough (1970) measured densities of juvenile rock lobsters with a single census mark-recapture method using baited lobster pots. Samples were collected at Seven Mile Beach and Garden Island. Garden Island, an area away from the centre of the coastal range of *P. cygnus*, was used as a test site. The initial population density of juveniles at Garden Island fluctuated greatly from year to year, ranging from 5 385 per ha in January 1967, to 1 212 per ha in January 1969, due to variations in recruitment. Natural mortality of juveniles also fluctuated with density.

There were similarities in the structure of the juvenile rock lobster population at Seven Mile Beach and Garden Island. Same size (age) groups occurred in both areas with variations in year class strength. Patterns of migration showed low dispersal of juveniles from January to October, whereas in November and December larger individuals migrated to deep-water habitats. Smaller juvenile *P. cygnus* (age group 2+ years) were present on the reefs by January. Catchability was correlated with water temperature, showing declines in autumn and increases in spring. Catch per unit effort was directly proportional to the density of the population at temperatures of 22.2-23 ºC during the month of January in five successive years. It was suggested that great fluctuations in the abundance of puerulus settling on the coastal reefs from year to year, and the holding capacity for juvenile rock lobsters at these reefs, is limited by availability of shelter.

Ford *et al.* (1988) conducted a density manipulation experiment at Seven Mile Beach to test whether high densities of juvenile rock lobsters limit growth and survival. Juvenile rock lobsters on a control reef were maintained at their natural high-densities, whereas juveniles on a treatment reef were reduced to approximately 25 % of original densities. To estimate size-specific growth rates, population densities and mortality rates of the animals, mark-recapture methods and direct estimates by divers were used on each reef at three-month intervals for a year.

The results showed no significant difference in growth within any age group between the control and treatment reefs. A significant difference was detected, however, in size-specific mortality rates between the different reefs. The mortality rate on the treatment reef was much lower than on the control reef, suggesting that lower densities of juvenile rock lobsters on a coastal reef may result in reduced mortality rates. The growth estimates obtained in the study were similar to those observed by Chittleborough (1970; 1975), Chittleborough and Phillips (1975) and Joll and Phillips (1984) at the same study site. However, moult increments of 3-year-old rock lobsters were significantly higher than at the low densities recorded in 1971-1974, even though population densities in 1981 were the greatest ever recorded.

Jernakoff *et al.* (1994**)** used scuba divers to survey populations of juvenile rock lobsters at Seven Mile Beach and Cliff Head over a two-year period. The aim was to determine densities, population structure and growth of the lobsters at both study sites. Divers estimated the number and size of lobsters and areas of habitat where the lobsters where located (cave, ledge and reef-face habitat). The size classes used for the density analyses were the same used by Ford *et al.* (1988): A (< 25 mm CL), B (25-38 mm CL) and C (39-55 mm CL). Estimates of the total early-juvenile population on each reef were higher (139 on first reef and 196 on second reef) than the visual diver estimates on the same two reefs (94 and 43, respectively). The total population density estimate of early juveniles, when combining the two areas, was also higher (330) than visual observations (137). Both early- and older-juvenile rock lobster densities were greater at Seven Mile Beach compared to Cliff Head, whereas the overall growth of juveniles was faster at Cliff Head. Densities of larger individuals (sizes B and C) were approximately three-times greater than densities of early juveniles (size A), at both sites.

The higher densities of juveniles at Seven Mile Beach may be due to a greater availability of suitable habitat for puerulus settlement at this site compared to Cliff Head. Approximately 60-70 % of the total reef area at both sites was face habitat and the rest mostly ledge. Only a small percentage of the reef was cave habitat. Densities in reef ledges were twice the densities found in caves, but caves showed ten-times the densities of reef faces. The patterns of habitat use observed in the study reflect ontogenetic changes in juvenile rock lobster habitat requirements with younger juveniles using holes in the reef face and ledges, whereas older juveniles were more common under ledges and in caves. This shift in habitat as lobsters grow coincides with the onset of gregarious behaviour at approximately 16-20 mm CL.

Meville-Smith and de Lestang (2006) obtained estimates of size at sexual maturity of both female and male western rock lobsters and investigated whether there has been a change in the size of maturity for female rock lobsters over time. Sampling occurred along 600 km of the West Australian coast in six different locations (Lancelin, Dongara, Abrolhos Islands, Fremantle, Jurien Bay and Kalbarri) during the independent breeding stock survey (IBSS) and the fishery-dependent commercial catch monitoring survey (DCCM).

Male lobsters were larger in size at first maturity than females at the same sites. Male lobsters attained both morphological and physiological maturity at similar sizes. There was a correlation between mean annual water temperature and the size at first maturity for both males and females, generally decreasing in size with increasing latitude along the mainland coast, with the smallest at the offshore Abrolhos Islands. Smaller sizes at maturity were observed for both male and female rock lobsters compared to previous estimates of carapace length at which half of the population is sexually mature (CL_{50}) for both sexes at corresponding sites (Fremantle, Dongara and the Abrolhos Islands). It was suggested that the differing sizes at maturity for both sexes of *P. cygnus* were possibly due to factors such as density and water temperature.

Babcock *et al.* (2007) conducted surveys of *P. cygnus* in sanctuary (no-take) and non-sanctuary (fished) shallow-water habitats surrounding Rottnest Island. The results showed significant variation in population structure between the two zones, with density, biomass, mean carapace length (CL) and egg production recorded at much greater levels in the sanctuary zone compared to the fished zone. Densities of legal and sub-legal sized lobsters were 34-times higher in the sanctuary zone than in the fished zone, with densities of legal-sized individuals estimated to be 50-times higher and densities sub-legal sized lobster 21.7-times higher within the sanctuary.

The results also showed a higher number of large lobsters in the sanctuary zone. The mean size of these lobsters was 8.4 mm larger than in fished zones. The largest individuals (≥ 115 mm CL) were all male and were almost exclusively found in the sanctuary zone. Although the majority of rock lobsters are expected to migrate to deeper waters (≥ 30 m) as they mature, the high abundance of large mature individuals found in the sanctuary zone around Rottnest Island suggests that these shallow-water habitats may be below their carrying capacity (in terms of biomass and egg production). It also indicates that not all rock lobsters migrate to deeper waters as they reach maturity and that they would potentially accumulate in the shallow-water areas if fishing pressure was reduced.

MacArthur (2009) investigated the within-reef and between-reef variability in density and size structure of *P. cygnus* over a two-year period in Jurien Bay Marine Park. Within-reef variability was larger than between-reef variability, possibly due to the aggregating behaviour of western rock lobsters. It was suggested that these aggregating interactions could be one of the most important processes controlling the spatial distribution of western rock lobsters within shallow coastal reef habitats. Three sets of reef characteristics: reef structure and biota, surrounding habitat and reef physical characteristics, e.g. distance from shore and depth, explained a significant proportion of the variation of total density (approx. 40-50 %) and size structure (approx. 20 %) of *P. cygnus*. A higher number and proportion of smaller lobsters (< 60 mm CL) were encountered at very shallow reefs (< 5 m) within 1 km of shore where the habitat consisted of small foliose brown algae, tufting filamentous algae and surrounding seagrass meadows. These findings may relate to increased settlement and/or survival on inshore reefs. Fewer lobsters were found in macroalgae-dominated pavement habitat around the reef. Deeper, offshore reefs had a higher proportion of larger lobsters (60-80 mm CL, i.e. 4-5+ years of age). Densities of legal-sized rock lobsters varied within years and between no-take zones and fished zones with legal-sized lobster abundance higher in November, before the fishing season. The densities of this group were also greater at sites within no-take zones than in the fished zones.

6.1.4.2 Deep-water habitats

Bellchambers *et al.* (2010) investigated whether a relationship exists between the abundance and size of western rock lobsters and their habitat at three different locations: Lancelin, Jurien and Dongara. The study was based on data from the annual western rock lobster independent breeding stock survey (IBSS) and towed video transects. The IBSS has been carried out since the early-1990s at five coastal and one offshore location, at depths of 36-73 m. Although a variety of sampling techniques were trialled during the study period, it was concluded that sampling of lobsters with baited pots was the only viable option for depths greater than 36 m.

Results of the study revealed that abundance and size of lobsters varied depending on the habitat. There was a high abundance of rock lobsters in habitats with high cover of *Ecklonia* sp. dominated assemblages. Larger lobsters were generally found in mixed habitats with sponges (e.g. Dongara), whereas smaller-sized lobsters were present in more structurally complex mixed assemblages with *Ecklonia* sp. (e.g. Lancelin). Jurien Bay had moderate abundances and sizes of rock lobsters. Abundance and size of rock lobsters could also be indicative of levels of fishing pressure, as Lancelin and Jurien had similar catch rates between 1996 and 2006 in the deep-water section (> 36 m) of the fishery. These two sites showed the greatest abundances and smallest size classes of lobsters (under minimum legal catch size for the fishery). Although low abundances of lobsters in Dongara (where fishing pressure is lower) were evident, the lobsters encountered were generally larger.

Table 6.1. Summary of research (completed and ongoing) investigating the movements and behaviour of western rock lobsters.

Author	Date	Location	Depth	Habitats	Methods	Size-class	Behaviour	Remarks
Chittleborough	1974	Metropolitan region – Garden Island and Seven Mile Beach			Intensive trapping over fine spatial scale	Juveniles (3-5 yrs)	Small foraging range at Garden Island (max 15 m radius) – may be related to low lobster densities. Foraging excursions > 50 m recorded at Seven Mile Beach.	Demonstrated that juvenile lobsters may return to home reef from > 400 m and are unlikely to settle on new reefs when moved from home range. Older and larger juveniles may dominate 2-yr-old lobsters, preventing them entering traps.
Jernakoff *et al.* Jernakoff	1987 1987a, b	Seven Mile Beach	< 5 m	Seagrass meadows (*Amphibolis* spp. and *Halophila ovalis*/ *Heterozostera tasmanica*)	Electro-magnetic tracking	55 - 68 mm	Juvenile lobsters used home dens found on reefs covered by *Amphibolis* but foraged for longer periods in *Heterozostera*/ *Halophila* beds. Lobster foraging nocturnal. Median foraging distance was 310 m, longest distance moved on a single night was 803 m.	Foraging rates averaged 1 m min^{-1} but could be as high as 18 m min^{-1} over sand. Males more active than females.
Melville-Smith and Cheng	2002	Jurien Bay and Cervantes	42 – 133 m		Tagging	Various	All lobsters recaptured, whether released at intermediate depths in Jurien Bay or in deep-water at Cervantes, moved in a northerly to north-westerly direction.	Lobsters tagged ashore (and released the following day) in both Cervantes and Jurien Bay moved significantly faster and further than lobsters tagged and released at sea.
Waddington	2005	Aquaria				Various	Mature, unmated, ovigerous females carrying stage-one eggs more catchable than males or females carrying late-stage eggs (moved from shelter more often and had greater food consumption).	Lobster in groups show higher rates of movement and food consumption than individuals.

Table 6.1. Continued.

Author	Date	Location	Depth	Habitats	Methods	Size-class	Behaviour	Remarks
MacArthur *et al.*	2008a	Jurien Bay Marine Park	< 15 m	Natural habitats and tank trials	Acoustic telemetry	60 - 85 mm including 'whites' and 'reds'	No significant difference was detected between 'white' and 'red' phase lobsters undertaking large-scale movements, suggesting that colour alone may not be a suitable indicator of long-distance movement. The majority of 4-5 year-old individuals tagged in the study were likely to stay close to the tag site during summer and autumn regardless of colour.	Results suggest that a high proportion of sub-adult, maturing 'white' phase *P. cygnus* may remain resident on coastal inshore reefs over a period of time rather than migrating offshore. Tagging can modify the foraging behaviour of *P. cygnus* for up to 3 days (and cause lobsters to become nomadic).
MacArthur *et al.*	2008b	Jurien Bay Marine Park	< 15 m	*Posidonia* & *Amphibolis* meadows & macroalgae-dominated pavement.	Acoustic telemetry	69 - 84.5 mm CL	90 % of lobster activity occurred within 60 m of the nearest high-relief reef irrespective of habitats. *Posidonia sinuosa* and macroalgae-dominated pavement habitats are important foraging habitats for lobsters (in addition to *Amphibolis* spp. and *Heterozostera/Halophila*).	Core (50% UD) and total (95% UD) nocturnal activity areas did not differ significantly between sites and averaged 2 556 ± 482 m^2 and 10 437 ± 2 221m^2, respectively. Nocturnal activity area of *P. cygnus* was not influenced by carapace length, sex, moon phase, water temperature or swell height.
Melville-Smith and Beale	2009	Dongara and Jurien Bay			Archival tags	Migrating and pre-migratory	Migrated only at night from darkness (after 2000 h) until after moonrise. Movement patterns were less constrained by the rising of the moon in deep-water. Most individuals had breaks in migration. Substantial proportion of 'whites' failed to migrate.	Mean speed of migration during periods of activity was 0.44 km h^{-1}.

Table 6.1. Continued.

Author	Date	Location	Depth	Habitats	Methods	Size-class	Behaviour	Remarks
Konzewitsch Toon	2009 ongoing	Aquaria and in situ			Video recordings of lobster behavior in traps.	Various	Agonistic interactions resulting in the retreat of submissive lobsters from the traps suggest that *P. cygnus* experience trap inhibition possibly due to food competition. Aquaria observations show that smaller lobsters spend longer near traps containing large females than large males.	Octopus observed consuming bait inside the traps or sheltering in the traps. The presence of an octopus in the trap appeared to have an inhibitory effect on the entry of lobsters to the traps and may affect catchability of lobsters.
Moore *et al.*	Ongoing (WAMSI)	Metropolitan region – Rottnest and Marmion	< 15 m	Seagrass beds (*Amphibolis* spp.)	acoustic telemetry (VRAP)		Predominately nocturnal foraging activity, within approx. 30 m of reef refugia.	Home range 665 ± 446 m^2, 50 % UD; 3 071 ± 665 m^2 95 % UD. Small numbers of lobsters tracked over 4-6 weeks.

6.2 Diet and trophic interactions

6.2.1 Background

The western rock lobster *Panulirus cygnus* has been classified as a generalist feeder with a diet composed of a wide range of plant and animal materials (Joll and Phillips 1984; Edgar 1990a, b; Jernakoff *et al.* 1993; MacArthur 2009). The majority of published studies on diet and foraging of *P. cygnus* have focused on shallow coastal ecosystems (< 5 m depth), such as Cliff Head and Seven Mile Beach in Western Australia (Joll and Phillips 1984; Edgar 1990a, b; Jernakoff *et al.* 1993), while deep-water habitats (> 35 m depth) have until recently received little attention.

Results from rock lobster dietary studies have revealed consumption of gastropods (e.g. *Cantharidus lepidus* and *Pyrene bidentata*), molluscs, polychaetes, small crustaceans, bivalves, chitons, sipunculid worms, non-coralline algae, seagrass, brachyuran crabs, ascidians, sponges, pycnogonids, hydrozoans and echinoids. Rock lobsters also consume large quantities of coralline algae, in particular *Corallina cuvieri* and *Metagoniolithon stelliferum* that are epiphytic on stems of the seagrass *Amphibolis*. It has been suggested that coralline algae may contribute both to the nutrition of rock lobsters, in particular for lobsters in macroalgae-dominated pavement and sand habitats (MacArthur 2009), as well as to the uptake of calcium to the exoskeleton of early intermoult juvenile animals (Joll and Phillips 1984). Dietary items and contribution to gut volume ranges of western rock lobsters are displayed in Table 6 of the Appendix.

The diet of rock lobsters shows significant variations between sites, seasons and moult stages (Joll and Phillips 1984; Edgar 1990a; b), reflecting the natural variability of prey (Edgar 1990a; b). Animal prey, in particular mobile invertebrates, seems to be preferred over plant items (e.g. algae and seagrass) when available in high densities. This preference for animal material has been shown to result in faster growth rates of lobsters in local patch reef populations compared to lobsters feeding mainly on coralline algae (Joll and Phillips 1984; Edgar 1990a; b). Even greater quantities of animal prey are found in the gut contents of rock lobsters collected from deep-water habitats with crabs, amphipods and isopods dominating the diet (Waddington *et al.* 2008). It has been suggested that bait input from the fishery may also be an important food source in deep-water, subsidizing lobster production during the fishing season. Data from diet studies of rock lobsters in shallow-water environments also indicates that bait is an important food source. For the 2009/10 fishing season, 4 576 t of bait was used by the fishery, equating approximately 0.8 kg of bait for every 1 kg of lobster landed. The role of cannibalism in the rock lobster diet has not been fully recognized until recently and has instead been attributed to ingestion of exuviae (Joll and Phillips 1984; Edgar 1990a; b). It has been suggested, however, that cannibalism may have a more significant role for lobster nutrition in shallow-water coastal environments than was previously thought (MacArthur 2009).

Due to the high number of rock lobsters inhabiting coastal reefs in Western Australia, it is likely that they play an important role in regulating benthic communities in these areas (Joll and Phillips 1984; Edgar 1990a; b). A study by Edgar (1990a) showed rapid declines in large > 2 mm gastropods, such as *Cantharidus lepidus, Stenochiton cymodocealis* and *Asteracmaea stowae*, when rock lobsters made a dietary shift from an algae- to a mollusc-dominated diet. Approximately 30 individuals of *C. lepidus*/m^2 were consumed, when seasonally abundant, accounting for an 89 % reduction of gastropods between April and June. Western rock lobsters have also been found to forage in a wide range of habitats surrounding reefs including seagrass beds (e.g. *Posidonia* spp. and *Amphibolis* spp.), areas of bare sand and flat pavement reef dominated by macro-algae (Joll and Phillips 1984; Jernakoff 1987b; Edgar 1990a; b).

Lobsters of different sizes were observed to forage in different habitats, due partly to predation susceptibility. Post-puerulus (< 25 mm CL) foraged on patch reefs amongst *Amphibolis* and macro-algae close to shelter (Jernakoff 1993), smaller juveniles (25-45 mm CL) foraged on turf and *Amphibolis* covered reef, and larger juveniles (45-85 mm CL) in open habitat of *Halophila, Heterozostera* and *Syringodium*, further away from shelter (Edgar 1990a, b). MacArthur (2009) showed that 68-85 mm CL lobsters also foraged in the vicinity of high-relief pavement reefs dominated by foliose red algae and among *Posidonia sinuosa* beds. Foraging activities of rock lobsters have been related to changes in light levels with lobsters leaving their dens at night and returning from foraging around dawn (Jernakoff 1987b). While small scale differences in rock lobster foraging patterns (Jernakoff 1987b) and diet (Edgar 1990a, b) have been related to the habitat patchiness, MacArthur (2009) indicated that large-scale trends in benthic habitat over areas of 100s of km^2 are a major influence on rock lobster diet. These large scale trends are at least equally important to the site level variability observed in other dietary studies (Joll and Phillips 1984; Edgar 1990a; b).

Although a number of predators are likely to consume western rock lobsters, few studies have investigated the role of predation on *Panulirus cygnus* in the food web. Howard (1988) identified a range of fish species that prey on small post-puerulus (< 26 mm CL), including sand bass (*Psammaperca waigiensis*), sea trumpeter (*Pelsartia humeralis*), brown-spotted wrasse (*Pseudolabrus parilus*), gold-spotted sweetlips (*Plectorhyncus flavomaculatus*), breaksea cod (*Epinephelides armatus*) and the Chinaman cod (*Epinephelus homosinensis*) (Table 7 of the Appendix). Sand bass was considered the most important predator with almost 16 % of collected individuals containing lobsters. Brown-spotted wrasse and sea trumpeter were also abundant during the study, and it was suggested that these fish species could be responsible for large reductions of small post-puerulus within the area.

The vulnerability of rock lobsters to predation seems to be strongly related to the size of individual lobsters, with small fish predators consuming large numbers of lobsters within their first year of settlement. The extent of mortality of juvenile *P. cygnus* due to predation is largely unknown due to a lack of information on the natural densities of both fishes and lobsters on shallow near-shore reefs. It has been suggested, however, that the annual removal of juvenile rock lobsters by fish could be as much as thousands of lobsters per hectare, suggesting that predation may be an important factor limiting the survival of this size class. As rock lobsters increase in size, predation decreases. Larger predators such as octopus, large fish and sea lions are thought to prey on larger lobsters (Table 7 of the Appendix), although the limited data available for these predators suggests that no one species relies completely on the consumption of rock lobsters.

Rock lobsters act as secondary consumers in shallow and deep-water habitats (Figure 6.1), as they derive much of their growth from benthic animal prey that feed on primary producers (Joll and Phillips 1984; Edgar 1990a; b; Jernakoff *et al.* 1993; Waddington *et al.* 2008; MacArthur 2009). The lobsters are also grazers in shallow-water habitats where significant quantities of coralline algae and seagrass are consumed (Joll and Phillips 1984; Edgar 1990a; b; Jernakoff *et al.* 1993; MacArthur 2009). Shallow-water lobsters also consume large numbers of sponges and ascidians.

6.2.1 Diet

6.2.1.1 Shallow-water habitats

Joll and Phillips (1984) investigated the natural diet of juvenile western rock lobsters at two sites in Western Australia. Comparisons between the low growth rate site (Seven Mile Beach) and the high growth rate site (Cliff Head) were made over several seasons and between sex/age-class groups within each location. Results from the study showed significant seasonal variations of lobster food items and degree of foregut tilling at Cliff Head, whereas Seven Mile Beach showed little variation of food items but a significant degree of foregut tilling with time of year. The diet at both sites consisted of a broad but similar range of animal and plant material, such as coralline algae, molluscs, seagrass and 'worms'. The dominant dietary component, however, differed between sites. At Seven Mile Beach, foliose forms of coralline algae were the dominant food item making up 41.37 % of the total volume. Molluscs dominated the diet of lobsters at Cliff Head, in particular the trochid *Prothalotia lepidus* and the mytilid *Brachydontes ustulatus* that contributed up to 30 % of the total volume in some samples.

Although 'worms' such as nereid and eunicid polychaetes and sipunculids only contributed a small percentage of the diet at both sites, the frequency of occurrence suggested that they were a common food source. The crustacean diet component in both locations consisted of isopods, amphipods, small crabs and exoskeletal fragments of *P. cygnus*. Fleshy green algae was the main non-coralline diet item at Seven Mile Beach, with no dominant non-coralline algae identified at Cliff Head.

Seagrass fragments of *Amphibolis* spp., *Halophila ovalis*, *Heterozostera tasmanica* and *Syringodium isoetifolium* were detected in diet samples from both sites. This suggested that high densities of juvenile lobsters on the shallow coastal reefs of Western Australia, along with their broad dietary spectrum, have a significant grazing and predatory role on the structure of benthic communities within this habitat.

Predator-prey interactions in seagrass beds have been investigated by Edgar (1990 a; b; c). The same sites used by Joll and Phillips (1984), Seven Mile Beach and Cliff Head, were used to examine the influence of macro-faunal abundance and size-structure on the diet and growth of western rock lobsters. The guts of 245 *P. cygnus* from Seven Mile Beach and 141 *P. cygnus* from Cliff Head were dissected and analysed. The diet of lobsters at the two sites encompassed a wide dietary spectrum. The majority of food items consumed at Seven Mile Beach included molluscs, 'worms' and large quantities of epiphytic coralline algae, whereas lobsters at Cliff Head primarily consumed invertebrates. These lobsters were also found to consume less than lobsters at Seven Mile Beach. A preference for slow-moving, benthic prey, in particular molluscs, in the size range 2-5.6 mm sieve size was detected. However, when such prey occurred in low numbers, large quantities of plant food were ingested.

There were significant variations in diet and abundance of foraging individuals between seasons and between habitats at Seven Mile Beach, although no relationship was found between selection of foraging habitat and food availability. Foraging lobsters at Seven Mile Beach also differed greatly in size between different habitats. Individuals found in *Amphibolis* and turf habitats were significantly smaller than individuals collected from *Halophila* beds (72 % of lobsters in *Amphibolis* and 56 % of lobsters in turf habitat were smaller than 45 mm CL); however, the reason smaller sized lobsters preferred *Amphibolis* and turf habitats and larger individuals preferred *Halophila* beds was unclear. Results showed an ontogenetic shift in diet between smaller individuals and larger individuals, mainly confounded by seasonal variations in the diets of the smaller lobsters. The smallest size class of lobsters (25-30 mm CL) consumed large quantities of molluscs and small quantities of coralline algae in the summer months (December and March) compared to larger-sized lobsters that ingested more coralline algae and smaller amounts of molluscs during the same period. This was mainly attributed to high summer densities of molluscs larger than 2.0 mm sieve size. During the winter months, this pattern was reversed and large lobsters were found to consume more molluscs and less coralline algae than smaller sized lobsters. Such ontogenetic dietary shift was not present at Cliff Head.

Consumption of animal food items was greater by lobsters foraging in turf habitats compared to *Halophila* beds, but greater in foraging lobsters collected from *Halophila* beds compared to those foraging in *Amphibolis* habitat. A large quantity of animal material was ingested by lobsters in December and was mainly attributed to swarms of polychaetes found in the water column during this time. December and March also showed a higher abundance of foraging lobsters, particularly in turf habitats, compared to June when greater abundances of lobsters were found amongst *Amphibolis* habitat.

The dietary differences between the two areas and the higher growth rate of rock lobsters at Cliff Head were largely attributed to a very high recruitment of gastropods, i.e. *Cantharidus lepidus*, in late-summer. *Panulirus cygnus* was found to be a size-selective predator, choosing foraging strategies that reflect the availability of molluscs or slow-moving prey species. The lobsters were also capable of targeting high nutrient prey, as evident at Cliff Head, or ingesting large quantities of lower nutritional value food, such as epiphytic algae at Seven Mile Beach in June (Edgar 1990a).

In a related study, Edgar (1990c) used predator exclusion caging experiments to quantify any predatory impact of rock lobsters on epifaunal gastropods and investigate potential exploitative competition for molluscs. Predator exclusion cages were set up at Cliff Head and the abundance of the most prominent mollusc, *Cantharidus lepidus*, was estimated inside and outside the cages. *Panulirus cygnus* had a negative impact on *C. lepidus* in the study area, particularly in autumn and winter. Declines, as well as mortality, of larger (> 2.0 mm) individuals also occurred during the rest of the year. Densities of *C. lepidus* declined by approximately 50 % of the original estimates in the cage control and open *Amphibolis* habitats, with only slight decreases in the fully caged *Amphibolis* habitats. Between April and August in one particular year, an estimated 54 % decline of *C. lepidus* caused by rock lobsters was observed. An even greater decline of 89 % was observed between April and June in another year. Rock lobsters caused similar declines of large gastropods at other sites where they occurred in large numbers. For example, at Seven Mile Beach, patterns of mortality indicate that predation by rock lobsters on gastropods > 2 mm is a major influence in declines.

Intraspecific competition for food sources was believed to occur between rock lobsters because of their predatory impact on gastropods in the area. Large densities of rock lobsters caused rapid declines of *C. lepidus* through predation, presumably increasing the timeframe for which animal prey was suboptimal for growth. It was further suggested that similar rapid declines of *Stenochiton cymodocealis*, *Asteracmaea stowae* and *Pyrene bidentata* at Seven Mile Beach was most likely caused by *P. cygnus*. Intraspecific competition could potentially be of even greater importance at Seven Mile Beach, where the growth of rock lobsters is even more affected by prey shortages.

Interspecific competition with other carnivorous organisms has the potential to adversely affect *P. cygnus*. The blue manna crab *Portunus pelagicus* significantly reduces densities of *C. lepidus* of a similar size range to those consumed by rock lobsters. The crabs pick up and ingest molluscs faster than rock lobsters and may consume twice as many *C. lepidus* as individual lobsters each night. Estimated densities of the blue manna crabs were 0.024 crabs m^{-2} in June 1985. These densities would have reduced the numbers of *C. lepidus* by almost 10 m^{-2} night^{-1} (Edgar 1990b).

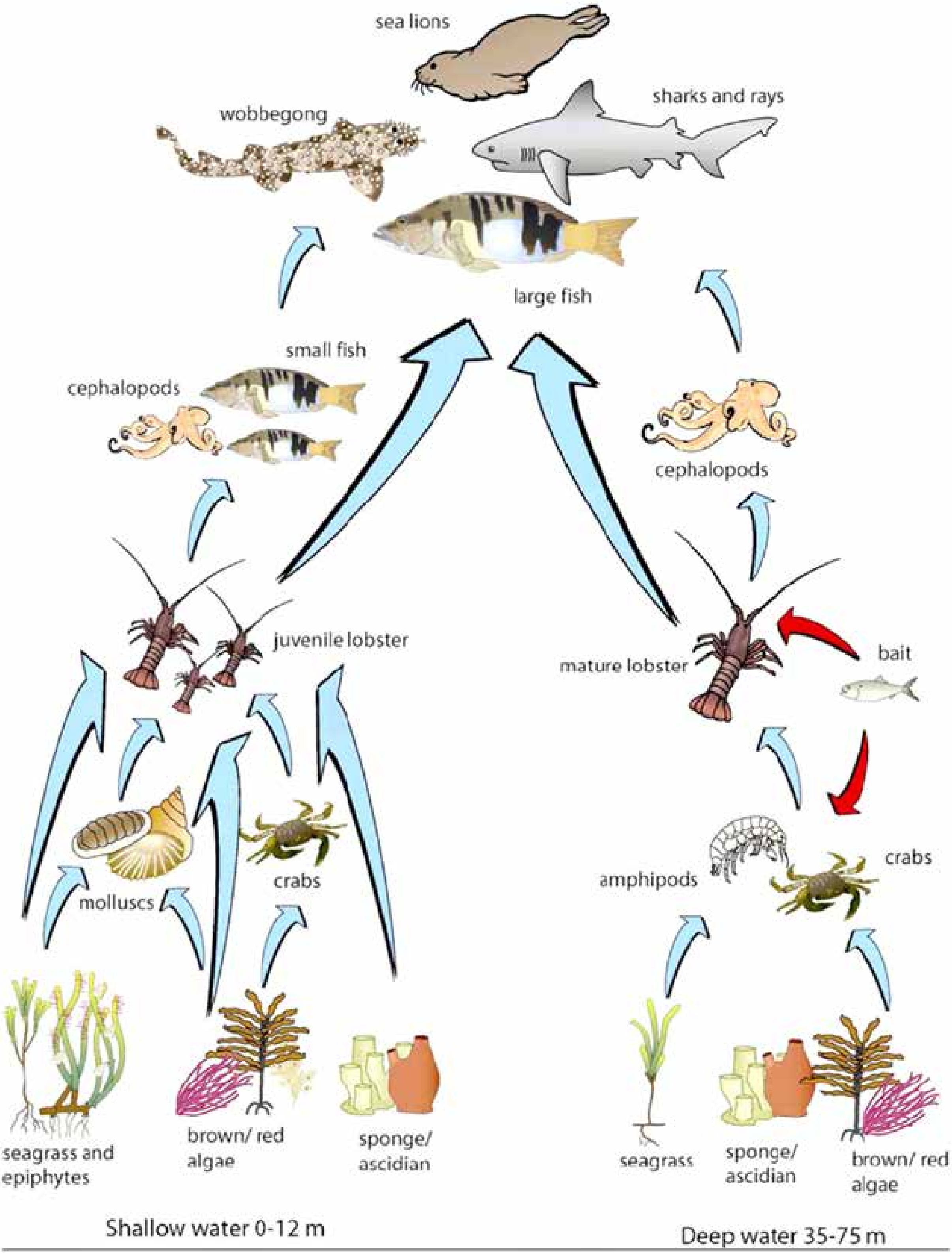

Figure 6.1. Food web of the western rock lobster showing energy flow between components in shallow-water and deep-water ecosystems (Source: MacArthur *et al.* 2007).

Other epifauna that consume large amounts of *C. lepidus* < 2.0 mm sieve size may be even greater competitors of rock lobsters than the blue manna crab. In an associated study by Edgar (1990c), densities of *C. lepidus* in microcosms were placed in the field with epifauna naturally occurring in *Amphibolis* habitats. Densities of *C. lepidus* were almost an order of magnitude lower (R+80 %) after a period of 2 months compared to identical microcosms where predators and competitors had been reduced. The number of *C. lepidus* was reduced by > 500 m^{-2} day^{-1} between March and May 1987. The epifaunal species that caused these reductions are likely have a greater effect on numbers of *C. lepidus* in a month, relative to the densities that would have been consumed by rock lobsters at Cliff Head over an entire year.

Jernakoff *et al.* (1993) wanted to determine whether the factors mentioned in the previous studies (e.g. range of diet, diet composition or food availability) were of equal importance in influencing the diet of post-pueruli. Ninety-five post-pueruli (CL< 25 mm) were collected from reef habitat and 106 from artificial collectors at Seven Mile Beach for foregut content analysis.

Foraging by post-pueruli occurred at night amongst *Amphibolis* beds and macro-algae and differed slightly from the 25-45 mm CL juveniles in Edgar's study (1990a) that foraged in *Amphibolis* beds and in 'turf' on reefs. They also differed from juveniles > 45 mm CL that had been found to forage in sparse *Heterozostera* and *Halophila* meadows away from the reef (Joll and Phillips 1984; Jernakoff 1987b; Edgar 1990a; b; c). The dominant dietary items of post-pueruli at all sampling times, all moult stages and from both natural reef environments and artificial collectors included coralline algae, molluscs and crustaceans. Post-pueruli from the reefs consumed greater quantities of coralline algae than molluscs, compared to post-pueruli from the collectors that mainly consumed molluscs. The observed differences in gut content of post-pueruli between natural reef habitats and artificial collectors may be due to differences in food availability. For example, the large amounts of molluscs consumed by lobsters from collectors may reflect the low availability of other dietary items settling on the collectors.

Significant dietary variation in relation to different moult stages of rock lobsters (e.g. foraging, proportion of dietary components and differences among sampling dates) was also observed. Intermoult post-pueruli were more abundant foragers than other moult stages, which could be attributed either to this moulting stage being more active foragers or a greater number of intermoult post-pueruli in the population. A higher percentage of pre-moult animals had foreguts < 10 % full compared to intermoult post-pueruli that were more likely to have foreguts > 10 % full, suggesting higher feeding rates of intermoult animals compared to pre-moult animals. The proportion of coralline algae was significantly higher in post-moult rock lobsters compared to other moult stages, whereas the proportion of molluscs was higher in intermoult animals compared to other moult stages. Intermoult post-pueruli showed significant variation in proportion of diet items at different times of sampling. Greater quantities of coralline algae were found in the foreguts of intermoult lobsters in March 1987 compared to December 1986 or February 1987. The highest amount of molluscs was detected in December 1986.

Joll and Phillips (1984) and Edgar (1990a; b; c) noted similar temporal variation for larger juvenile rock lobsters suggesting this variation may reflect the relative abundance of prey at the site. The dietary spectrum of the post-pueruli and larger juveniles at Seven Mile Beach was also similar; all sizes of rock lobsters consumed coralline algae, molluscs, crustaceans and 'worms', although there was variation in the proportion of each dietary item. Differences in abundance of prey, ability to capture food or an active preference for certain food items may be responsible for this variation.

MacArthur (2009) investigated whether the diet, nutrition and trophic interactions of *P. cygnus* would be significantly influenced by the benthic habitats (*Amphibolis* spp. meadow, *Posidonia* spp. meadow and macroalgae-dominated pavement) surrounding reefs. Stable isotope and gut content analysis were performed to determine individual diets of lobsters collected from eight shallow reef sites within Jurien Bay Marine Park. Stable isotope data was also used to ascertain whether rock lobster nutrition is supplemented by articulated coralline red algae and whether trophic linkages exist between rock lobsters and primary producers. A distance-based redundancy analysis was generated to compare habitat related variation (*Amphibolis* spp., *Posidonia* spp. and macro-algae/sand) with between-site spatial variation (8 sites), temporal variation (April or October), between sex variation (male or female), carapace length variation, and gut fullness variation. A modified mass balance mixing model (IsoSource) was performed incorporating nine natural food sources considered important to rock lobster diet, as well as bait input for animals collected from macro-algae/sand habitat. These habitats were subjected to commercial and recreational fishing activities in the fishing season (using baited pots) throughout the course of the study.

The distance-based redundancy analysis showed that the most important influence on dietary variation of rock lobsters in Jurien Bay Marine Park was benthic habitat surrounding reefs, such as seagrass or macro-algae/sand. Different habitat composition accounted for variations of 7.0 and 52.7 % in gut contents and stable isotopes, respectively. These habitat-related variations were attributed to significant differences between seagrass meadows and macro-algae/sand habitats. Rock lobsters in the marine park were found to consume a range of animal and plant food. Animal prey included gastropods, polyplacophorans, bivalves, crustaceans, echinoderms, polychaetes, sipunculans, hydrozoans, bryozoans, ascidians, sponges and teleosts. Gastropods, crustaceans and sponges/ascidians contributed greater volumes to gut contents than other groups.

Lobsters collected from macro-algae/sand habitats contained greater quantities of animal material than plant material (51.5 vs. 38.1 %). The reverse was observed in lobsters collected from seagrass meadows (37.4 vs. 55.4 %). Lobsters in seagrass meadows consumed greater volumes of gastropods, in contrast to lobsters in macro-algae/sand habitats that consumed greater volumes of echinoderms and sponges/ascidians. Shell fragments of *P. cygnus* were a dominant feature in lobsters collected from macro-algae/sand habitats indicating that cannibalism may play an important role in lobster nutrition in shallow-water habitats. It was also suggested that bait input from the fishery may provide an important contribution to the nutrition of lobsters in areas exposed to fishing activities. The high consumption of animal prey indicated that although rock lobsters act as a functional omnivore, their role in the ecosystem energy transfers is more of a carnivore.

A range of coralline algae and seagrasses were consumed by rock lobsters, particularly articulated coralline red algae, which was the most important food source in terms of volume (28.0-33.3 %). *Amphiroa anceps*, *Metagoniolithon* sp., *Haliptilon roseum* and *Jania* sp. were the main species of articulated coralline red algae found in lobster guts, while the main species of seagrass included *Amphibolis* spp. and *Posidonia* spp. Articulated coralline red algae was the most important food source in macro-algae/sand habitats and was shown to contribute to the muscle nutrition in *P. cygnus*. It is likely that articulated coralline red algae provide an important resource for rock lobsters throughout their range. Although the consumption of this particular food source is high, animal prey, such as mobile invertebrates, were found to be more important to lobster nutrition (at least 44 % of diet) in both types of habitat (seagrass and macro-algae/sand). A higher contribution of animal prey to lobster nutrition in seagrass habitat (possibly contributing up to 98 % of the diet) compared to macro-algae/sand habitat (78 % of diet) was observed. The reason for this pattern is most likely due to the higher availability of invertebrate prey in seagrass habitats. Shallow inshore areas where seagrass beds are dominant and where lobster diet is dominated by mobile invertebrates may support higher growth rates of rock lobsters compared to areas surrounded by macroalgae-dominated pavement and bare sand.

The configuration of benthic habitats and patch reefs over areas of 100s of km^2 may be an important determinant of rock lobster diet in shallow-water habitats and would be equally important with the site level variability found in other studies (Joll and Phillips 1984; Edgar 1990a; b; c). A direct trophic link between rock lobsters and primary producers through consumption of articulated coralline red algae was detected although the strongest trophic link was the consumption of invertebrate prey, in particular mobile invertebrates. In addition, it was suggested that bait input from the fishery provides an important contribution to the nutrition of lobsters in areas exposed to fishing activities, which has also been shown for rock lobsters in deep-water habitats (Waddington *et al.* 2008). The results also showed that cannibalism may occur in populations of rock lobsters in shallow coastal waters and could provide an important source of nutrition.

Dumas (2010) examined prey preferences of different sized western rock lobsters in the laboratory to gain a better understanding of size-associated differences in predator-prey interactions of *Panulirus cygnus*. The study found that large lobsters preferred crabs and mussels to other food items, whereas medium and small lobsters showed preferences for crabs rather than mussels, gastropods and sea urchins. In the wild, large *P. cygnus* may have strong potential predator-prey interactions with mussels and crabs, while medium and small *P. cygnus* may only have strong interactions with crabs. As both mature and juvenile lobsters showed a preference for crabs, it was suggested that differences in prey selection between deep and shallow coastal rock lobsters may reflect differences in prey availability between these ecosystems. The study also found that only large western rock lobsters were capable of consuming sea urchins, supporting field-based studies that showed a weak predator-prey interaction between *P. cygnus* and sea urchins (Edgar 1990b; Joll and Phillips 1984). Weak predator-prey interactions between *P. cygnus* and gastropods found in this study contrast with a field-based study by Edgar (1990c), where juvenile rock lobsters were found to strongly influence the abundance and size distribution of a trochid gastropod *Cantharidus lepidus*.

6.2.1.2 Deep-water habitats

Few studies have investigated the diet of rock lobsters in deep-water habitats. Waddington *et al.* (2008**)** used stable isotope and gut content analyses to provide a preliminary evaluation of the diet and trophic position of *P. cygnus* in mid-shelf coastal environments (35-60 m depth) at Lancelin, Jurien and Dongara. Catch and effort statistics from the Department of Fisheries, Western Australia, show a significant difference in the size structure of lobsters in deep-water habitats to those in shallow-water habitats. The largest proportion of the adult population inhabits deeper, offshore environments with approximately 25 % of rock lobsters being > 80 mm CL in water deeper than 35 m.

Lobsters were found to be primarily carnivorous consuming large quantities of crabs, amphipods/isopods, bait (from pots and discards) and small amounts of foliose red algae, sponges and bivalves/gastropods. The diet did not differ significantly between sexes and sizes of lobsters or among locations. Both techniques used in the study showed that bait contributes 30-80 % of the diet, although the two techniques gave different outcomes in relation to the proportion of prey to lobster diet. The gut content analysis indicated that crabs were the main food source of rock lobsters, whereas the stable isotope analysis identified bait as the most important food source. This difference may be attributed to the different time scales of each method and the variation in prey evacuation rates from lobster guts. For example, the survey was conducted during the peak fishing season, which may have been a contributing factor to the large quantities of bait identified in the diet of lobsters, and it was suggested that bait contribution to lobster diet might be lower throughout the entire year. The higher contribution of crabs to the diet of rock lobsters, derived from gut content analysis, may also be an overestimate. It was acknowledged that slow evacuation rates of this hard-shelled prey species from lobster guts, in comparison to other rapidly evacuated prey such as foliose red algae, might have influenced the high amount of crab substance found.

A clear electivity by rock lobsters for certain prey at Jurien was observed and suggested that a variety of factors, including selection for or against prey, accessibility of prey or varying evacuation rates of prey, may be responsible for this pattern. The strong selection for crabs and amphipods/isopods relative to polychaetes, sponges and foliose red algae (important food items of lobsters in shallow coastal ecosystems) most likely reflects differences in availability of these prey items between the systems with low availability of polychaetes, sponges and foliose red algae in deep-water habitats.

The carnivorous diet of *P. cygnus* in deep-water environments suggests a stronger interaction between lobsters and macro-invertebrates in these habitats compared to shallow-water ecosystems where lobsters are omnivores. Lobster removal due to fishing activities would therefore have a greater impact on macro-invertebrate community composition in deep-water habitats. The trophic position of lobsters differed significantly between locations and ranged between 1.90 and 2.18. Lobsters at Lancelin showed the highest trophic level, while Jurien lobsters were intermediate and lobsters from Dongara occupied the lowest trophic level. In contrast, the trophic position of lobsters in shallow-water habitats at Jurien ranged between 1.50 and 1.60 (MacArthur 2009), thus reflecting the importance of algae in these habitats (Joll and Phillips 1984; Edgar 1990a; b; c; Jernakoff *et al.* 1993).

6.2.2 Predators

6.2.2.1 Shallow-water habitats

Howard (1988) conducted a trophic study at Seven Mile Beach to determine whether the fish community in reef nursery areas is responsible for significant juvenile lobster mortality. A total of 1 735 fishes of 75 species were collected using gill-nets and rotenone. Abundance and habitat associations of fishes, timing of predation, frequency of occurrence and volume of *P. cygnus* in fish diets and size distribution of predators and prey were investigated.

Juvenile *P. cygnus* was found in the gut content of five fish species at the study site: the sand bass *Psammaperca waigiensis* (Centropomidae), the sea trumpeter *Pelsartia humeralis* (Teraponidae), the brown-spotted wrasse *Pseudolabris parilus* (Labridae), the gold-spotted sweetlip *Plectorhyncus flavomaculatus* (Pomadasyidae), and the breaksea cod *Epinephelides armatus* (Serranidae). Predation was concentrated on small, newly-settled lobsters (8-15 mm CL) and occurred throughout the day. *Psammaperca waigiensis* was the main predator of lobsters, with 16 % of individuals found to have consumed juvenile lobsters. Proportion of lobsters found in the diet (in terms of total dietary volume) was also higher for the sand bass (16.3 %) than other species of fish collected (< 5 %). It was suggested that sand bass may be a specialist predator on lobsters in nursery habitats. Since the study site was located near the southern end of the distribution of *P. waigiensis*, impacts of this fish on juvenile rock lobsters may possibly be greater in areas at the northern end of *P. cygnus'* geographical range, which would overlap with the centre of the range of *P. waigiensis*, where numbers may be higher. Another frequent predator of juvenile rock lobsters at Seven Mile Beach was the sea trumpeter (*Pelsartia humeralis),* although consumption of *P. cygnus* by this species most likely represents the upper size limit of prey. The other fish predators of *P. cygnus* collected in this study did not appear to have the same impact on juvenile rock lobsters as *P. waigiensis* and *P. humeralis*.

Fish collected from reefs or reef-edge habitats were found to have consumed the highest amount of *P. cygnus*. A size-dependent pattern of predation emerged with lobsters taken by fish being < 26 mm CL, representing the 1+ age class of lobsters. This may be due to smaller sized predators (< 40 cm) being more common in the area than larger predators.

Predation of juvenile *P. cygnus* was determined to be a common occurrence in limestone nursery reef habitats with an average mortality rate, due to predation, of 2 500 individuals ha^{-1} of reef habitat. This number is most likely an underestimate because of the low sampling effort relative to size of study area.

6.2.2.2 Deep-water habitats

There have been no studies investigating predation of Western Australian rock lobsters in deep-water ecosystems.

6.2.3 Modeling

6.2.3.1 Shallow-water habitats

An Ecopath model was developed by Lozano-Montes *et al.* (2011) to quantify the interaction of prey, predators and the rock lobster fishery in Jurien Bay Marine Park. The model contained 250 species that were aggregated into 80 functional groups based on similar functional ecosystem roles or significance to fishing. A set of model parameters including *Biomass*, *Consumption rates* (*Q/B)*, *Production per unit of biomass* (*P/B*) and *Diet composition* were used in the analysis.

The functional species groups covered more than four trophic levels (TL). Sharks occupied the highest trophic level of the ecosystem, whereas primary producers, detritus and other non-living groups (e.g. detached algae and bait) represented the lowest level (TL1). Due to the nature of rock lobster dietary characteristics (generalist feeders that feed on a range of plants and animals) the TL of adult lobsters was 2.7. Jurien Bay Marine Park was found to be dominated by the lowest trophic levels (TL1 and TL2), as the majority of functional species groups had a trophic level lower than 3.5 and comprised 80 % of the total biomass (1 229 t km^{-2} $year^{-1}$).

The mixed trophic impact analysis (MTI) showed that several of the functional groups (> 60 %) were influenced by changes in the biomass of benthic groups (e.g. *Ecklonia*, seagrasses, macro-algae, phytoplankton and benthic invertebrates). When the biomass of *Ecklonia* increased, the biomass and trophic flows for groups such as post-puerulus rock lobster, juvenile rock lobster and crabs also increased. The overall relative change in MTI (biomass and energy flow) of post-puerulus, juvenile and adult rock lobsters was 0.22 (a change almost double the magnitude of change in *Ecklonia* production). A possible explanation for this strong response by lobsters to changes in biomass of *Ecklonia* could be attributed to the food substrata and shelter the seaweed provides for lobsters. The MTI analysis also investigated the trophic role of adult rock lobsters and showed that even a small simulated increase in the MTI of adults resulted in a theoretical increase in lobster catch (18 %) and a small decline of biomass and trophic flows of lobster prey (e.g. coralline algae, small gastropods, epifauna, crabs and small grazers), as well as a decrease in biomass and trophic flow to juvenile lobsters. The increase in adult lobsters also resulted in a small theoretical increase in biomass and trophic flow of lobster predators such as small sharks, rays, octopus and sea lions.

The results of the study indicate that Jurien Bay Marine Park is a dynamic ecosystem (Primary Production:Biomass ratio = 1.68) showing low recycling rates and is dominated by benthic functional groups (biomass of benthic:pelagic groups = 1.27). The dominance of benthic communities suggests a greater importance of bottom-up processes than top-down interactions, driven primarily by *Ecklonia*, seagrasses and macro-algal communities that are the main habitat and food source for many invertebrates and fish species in the marine park.

6.2.3.2 Deep-water habitats

Waddington and Meeuwig (2009) constructed a mass balance model to determine potential contribution of bait to lobster diet in deep coastal ecosystems at Jurien. The model was based on the principle that rock lobster biomass reflects variation between inputs (growth and immigration parameters) and outputs (natural and fishing mortality and emigration parameters). This approach was used to determine rock lobster biomass in the area and compare food required to explain observed lobster growth, thus allowing examination of the potential contribution of bait versus natural food items to lobster diet. The model used reef habitat as the study area and incorporated a year's data between November 2002 and November 2003 to ensure inclusion of the fishing season.

Several parameters were used in the model including lobster *biomass* (sub-legal and legal), *growth coefficient* of the population, *immigration*, *natural mortality* and *fishing mortality*, *emigration*, *estimated reef area*, *Food Conversion Ratio* (FCR), *abundance of natural food items* and *bait input*. Biomass of lobsters was 876 096 kg at the start of the study period, and the population growth coefficient was estimated as 0.043 kg month^{-1}. Immigration biomass into the study area was 456 077 kg, whereas emigration from the area was assumed to be nil, as lobsters do not tend to migrate inshore after migration to deep-water habitats. Coefficient of natural mortality was estimated as 0.23 and fishing mortality as 664 609 kg yr^{-1}. Reef area parameter encompassed 35 000 ha and the value of FCR was 9.09. Abundance of natural dietary components was 266 ±101 kg ha^{-1}yr^{-1} whereas bait input was estimated to be 582 275 kg yr^{-1}. Uncertainty around model estimates was managed by estimating lower and upper limits for each model parameter.

In a year, bait was found to contribute approximately 13 % of lobster food requirements over the whole ecosystem, assuming preferential consumption of bait. It was suggested that the contribution of bait was most important between December and April with potential contribution averaging 26 %. The highest contribution of bait was recorded in January (33 %) and April (34 %), when fishing effort, and hence bait input, was the highest. The suggestion by Waddington *et al.* (2008) that bait may comprise up to 80 % of western rock lobster diet, based on stable isotope analysis (or 13 % based on gut content analysis) is therefore most likely an overestimate. The sites selected for sampling in the 2008 study were located in high relief areas (areas of optimal lobster habitat) with collection of lobsters occurring in April-May (fishing season), resulting in overestimation of the importance of bait to lobster production when considered on the scale of the whole ecosystem.

The consumption of bait by rock lobsters in the study area may cause a significant reduction in predation pressure on taxa that normally form the basis of rock lobster diet such as crabs, amphipods and isopods. This release of predation pressure could result in such taxa increasing in abundance on a localized scale, thereby increasing competition with small invertebrate fauna (e.g. polychaetes). This could have important implications on ecosystem functioning in areas of high bait input. The amount of bait added annually to the study area is significant (1.13 kg of bait added for every 1 kg of lobster) given the oligotrophic nature of the marine environment in Western Australia and raises concerns in relation to the eco-efficiency of bait usage in the fishery. Bait input represents a direct subsidy to lobster production and will be most important to sub-legal rock lobsters (due to specific fishery requirements) and in areas where rock lobsters are thought to be most abundant, thereby increasing contribution of bait to populations on a localized scale. Potential bait contribution will show temporal and spatial variation over the year reflecting variation in fishing effort and could be as high as 35 % in months when fishing effort is high. This result is consistent with stable isotope dietary studies.

Metcalf *et al.* (2011) produced a series of qualitative models of varying complexity to investigate indirect trophic change of deep-water habitats in Jurien Bay caused by the West Coast Rock Lobster Managed Fishery. The models were designed to identify potential indicators of indirect trophic change and to assess species closely associated with rock lobster (e.g. octopus) and impacts of the fishery and bait on the trophic web. Complex, intermediate and simplified models were used to assess the effect of simplification (aggregation of variables) and determine the best model to use for identification of indicators. Dietary information for a range of species in the ecosystem was gathered and used as input in the model. When there was no site-specific diet information, dietary data from other sites in southwestern Australia, similar to Jurien Bay, was used. A complex model was constructed incorporating all dietary information. To reduce uncertainty, the model underwent a simplification process and alternative models were produced. A model of intermediate complexity was used to identify more specific indicators of trophic change.

Species with comparable functional roles in the trophic web (e.g. bycatch species), the fishery and those that shared similar life history traits and habitat requirements were aggregated into single variables. For example, the variable *demersal scalefish* was comprised of dhufish, pink snapper, baldchin groper and breaksea cod, whereas the variable *small fish* (*unidentified*) was combined with the footballer sweep, old wife, king wrasse and foxfish to generate a single variable called *general fish*. Amphipods were aggregated with isopods into the variable *small crustaceans* and gastropods were merged with bivalves. The *predator* variable included *Australian sea lions* and *small sharks*. The intermediate model further disaggregated the indicator variable *general fish* into four new variables: *sweep, wrasse*, *foxfish, old wife* and *small fish* based on similarities of prey and predators. All these variables were given an indirect positive impact from the fishery through bait input and subsequent increase in *small crustaceans*. The *foxfish* variable was the only disaggregated variable predicted to decline from impacts of the fishery.

The results identified the variable *general fish* as the most suitable indicator of overall change to the ecosystem caused by fishing activities, as the fishery was found to have an indirect impact on the abundance of this variable. This species group benefits from reduced competition for food resources through the removal of lobsters by the fishery. In addition, bait input into the system was believed to increase the abundance of this group through the increased availability of prey. The variable *small crustaceans* was found to be a suitable indicator of bait effects. The results of this study support the suggestion by Waddington and Meuuwig (2009) that bait input may have significant effects on the trophic webs of coastal ecosystems. Evidence of indirect fishery impacts at multiple trophic levels within the ecosystem could be obtained by using all identified indicators of change caused by the fishery (*old wife*, *footballer sweep* and *king wrasse* and *small crustaceans*).

Table 6.2. Summary of research (completed and ongoing) investigating the trophic role of western rock lobsters.

Author	Date	Location	Depth	Habitat	Methods	Size-class	Trophic findings	Remarks
Joll and Phillips	1984	Cliff Head and Seven Mile Beach	< 5 m	Open reef face, reef ledge and cave habitats	Gut content	Juveniles	Foliose coralline algae (predominantly two spp.) important at Seven Mile Beach. Molluscs important at both sites, but volumetric contribution fluctuated between sites and seasons.	Fluctuations in a small number of mollusc spp. at Cliff Head responsible for seasonal variation at that site. Juveniles had higher growth rates at Cliff Head.
Howard	1988	Seven Mile Beach	2-4 m	Seagrass covered limestone reefs and open habitats	Gut content of fish caught by gill net and rotenone	Small post-puerulus (< 26 mm).	Sand bass (*Psammaperca waigiensis*), sea trumpeter (*Pelsartia humeralis*) and brown-spotted wrasse (*Pseudolabrus parilus*) most important predators of post-puerulus.	The vulnerability of lobsters to predation strongly related to size (greatest predation on 8-15 mm CL). Cryptic habits of newly-settled stages related to predation risks.
Edgar	1990a; b; c	Cliff Head and Seven Mile Beach	< 5 m	*Amphibolis*, *Halophila* and turf habitats.	Gut content	Juveniles (25-85 mm)	*Cantharidus lepidus* consumed in high quantities when seasonally abundant at Cliff Head and polychaetes consumed in large numbers when seasonally abundant at Seven Mile Beach.	Lobsters can significantly reduce epifaunal gastropods densities in seagrass meadows adjacent to reefs.

Table 6.2. Continued.

Author	Date	Location	Depth	Habitat	Methods	Size-class	Trophic findings	Remarks
Jernakoff *et al.*	1993	Seven Mile Beach	< 5 m	Natural habitats dominated by seagrass (*Amphibolis* spp. and *Halophila ovalis*/ *Heterozostera tasmanica*) and artificial collectors	Gut content	Post-puerulus juveniles within 1st year after settlement, (< 25 mm)	Dominant dietary items were coralline algae, molluscs and crustaceans. Coralline algae important to post molt stages. Proportionally, post-pueruli consume less coralline algae and more molluscs than the larger juveniles (> 25 mm) at the same sites.	Post-pueruli not foraging in turf on top of reefs (unlike older age classes). Molluscs greatest component of diet of post-pueruli on collectors (Possibly because coralline algae not available on collectors).
MacArthur *et al.*	2007	South West Marine Region	Shallow and deep		Synthesis		Reviews previous trophic work. Includes comments on the prey and predators of western rock lobster. Highlights gaps in knowledge of trophic relationships in deep-water.	Comments on the potential of predation by different species including small sharks and sea lions.
Waddington *et al.*	2008	Lancelin, Jurien, Bay Dongara - mid-shelf coastal	35 - 60 m	*Ecklonia*-dominated reef	Gut content & stable isotopes	53 to 145 mm CL	Main dietary items included crabs, amphipods/isopods, lobster bait and smaller amounts of foliose red algae, sponges and bivalves/ gastropods. Gut content analysis suggested crabs important – (slow evacuation rate for hard shelled items). Stable isotopes suggest bait important at certain times (varies seasonally).	Trophic position of lobsters differed significantly between locations and ranged between 1.90 at Dongara and 2.18 at Lancelin. Jurien Bay lobsters were intermediate (all higher than shallow-water where algae is important).

Table 6.2. Continued.

Author	Date	Location	Depth	Habitat	Methods	Size-class	Trophic findings	Remarks
MacArthur	2009	Jurien Bay Marine Park	< 15 m	Seagrass or macroalgae/ sand	Gut content & stable isotopes	36 - 98 mm	Type of habitat surrounding a reef was a better predictor of *P. cygnus* diet on a landscape scale than site, sex, carapace length or month. Animal prey including mobile invertebrates important to lobster nutrition and preferentially assimilated over articulated coralline red algae. Trophic position of lobsters ranged between 1.50 and 1.60.	Macro-algae, rather than seagrass, most likely autochthonous energy source driving lobster production in shallow coastal waters, but seagrass likely plays an important role providing lobsters with mobile invertebrate prey and shelter whilst foraging. Bait and cannibalism may have a more significant role for lobster nutrition in shallow environments than previously thought.
Waddington and Meeuwig	2009	South West Marine Region	Shallow and deep		Modelling - mass balance		Abundance of natural diet items on the benthos sufficiently explain the observed growth of lobsters, with bait contributing max 13% of lobster food requirements over the whole ecosystem. Contribution of bait varies spatially and temporally reflecting uneven distribution of fishing effort (may be ca 35% during some months of the fishing season).	Concludes that it is likely that the effects of bait addition on ecosystem function are more widespread than lobster production.

Table 6.2. Continued.

Author	Date	Location	Depth	Habitat	Methods	Size-class	Trophic findings	Remarks
Lozano-Montes *et al.*	2011	Jurien Bay Marine Park	Shallow water	Various	Modelling - Ecopath	Various including post-puerulus and adults	Many functional groups, including rock lobster, are influenced by changes to biomass of benthic groups e.g. *Ecklonia*. (due to food and shelter *Ecklonia* habitats provide). Changes to lobster biomass affect the simulated biomass of key prey groups and predators of lobster.	Based on diet literature and expert opinion/workshops. The simulations suggest that the structure of this ecosystem is characterized more by bottom-up than top-down processes i.e. benthic primary production is a major limiting factor.
Metcalf *et al.*	2011	Jurien	Deep water	*Ecklonia*-dominated reef	Modelling - qualitative	Mature / near mature	Conceptualises trophic relationships in deep-water benthic ecosystem by synthesizing available diet literature. Results suggest general fish and small crustaceans have potential as indicators of ecosystem effect of lobster fishing.	Qualitative modelling used to identify potential indicators of ecosystem change. Results also highlight gaps in trophic knowledge, i.e. relationships between octopus and lobster fishery.
Moore *et al.*	Ongoing (WAMSI)	Metropolitan region. Areas of contrasting lobster abundance (sanctuaries)	< 15 m	Seagrass beds (*Amphibolis* spp.)	Gut content and stable isotopes. Seagrass assemblage structure.	up to 112 mm	Assemblage structure noisy (highly variable between replicates). Density effect not apparent on whole assemblage, only small number of molluscs in some months.	Appears to be negative relationships between lobster density and mollusc abundance (trochids). Density of lobster does not appear to affect diet (based on stable isotope signatures).

6.3 Climate Change

Caputi *et al*. (2010a) investigated climate change effects on puerulus settlement, catchability, females moulting from setose to non-setose, timing of moults, and peak catch rates of the western rock lobster. Environmental factors such as water temperature, the Leeuwin Current (strongly influenced by El Niño events) and storms and westerly winds in late-winter/spring were assessed as they affect several stages of the western rock lobster lifecycle. The study focussed on changes that have occurred over the past 35 years.

Climate change has caused a significant warming trend (about 0.02 °C $year^{-1}$) in sea-surface temperatures in the southeastern Indian Ocean, including the centre of western rock lobster distribution. This increase in temperature has resulted in a decrease in size at maturity of western rock lobsters, and declines in size at maturity of about 10 mm CL between 1973 and 2006 has been reported (Melville-Smith and de Lestang 2006). The onset of maturity at a smaller size could affect overall growth rate and productivity of the lobster stock. The study also showed that there has been a decrease in the size of migrating lobsters from shallow to deep-water (approximately 3 mm CL over 32 years), increases in abundance of undersized and legal-sized lobsters in deep-water relative to shallow-water, with increases in catch rates of 4.9 % in the northern region and 3.8 % per year in the southern region over 36 years, and shifts in catch to deep-water.

Climate change also weakens westerly winds in the winter months and causes increases in the frequency of El Niño events. If this trend continues, it would have a proportionally greater impact on the southern part of the fishery. Further knowledge of climate change impacts on the western rock lobster is necessary, especially due to the low settlement of puerulus in the past three years (2008 showed the lowest settlement in 40 years). Due to this low-settlement pattern, the lowest catch in over 40 years is predicted for 2011-2012. The warming trend is predicted to continue with increases of 1-2.8 ºC expected by 2030. As many stock assessment models make assumptions that key parameters such as growth, mortality, size at maturity, and size of migration are stable, it is important to question such assumptions if the fishery is being modelled over years when climate changes have occurred.

The aim of a recent FRDC tactical research funded project, conducted by Caputi *et al*. (2010b), was to determine the relative contribution of larval production from different areas to the abundance and spatial distribution of puerulus settlement over 15 years using a larval advection model. The project has provided an initial oceanographic model of the larval stage of the western rock lobster that enables a preliminary assessment of the source-sink relationships for this stock.

The results of the model indicated that settlement success is much higher for phyllosoma released from deeper water areas (60 and 80/100 m depths compared to 40 m) closer to the edge of the continental shelf. This could be a reflection of the additional mortality associated with shallower-released phyllosoma staying on the shelf for a more extended period compared with those released in deeper water. The model also showed that early larval release (mid-October to early-December) resulted in a greater survival rate of puerulus compared to late release (mid-January to February). Early-release phyllosoma larvae experience a longer period of warmer temperatures during the summer, which enable them to grow faster and increase their chance of survival.

While the model showed a general north to south trend in settlement success from larval releases from Abrolhos (28° S) to the Fremantle region (32° S), there was variability in this trend between years. This declining trend of likely settlement success from north to south indicates that the more northern sources are likely to be more important in most years. However, a limited assessment of variations in the source-sink relationship among years did highlight that the north-south trend can vary significantly with the southern areas more important than the northern regions in some years. The initial results therefore suggest that while the breeding stocks in the northern areas, including the deep-water Big Bank stocks, may be particularly important, the breeding stocks in all regions need to be maintained at appropriate levels.

7.0 Current and On-going Research

7.1 Houtman Abrolhos Islands

7.1.1 Background

The Houtman Abrolhos Islands (Abrolhos) are an archipelago of small islands approximately 65-90 km offshore from Geraldton, Western Australia, (28 to 29° S and 113°35' to 114°03' E) (Wells 1997). The Abrolhos are divided into three island groups, the North Island-Wallabi Group, Easter Group and Pelsaert (Southern) Group, separated by channels with depths of about 40 m. Situated near the edge of the continental shelf, the Abrolhos contain the southern most coral reefs in the Indian Ocean. The islands are extremely diverse for the high latitude at which they occur, with 184 species in 42 genera recorded (Veron and Marsh 1988; Wells 1997). This is due primarily to the Leeuwin Current, a warm, southward flowing current that is strongest in autumn and winter and bathes the islands in tropical water. The unusual current pattern provides the islands with a unique habitat, made up of a mixture of tropical and temperate species (Wells 1997). The uniqueness and ecological value of the Abrolhos resulted in their placement on the National Estate Register (under the Australian Heritage Act [1975]), and were gazetted as Western Australia's first Fish Habitat Protection Area under the Fish Resources Management Act (1984) (Webster *et al*. 2002).

The Abrolhos also have a significant economic value due to the commercial fisheries that operate at the islands, the most significant of which is for the western rock lobster (*Panulirus cygnus*). This fishery began in the 1940's, with the catch taken from the islands making up approximately 5 % of the annual catch in Western Australia (Fletcher and Santoro 2010). While the islands provide a significant source of the annual western rock lobster catch, they are also important to the fishery as a significant source of the total western rock lobster egg production. Thus, the islands provide a critical habitat for the continued sustainability of the fishery (Webster *et al.* 2002).

Understanding the source and magnitude of anthropogenic disturbance from fishing and other activities on the corals of the Abrolhos is critical to the management and conservation of the islands' coral habitats. Ultimately, the health of the islands affects their economic, ecological and social value. As one of the biggest users of the Abrolhos, the western rock lobster fishery may be a significant source of anthropogenic disturbance on the coral ecosystems of the islands. There are several current and on-going studies being conducted by Department of Fisheries WA to assess the benthic habitats and determine the extent and impact of lobster potting on the sensitive habitats of the Abrolhos.

7.1.1.1 Habitat mapping

In 2010, Department of Fisheries WA obtained State Natural Resource Management (NRM) funding to map the shallow reef habitats of the Abrolhos. In collaboration with Department of Environment and Conservation (DEC – Remote Sensing), ALOS AVNIR imagery (high spatial resolution data) has been used to produce a 'first-pass' classified image of the Abrolhos. This habitat map has been used to select sites for field validation of the habitat classes. Field validation for the Wallabi Group was conducted in March and April 2010 using towed and drop cameras. The results of the field validation and expert knowledge/input are currently being used to adjust and re-analyse the habitat classification for the Wallabi group. Completed habitat maps of the Abrolhos Islands will be available in late-2011.

7.1.1.2 Determining potting density on sensitive habitats

To determine the density of potting around the Abrolhos, Department of Fisheries conducted aerial surveys at the start and end of the western rock lobster fishing season. The first aerial survey was conducted in June 2006. Using a high-winged Cessna 210, a total of 11.5 flying hours were completed, flying at a height of approximately 500 ft and speed of 100 knots. The second aerial survey was conducted in April 2011 using the same methods. A structured survey was conducted using a minute-by-minute grid pattern, either by latitude or longitude, but flown in the same direction per island group. At each minute along the survey line, observers recorded the number of pot floats in the area. Potting density was recorded from both sides of the aircraft to a set distance of approximately 500 m. This distance was calculated by marking the windows of the plane so the viewing angle below the line was approximately 73 degrees. Only pots seen under the window mark, within a 500 m swath of the planes flight path (on both sides of the plane, which equates to approximately 1000 m wide survey swath) were recorded. To ensure the survey area was similar for each observer, the observers adjusted their seating positions to the same level.

Potting abundance data from the June 2006 surveys were overlaid onto geo-referenced aerial photographs of the Abrolhos using ArcMap GIS software. Habitat data from Webster *et al*. (2002) and Hatcher *et al*. (1988) were also overlaid onto the aerial photographs to calculate the number of pots habitat type^{-1} hectare^{-1} for each island group. Using Hatcher *et al*. (1988), each habitat type was assigned a biological sensitivity (low, medium or high), which allowed the level of potting to be expressed for each level of habitat sensitivity.

Despite a number of management changes between 2006 and 2011, potting effort (total number of pots) was similar between the two surveys (Table 7.1). The distribution of effort amongst the islands groups has shifted, however, with less effort in the Southern Group during the 2011 surveys.

Table 7.1. Total number of pots counted during aerial surveys in 2006 and 2011

Island group	Total number of pots	
	2006	2011
Pelsaert (Southern) Group	614	366
Easter Group	552	618
North Island-Wallabi Group	881	924
Total	**2 047**	**1 908**

The aerial surveys revealed that western rock lobster potting does occur in highly sensitive habitats (Figures 7.1 and 7.2). In the North Island-Wallabi Group and Easter Group, the level of potting effort per hectare, was greater in highly sensitive habitats compared to other habitat sensitivities (Figure 7.3). In the Southern Group, moderately sensitive habitats received the greatest potting effort on a per unit basis (Figure 7.3). Across the Abrolhos, all highly and moderately sensitive habitats received more potting effort per hectare of habitat than low sensitivity habitats, with an exception in moderately sensitive habitats in the Wallabi Group (Figure 7.3).

Further analysis of the aerial survey data will occur in 2011.

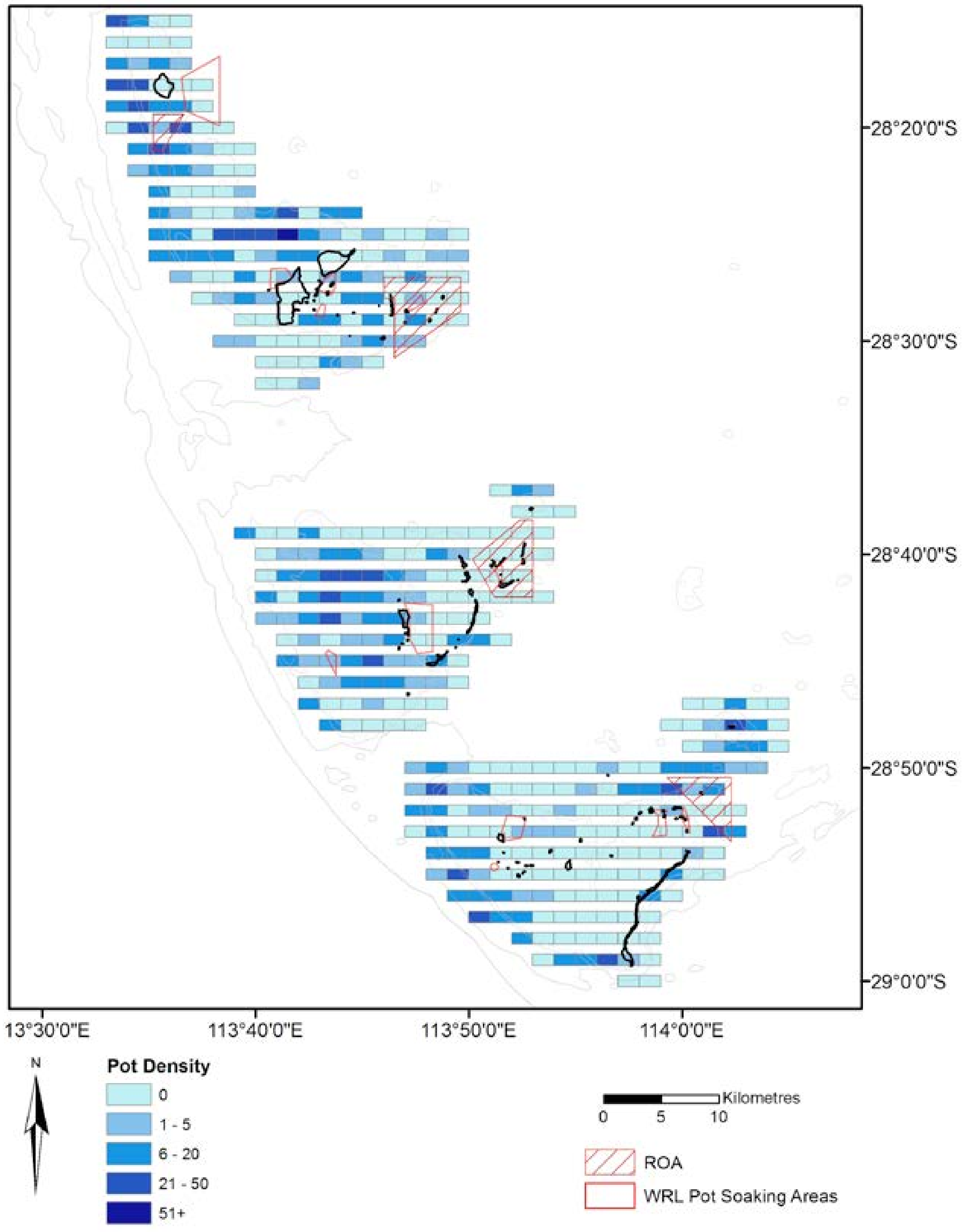

Figure 7.1. Potting effort (total number of pots) in June 2006 for all island groups.

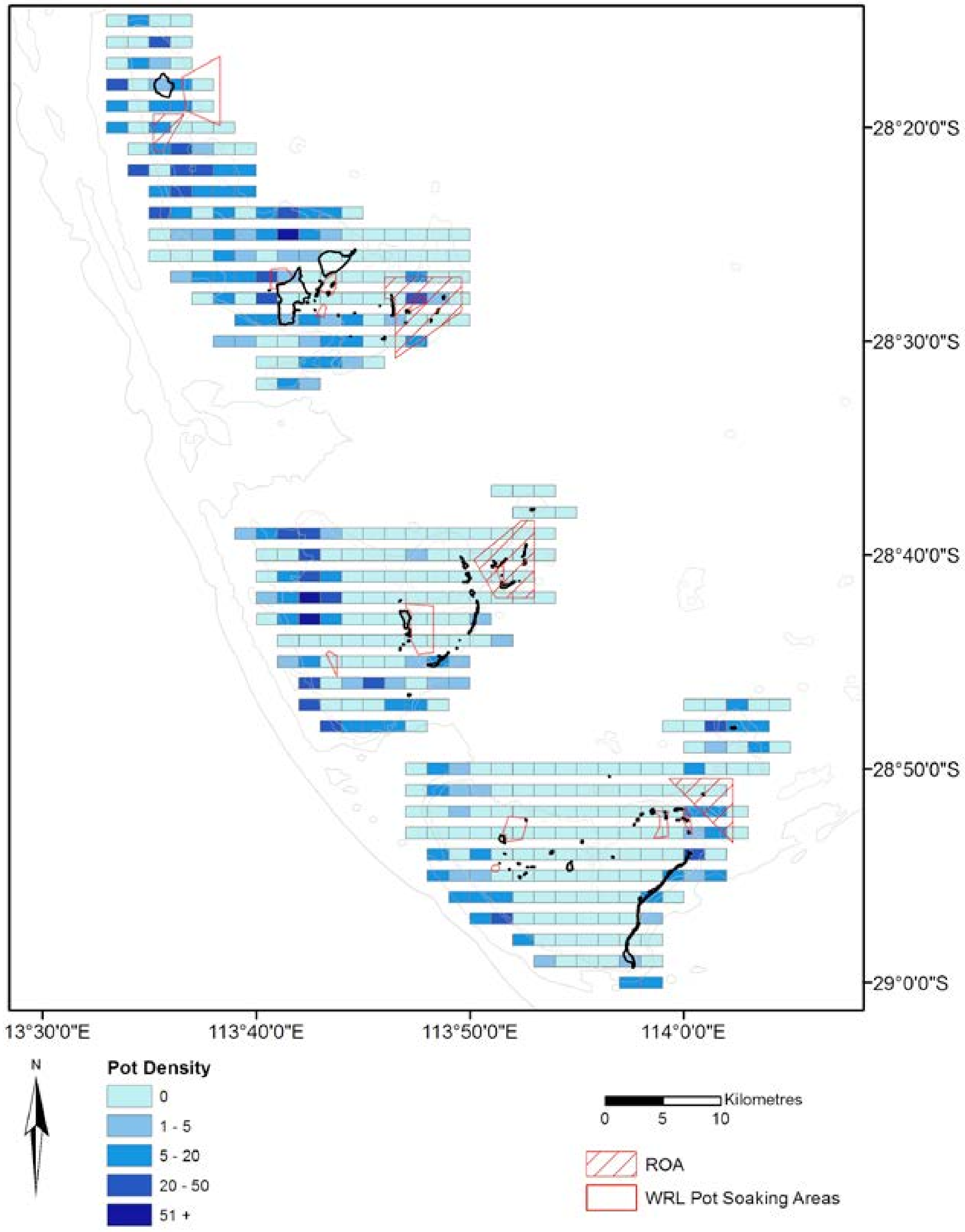

Figure 7.2. Potting effort (total number of pots) in April 2011 for all island groups.

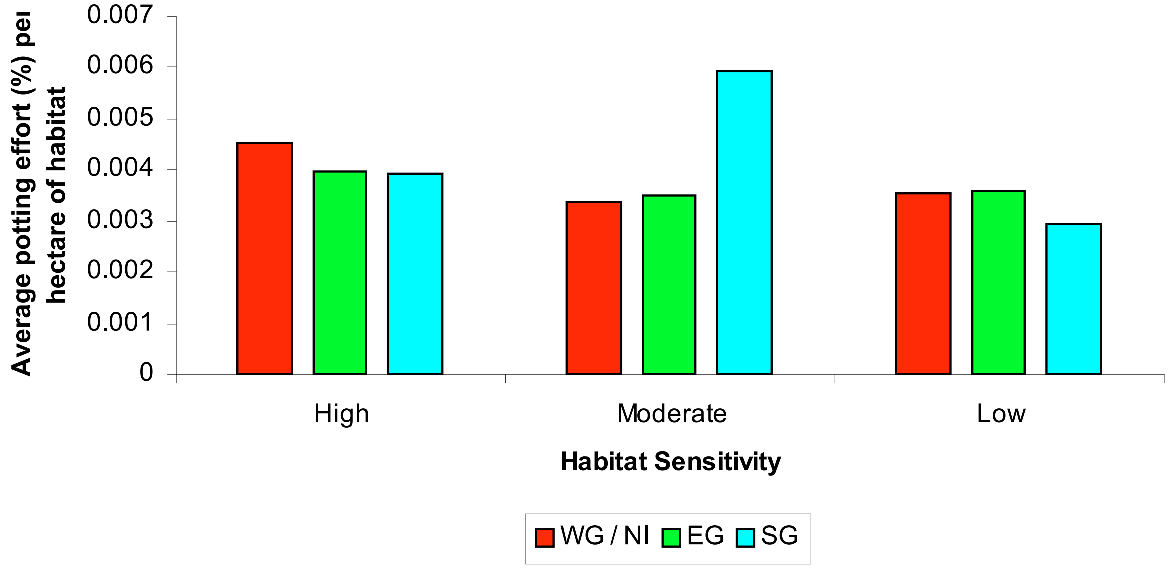

Figure 7.3. Average seasonal potting effort for each island group among high, moderate and low sensitivity habitats (2006 only). For example, every one hectare of highly sensitive habitat in the Wallabi Group receives 0.0045 % of the total average potting effort across all habitats within this group. WG /NI: Wallabi Group and North Island; EG: Easter Group; and SG: Southern Group. Note NI not available and assumed to be consistent with WG.

7.1.1.3 Physical Impact of Potting

Seven sites across the Abrolhos were selected using the data from the 2006 aerial surveys and habitat data from Hatcher *et al*. (1988) and Webster *et al*. (2002). At each site three 100 m permanent transects were established to monitor and assess damage caused by western rock lobster fishing. The survey sites were areas that had high to moderate habitat sensitivity (Hatcher 1988) and a high to moderate level of potting during the 2001 (Webster *et al*. 2002) and 2006 aerial surveys. Three sites were established in the Pelsaert (Southern) Group; two in the Easter Group and one site each in North Island and Wallabi Groups (Table 7.2). At each site the three replicate transects were marked at each end by a one metre star picket with a float attached, they were also marked every 10 m with 10 mm diameter steel bars (600 mm in length).

Table 7.2. Geomorphological classification of survey sites and their associated sensitivity according to Hatcher *et al*. (1988).

Site	Geomorphological Unit	Sensitivity
NI	Exposed Reef Slope / Dissected Limestone Platform / Submerged Reef Platform	Moderate / High Sensitivity
WG	Isolated Patch Reef	High Sensitivity
EG 1	Isolated Patch Reef	High Sensitivity
EG 2	Isolated Patch Reef	High Sensitivity
SG1	Dissected Limestone Platform	High Sensitivity
SG2	Isolated Patch Reef	High Sensitivity
SG3	Sheltered Reef Slope	High Sensitivity

Transects were established in February 2007. Monitoring was conducted in February, prior to the start of the western rock lobster season and in June, following the closure of the season. Transects were videoed by divers using a high-definition video camera in an underwater housing. In 2010, an additional three sites were added to ensure coverage of all the major habitat types and monitoring was reduced to once a year, prior to the start of the fishing season (i.e. February through early-March). Analysis of video footage and associated data is ongoing.

7.2 Deep-water research

7.2.1 Background

The initial certification process for the West Coast Rock Lobster Fishery (WCRLF) to obtain accreditation by the Marine Stewardship Council (MSC) in 2000 required an ecological risk assessment to be undertaken. Although that process, which was completed in 2001, rated the effects of lobster fishing on the overall ecosystem as a low risk, the lack of research data about the ecological impacts of removing rock lobster biomass from the environment, particularly from deep-water remained a concern.

An Ecosystem Scientific Reference Group (EcoSRG) was formed in 2003 to provide advice on research directions for determining the effects of western rock lobster fishing on the ecosystem. Among a range of priority information gaps, they identified the need to collect basic ecological information to determine if changes in lobster density and size structure, due to fishing, had caused significant changes in habitat structure and benthic community composition in deep-water. A second risk assessment identified that the potential ecological impacts of lobster fishing, while remaining a low risk within shallow waters, were a moderate risk within deep-water regions. Therefore, additional research was required to address these knowledge gaps.

The EcoSRG recognised that any new research within deep-water regions needed to occur in a structured manner and devised a strategic framework, which recommended that the initial work should focus on identifying and observing any ecosystem patterns associated with levels of fishing pressure, lobster population size structure and benthic structure. The patterns observed across these gradients were expected to provide some information on these relationships and assist in determining whether research using fished versus unfished areas was necessary within these regions.

An FRDC (2004/049) project provided the critical baseline data on the relationships between the abundance and size distributions of rock lobster and the different benthic habitats located in deeper waters (Bellchambers 2010). This project also provided preliminary information on the trophic role of rock lobster within these depths. However, despite the identification of gradients in the abundance of lobsters within similar habitats, this technique ultimately proved ineffective in providing sufficient information to clarify these relationships to reduce the risk level. Thus, a risk assessment of the WCRLF, completed in 2007, determined that there was a moderate risk that the removal of lobster biomass may be altering the relative abundance of species within deep-water communities. To meet the 2006 Action Plan for MSC recertification, an adequate understanding of the impacts of the fishery on trophic linkages between lobsters and their predators and prey at the main stages of lobster life history was required. Given the outcomes of this assessment, it was recognised that research in deep-waters would have to compare fished and unfished areas using research closures. Consequently, this would require the establishment of suitable fished and unfished areas, plus the collection of baseline information to enable such ongoing comparisons to occur.

An industry closed-area working group, reporting to RLIAC, was formed in August 2007 with the specific aim of identifying and ranking areas on their potential to become closed areas. The working group nominated a total of six locations, between the Abrolhos and the Capes, as potential sites for a closed area. Each location was assessed against the selection criteria formulated by the Ecosystem Scientific Reference Group (EcoSRG). The criteria were that the closed area must be:

- representative of western rock lobster demographics,
- central to and generally representative of the fishery,
- accessible,
- representative of deep-water lobster habitat based on information obtained from previous habitat mapping work,
- an optimum location for enforcing compliance of the closure, and
- an appropriate size to assess the impacts of lobster biomass removal.

Two locations were short listed, the southern part of the Abrolhos zone and 30° S latitude line, for which towed video habitat information was collected. On the basis of the benthic habitat information, an in-principle agreement was reached for the location of the proposed area around the 30° S latitude line, demarcating the boundary between B and C fishing zones. A systematic potting survey was then implemented to determine if the demographics of lobsters within and surrounding the proposed site were representative of fished habitats.

Subsequently, a Scientific Advisory Group (SAG) was formed in February 2009 to independently review the methods to be used in the associated project, including the size and position of the closed area. After reviewing the recommendations of the closed area working group and information provided by Department of Fisheries on the habitat and lobster demographics, the Scientific Advisory Group was confident that lobster demographics in the proposed area (30° S latitude line) were representative of the fishery and comparable to those found in the nearby Jurien Independent Breeding Stock Survey site.

Subsequent negotiations between representatives of WRLC, RLIAC, SAG and DoF reached a compromise of a 12 nm^2 area located on the border of B and C zones (Figure 7.4). This area was officially closed to lobster fishing 15 March 2011 for a period of five years, after which the arrangements will be reviewed.

While negotiations were progressing with the industry and scientific working groups, DoF secured funding to conduct research in the closed area from FRDC and WAMSI (4.3 Trophic Interactions). The objectives of the two projects are listed below:

1. Identification and assessment of suitable unfished reference areas to exclude rock lobster fishing in deep-water
2. Development of a qualitative trophodynamic model that will provide a conceptual framework for determining sampling protocols, indictors and targets
3. To provide cost effective methods to measure deep-water ecosystems in both fished and unfished reference areas.

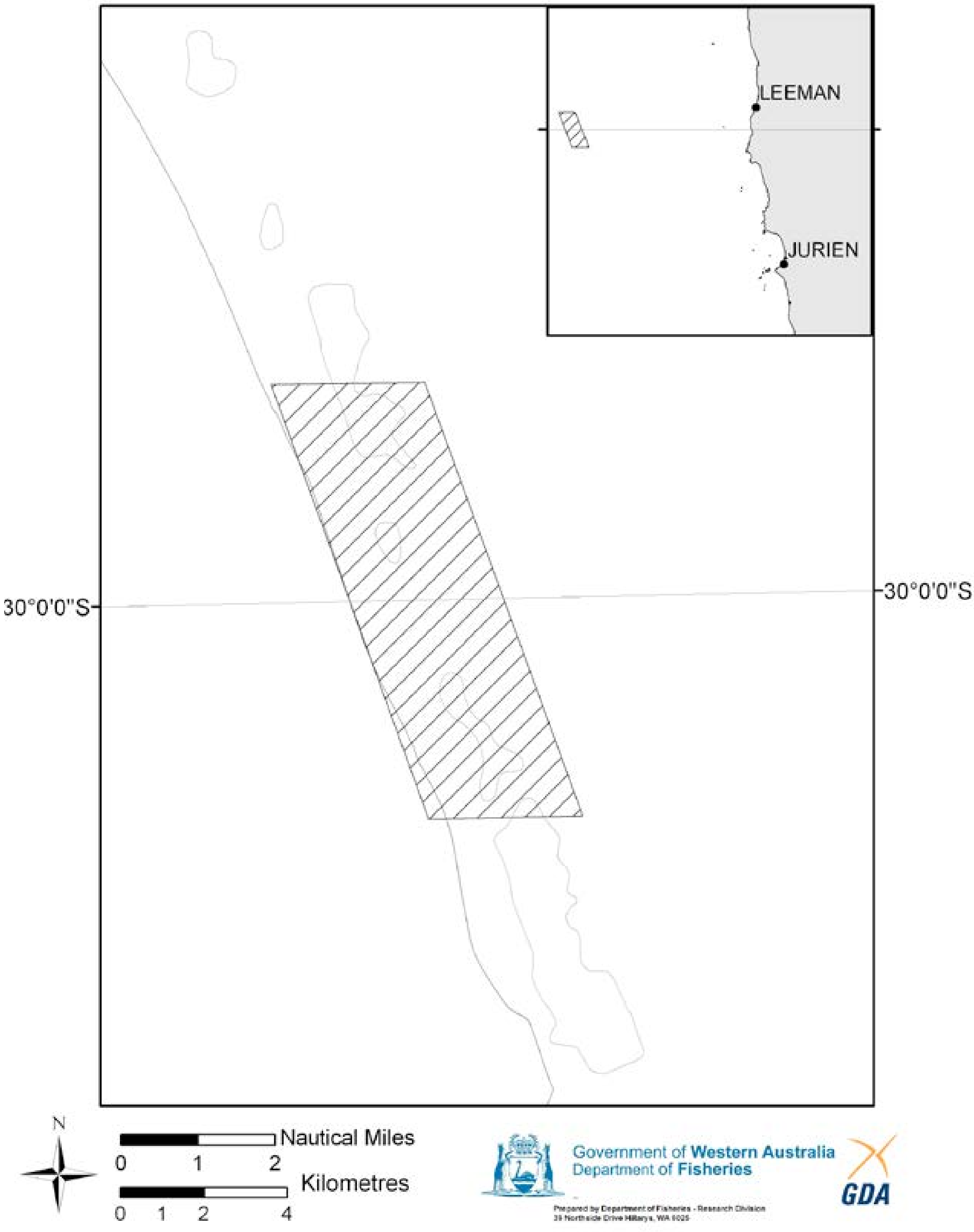

Figure 7.4. Area closed to western rock lobster fishing. 3 nm above the 30° S latitude line (B Zone), 3 nm below 30° S latitude line (C Zone) and 2 nm West – East from the 100 m contour line.

7.2.2 Progress to date

The closed area has been hydro-acoustically surveyed and habitats have been quantified. Habitat modelling is currently being finalised and will produce a fine-scale habitat map and allow future sampling of lobster and other taxa to be stratified by habitat.

The sampling methods, which incorporated outputs from the qualitative modelling, have now been independently reviewed by the Effects of Fishing Advisory Group (EFAG). EFAG, comprising of ecological experts from across Australia, was convened by Department of Fisheries WA to comment on ecological aspects of research relating to western rock lobster.

Small crustaceans, which were identified from qualitative modelling as potential indicators of the effects of fishing, were sampled in October 2010 using baited scavenger traps. Similarly, monitoring of small fish, and larger fish which may be predators of lobster, commenced in early-2011 using stereo baited remote underwater videos.

Lobster sampling has been undertaken since 2008 in conjunction with annual IBSS in October, providing three years of information on lobster abundance and size structure prior to closure (Figure 7.5). This information is directly comparable to the long-term data available for the Jurien IBSS control site. Preliminary analysis of these data sets demonstrates considerable annual variation in lobster abundance. Sampling with small meshed pots and a tag-recapture study conducted in October 2010 provided additional information on lobster abundance and size structure. Analysis of this data is continuing.

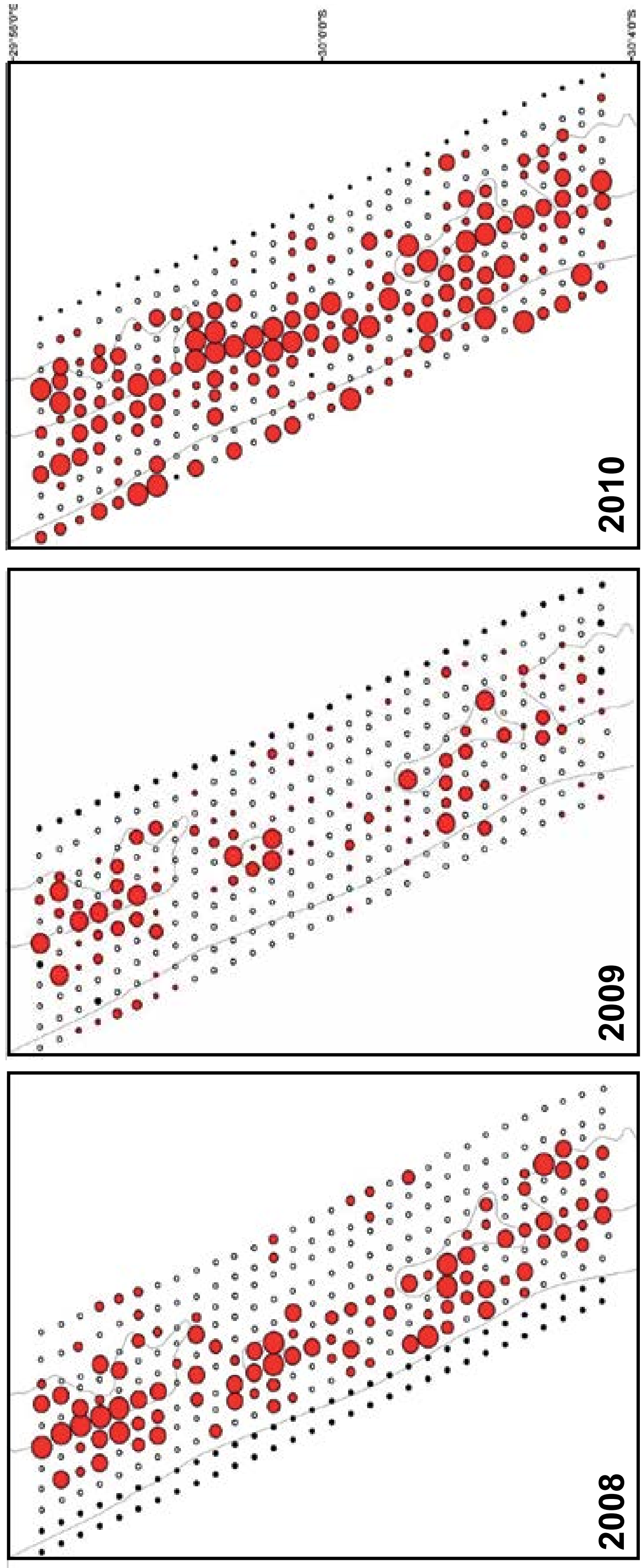

Figure 7.5. Spatial distribution of catch rates of western rock lobster surrounding the closed area. Catch rates are for the total number of lobsters caught in modified commercial lobster pots each October (2008 to 2010) during the annual Independent Breeding Stock Survey (IBSS).

7.3 Shallow-water research

Recent shallow-water research (WAMSI 4.3.1)* ,focused on the relationship between lobster density and community structure, indicated high spatial and temporal variability among benthic assemblages that potentially masked density driven effects due to differences in lobster abundance. There was some indication that lobsters influence the abundance of trochids, suggesting potential for some flow-on effects on epiflora abundance/biomass, although there was no evidence of this from the study.

High benthic diversity and small-scale spatial variations, possibly due to larval supply and physical parameters, may have a stronger structuring influence than top-down pressures due to lobster predation. This made it difficult to identify any patterns in the abundance of a number of lobster prey items, such as crustaceans. Stable isotope analysis revealed no difference in lobster diet between areas with high and low lobster densities, in either macro-algal or seagrass habitats or between large and small lobsters. High densities of lobsters suggested the potential for 'halo' effects at small spatial scales, approximately 30 m away from their reef shelters; however, they are unlikely to have any significant impact on the benthic assemblages at distances greater than 30 m.

Based on these results, it was concluded that removal of legal size lobster (> 77 mm carapace) by the WCRLF is unlikely to have a significant impact on benthic algal and faunal assemblages of shallow limestone reefs and seagrass meadows. Issues and research gaps identified by this research include:

- Historic comparison. Prior to heavy commercial fishing on inshore populations (pre-1960s), there would have been higher numbers of large lobsters that may have had a greater role in structuring benthic assemblages. The current study areas, with the possible exception of Kingston Reef, are unlikely to have had the pre-commercial fishing size structure.
- There was significant background noise in the data due to large spatial and temporal variability in benthic assemblages that was probably due to natural fluctuations in recruitment and physical habitat, rather than lobster predation pressure.
- Over 30 years of shallow-water research data available throughout the range of western rock lobster shows similar patterns. It would appear that there are only relatively small-scale differences in lobster behavior and diet across latitudinal gradients and that the impact on their ecology is not great.
- The large-scale removal of lobster by the WCRLF has not been found to have a measurable effect on benthic assemblages in shallow-water seagrass meadows and limestone reefs of the study areas. However, this may need to be tested at lower/warmer latitudes (higher metabolic rates), higher densities and in other habitats (e.g. coral). There appears to be value in undertaking a larger-scale latitudinal (whole range) study in shallow waters.
- The impact of rock lobster density on the ecology in shallow water appears to be minimal, as all the research results point to them being ecosystem trackers rather than either ecosystem engineers or a keystone ecological species.

Bellchambers *et al*. (2009) aimed to provide a baseline of biological information for western rock lobsters in the Swan Catchment Region, as well as a cost-effective and efficient sampling protocol for the continued assessment and recording of these biological parameters into the

* http://www.wamsi.org.au/fisheries-ecosystems-node-4/science-documents-43

future. Another objective of the research was to produce a long-term time series as an indicator of relative "health" of the Swan Catchment ecosystem.

Four locations were sampled within three marine reserves: Marmion Marine Park-"The Lumps"; Shoalwater Islands Marine Park-proposed Penguin Island sanctuary zone; Rottnest Island Marine Reserve-Armstrong Bay and Rottnest Island-Parker Point. Pot-based surveys and Underwater Visual Census (UVC) were conducted inside the closed zones and in the open fishing areas adjacent to the closed zones. Over 350 lobsters were tagged and released.

The results of the project showed that a multi-disciplinary approach combining a potting program with UVCs provided a superior assessment of the lobster populations. Lobster pot design had a significant impact on the proportion of the population available for capture, allowing the targeting of lobsters of a certain size. A greater number of lobsters were found at the Rottnest Island Marine Reserves than the other two coastal sites. This was attributed to the greater habitat available for lobsters at Rottnest Island, as well as the closer proximity of deeper "less exploitable" lobster grounds in the area. Other factors that had a potential influence on the observed differences in abundance between sites included the size of the marine reserve, location, time since protection and benthic communities. In an overall comparison, the results from the potting data showed a significant zoning effect with more lobsters caught in the closed zones than the open zones. However, this result was not evident within individual marine parks. Only one marine reserve (Parker Point) showed within park differences in the abundance of lobsters from the legal-sized proportion of the population, with more legal lobsters in the closed zone than the open zone. This may be reflective of local environmental conditions, rather than differential fishing pressure resulting from management zoning.

It is anticipated that the continued collection of the above data and the production of indices such as, growth rates and size at maturity, from this on-going project will provide a good measure of environmental change in the future.

7.4 Climate Change

Two new FRDC research projects, conducted by Department of Fisheries, are currently underway; the first is investigating factors affecting the low western rock lobster puerulus settlement in recent years (FRDC 2009/018), and the second is examining management implications of climate change effects on fisheries in Western Australia (FRDC 2010/535). The low puerulus settlement in 2006/07, 2007/08 (the second lowest in 40 years) and 2008/09 (preliminary) was the initial impetus to developing the first project. The aim of this three-year project is to examine the relative importance of short-term environmental factors, and/or long-term climate change effects and/or breeding stock effects in the resultant low settlement. The project is utilising biological data and an integrated stock assessment model to assess the status of the breeding stock overall and in separate areas of the fishery, specifically any source locations identified by the oceanographic model.

The second project was developed to understand the research and management implications that climate change may be having on fish stocks in Western Australia, including the western rock lobster. It builds on the existing collaboration between CSIRO Marine and Atmospheric Research and Department of Fisheries that has successfully completed an assessment of climate change effects on the western rock lobster fishery (Caputi *et al*. 2010b) and an understanding of the source-sink relationships of western rock lobster stocks (Caputi *et al.* 2010a). It is currently undertaking an assessment of the factors affecting the low puerulus settlement of the western rock lobster (FRDC project 2009/018). The objectives of the project are to:

- Assess future climate change effects on the Western Australia marine environments using a suite of IPCC model projections, downscaled to the key shelf regions and the spatial and temporal scales relevant for key fisheries
- Examine the modelled shelf climate change scenarios on fisheries and implications of historic and future climate change effects
- Review management arrangements to examine their robustness to possible effects of climate change.

Planned outputs of the project will enable:

- Use of variable biological parameters (e.g. growth, recruitment) in stock assessment that take into account changes in parameters due to climate change effects
- Sensitivity analyses to explore potential effects of projected changes on stock assessment
- Identification of key fisheries to monitor closely for predicted changes
- Development of management policies on dealing with the key climate change effects, e.g. fixed management boundaries if distribution changes and examination of potential changes in total allowable catch and/or fishing effort.

de Lestang et al. (2010a) initiated a project in response to the lower than expected puerulus settlement for the western rock lobster (*Panulirus cygnus*) on the Western Australian coast during 2008. The objectives were to monitor the community composition of marine flora and fauna along the Western Australian coastline, while developing standard methodology for assessing the spatial and temporal variability in their settlement. The aim was to determine what environmental factors may be linked to the majority of variation in the floral and faunal communities colonizing puerulus collectors, focusing on those relating to puerulus settlement, and to identify what species could be used as indicator species for monitoring climate change effects along the West Australian coast.

The project was commenced during the 2008/09 and 2009/10 seasons and encompassed five sites covering over 1000 km of coastline from Coral Bay to Warnbro. Each site was monitored in both winter and spring seasons, with two sites monitored in all four seasons. Out of the total 157 740 individuals sampled, the Order *Amphipoda* encompassed almost half of all individuals and was three-times greater in abundance than the second most abundant taxa (Class *Gastropoda*), which were double that of *Isopoda*, *Tanaidacea* and *Ostracoda* (Class). There was significant spatial and seasonal variation in the composition of the communities, in particular between sites located in the tropics/sub-tropics and those located in temperate zones. This difference was thought to be due to the greater abundance of taxa in the temperate locations compared with the tropics.

Climate change parameters such as increased water temperature and salinity, as well as less frequent and severe storm events, significantly impacted on the abundance of a number of taxa found commonly on the collectors. Such relationships, along with the discovery of some individuals found outside of their normal distributional range, e.g. the tropical species *Strombus mutabilis*, indicate that the monitoring of a range of species on the puerulus collectors can provide an indication of the localised environment and the impact of climate change.

Table 7.3. Summary of current and planned research on effects of fishing for western rock lobster on the ecosystem. Letters in column marked *Conceptual Model* correspond to bold type letters on the conceptual model (See Figure 1 of the Appendix).

Project Title	Lead Agency/ Publications	Funding Source	Study Location	Objectives / Project Description	Status	Conceptual Model
Assessing the ecological impact of the Western Rock Lobster fishery in fished and unfished areas (FRDC 2008/013)	DoF	FRDC	Jurien (30° line)	Identification and assessment of suitable unfished reference areas to exclude rock lobster fishing in deep-water Development of a qualitative trophodynamic model that will provide a conceptual framework for determining sampling protocols, indictors and targets. To provide cost effective methods to measure deep-water ecosystems in both fished and unfished reference areas	Funded 2010/2012	A, B, C, E, F
Trophic interactions and ecological modelling for EBFM	DoF and ECU	WAMSI 4.3	Jurien (deep-water) and Metro region (shallow-water)	Improve understanding of the possible indirect impacts of fishing or other affects on trophic interactions (e.g. removal of keystone species) To determine the main processes leading to changes in trophic interactions To design experiments to examine the potential impact of fishing on benthic habitats, community structure or biodiversity	Funded 2009/2011	B, E, F
Indicative Development Plan, including baseline habitat and human use maps, to guide future development within the Houtman Abrolhos Islands	DoF	State NRM	Abrolhos Islands	Map the shallow-water benthic habitats of the Abrolhos Islands using remote sensing techniques and field based ground truthing.	Funded 2010/2011	A

Table 7.3. Continued

Project Title	Lead Agency/ Publications	Funding Source	Study Location	Objectives / Project Description	Status	Conceptual Model
Abrolhos Islands long term monitoring	DoF	Internal	Abrolhos Islands	Long-term monitoring of benthic habitats using a series of permanent transects. Transects are surveyed annually and the percentage cover of benthic habitats are recorded using diver operated stereo video	2006 - ongoing	A, D
Spatio – temporal variability in assemblages of mobile invertebrates colonizing artificial habitats along the coastline of Western Australia	DoF/UWA (de Lestang *et al.* 2010a)	FRDC	Various coastal locations	Monitoring community composition of marine flora and fauna colonizing puerulus collectors along the Western Australian coastline Determine the influence of environmental parameters on the floral and faunal communities colonizing puerulus collectors	Funded 2010/2011	F
IMOS	National	National	WAIMOS (Jurien/ Abrolhos/ Rottnest)	Monitoring benthic habitats using AUV	Funded	A, D
Catchability of Western Rock lobster (*Panulirus cygnus*); the influence of temperature, light intensity, habitat and commercial fishing apparatus	Murdoch	FRDC		To examine the effects of a number of factors on the catchability of lobsters	Funded, to be completed in 2012	F
Development of an industry-based habitat mapping/ monitoring system	DoF	FRDC	Statewide	Development of a cost-effective digital monitoring system Comparison of functionality and effectiveness with conventional habitat mapping methods Trial use of system by industry and development of habitat maps	FRDC Full Proposal 2010/11	A, D, F

Table 7.3. Continued

Project Title	Lead Agency/ Publications	Funding Source	Study Location	Objectives / Project Description	Status	Conceptual Model
Understanding processes that affect recruitment of western rock lobster to the fishery over a latitudinal gradient	DoF/UWA	FRDC	Statewide	Determine the relationship between benthic habitat composition and the abundance and distribution of different life stages of the western rock lobster Develop a low cost monitoring program for on going assessment of on benthic habitats and western rock lobster	Proposed FRDC EOI 2011/12. Some components currently being conducted by DoF	A, D, F
Identifying factors affecting the low western rock lobster puerulus settlement in recent years (FRDC 2009/018)	DoF	FRDC	Statewide	To use a larval advection model and the rock lobster population dynamics model to assess the effect of spatial distribution of the breeding stock on the puerulus settlement To assess environmental factors (water temperature, current, wind, productivity, eddies) and breeding stock affecting puerulus settlement To examine climate change trends of key environmental parameters and their effect on the western rock lobster fishery	July 2009 - June 2012	N/A
Development of a long-term program to monitor coastal communities within the Swan region	DoF (Bellchambers *et al.* 2009)	DoF	Rottnest Island	Provide a baseline of biological information for western rock lobster in the Swan Catchment Region Provide a cost-effective and efficient sampling protocol for the continued assessment and recording of these biological parameters into the future Produce a long-term time series as a robust indicator of relative “health” of the Swan Catchment into the future	2008 - ongoing	E, F

Table 7.3. Continued

Project Title	Lead Agency/ Publications	Funding Source	Study Location	Objectives / Project Description	Status	Conceptual Model
Management implications of climate change effect on fisheries in Western Australia (FRDC 2010/535)	DoF (Caputi *et al.* 2010b)	FRDC	Statewide	Assess future climate change effects on the Western Australia marine environments using a suite of IPCC model projections, downscaled to the key shelf regions and the spatial and temporal scales relevant for key fisheries Examine the modelled shelf climate change scenarios on fisheries and implications of historic and future climate change effects Review management arrangements to examine their robustness to possible effects of climate change	January 2011 - December 2013	N/A

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9.0 Appendix

Table 1. List of hazards identified during 2001 and 2005 ERA workshops and their risk assessment ranking. The current median score is shown in bold face. The range of scores is shown in parentheses.

Hazard	Section	2001 Rating	2005 Rating
1. Possibility that estimate of egg production is incorrect (effect on spawning biomass)	6.1.1	Moderate	(low to) **MODERATE**
2. Increasing recreational fishing population (effect on spawning biomass)	6.1.3	Moderate	**LOW** (to high)
3. Increase in fishing efficiency- shift to campaign fishing (effect on spawning biomass)	6.1.4	New hazard	**MODERATE** (low to extreme)
4. Mortality and loss of productivity from handling undersized and setose individuals (effect of spawning biomass)	6.1.5	Low	**LOW** (to moderate)
5. Market decline and additional pressure of the resource (effect on spawning biomass)	6.1.6	New hazard	**LOW** (to moderate)
6. Effects of fishing on the genetic structure of the lobster population	6.1.2	New hazard	**LOW** (to moderate)
7. Removal of octopus (bycatch)	6.2.1	Low	**LOW** (to moderate)
8. Removal of scale fish and sharks (bycatch)	6.2.2	Low	**LOW** (to moderate)
9. Removal of deep sea crabs	6.2.3	Low	**LOW**
10. Whale entanglements in pot ropes (ecological impact)	6.3.1	Low	**LOW** (to moderate)
11. Whale entanglements in pot ropes (social impacts)	6.3.1	Low	**MODERATE** (low to extreme)
12. Sea lion mortality in pots (without management)	6.3.2	Moderate	**MODERATE** (low to extreme)
13. Sea lion mortality in pots (with management)	6.3.2	New hazard	**LOW** (to moderate)
14. Sea turtles	6.3.3	Moderate	**LOW** (to moderate)
15. Manta rays	6.3.4	Low	**LOW**
16. Moray eels	6.3.5	Low	**LOW**

Table 1. Continued

Hazard	Section	2001 Rating	2005 Rating
17. Sea horses	6.3.6	New hazard	**LOW**
18. Uncertainty in data relating to endangered, threatened and protected species	6.3.7	New hazard	**LOW** (to moderate)
19. Effect of fishing on the Abrolhos environment	6.4.1a	New hazard	**LOW** (to high)
20. Effect of fishing on the Leeuwin-Naturaliste environment	6.4.1b	New hazard	**LOW** (to moderate)
21. Effect of fishing on the Central west coast shallow environment (including coastal development)	6.4.1c	New hazard	**MODERATE** (low to high)
22. Effect of fishing on the Central west coast deep environment	6.4.1d	New hazard	(low to) **MODERATE**
23. Effect of fishing on the Kalbarri-Big Bend environment	6.4.1e	New hazard	**LOW** (to moderate)
24. Ghost fishing	6.4.2	Low	**LOW**
25. Fishing effects (pots and boats) on benthic biota (coral, limestone reefs, seagrass)	6.4.3	Moderate	**LOW** (to moderate)
26. Effects on other fisheries of demand for bait	6.4.4	New hazard	**LOW** (to moderate)
27. Introduction of disease or pathogens in bait	6.4.5	Low	**LOW** (to moderate)
28. Changes in behaviour of attendants (birds, dolphins, sharks, sea lions, sea lice)	6.4.6	Low	**LOW**
29. Illegal feeding of dolphins	6.4.7	Low	**LOW**
30. Abrolhos Islands marine issues	6.4.8		**LOW** (to moderate)
31. Abrolhos Islands terrestrial biosecurity	6.4.9		**LOW** (to moderate)
32. Dusky whaler shark entanglement in bait bands	6.4.10	Low	**LOW**
33. Trawling effects on seagrass	6.5.1	New hazard	**LOW**
34. Effects of aquaculture	6.5.2	New hazard	**LOW**
35. Oil spills	6.6.1	New hazard	**LOW**
36. Climate change	6.6.2	New hazard	**LOW** (to moderate)
37. Jurisdictional issues	6.7.1	New hazard	**LOW** (to moderate)

Table 2. List of hazards identified during the first and second ERA process for which there was consensus among the expert group at the second workshop that the hazards were low and no further investigation or analysis was warranted.

Hazard	Section	Rating
Contributions to climate change	6.6.2	**LOW**
Additional food from bait in pots	6.4.1	**LOW**
Impacts on cormorant population	6.4.6	**LOW**
Addition of nutrients to system	6.4.1	**LOW**
Removal of lobster biomass and effect on sea lions-loss of food	6.4.1	**LOW**
Disease introductions to dolphins		**LOW**
Removal of baldchin groper, dhufish and cod	6.2.2	**LOW**
Dolphin entanglement in pot ropes	6.3.1	**LOW**
Plastic ingestion/entanglement of marine spp.	6.4.10	**LOW**
No ecological baseline due to absence of closed areas	6.4/6.4.1	**LOW**
Reduction of food source resulting from intensive fishing of white migration	6.4/6.4.1	**LOW**
Presence of oil fields	6.4/6.4.1	**LOW**
Coastal development	6.4/6.4.1	**LOW**

Table 3. Hazards from the 2005 ERA relevant to ERAEF Level 2 analysis.

2005 ERA Ref No.	Hazard identified in the 2005 ERA	Internal or external threat	Ecological component	Direct capture or other interaction
3	Efficiency changes	Internal	Target species	Direct capture
4	Mortality, productivity loss from handling	Internal	Target species	Direct capture
7	Octopus	Internal	By-catch species	Direct capture
8	Scalefish and sharks	Internal	By-catch species	Direct capture
10	Whales	Internal	TEP species	Direct capture
12	Sea lions	Internal	TEP species	Direct capture
14	Sea turtles	Internal	TEP species	Direct capture
19	Abrolhos ecosystem	Internal	Community	Direct capture
20	Leeuwin – Naturaliste	Internal	Community	Direct capture
21	Central west coast – shallow	Internal	Community	Direct capture
22	Central west coast – deep	Internal	Community	Direct capture
23	Kalbarri – Big Bank	Internal	Community	Direct capture
25	Benthic biota	Internal	Habitat	Direct capture
30	Marine issues – Abrolhos water quality	External	Community	Other interaction
32	Bait bands – Dusky whalers	Internal	By-catch species	Other interaction

Table 4. Hazards ranked moderate-risk, based on existing management controls.

Hazard No.	Hazard description	Ecological component	Risk ranking (existing controls)	Reason for moderate risk
3	Efficiency changes	Target species	Moderate to low	Acknowledged uncertainty in the estimates of industry efficiency gains.
22	Central west coast, deep	Community	Moderate	Paucity of data from deep-water.
23	Kalbarri–Big Bank, deep	Community	Moderate	Paucity of data from deep-water.
32	Bait bands: Dusky whalers	By-catch species	Moderate	Age of Dusky whaler maturity is older than previously thought, and reporting is not systematic. The critical component of the stock is the adult population.

Table 5. Results of suggested risk treatment for hazards ranked moderate-risk.

Hazard No.	Hazard description	Ecological component	Planned or suggested remedial action	Risk ranking (treated risk)	Remarks
3	Efficiency changes	Target species	Contemplating offsetting efficiency gains with effort reductions. Improve the estimate of the efficiency gains in the fishery.	Low	Opinion expressed that no specific new management response is needed—ongoing management is appropriate for mitigating this hazard.
22	Central west coast, deep	Community	Planned workshop in August 2007 with international experts and the WRL Ecological Scientific Reference Group, to review deepwater research, and to develop ongoing project proposals including the possible use of fished and unfished areas. WA Marine Science Institution (WAMSI) projects. Research to begin informing management decisions, beginning about 2008 (as expressed in MSC timetable).	(not re-assessed)	Moderate risk under existing management controls.
23	Kalbarri–Big Bank, deep	Community	Same as for Central west coast, deep.	(not re-assessed)	Moderate risk under existing management controls.
32	Bait bands: Dusky whalers	By-catch species	Zero tolerance of bait bands by the rock lobster fishery.	No risk	Suggested elimination of bait bands eliminates hazard.

Table 6. Dietary items and contribution to gut volume ranges of western rock lobsters. * Indicates additional dietary items identified from Waddington (2008) and MacArthur (2009) and do not contribute to % Volume in guts (Source: MacArthur *et al.* 2007).

Prey	% Volume in Guts
Coralline algae	**0-82.8**
Metagoniolithon stelliferum	
Metagoniolithon spp.	
Haloptilon roseum (Corallina cuvieri)	
Jania spp.	
*Amphiroa anceps**	
Non-coralline algae	**0-22.3**
Caulerpa cactoides	
Filamentous green and red algae	
Seagrass	**0-24.1**
Amphibolis spp.	
Halophila ovalis	
Heterozostera tasmanica	
Syringodium isoetifolium	
"Worms"	**0-29.2**
Nereids	
Eunicid polychaetes	
Sipunculids	
Molluscs	**0.3-37.9**
Trochid gatropods e.g. *Cantharidus lepidus*	
Phaseanellid gastropods	
Turbinid gastropods	
Collumbellid gastropods	
Cerithiid gastropods	
Rissoid gastropods	
Lucinid bivalves	
Solemyid bivalves	
Mytillid bivalves	
Limpets*	
Chitons*	
Crustaceans	**0-23.9**
Isopods	
Amphipods	
Xanthid crabs*	
Pilumnid crabs*	
Dromiid crabs*	
Halicarcinus spp.	
***Panulirus cygnus* shell**	**0-18**
Other organisms	**1-17.1**
Foraminifera	
Echinoderm (urchin) fragments	
Sponge tissue and spicules	
Ascidians	
Pycnogonids	
Hydrozoans	
Fish bones, scales and tissue	

Table 7. Known and potential predators of *Panulirus cygnus (Source: MacArthur et al. 2007).*

Common Name	Scientific Name	Known/Potential
Teleost fish		
Sand bass	*Psammaperca waigiensis*	K
Sea trumpeter	*Pelsartia humeralis*	K
Brown-spotted wrasse	*Pseudolabrus parilus*	K
Breaksea cod	*Epinephelides armatus*	K
Chinaman cod	*Epinephelus homosinensis*	K
Gold-spotted sweetlips	*Plectorhyncus flavomaculatus*	K
Dhufish	*Glaucosoma hebraicum*	K
Baldchin groper	*Choerodon rubescens*	K
Pink snapper	*Pagrus auratus*	P
Blue groper	*Achoerodon gouldii*	P
Large trevally	Carangidae	P
Large cod	*Epinephelus* spp.	K
Sharks and Rays		
Gummy shark	*Mustelus antarcticus*	K
Whiskery shark	*Furgaleus macki*	K
Sandbar shark	*Carcharhinus plumbeus*	P
Wobbegongs	*Orectolobus*spp.	K
Rays	*Dasytis* spp., *Myliobatis australis*	P
Mammals		
Australian sea lion	*Neophoca cinera*	K
Cephalopods		
Octopus	*Octopus tetricus* and *Octopus* spp.	K
Cuttlefish	*Sepia apama*	K

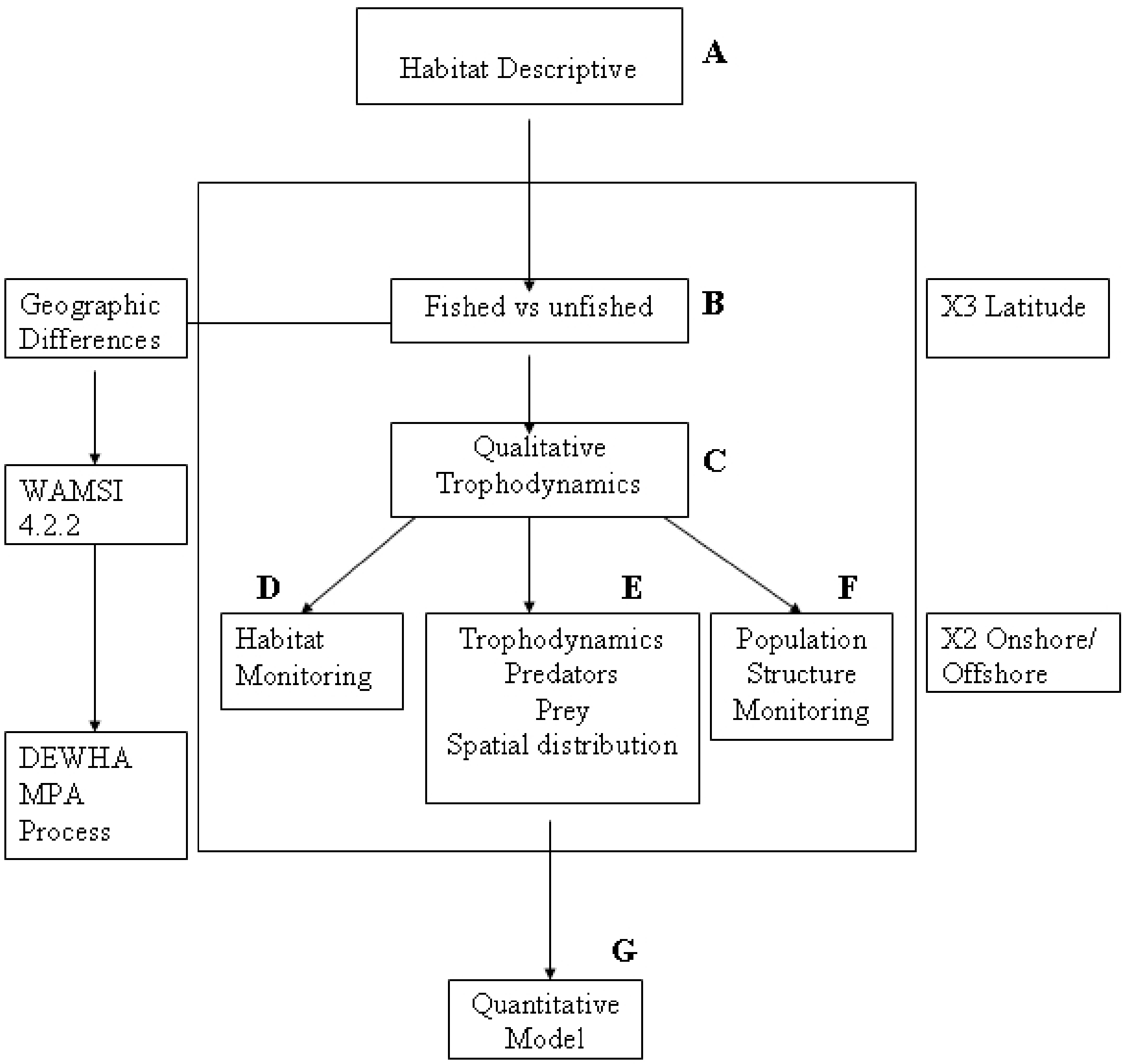
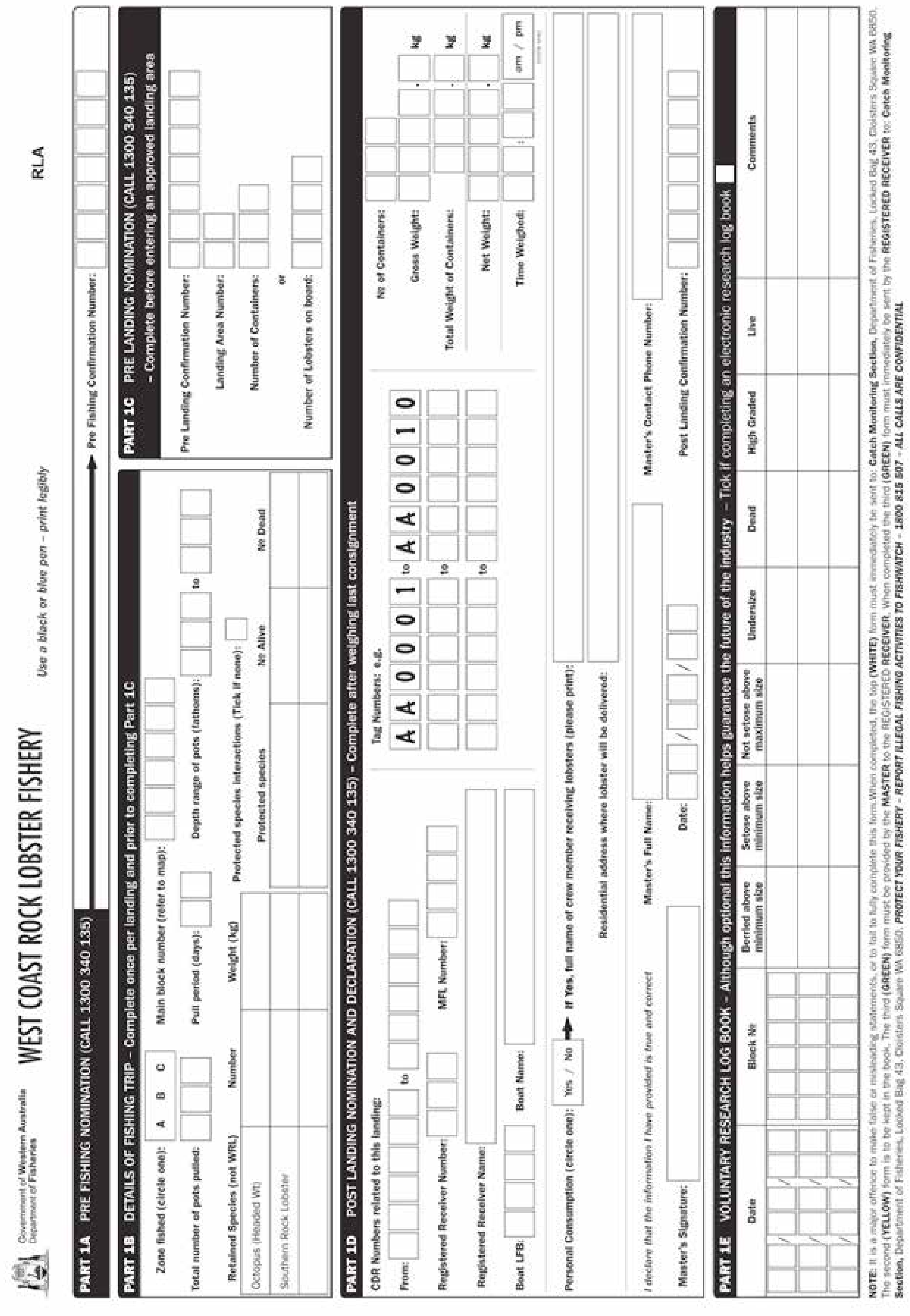


Figure 1. Effects of Fishing Advisory Group (EFAG) preliminary conceptual model for ecosystem research on western rock lobster. Bold letters correspond to current research projects listed in Table 7.3



Government of Western Australia
Department of Fisheries

WEST COAST ROCK LOBSTER FISHERY

Use a black or blue pen – print legibly

RLA

PART 1A PRE FISHING NOMINATION (CALL 1300 340 135)

Pre Fishing Confirmation Number:

PART 1B DETAILS OF FISHING TRIP – Complete once per landing and prior to completing Part 1C

Zone fished (circle one): A B C

Main block number (refer to map):

Total number of pots pulled:

Pull period (days):

Depth range of pots (fathoms): to

Retained Species (not WRL)	Number	Weight (kg)
Octopus (Headed Wt)		
Southern Rock Lobster		

Protected species interactions (Tick if none):

Protected species	№ Alive	№ Dead

PART 1C PRE LANDING NOMINATION (CALL 1300 340 135) – Complete before entering an approved landing area

Pre Landing Confirmation Number:

Landing Area Number:

Number of Containers:

or

Number of Lobsters on board:

PART 1D POST LANDING NOMINATION AND DECLARATION (CALL 1300 340 135) – Complete after weighing last consignment

CDR Numbers related to this landing:

From: to

Tag Numbers: e.g. A A 0 0 0 1 to A A 0 0 1 0

to

to

Registered Receiver Number:

MFL Number:

Registered Receiver Name:

Boat LFB:

Boat Name:

№ of Containers:

Gross Weight: . kg

Total Weight of Containers: . kg

Net Weight: . kg

Time Weighed: : am / pm

Personal Consumption (circle one): Yes / No → If Yes, full name of crew member receiving lobsters (please print):

Residential address where lobster will be delivered:

I declare that the information I have provided is true and correct

Master's Signature:

Master's Full Name:

Master's Contact Phone Number:

Date: / /

Post Landing Confirmation Number:

PART 1E VOLUNTARY RESEARCH LOG BOOK – Although optional this information helps guarantee the future of the industry – Tick if completing an electronic research log book

Date	Block №	Berried above minimum size	Setose above minimum size	Not setose above maximum size	Undersize	Dead	High Graded	Live	Comments
/ /									
/ /									
/ /									

NOTE: It is a major offence to make false or misleading statements, or to fail to fully complete this form. When completed, the top (WHITE) form must immediately be sent to: Catch Monitoring Section, Department of Fisheries, Locked Bag 43, Cloisters Square WA 6850. The second (YELLOW) form is to be kept in the book. The third (GREEN) form must be provided by the MASTER to the REGISTERED RECEIVER. When completed the third (GREEN) form must immediately be sent by the REGISTERED RECEIVER to: Catch Monitoring Section, Department of Fisheries, Locked Bag 43, Cloisters Square WA 6850. PROTECT YOUR FISHERY – REPORT ILLEGAL FISHING ACTIVITIES TO FISHWATCH – 1800 815 507 – ALL CALLS ARE CONFIDENTIAL

Figure 2. The Catch and Disposal Record (CDR) used by the rock lobster fishing industry to record interactions with ETP species.

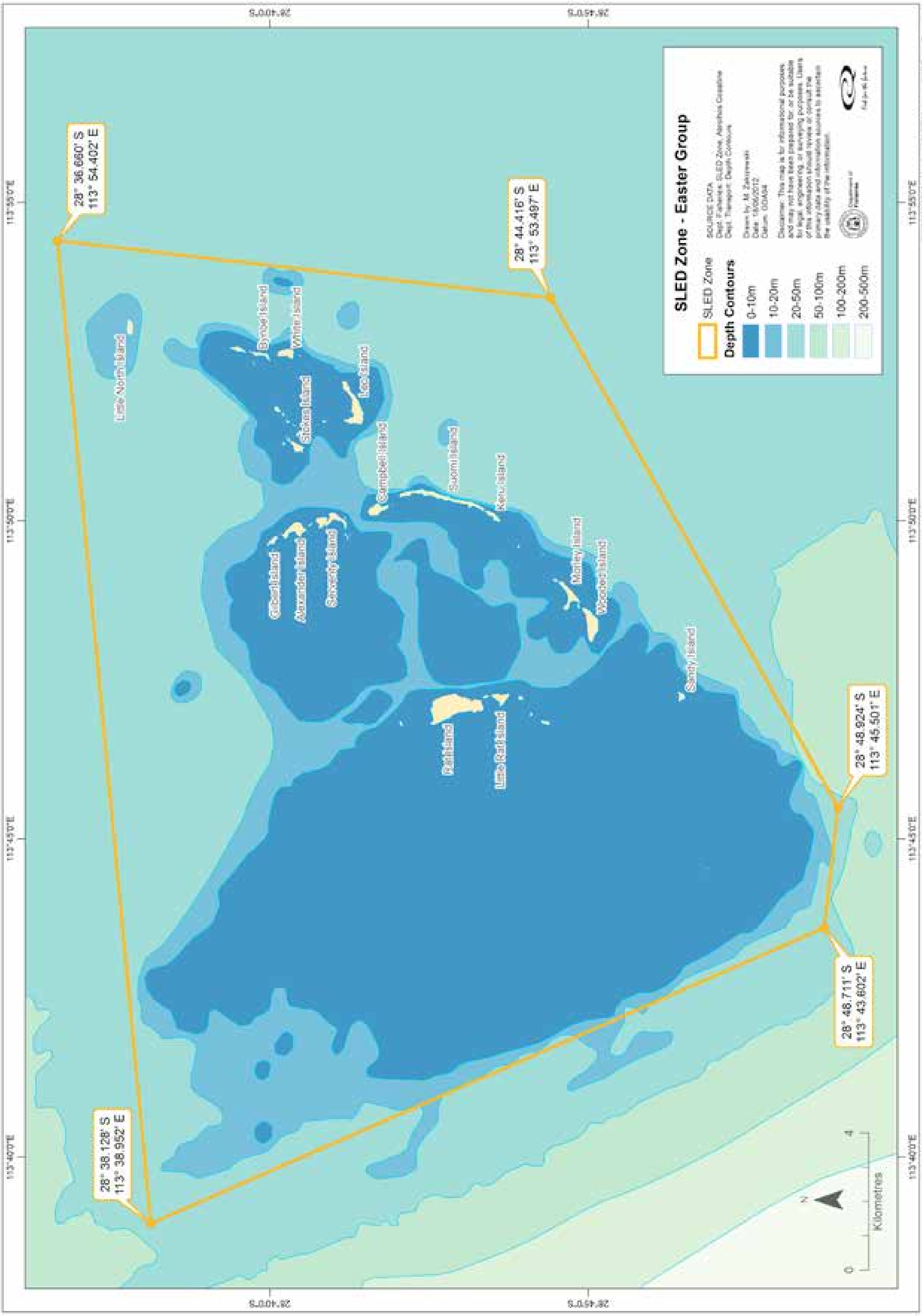


Figure 3a. Proposed SLED zone for the Easter Group of the Houtman Abrolhos Islands.

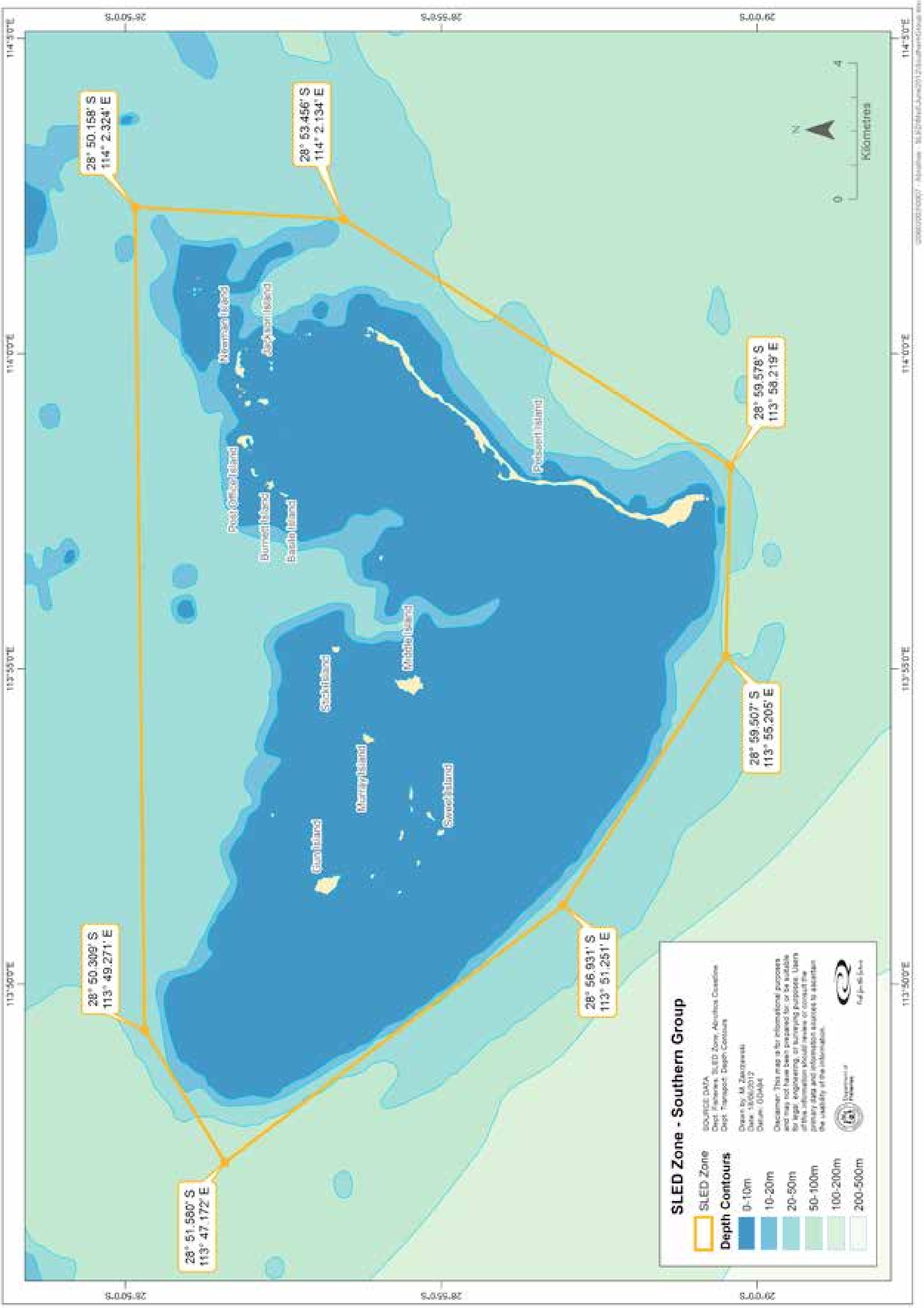


Figure 3b. Proposed SLED zone for the Pelsaert (Southern) Group of the Houtman Abrolhos Islands.