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Western rock lobster in ecosystem processes of south-western Australia

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1. Executive summary

This report provides a summary of information on the role of the western rock lobster, *Panulirus cygnus*, in ecosystem processes within Australia's South-west Marine Region (SWMR). It brings together relevant published information as well as referring to reports and current ongoing research projects.

The western rock lobster is one of the most abundant large invertebrates within the SWMR. It has a distribution ranging from shallow, inshore state waters to deep offshore reefs at depths of 150 m along the lower west coast of Australia. The western rock lobster has a complex, spatially segregated life-cycle, with juveniles aged up to 3 years predominating in shallow coastal lagoons <12 m deep, adolescents 4-5 years present in coastal lagoons and deeper offshore waters (0-150 m), whilst mature adults ≥6 years are more abundant at depths of 30-150 m. It would therefore appear that the SWMR, containing waters predominantly outside coastal waters, comprises mainly adolescent and adult lobster. The proportion of total lobster biomass within the coastal lagoons (ca 87% at centre of distribution) is thought to be considerably higher than the proportion of lobster biomass further offshore within the SWMR. Lobster ≥4-5 years old are exploited by the fishery, which removes between 8,000 and 12,500 t of biomass per season. The recruitment of lobsters into the coastal lagoons is highly variable and is strongly influenced by the strength of the Leeuwin Current, whereby a strong Leeuwin Current increases the survival and settlement of larvae. At small spatial scales, lobster biomass can be highly variable, but at large spatial scales most of the biomass is concentrated along the coast between Perth and Geraldton which returns the highest and most consistent fishery landings.

The western rock lobster consumes a wide variety of plant and animal prey, although plant material, such as coralline algae, plays a more important role in shallow water habitats. Due to its wide dietary range, use of a number of different foraging habitats, and often high abundance, it potentially has a negative impact on a number of invertebrate prey species. This has been demonstrated for lobster foraging on gastropods in shallow water seagrass meadows near reef. The potential for lobster to significantly alter community structure has not been tested in Western Australia, but in other parts of the world lobster can exert considerable control on benthic ecosystems, with areas of high and low lobster density showing considerable variation in community structure. Further testing is required to determine if this holds true for the western rock lobster, with Marine Protected Areas being the most suitable means to address this question.

Although the western rock lobster is likely to be a prey species for a number of different marine predators, there is a clear lack of information regarding this role in the food web. Predation of rock lobster is particularly high on shallow near-shore reefs where lobsters are consumed by small fish predators within their first year after settlement. With the exception of the sand bass, rock lobsters comprise only a small proportion of the diet to these fish, and it is therefore likely that a large number of fish species each remove a small proportion of the total biomass consumed. Predation decreases as lobsters increase in age and these lobsters are likely to be preyed upon by larger species such as octopus, large fish, sharks and sea lions. However, there is a paucity of dietary data for these known and potential predators and what data exists suggests that currently, no one species relies on western rock lobster as its main food source, i.e. there does not appear to be one ‘key’ predator of the western rock lobster.

Whilst rock lobsters are likely to be important to the flow of energy in deep and shallow water ecosystems, their role in these two systems probably differs to some extent. Western rock lobsters in shallow water graze large quantities of plant material, such as coralline algae, whilst plant material does not appear to be an important dietary item for lobster in deep water. Furthermore, the ca 14,000 tonnes of bait, introduced into the ecosystem each year by commercial fisherman may be an important source of energy for deep-water lobster, as well as for their prey and predators.

2. Report Focus

This report aims to provide information on the western rock lobster, *Panulirus cygnus*, with regard to ecosystem processes within the SWMR. It specifically attempts to compile findings from published research articles and reports, as well as ongoing, unpublished studies, to establish whether this species plays an important ecological role as a predator and prey species. As an important predator, *P. cygnus* would have the potential to exert strong feeding pressure on benthic communities. While as an abundant prey species it would also be a significant component for the flow of energy up through coastal ecosystem food webs. Since nearly all ecological data for the western rock lobster have been collected in shallow, state waters, and processes in those waters are likely to represent at least some of the processes in deeper, commonwealth waters, this report compiles relevant information from both regions.

3. Geographical range and relative abundance within South-west Marine Region

The western rock lobster, *Panulirus cygnus*, is distributed between Cape Leeuwin (34°22’S) and North West Cape (21°45’S) on the Western Australian coast to depths of at least 150 m (Chittleborough and Phillips 1975, Sheard 1962). It is therefore found along approximately half the coastline abutting the SWMR, which stretches from Cape Inscription, Shark Bay, to the eastern tip of Kangaroo Island, South Australia containing Commonwealth Marine waters between 3nm – 200nm (http://www.environment.gov.au/coasts/mbp/south-west/index.html). Within the SWMR, and with regard to the Integrated Marine and Coastal Regionalisation of Australia (IMCRA v.4.0), western rock lobster are found throughout the Southwest transition and the northern part of the South West province (Commonwealth of Australia 2006). The component of the stock contained within the SWMR is likely to comprise mainly adolescents (4-5 years) and mature adults (≥6 years).

The western rock lobster fishery is Australia’s largest single species fishery in, with catches averaging 11,000 t per annum, which are valued between AUS $250-350 million (de Lestang and Melville-Smith 2006). The abundance of the western rock lobster relative to other large benthic invertebrates is difficult to assess, however, fisheries landings within and adjacent to the SWMR far exceed those of other invertebrate fisheries that co-occur with western rock lobster (Table 1). This is not a true indication of relative abundance, since not all large benthic invertebrates are fished, and those that are fished are caught using differing methods and levels of effort. Furthermore, size restrictions on some species means that only a proportion of the available catch is landed. For the western rock lobster, less than 20% of total biomass is landed by commercial fishers in any one season (Fletcher et al. 2005).

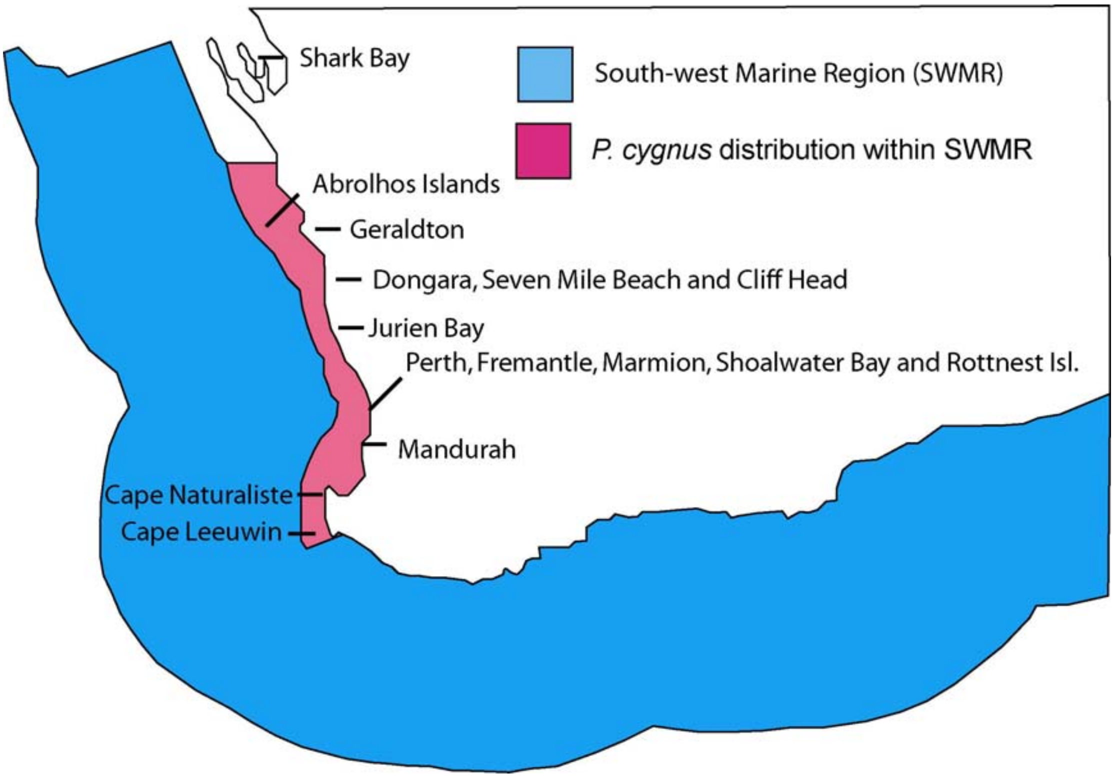


Figure 1. Map of Western Australia with place names showing distribution of *P. cygnus* within the SWMR

Table 1. Ranked biomass of commercial catches for invertebrate species co-occurring with western rock lobster within the South-west Marine Region. Data derived from 2004/05 Department of Fisheries Western Australia statutory monthly returns (Fletcher and Head 2006) * indicates that some part of the catch was derived from outside the South-west Marine Region or outside the range of the western rock lobster.

Common name	Scientific name	Live weight (kg)
Western rock lobster	*Panulirus cygnus*	12, 333.4
Saucer scallop	*Amusium balloti*	6, 162.0*
Western king prawn	*Penaeus latisulcatus*	1, 514.2*
Blue swimmer crab	*Portunus pelagicus*	1, 033.8*
Octopus	*Octopus* spp.	236.9
Greenlip abalone	*Haliotis laevigata*	164.3*
Roe's abalone	*Haliotis roei*	103.5
Squid	*Sepioteuthis* & *Loligo* spp.	73.7*
Cuttlefish	*Sepia* spp.	69.9*
Brownlip abalone	*Haliotis conicopora*	36.3*
Slipper lobsters (Bugs)	Scyllaridae	31.2*

4. Western rock lobster life-cycle and habitat use

The western rock lobster has a complex, spatially segregated life-cycle that includes an oceanic larval phase followed by a much longer benthic phase (Fig. 2). Benthic juveniles and adults occupy reef systems along the lower west coast to depths of at least 150 m (Chittleborough and Phillips 1975), but also utilise surrounding habitats such as seagrass meadows to forage (Jernakoff 1987, Edgar 1990a). Lobsters also move between reefs and undertake large scale migrations (Jernakoff 1987, Phillips 1983). The life-cycle and habitat usage can be broken into the following categories.

4.1 Mature lobster

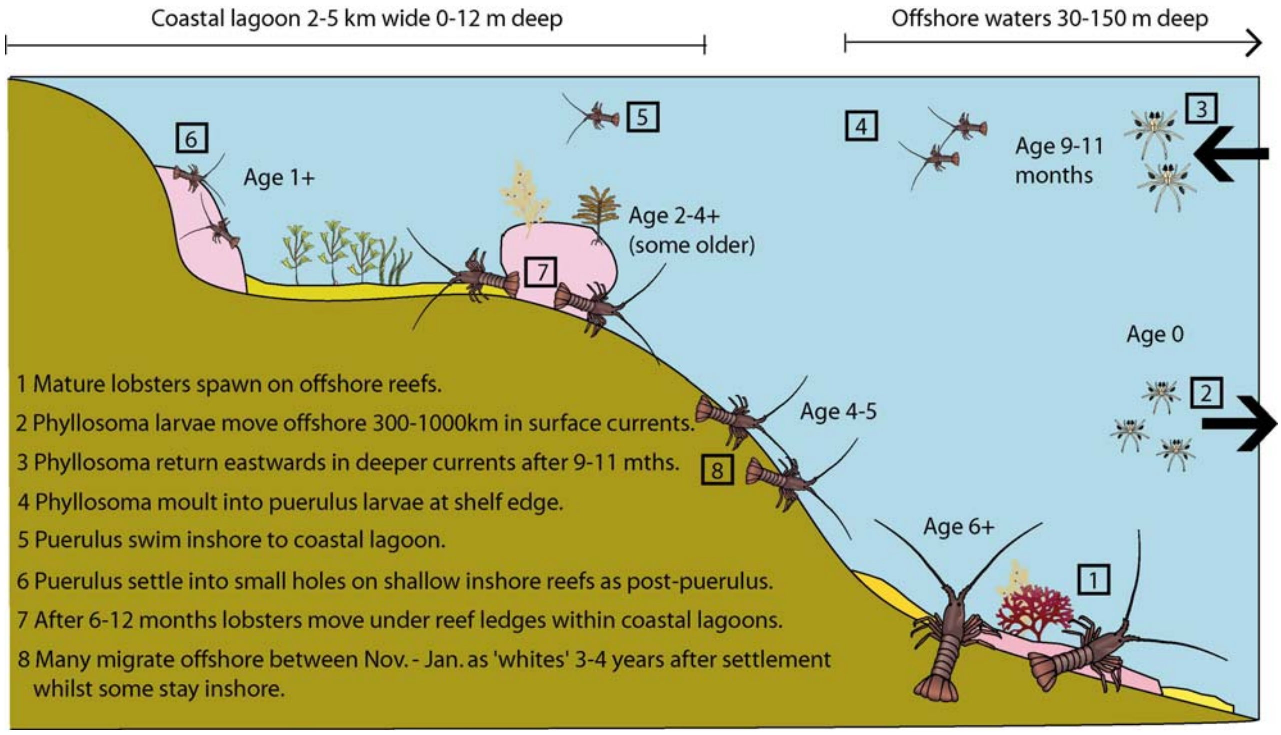
Mature western rock lobster are most abundant at depths greater than ca 30 m and occur to depths of ca 150 m, that is, between the outer edge of the coastal lagoons and the edge of the continental shelf (Chittleborough and Phillips 1975) where they primarily occupy limestone reef habitat, although they also use granite reef systems along the southern range (between Cape Naturaliste and Cape Leeuwin), and coral reef systems in the northern part of their range (i.e.Abrolhos Islands, Gray 1992; Ningaloo Reef, Babcock unpublished observations). Apart from their utilisation of hard reef substrata there is little known of their habitat preferences with regard to sheltering and foraging in these deeper waters. This is due to a lack of deep water habitat mapping within the western rock lobster's range. However, current projects undertaken by Marine Futures and the Department of Fisheries Western Australia due for completion in 2008 and 2007, respectively, are addressing these gaps in knowledge by mapping deeper water habitats (e.g. CSIRO Marine and Atmospheric Research, Contact Dr. John Keesing; Marine Futures, http://sponsored.uwa.edu.au/mf/index Contact: Dr Heather Taylor heather.taylor@uwa.edu.au), and relating deep water lobster density and size-structure to habitat type, as well as measuring lobster movements between habitats

(Department of Fisheries Western Australia, FRDC Project 2004/049, Contact: Dr Lynda Bellchambers, Lynda.Bellchambers@fish.wa.gov.au).

Studies on breeding rock lobsters indicate that 50% of female rock lobster reach sexual maturity once they have attained a carapace length of between ca 75 and 88 mm, although this varies with location and water temperature, and females at the Abrolhos Islands reach sexual maturity at smaller sizes (Melville-Smith and de Lestang 2006). Males typically reach sexual maturity at carapace lengths 5-15 mm larger than females at any given location (Melville-Smith and de Lestang 2006). Mating first occurs in July and August and is concentrated at depths of 40-80 m although mated females are also caught close to the shore in areas such as Kalbarri, Jurien-Cervantes and between Cape Naturaliste and Cape Leeuwin (Gray, 1992). During mating, males deposit spermatophores onto females, which then fertilise these eggs up to 69 days later (Gray 1992). Eggs are incubated attached to the female’s pleopods for between 19 and 68 days, depending upon temperature (Chittleborough 1976), and hatching is generally completed by the end of February or March (Gray 1992).

4.2 Larvae

After hatching in February-March larvae, known as phyllosoma (Fig. 3a), are carried offshore by nightly wind-driven currents as far as 1500 km from the mainland, although by April, most are located between 300 and 1000 km from the mainland (Gray 1992). In these waters, which are outside the reach of the southward flowing Leeuwin Current, phyllosoma larvae feed on zooplankton and undergo a series of moults as they increase in size. The offshore wind-driven currents decrease in strength between May and October and phyllosoma move deeper in the water column where they are transported shorewards by easterly flowing currents (Gray 1992). Between August and December, 9-11 months after hatching, late-stage phyllosoma larvae are concentrated near the edge of the continental shelf edge and undergo a final larval moult into the morphologically distinct puerulus larva (Fig. 2 and 3b), which resembles the benthic form of juveniles and adults. Unlike the phyllosoma, puerulus are able to swim and migrate 40-60 km towards the coast before settling (Gray 1992). Puerulus have been reported to settle on reefs at least 30 m deep (Fitzpatrick et al. 1989), although the majority of juveniles are found on shallow reefs (< 10 m) within the coastal lagoons (Chittleborough 1975) suggesting greater numbers settle and/or survive on these reefs. Settlement occurs throughout the year, but peaks in spring and summer (Gray 1992).



1 Mature lobsters spawn on offshore reefs.
2 Phyllosoma larvae move offshore 300-1000km in surface currents.
3 Phyllosoma return eastwards in deeper currents after 9-11 mths.
4 Phyllosoma moult into puerulus larvae at shelf edge.
5 Puerulus swim inshore to coastal lagoon.
6 Puerulus settle into small holes on shallow inshore reefs as post-puerulus.
7 After 6-12 months lobsters move under reef ledges within coastal lagoons.
8 Many migrate offshore between Nov. - Jan. as 'whites' 3-4 years after settlement whilst some stay inshore.

Figure 2. Western rock lobster life cycle.

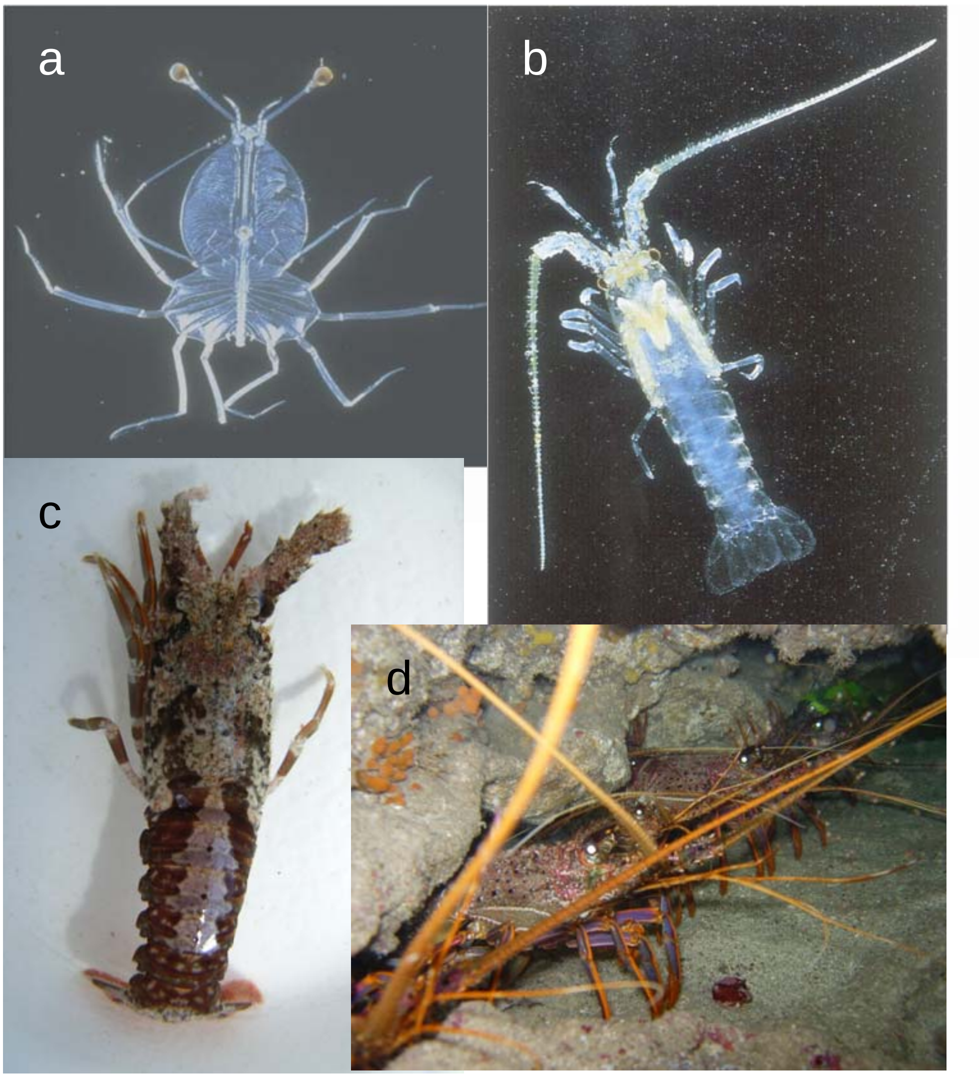


Figure 3. Life-cycle stages of the western rock lobster: a. Phyllosoma (20 mm Total Length), b. Puerulus (35 mm TL), c. Benthic post-puerulus (9 mm CL), d. Aggregation of juveniles (ca 70 mm CL) under reef ledge. Images a and b from Caputi et al. (in prep.)

4.3 Juveniles

Post-settlement juveniles up to at least 4 or 5 years old are most abundant within the coastal lagoons (Gray 1992). These lagoons are a distinctive geomorphological feature of the lower west coast of Australia that are formed by fringing reef lines 2-5 km offshore that absorb 40-70% of open ocean swell and wave energy (Sanderson 2000) thereby protecting shallow waters (typically <12 m deep) between them and the shore. Within these lagoons, patch reefs, macroalgae covered pavement, seagrass meadows and areas of bare sand predominate. The two major meadow forming seagrass genera over this range are *Amphibolis* and *Posidonia* (Kirkman and Walker 1989). Newly settled puerulus, often referred to as post-puerulus (Fig. 3c), occupy small holes and cracks in the shallow limestone reefs that closely match their body size and protect them from predation (Fitzpatrick et al. 1989, Jernakoff 1990). These spaces are occupied during the day but are vacated at night as the post-puerulus move short distances to forage over vegetated reef (Jernakoff et al. 1993). Once post-puerulus lobsters have attained a carapace length of ca 25 mm they move to larger ledges and caves at the base of the reefs, commonly referred to as ‘dens’, and aggregate with other lobsters of similar or larger size (Fig. 2 and 3d) (Jernakoff 1990). Lobsters between the sizes of 25 and 85 mm carapace length have been shown to utilise both reef and surrounding benthic habitat to foraging, leaving their dens soon after sunset and returning to the same den or nearby dens before sunrise (Cobb 1981, Jernakoff 1987).

Juvenile and sub-adult and adult lobsters have been shown by a series of studies in the 1980s to forage on reef tops covered in algal turf and *Amphibolis* as well as in seagrass meadows of *Amphibolis* and *Halophila/ Heterozostera* (Edgar 1990a, Jernakoff 1987). Recent ongoing work indicates that they also forage in meadows of *Posidonia* and over areas of macroalgae dominated pavement (MacArthur, unpublished data). Jernakoff et al. (1987) found by electromagnetic tracking that lobster were very mobile with 95% of nightly foraging movements covering a distance between 72 and 585 m. Despite covering potentially large distances, ongoing tracking work on juveniles between 69 and 85 mm CL, using acoustic tags, indicates that most of rock lobster movement occurs within ca 50 m of high-relief reef edge, i.e. shelter habitat (MacArthur, unpublished data). With the exception of bare sand, both sets of studies have now shown that all common vegetated habitats within the coastal lagoon can be used by foraging lobster and that most of this usage occurs within close range of lobster holding habitat, i.e. ledges and caves under high-relief reef.

4.4 Migratory adolescents

After juveniles have spent 3-4 years within the coastal lagoon habitat, many 4-5 year old lobster, at around the legal minimum size at capture (77 mm CL), migrate to waters further offshore between November and January (Phillips 1983). This occurs after a synchronised moult in October and November in which the old red exoskeleton is shed and replaced by a pale pink one. These lobsters are colloquially known as ‘whites’ (George 1958). The exact proportion of lobster migrating offshore is not known, however at present few lobsters larger than this legal size remain in the coastal lagoons due to recreational and commercial fishing pressure (Phillips 1983). In Marine Protected Areas like Kingston Sanctuary at Rottnest Island, large numbers of adult lobsters exist in shallow waters protected from fishing, suggesting that a proportion of adolescents do not migrate from shallow water after moulting (Babcock et al. 2007).

Recent acoustic tracking work in the Jurien Bay Marine Park also found that many ‘white’ lobsters remained on a near-shore reef during the migration season between November and January (MacArthur, unpublished data). Tagging research by Phillips (1983) indicates that at least some of the lobster that do migrate travel up to 68 km offshore to the edge of the continental shelf. In December and January, pots set over sand in offshore, deeper water habitat catch large numbers of ‘whites’ whilst at other times catch very few lobster, suggesting sand habitat is used to a greater extent by the ‘white’ lobsters during the migratory season, perhaps as part of their migratory route (Gray 1992).

5. Spatial and temporal variability of the western rock lobster population

5.1 Temporal changes in biomass

Much of the temporal variation in rock lobster abundance/biomass in the South-west Marine Region is linked to oceanographic processes that fluctuate from year to year and affect larval survival and settlement. The strength of the Leeuwin Current, which fluctuates with the El Niño/ Southern Oscillation (ENSO), correlates strongly with the number of puerulus larvae that return to the shallow inshore reefs and settle (Caputi et al. 2003). Puerulus settlement is strongest in La Nina years when Leeuwin Current flow is strongest. Settlement of puerulus on puerulus collectors, deployed by the Department of Fisheries WA, has been shown to be closely correlated to ENSO fluctuations, and this variation in puerulus recruits is also correlated to variability in the biomass and catch of legal-sized lobster of the same cohorts 3-4 years later (Caputi et al. 2003).

The Leeuwin Current is a southward flowing current that brings warm, nutrient-poor waters down the West Australian coast along the edge of the continental shelf (Caputi et al. 2003). It flows most strongly during winter months (April to September) when opposing winds are at their weakest (Godfrey and Ridgway 1985). In years of high Leeuwin Current strength, puerulus settlement increases, although the exact cause of this increase is not fully understood. Two possible causes are that Leeuwin Current associated eddies aid in the retention of larvae near the coast and that higher water temperature during strong Leeuwin Current years increase phyllosoma survival and development (Caputi et al. 2001). Griffin et al. (2001) modelled the effect of large-scale advective processes on larval transport and found that variations in puerulus settlement were not explained by the advective model. These authors suggested that increased water temperature during Leeuwin Current years may therefore be the most important factor influencing larval survival and settlement. The Leeuwin Current does, however, seem to have an effect on the latitudinal distribution of puerulus. In years with strong Leeuwin Current flow higher puerulus settlement is found on the more southern collectors, and correlates with increased catches at the southern extent of the fishery (Caputi et al. 2003). On top of Leeuwin Current factors, wind direction and strength may play a role in larval settlement. Caputi et al. (1996) found a correlation between winter westerly winds (inferred from rainfall) and puerulus settlement suggesting that additional to Leeuwin Current effects, onshore winter winds aid larval settlement.

The fishable section of the lobster population, i.e. the proportion that falls within legal size-limits, is believed to make up to 10 or 20% of total lobster biomass at any one time (Fletcher et al. 2005). Most of this biomass is exploited, and the level of fishing effort remains fairly constant from year to year due to restrictions on effort imposed by the Department of Fisheries. The annual catch, however, varies by over 50% (between 8,000 and 14,500 t over the last 20 years; Fletcher et al. 2005) due mainly to natural variations in settlement of rock lobster which is influenced by environmental factors such as the Leeuwin Current strength.

5.2 Spatial changes in biomass

Distribution of lobster biomass along a cross-shelf gradient suggests that most of the lobster biomass is contained within the inner-shelf coastal lagoons. Estimates of lobster biomass by Fletcher et al. (2005), based on data at the centre of the western rock lobster's range between latitudes 29 and 30°S, suggest that juveniles aged up to 4 years which occur predominantly in shallow coastal lagoons (< ca 12 m deep) account for 87% of the total benthic lobster biomass. Within the coastal lagoons, lobster density can be highly variable between reefs but size-structure tends to follow a pattern with smaller juveniles of 3 or less years of age being more abundant on reefs within a few hundred metres from shore (MacArthur et al. 2006). Between November and January, many 'white' western rock lobsters migrate offshore from coastal lagoons to deeper areas (Phillips 1983), although the exact proportion of the biomass that moves is unknown.

Whilst lobsters are caught between Augusta and Shark Bay, most of the biomass is taken along the coast between Fremantle and Geraldton (2001/2001-2002/2003 season, Chubb and Barker 2005). A large proportion of the biomass is also taken in a relatively small area around the Abrolhos Islands (Fig. 1), which consistently returns the highest catch per unit effort. Catch per unit effort can be high around Shark Bay and the Capes region (Capes Leeuwin & Naturaliste, Fig. 1) at the south of the western rock lobster's range, however, these areas are lightly and inconsistently fished (Chubb and Barker, 2005). Recruitment of lobster between Cape Naturaliste and Cape Leeuwin is far more variable than in the centre of its range and fluctuates strongly with changes in the Leeuwin Current strength (Caputi et al. 2003). Current work by the Department of Fisheries is aimed at mapping the distribution of spawning stock on a fine-scale (Melville-Smith et al. in prep.).

6. Role as consumer

6.1 Shallow water habitats (<12 m)

All of the published data on rock lobster foraging comes from two shallow water sites, Cliff Head and Seven Mile Beach, near Dongara, Western Australia at the centre of the lobster's geographical range but inshore of the SWMR (Fig. 1). These dietary studies indicated that *P. cygnus* is an omnivorous species that consumes an extremely wide range of benthic food items (Table 2; Joll and Phillips 1984, Edgar 1990a, Jernakoff et al. 1993). Gut content analyses from these sites has revealed that lobster feed to a large extent on coralline algae, mainly *Corallina cuvieri* (*Haliptilon roseum*) and *Metagoniolithon stelliferum*, both epiphytic on the stems of the seagrass genera *Amphibolis*, as well as consuming large quantities of gastropods such as *Cantharidus lepidus* and *Pyrene bidentata.* Other prey consumed include bivalves, chitons, sipunculid worms, polychaetes, non-coralline algae, seagrass, brachyuran crabs, ascidians, sponges, pycnogonids, hydrozoans and echinoids (Table 2). The relative proportion of prey consumed in these studies, however, differed greatly between sites and seasons. Ecological surveys of reef community structure comparing Dongara with other sites between Green Head and Perth have shown that the low profile seagrass covered reefs of Dongara are not representative of the broader regions lagoonal reef habitats (R. Babcock, unpublished data). Current work on lobster diet from a broader range of sites in Jurien Bay (Fig. 1), including deeper lagoonal sites to 12 m, and sites dominated by different benthic habitats i.e. *Posidonia sinuosa* meadow and macroalgae dominated pavement (MacArthur, unpublished data), has shown that lobster forage on similar types of prey to those found in previous studies, but consume larger volumes of sponges, ascidians and small crabs.

The variation in lobster diet between sites and seasons has been shown to follow natural variability of prey (Edgar 1990a). It therefore appears that the western rock lobster is highly adaptable with respect to the type of food it can consume. In particular, animal prey seems to be preferred to plant material when present in high densities. For example, *Cantharidus lepidus* was consumed in high quantities when it became seasonally abundant at Cliff Head, whilst polychaetes were consumed in large numbers when seasonally abundant at Seven Mile Beach (Edgar 1990a). These results were confirmed in tank experiments conducted by Chittleborough (1976) which found that animal prey was preferred over plant material by western rock lobster and resulted in higher growth rates. Nevertheless, coralline algae is nearly always present in the guts of lobster from past shallow water dietary studies, and laboratory experiments by Joll and Crossland (1983) have shown that coralline algae plays a role in post-moult remineralisation of lobster exoskeleton by providing an additional source of calcium. It has also been suggested as a readily available ‘holding’ diet for western rock lobster which has been shown to provide up to 83% of the western rock lobster’s energy requirements and may aid in the uptake of nitrogen when ingested as a supplement to animal prey (Joll and Crossland 1983). Certainly, rock lobsters fed only on coralline algae (*Amphiroa anceps*) have been observed to survive for at least 119 days in captivity (Waddington and MacArthur, in press)

Western rock lobsters have been observed to forage in a wide range of habitats. Results from Jernakoff (1993) and Edgar (1990a) have shown that different size classes of lobster will forage in different habitats, which may in part be related to their susceptibility to predation. Post-puerulus lobsters (< 25 mm CL) have been observed to forage on the surface of patch reefs amongst *Amphibolis* and macroalgae close to shelter (Jernakoff 1993). Slightly larger juveniles (25-45 mm CL) have been shown to forage on turf and *Amphibolis* covered reef, whilst larger juveniles (45-85 mm CL) were found in more open habitat of *Halophila*, *Heterozostera* and *Syringodium*, further away from shelter (Edgar 1990a). Edgar (1990a) suggested that these patterns may be related to predation pressure with smaller animals, more susceptible to predation, preferring to forage in vegetated habitats that provide more vegetative cover and are in closer proximity to reef shelters. In addition to these results from Seven Mile Beach and Cliff Head, ongoing work at Jurien Bay has revealed that western rock lobster (68-85 mm CL) also forage amongst meadows of *Posidonia sinuosa* and over pavement reef dominated by foliose red algae, although only within close proximity to high-relief reef (MacArthur, unpublished data).

Table 2. Dietary items and contribution to gut volume ranges from published studies on western rock lobster diet (Edgar 1990a, Joll and Phillips 1984). * indicates additional dietary items identified from unpublished dietary studies on western rock lobster by K. Waddington and L. MacArthur and do not contribute to "% Volume in guts".

Prey	**% Volume in guts**
Coralline algae	**0 – 82.8%**
Metagoniolithon stelliferum	
Metagoniolithon spp.	
Haliptilon 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 gastropods 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	

Due to the wide variety of prey consumed by western rock lobster, and its use of a variety of different habitats, it is likely that this species plays an important role as a consumer in coastal ecosystems. Edgar (1990b) suggested that western rock lobster could influence the population dynamics of large epifaunal gastropods when they are present in high densities near lobster habitat. Evidence supporting this comes from his studies at Seven Mile Beach where rapid declines in the large (>2 mm) gastropods, *Cantharidus lepidus*, *Stenochiton cymodocealis* and *Asteracmaea stowae* coincided with a switch from an algae to mollusc dominated diet by rock lobster. Measurements made on gastropod consumption rates of rock lobster at this study site showed that rock lobster consumed about 30 individuals of *C. lepidus* per square metre when they were seasonally abundant, which accounted for 89% of the decline in these gastropods between April and June (Edgar 1990b).

Whilst western rock lobster can cover large distances when foraging, recent results suggest that most of the foraging effort is concentrated on and around reefs in which they shelter (MacArthur, unpublished data). It is therefore likely that lobster impacts on gastropod prey, such as those observed at Seven Mile Beach, are most likely to occur at the boundary of reef and neighbouring habitat. A boundary effect, where haloes of reduced prey densities were found close to reef, has been observed for the southern rock lobster *Jasus edwardsii*, which has been shown to have a negative impact on populations of the bivalve *Dosinea subrosea* (Langlois et al. 2005). Ongoing work, investigating population dynamics of gastropod communities in seagrass habitats near reef, suggests that haloes of reduced gastropod density exist around reefs on the west coast of Western Australia (F. Tuya, unpublished data), which may in part be caused by lobster foraging. Since the western rock lobster consumes other animal prey besides molluscs, such as crabs, polychaetes, etc., they may also have a localised negative impact on these taxa when present in high densities.

6.2 Deep water habitats (35-75 m)

The influence of lobster feeding on deep-water ecosystems outside the coastal regions and within the SWMR is largely unknown. The difficulty of access to these areas by divers has resulted in a lack of data on the basic ecology of lobster at these depths, including diets, foraging habitats, natural distribution and density of prey, as well as a lack of any experimental work conducted at these depths. Habitats at these depths are still being mapped and characterised, but work at deep water sites (35-75 m) at Jurien Bay, Lancelin and Dongara as part of FRDC project 2004/049, has shown that the main habitats at these sites included flat limestone pavement dominated by sponge beds, coralline algae, brown algae such as *Ecklonia* spp. and *Sargassum* spp. and red algae, as well as areas of the seagrass, *Thallasodendron pachyrhizum* (K. Waddington, unpublished data). Invertebrate fauna collected at these sites were dominated by brittle stars, decapods, polychaetes, bivalves, gastropods, amphipods, isopods and sipunculids (K. Waddington, unpublished data). Thus, prey available at these depths are similar to those at shallower sites. However, the gut contents of lobsters collected from these sites indicate that animal prey is far more prevalent in the diets of lobsters from deep water than in animals from shallower water, with decapod crabs, amphipods and isopods predominating (K. Waddington, unpublished data). Stable isotope data from these lobsters also indicate that discarded bait from commercial pots may be an important food source at these depths (K. Waddington, unpublished data). On average, 14 000 tonnes of fish bait from lobster pots is introduced into the ecosystem per year (Fletcher et al. 2005). This roughly equates to 1.3 kg of bait for every 1 kg of lobster landed.

6.3 Comparisons to other studies

Spiny lobster from the family Palinuridae have been identified as having strong predatory impacts on invertebrate prey in many parts of the world (e.g. Pollock et al. 1979, Tegner and Dayton 1981, Babcock et al. 1999, Pederson and Johnson 2006, Langlois et al. 2006). Their relatively large size, high abundance and ability to consume hard-shelled prey are factors that enable them to significantly reduce communities of bivalves, gastropods and sea urchins. In some instances, the effects of lobster predation, and flow-on effects from that predation, can lead to vastly disparate benthic communities between areas of high and low lobster density (e.g. Pollock et al. 1979, Babcock et al. 1999).

The congeneric *Panulirus interruptus*, on the southern coast of California, has been found to exert strong predatory pressure on the sea urchins, *Strongylocentrotus franciscanus* and *S. purpuratus*, in kelp forests (Tegner and Dayton 1981), and on mussel communities of *Mytulis californianus*, *M. edulis* and *Septifer bifucatus* on rocky shorelines (Robles 1987). On the west coast of South Africa, the lobster, *Jasus lalandi*, has a major influence on the structure of benthic communities to the extent that areas with high and low densities of lobster show dramatic differences in their composition of slow moving invertebrate prey. Populations of the mussels, *Aulacomya ater*, and *Choromytilus meridionalis*, are heavily influenced by *Jasus lalandi*, as are communities of sea urchins and the abalone, *Haliotis midae* (Pollock et al. 1979, van Zyl et al. 2003). Temperate reefs of north-east New Zealand and the eastern Tasmanian coast of Australia have demonstrated a strong trophic link between populations of the rock lobster, *Jasus edwardsii*, and invertebrates on which they prey. Studies in Tasmanian marine reserves have indicated that, more than any other predator, *Jasus edwardsii* exhibits a strong predatory effect on the sea urchin *Heliocidaris erythrogramma*, and is largely responsible for causing low sea urchin densities in areas with high lobster populations (Pederson and Johnson 2006). On New Zealand reefs, *Jasus edwardsii* significantly reduces the density of the urchin, *Evechinus chloroticus*, along with the snapper, *Pagrus auratus*, to the point where sea urchin grazing on kelp is significantly reduced in areas of high lobster density. This has led to differences in the benthic habitat between protected and non-protected areas, with higher biomass of kelp inside reserves, and larger areas of urchin barrens (grazed areas dominated by coralline algae) outside reserves (Babcock et al. 1999). *Jasus edwardsii* has also been shown to have a significant impact on infaunal bivalve populations such as those of *Dosinea subrosea* in soft sediments adjacent to reef habitat (Langlois et al. 2006).

The western rock lobster shows similarities to these studies in that it has been shown to significantly reduce numbers of abundant invertebrates, namely epifaunal gastropods (Edgar 1990a, b), however, the habitats and types of abundant invertebrate prey differ between the studies mentioned above and those undertaken on the western rock lobster. Research into the foraging ecology of western rock lobster has been undertaken at shallow coastal lagoon sites dominated by sand and seagrass meadows whilst the focus of the other studies mentioned above has been on kelp dominated reef, often with higher densities of other large invertebrates, such as abalone, urchins and mussels. Furthermore, other studies differ in that many have used Marine Protected Areas (MPAs) as a means of comparing benthic community structure between areas of differing lobster density and/or size structure. Protection from fishing has been linked to an increase in density and changes in size structure of the western rock lobster (Babcock et al. 2007), with more than 313 times higher biomass of lobsters in the no-take zone at Rottenst Island. This is equivalent to or greater than the differences in biomass found in comparative studies from South Africa, California, New Zealand and Tasmania where lobsters have been shown to exert strong influences on benthic prey communities and even to produce cascading trophic effects. In contrast to studies of benthic community structure in these other areas, comparisons of benthic community structure inside and outside the Rottnest Is. no-take area showed there was little or no difference in invertebrate or algal populations across the lobster density gradient (Babcock et al 2006). However there has been no long-term data monitoring of MPAs from inception in Western Australia that have simultaneously looked at lobster density/ size structure and benthic community structure.

7. Role as a prey species

7.1 Natural mortality of western rock lobster

Mortality estimates for the western rock lobster give an indication of how predation affects lobster abundance, since predation is likely to be an important component of lobster mortality (Howard 1988). Mortality estimates by Phillips et al. (2003), using both fixed and density-dependent mortality derived from puerulus settlement near the centre of the western rock lobster's distribution (29°S to 30°S), suggest that highest mortality occurs during the first year after settlement, between ages 1 and 2, and may be as low as 80% or as high as 97%. Results from this study using density-dependent mortality, which was considered more biologically defensible by Phillips et al. (2003), are presented in Table 3.

Table 3. Estimated natural mortality between year classes of benthic western rock lobster from settlement (1 year) to mature adult (6 year) using puerulus settlement estimates during 1987/88 and 1988/89 between 29°S and 30°S. Data from Phillips et al. (2003)

	1987/1988		1988/1989	
Age (years)	Number (million)	% mortality	Number (million)	% mortality
1	338		483	
2	68.37	79.8	77.58	83.94
3	26.72	60.92	29.39	62.12
4	12.20	54.34	13.28	54.82
5	5.92	51.48	6.41	51.73
6	2.96	50.00	3.19	50.23

Western rock lobster in their first year post-settlement suffer the highest mortality with only ca 20% surviving to 2 years old (Table 3). Over the next 4 years, mortality decreased as lobsters increased in age, to about 50% between the 5 and 6 year age classes. Due to the high biomass and high natural mortality of 1-4 year old lobster, which predominate in shallow coastal lagoon waters, it is likely that predation on these lobster, especially those in their first year post-settlement, is an important energy transfer within shallow coastal ecosystems. When viewing the entire lobster population as a whole, loss of biomass through predation within coastal lagoons, situated mainly inshore of the SWMR, is much greater than in deeper waters within the SWMR since it is has been estimated that nearly 87% of lobster biomass is concentrated in shallow waters (Fletcher et al. 2005). Whilst less biomass is found in more offshore waters, natural mortality is still estimated to be quite high (e.g. ca 50% mortality between 5 and 6 year old lobster) so predation on adult lobster may also form an important component in trophic energy transfer in deep-water ecosystems.

Table 4. Known and potential predators of western rock lobster

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	*Dasyatis* spp., *Myliobatis australis*	P
Mammals		
Australian sea lion	*Neophoca cinera*	K
Cephalopods		
Octopus	*Octopus tetricus* and *Octopus* spp.	K
Cuttlefish	*Sepia apama*	K

7.2 Teleost predators

Small post-puerulus lobster of less than ca 25 mm CL are particularly susceptible to predation due to their small size, and are potential prey for a number of shallow water fish species. Natural mortality indicates that at least ca 80% of these do not survive their first year post-settlement, suggesting a very large proportion of the total lobster biomass is lost through predation during this phase. A number of fish predators on these small post-puerulus rock lobster were identified by Howard (1988), who studied the diets of fish collected around patch reefs at Seven Mile Beach, near the centre of the western rock lobster's distribution (Table 4, Fig. 1).

Sand bass (*Psammaperca waigiensis*), sea trumpeter (*Pelsartia humeralis*), brown-spotted wrasse (*Pseudolabrus parilus*), gold-spotted sweetlips (*Plectorhyncus flavomaculatus*), and breaksea cod (*Epinephelides armatus*) all consumed small western rock lobster <26 mm CL (Howard 1988). Furthermore, observations of Chinaman cod (*Epinephelus homosinensis*) at the study site also indicated it was a predator on western rock lobster. Of these species, the sand bass was the most important predator with 15.7% of fish having lobster in their guts, which accounted for 16.3% of total gut volume (Howard 1988). This species was also relatively abundant at the study site, being the fourth most abundant species in gillnet catches (Howard, 1988). It may therefore be singularly responsible for the removal of large quantities of lobster along the west coast. The brown-spotted wrasse and the sea trumpeter were also amongst the most abundant fish species, as determined by gillnet catches, ranking seventh and eighth in abundance, and therefore may also be responsible for removing significant quantities of small post-puerulus lobster (Howard 1988).

It is highly likely that there are more fish species that prey on small rock lobster in shallow water that were not present or caught during the Howard study, but which may be abundant in other parts of the western rock lobster's range. Other fish species that prey on crustaceans and have similar mouth sizes to the fish mentioned above, as well as being crepuscular or nocturnal feeders around reefs, are potential predators on small post-puerulus lobster in their first year post-settlement. Whilst as individuals they may not remove large quantities of lobster, their cumulative effect may be significant. Howard (1988) suggested that for some fish species with small mouths, like the sea trumpeter, larger lobster (>26 mm CL) may be too big to consume but others like the serranids, *E. armatus* and *E. homosinensis*, are likely to be able to consume larger lobster. These two species also occur at much greater depths than at the study site (Hutchins and Swainston, 1986) which was less than 4 m, and thus may be important predators on larger lobster in deeper waters.

There is very little information on how large fish predators may influence populations of larger rock lobster (>25 mm CL). However, there are a number of potential predators, and some that have had western rock lobsters recorded in their gut contents. Some of these species are commercial and recreationally important due to their large size and value as table fish. As such, their distribution, size-structure and abundance is likely to be different than it was before fishing pressure increased to current levels. As a consequence, their predatory effect may be less now than it was historically. The West Australian dhufish (*Glaucosoma hebraicum*), pink snapper (*Pagrus auratus*), baldchin groper (*Choerodon rubescens*) and breaksea cod (*E. armatus*) are all caught by commercial and recreational fishers in deep waters, reach relatively large sizes and could potentially be important predators of western rock lobster. The first two species are primary targets for the commercial wetline fishery on the west coast of Western Australia, whilst the second two are also caught, but in smaller numbers (St John and King 2006). Other species, such as the blue groper, *Achoerodon gouldii*, are probably less abundant and do not form major fisheries.

The dhufish, *G. hebraicum*, occurs between Shark Bay and Cape Leeuwin on the west coast of Western Australia and then eastwards to the Recherche Archipelago (Hutchins and Swainston 1986) with fish greater than 300 mm long inhabiting waters between 10 and 150 m (Hesp et al. 2002). Lek (2004) studied the diets of fish collected from between Perth and Geraldton (Fig. 1), and found that this species consumed teleost fish, crustaceans and cephalopods, but western rock lobster was not identified as a prey item. Previous unpublished studies by Robinson (1987) and Marr (1980), which concentrated on large fish greater than 500 mm, found western rock lobsters contributed less than 5% to the total abundance of prey present in dhufish stomachs, with teleost fish and cephalopods being the most important prey species. Small rock lobsters have also been identified in the guts of dhufish caught by recreational fishers (Jill St John, Department of Fisheries WA, pers. comm.). Due to the relatively small proportions of lobster found in dhufish guts, it appears that as a species, dhufish is not a singularly important predator of western rock lobster.

The baldchin groper, *C. rubescens*, occurs between Shark Bay and Geographe Bay on Western Australia's west coast (Hutchins and Swainston 1986). Dietary studies by Lek (2004) on baldchin groper collected from the Abrolhos Islands found that this species feeds predominantly on molluscs and echinoderms and that lobster (Palinuridae) comprised only 1.1% to the gut volume and were present in only 1.4% of guts examined. Furthermore, Walker (1983) in an earlier study, found that only 6 out of 500 baldchin groper collected from the Abrolhos Islands had western rock lobster in their guts. Thus, as a natural predator of western rock lobster, baldchin groper is probably not singularly important.

Pink snapper, *P. auratus*, is distributed along the southern coastline of Australia from Barrow Island in Western Australia to Hinchinbrook Island in Queensland to depths of 200 m (Kailola et al. 1993). Pink snapper from Victorian waters consume crustaceans, bivalves and small fish and adults from South Australian waters have been shown to consume thick-shelled prey such as mussels and the blue swimmer crab, *P. pelagicus* (Kailola et al. 1993). There are no dietary data from Western Australia that suggest that pink snapper are a predator of western rock lobster, but due to their large size and potential to consume hard-shelled crustaceans, such as *P. pelagicus*, they must be considered a potential predator on western rock lobster, although it is unlikely that lobster are singularly an important prey item.

The western blue groper, *A. gouldii*, is a large labrid that occupies coastal reef systems to a depth of 65 m (Scott et al. 1974). Its diet consists of benthic crustaceans such as crabs as well as echinoderms, molluscs and fish, whilst the diet of the con-generic, *A. viridis* from the east coast, in large size classes (>300 mm), was dominated by echinoderms and mussels (Gillanders 1995). Since, the western blue groper attains a large size (1750 mm; May and Maxwell 1986), occupies shallow and deep reef systems and consumes hard-shelled invertebrate prey, it is a potential predator on western rock lobster. However, it is probably far less abundant than other large fish predators and therefore any predatory effect on western rock lobster is likely to be relatively minor.

Large cod species, such as the breaksea cod and western wirrah, are potential predators of large western rock lobster (>25 mm CL) due to their large size and distribution to deep waters. Breaksea cod has been identified as a predator of small rock lobster (<25 mm CL) in shallow water (Howard 1988), but no dietary data exists for this species in deeper water. There is no dietary data for the western wirrah, but since it belongs to the same family (Serranidae) as breaksea and chinaman cod, and has a similar morphology, it may be a potential predator of western rock lobster.

7.3 Elasmobranch predators

A number of shark and ray species are potential or known predators of large western rock lobster (Table 4). These species co-occur with lobster at least over part of their distribution and occupy similar depths as lobster. Shark species such as the gummy shark, whiskery shark and sandbar shark are targeted by west coast demersal gillnet and longline fisheries (McAuley 2006), and are therefore at levels that are lower than they have been historically. Whilst there is evidence that some prey on western rock lobster, there is no evidence that lobsters are a singularly important prey item.

The gummy shark, *Maculatus antarcticaus*, is distributed around the southern coastline of Australia to at least as far north as Geraldton on the west coast, and at depths to at least 80 m (Last and Stevens 1994) and forms part of the commercial shark fishery especially on the southern coast (McAuley 2006). There are no dietary data from the west coast to suggest that lobsters are an important prey item. However, diets of gummy sharks caught in Bass Strait contained southern rock lobster, *Jasus edwardsii*, suggesting that they are capable of consuming western rock lobster (Kailola et al. 1993). Furthermore, gummy sharks consume other prey such as cephalopods and other types of crustaceans. The whiskery shark, *Furgaleus macki*, is found along the south coast of Australia up to North-west Cape in Western Australia to a depth of 220 m (Last and Stevens 1994) and is an important species in the Western Australian shark fishery (McAuley 2006). They feed mainly on octopus, but squid, fish and rock lobsters are also eaten (Kailola et al. 1993). The sandbar shark, *Carcharhinus plumbeus*, is found down along the Western Australian coast to Esperance and to a depth of 280 m (Last and Stevens 1994). It forms an important component of the demersal longline and gillnet fishery on the west coast (McAuley 2006) and feeds on fish, crustaceans and teleosts (Last and Stevens 1994), although there is no evidence that rock lobster are an important prey item. Several species of wobbegong, *Orectolobus* spp., are found on inshore reefs as well as more offshore reefs to depths of over 100 m along the lower west coast of Western Australia (Last and Stevens 1994). They forage in seagrass and reef habitats at night and prey upon benthic prey such as octopus, crabs, small fish but also western rock lobster (Last and Stevens 1994). The southern eagle ray, *Myliobatis australis*, smooth stingray, *Dasyatis thetidis*, and black stingray, *D. brevicaudata*, are large rays found along the west coast to Shark Bay at depths similar to western rock lobster and may also prey on lobster due to their diet of benthic invertebrates (Last and Stevens 1994).

7.4 Cephalopod predators

There are several species of octopus located within the range of the western rock lobster, but of these, the most important predator of western rock lobsters is *Octopus tetricus* (Joll, 1977). In the 2004/05 fishing season, 182,794 octopus were caught in lobster pots at an average of 0.029 individuals per pot lift (de Lestang and Melville-Smith 2006). Studies by Joll (1977) indicate that pot-predation by *O. tetricus* is far greater than pot-predation by cuttlefish, *Sepia apama*, or fish predators, and is primarily caused by octopus over 500 g in weight. Whilst *O. tetricus* is an important predator of lobster in pots, there are no dietary data to suggest that they are an important predator of lobster in their natural environment. Aquarium observations of octopus/lobster interactions indicate that the western rock lobster can easily evade *O. tetricus*, whilst examination of food mounds around octopus shelters have not revealed rock lobster carapaces (Joll 1977). If natural predation does exist by *O. tetricus,* it is likely to be more prevalent at depths less than 20 m as Joll (1977) found more caught in pots at these depths than further offshore.

Puncture marks inflicted by the cuttlefish, *S. apama* on pot-caught western rock lobsters indicate that this species has a predatory impact (Joll, 1977), although compared to predation by *O. tetricus*, this is likely to be minor (1-12 % of total predation; Joll 1977). There have been no dietary studies indicating that *S. apama* is an important predator outside of pots, but the fact that this species preys on lobsters in pots indicates that natural predation may exist.

*7.5 Sealion (*Neophoca cinerea*) predation*

Sea lions are a benthic forager (Costa and Gales 2003), and at Kangaroo Island, South Australia, have been found to consume southern rock lobster, although cephalopods such as octopus and cuttlefish were the most important prey species (McIntosh et al. 2006). Juvenile sea lions have been observed to “steal” western rock lobster from pots, and are occasionally caught in the pots as a consequence of this foraging behaviour (Fletcher et al. 2005). Sea lion exclusion devices will soon be introduced to the fishery to prevent this by-catch occurring (de Lestang and Melville-Smith 2006). The level of natural predation of western rock lobsters by sea lions is not known, however, sea lions can dive to depths of 60-105 m, so can potentially prey on both juvenile and adult lobster (Costa and Gales 2003). Since cephalopods appear to be the preferred prey for sealions (McIntosh et al. 2006), and sea lions are relatively few in number (Australian pop.: 9 300 – 11 700; Gales et al. 1994), they are probably not a singularly important predator of western rock lobster.

7.6 Cannibalism

Aquarium studies have indicated that under limited food supply, western rock lobster will cannibalise each other (Gray 1992). This was observed to occur on lobster that had recently moulted, resulting in greater susceptibility to attack due to their soft shell. Whilst dietary studies have identified western rock lobster exuviae (shells) in the diets of western rock lobster, these fragments have not had any tissue attached and appeared to be old shell, i.e. with attached fouling organisms, and thus these fragments are more likely to have come from discarded moults (Joll and Phillips 1984). Furthermore, it has been suggested that western rock lobster consume discarded shells as a source of calcium for remineralisation (George 1958). Since western rock lobster heads appear to be more of a deterrent than an attractant when used as bait (Gray 1992), it seems likely that cannibalism is not overly prevalent under natural conditions, however, it may occur under certain circumstances, such as reduced food supply and high lobster density, at certain times i.e. after moulting, or with differing frequencies at different life-stages e.g. for juvenviles.

7.7 Mortality during migration and after moulting

Many western rock lobsters undergo a migration at about 4 to 5 years of age (Phillips 1983). Movement from shallow to deeper water may potentially increase predation, as lobsters are believed to travel extensively across open sand habitat at this time (Gray 1992). This is likely to provide less cover from predators than vegetated or reef habitats. However, mortality estimates, which may be used as an indication of predation, do not indicate that mortality increases between these year classes, so presumably the act of migrating does not significantly increase the risk of predation by western rock lobster (Table 3).

Benthic lobster moult about 6 times a year in their first year post-settlement, 4 in their second year, 3 in their third year and 2 in their fourth year (Gray 1992). Large adult western rock lobster may moult only once a year or every second year in some cases (Gray 1992). Moulting usually occurs overnight and it then takes 3 or 4 days for the new shell to harden. During this time western rock lobster are more vulnerable to predation and shelter deep within ledges (Gray 1992). It is likely that predation by predators that are able exploit these ledges, e.g. octopus, cuttlefish and other lobster, increases when western rock lobsters are moulting, although there is no direct evidence that this occurs.

8. Flow of energy in ecosystems

Dietary studies, and current stable isotope research indicates that lobsters derive much of their growth from benthic animal prey that graze primary production (Joll and Phillips 1984, Edgar 1990a,b, Jernakoff et al. 1993, MacArthur et al. 2006, Waddington , unpublished data). Lobsters therefore act as a secondary consumer in both shallow and deep benthic ecosystems (Fig. 4). However, in shallow waters located inshore of the SWMR, significant quantities of coralline algae and seagrass material have been identified in the gut contents of western rock lobster (Joll and Phillips 1984, Edgar 1990a,b, Jernakoff et al. 1993, MacArthur, unpublished data). Coralline algae have been demonstrated to be able to supply much of the lobster's energy requirements although may not contribute significantly to growth (Joll and Crossland 1983). Therefore, in shallow water ecosystems, lobster also play a role as a grazer consuming, seagrass, seagrass epiphytes and articulated coralline algae from the reef (Fig. 4). Shallow water lobster have also been shown to consume large quantities of sponges and ascidians, which are filter feeders removing carbon from the water column (MacArthur, unpublished data), however, the contribution of these dietary sources to growth is not yet known. Lobsters collected from deepwater within the SWMR differ in that they appear to graze little on primary producers, and feed more on consumers such as amphipods, isopods and decapod crabs (Waddington, unpublished data; Fig. 4), however it is not yet clear whether this is an ontogenetic or habitat related diet shift. An allocthonous source of energy, in the form of bait discarded or removed from pots, may also play an important role in the energy budget of western rock lobster in deep water (Waddington, unpublished data; Fig. 4). About 1.3 kg of bait is used to capture 1 kg of western rock lobster which amounts to about 14 000 t per year (Fletcher et al. 2005).

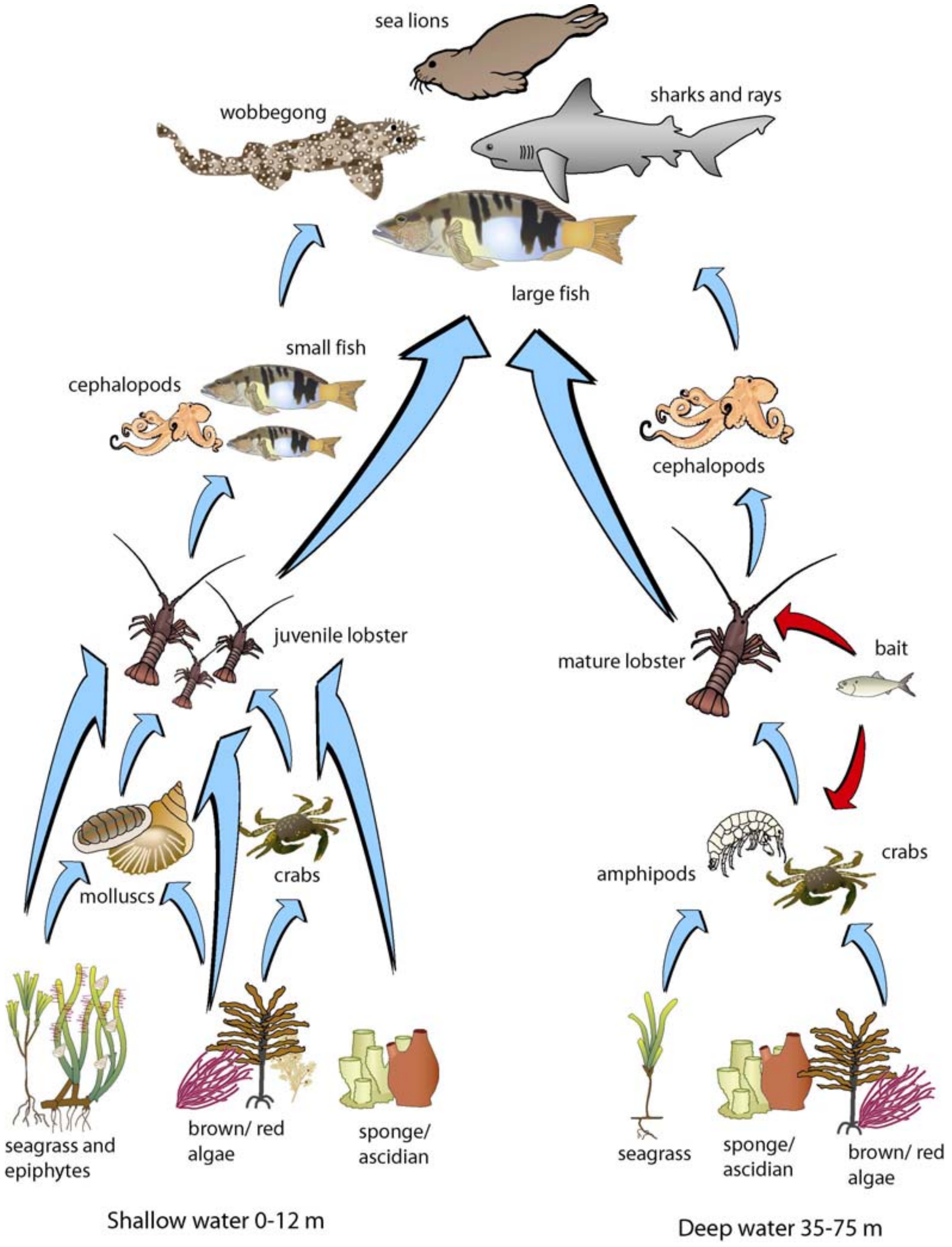


Figure 4. Food web of shallow-water and deep-water ecosystems of the western rock lobster showing energy flow between components. The size of the icons is not proportional to magnitude

9. Marine Protected Area (MPA) studies

Marine Protected Areas can be a useful tool in determining ecological processes in marine areas by examining different ecosystem components between fished and unfished areas. Densities of exploited species are often higher inside than outside protected reserves (e.g. Babcock et al. 1999), and thus the strength of relationships can be observed by monitoring any changes to the ecosystem after MPA implementation. MPAs can also safeguard against the sliding-baseline phenomena, where our understanding of a natural ecosystem changes over time as components are reduced or become absent.

The use of MPAs has helped researchers determine important links between lobsters and other ecosystem components, e.g. sea urchin prey, as lobster size structure and biomass typically increases inside protected areas (e.g. Edgar and Barrett 1999, Kelly et al. 2000, Babcock et al. 2007). In some cases, lobsters have been found to significantly reduce numbers of prey such that prey densities inside and outside reserves differ dramatically (e.g. Babcock et al. 1999, Pederson and Johnson 2006). These effects may even cascade down to the level of primary producers if prey species have significant grazing capability (e.g. Babcock et al. 1999).

No-take areas may also give a useful insight into the direct effects of fishing on exploited populations that cannot necessarily be obtained through more conventional methods of fisheries science. For example, the relative levels of lobster biomass were more than three hundred times higher, and the levels of egg production one hundred times higher inside the Kingston Sanctuary relative to fished areas at Rottnest Island (Babcock et al. 2007). These results have potential implications on the levels of fishing relative to the unfished spawning biomass currently estimated for the population. It would be prudent, therefore, to examine some of the assumptions about the status of rock lobster stocks, preferably using fisheries independent methods, in order to be reassured that we fully understand the status of *P. cygnus* populations.

One means of obtaining this fisheries independent information can be to use a well designed, stratified and representative network of no-take areas to provide baselines and reference points for management. They are probably also the only way of comprehensively demonstrating the ecological "importance" of western rock lobster and the effects of fishing on spatial scales large enough to provide results that can be robustly interpreted at the whole-ecosystem level. Studies are currently underway monitoring lobster abundance and benthic community parameters at the recently gazetted Jurien Bay Marine Park (Edgar et al. 2003, MacArthur, unpublished data), whilst similar studies are planned for sanctuary areas at Marmion, Rottnest Island and Shoalwater sanctuary zones by the Department of Fisheries, Western Australia and the Swan Catchment Council. These studies are restricted to relatively shallow waters, however, and are centred on only one of the three major western rock lobster fishery zones.

10. Conclusions

As an abundant and wide-ranging consumer, the western rock lobster is likely to play an important role in ecosystem processes on the shelf waters within the SWMR. In shallow waters (< ca 10 m), western rock lobster have been identified as being able to significantly reduce the densities of invertebrate prey, such as epifaunal gastropods, and to have a varied and highly adaptable diet. However, there is a lack of similar experimental studies in deep water (>20 m) within the SWMR to assess if they negatively influence prey populations at this depth. What little information that does exist for deep water populations suggests that, in contrast to shallow water, lobster forage primarily on animal prey, which is dominated by crustaceans, such as decapod crabs and amphipods. However, there is no quantitative data to indicate if this impact is significant. The role of western rock lobster as a consumer in deep water may have changed as a result of fishing as a large proportion of the deep water lobster biomass is removed annually (8,000 – 12,500 t), whilst a similar weight of bait from pots (ca 14 000 t) is introduced annually to the ecosystem and consumed by western rock lobsters amongst other species.

For both shallow and deepwater habitats, there is a general lack of information on foraging impacts of western rock lobster on the broad community or ecosystem level. One effective means to address this issue would be to create gradients in lobster abundance, using no-take zones, in conjunction with monitoring of the benthic community. Currently, only a few shallow water no-take zones in Shoalwater Islands, Rottnest Island, Marmion and Jurien Bay marine parks have been gazetted where lobster cannot be fished and there has been little research on lobster within these zones. In other parts of Australia and the world, such as Tasmania, New Zealand, South Africa and North America, MPAs have led to key interactions being identified between lobster and prey species.

As a prey species, there does not appear to be one single predator, or group of predators that rely on lobster as their primary prey. However, the sand bass may be the closest species in terms of a ‘key’ predator, with a significant portion of their diet consisting of lobster (ca 16%). This species is relatively abundant around near-shore reefs at Dongara, and may also be abundant at inshore reefs elsewhere although these areas are inshore of commonwealth SWMR waters. A number of fish, cephalopod and elasmobranch species that are found within SWMR waters consume western rock lobster, however, for those that have had their diets studied, western rock lobster have made only small contributions to gut volume (< 5 %). As single species, their predatory effect on rock lobster may be small, but their combined effect may be large. For example, ca 80% of lobsters do not survive their first year post-settlement, and much of this mortality is likely to be attributed to predation.

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