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No. 9, 2016

Resource Assessment Report Western Rock Lobster Resource of Western Australia

S. de Lestang, N. Caputi and J. How

Government of **Western Australia**
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Fish for the future

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Executive Summary

The western rock lobster *Panulirus cygnus* (George) is taken by commercial and recreational fishers throughout its geographic range along the lower west coast of Western Australia. The main commercial fishery for *P. cygnus* is the West Coast Rock Lobster Managed Fishery (WCRLMF), which is Australia's largest single-species fishery, currently worth about $400 million annually. Western rock lobster provides the basis for the economies of a number of coastal towns and also supports a recreational fishery.

The western rock lobster is an omnivorous crustacean, found predominantly along the mid- and lower west coast of Western Australia in shallow and deep (< 100 m) reef habitats. After a 9 – 11 month planktonic stage spent off the continental shelf, the larvae metamorphose into pueruli before they return to the coast and settle on shallow near-shore reefs. Here they grow for about four years before migrating offshore as juveniles, which is when they start to recruit to the fishery. Large and mature lobsters are mainly found in the deep-water (40 – 100 m) breeding grounds.

In 1963 the WCRLMF was declared a limited-entry fishery, freezing pot and licence numbers. Since that time the fishery has undergone a number of management changes designed to maintain stock sustainability, most recently transitioning to an individual transferable quota management regime. The long-term average catch has historically been about 11 million kg per annum of western rock lobster. The recreational fishery issues about 45,000 licences annually, and currently accounts for about 5% of the total catch of the fishery.

The WCRLMF was the first fishery in the world to receive Marine Stewardship Council (MSC) Certification as a sustainable fishery in 2000 and was recertified in 2006 and 2012. To maintain accreditation, the fishery must satisfy the criteria set by the MSC which has resulted in considerable research being undertaken on the potential ecological impacts of the fishery as well as those on the stock.

Management of the fishery is based on maintaining an acceptable status of zone-specific breeding stocks relative to their threshold Biological Reference Points (BRP), which are designed to:

"Ensure that the egg production in each Zone of the fishery remains above its threshold level and the probability of still being above this level in five years' time is at least 75%."

Department of Fisheries researchers have an ongoing program to monitor settlement of puerulus, catches of the commercial fleet (through on-board sampling and catch returns), the breeding stock, recreational catches, and environmental conditions. This information is used to assess changes in the western rock lobster stock and input into an integrated population model which forms the basis of advice for management decisions.

Stock assessment for the fishery is based on a number of empirical and modelled indices that are considered collectively in a "weight-of-evidence" approach and used to inform a risk assessment on the sustainability of the fishery. Specific indices considered and their current assessments are listed in the table below, with the maximum risk score for the Western Rock Lobster resource in the West Coast Bioregion being 4, which was generated by the combination of a high likelihood of minimal stock depletion. This constitutes a **Low Risk** which is the minimum acceptable risk level.

This score assumes the total catch will be maintained within a 5% increase per season over the following two seasons. Total Allowable Commercial Catch (TACC) scenarios outside of this range will require a re-assessment.

Table summarising the lines of evidence used in the "weight-of-evidence" approach to inform a risk assessment on the sustainability of the fishery.

Category	Lines of evidence (Consequence / Status)
Catch	Catches in the WCRLMF have increased slightly over the past few seasons due to small increases in quota and an increase in recreational catch; however they remain below 55% of the historical average level of catch. The catches being relatively low and quotas having historically been easily obtained, indicates that there is a low risk of the stock being over exploited.
Catch distribution	The slight change in the spatial distribution of the catch to increased landings in deep-water regions during the whites migration has been in response to increased market demand and thus higher beach prices being offered during this period. The data do not represent a spatial shift in effort indicative of serial depletion within the fishery.
Catch rates	Standardised catch rates provide an overall measure of lobster biomass. Trends in these indices indicate that biomasses in recent years are over three-times greater than they were under input controls and are either remaining stable under current harvest rates or increasing. These indices suggest that the lobster stock is at low risk of being overfished. The Biomass Dynamics Model (BDM) indicates that at slightly increased TACC levels (e.g. 6300 t) the catch rates will increase slightly or remain steady over the subsequent five seasons. The Integrated Population Model (IPM) indicates that catch rates in all locations of the fishery will continue to increase with a continuation of fishing at similar or slightly higher TACCs (e.g. 6300 t).
Fishery-independent monitoring	Fishery-independent recruitment (puerulus) monitoring indicates that the current puerulus settlement is continuing its recent pattern. The IPM suggests that this current level of settlement is sufficient to maintain/increase stock abundance levels at current harvest levels. Fishery-independent index on lobster damage indicates that recent increases in high-grading are not leading to increases in the proportion of lobsters in the population with damaged appendages.
Vulnerability (PSA)	The total PSA scores was 1.96 for the Western Rock Lobster, with the MSC PSA score being 96 out of 100. This classifies this species as being of low risk to over-exploitation.

Age and / or size composition	There is no indication of a reduction in the contribution of large lobsters to the commercial catch.
Fishing mortality (*F*)	The BDM currently predicts that the fishery is fishing at harvest rates of about 30%. These will remain similar or to decline at current or slightly higher TACCs. The IPM currently predicts that the fishery is fishing at harvest rates of between 25 and 30%. These will continue to decline at current or slightly higher TACCs.
Spawning biomass (*B*)	Fishery-independent egg production indices at all sites are well above long-term levels. These indices indicate high levels of spawning stock exist throughout the fishery. The BDM indicates that the stock biomass is currently high, more than double that in the early 2000s and that at slightly increased TACC levels (e.g. 6300 t) the biomass will increase slightly or remain steady over the subsequent five seasons. The IPM indicates that the biomass and egg production in all locations of the fishery is at record high levels since the mid-1970s, and that a continuation of fishing at similar or slightly higher TACCs (e.g. 6300 t) will continue to result in increasing biomass and catch rates.

List of Abbreviations

BDM	Biomass Dynamics Model
DCCM	Dependent Commercial Catch Monitoring
DoF	Department of Fisheries (Western Australia)
EBFM	Ecosystem-Based Fisheries Management
ESD	Ecologically Sustainable Development
EPBC	Environment Protection and Biodiversity Conservation (Act)
FRMA	Fish Resources Management Act
HR	Harvest rate (also referred to as Legal Proportion Harvested)
IBSS	Independent Breeding Stock Survey
IPM	Integrated Population Model
LPH	Legal Proportion Harvested / Harvest Rate
MSC	Marine Stewardship Council
RDAG	Research and Development Assessment Group
SAFS	Status of Australian Fish Stocks
WA	Western Australia
WRL	Western Rock Lobster
WRLC	Western Rock Lobster Council

1 Scope

This document provides a description and assessment of the Western Rock Lobster Resource and all of the fishing activities (i.e. fisheries / fishing sectors) affecting this resource in Western Australia (WA). The report is focused on the single species that comprises this resource (Western Rock Lobster *Panulirus cygnus*). This species is captured by commercial and recreational fishers, primarily using by baited pots (traps), throughout its geographic range along the west and south coasts of WA (Section 6).

The report contains information relevant to assist the assessment of the resource against Environment Protection and Biodiversity Conservation (EPBC) Act export approval requirements and the Marine Stewardship Council (MSC) Principles and Criteria for Sustainable Fishing, as well as for other reporting requirements, e.g. Status of Australian Fish Stocks (SAFS).

2 How the Department Operates

Fisheries management in WA has evolved over the last 40-50 years from a focus on managing catch of target species by commercial fishers to a fully integrated Ecosystem-Based Fisheries Management (EBFM) approach, which ensures that fishing impacts on the overall ecosystems are appropriately assessed and managed (Fletcher et al. 2010). In line with the principles of Ecologically Sustainable Development (ESD; Fletcher 2002), the EBFM approach also recognises that the economic and social benefits of fishing to all users must be considered.

Implementation of EBFM involves a risk-based approach to monitoring and assessing the cumulative impacts on WA's aquatic resources from all fishing activities (commercial, recreational, customary), operating at a bioregional or ecosystem level. The level of risk to each resource is used as a key input to the Department of Fisheries (DoF) Risk Register, which is an integral component of the annual planning cycle for assigning activity priorities (research, management, compliance, education etc.) across each bioregion. A summary of the Department's risk-based planning annual cycle that is delivering EBFM in the long-term is provided in Figure 2-1.

To ensure that management is effective in achieving the relevant ecological, economic and social objectives, formal harvest strategies are being developed for each resource. These harvest strategies outline the performance indicators used to measure how well objectives are being met and set out control rules that specify the management actions to be taken in situations when objectives are not being met. The WA harvest strategy policy (DoF 2015) has been designed to ensure that the harvest strategies cover the broader scope EBFM and thus considers not only fishing impacts of target species but also other retained species, bycatch, endangered, threatened and protected (ETP) species, habitats and other ecological components (Fletcher et al. 2016).

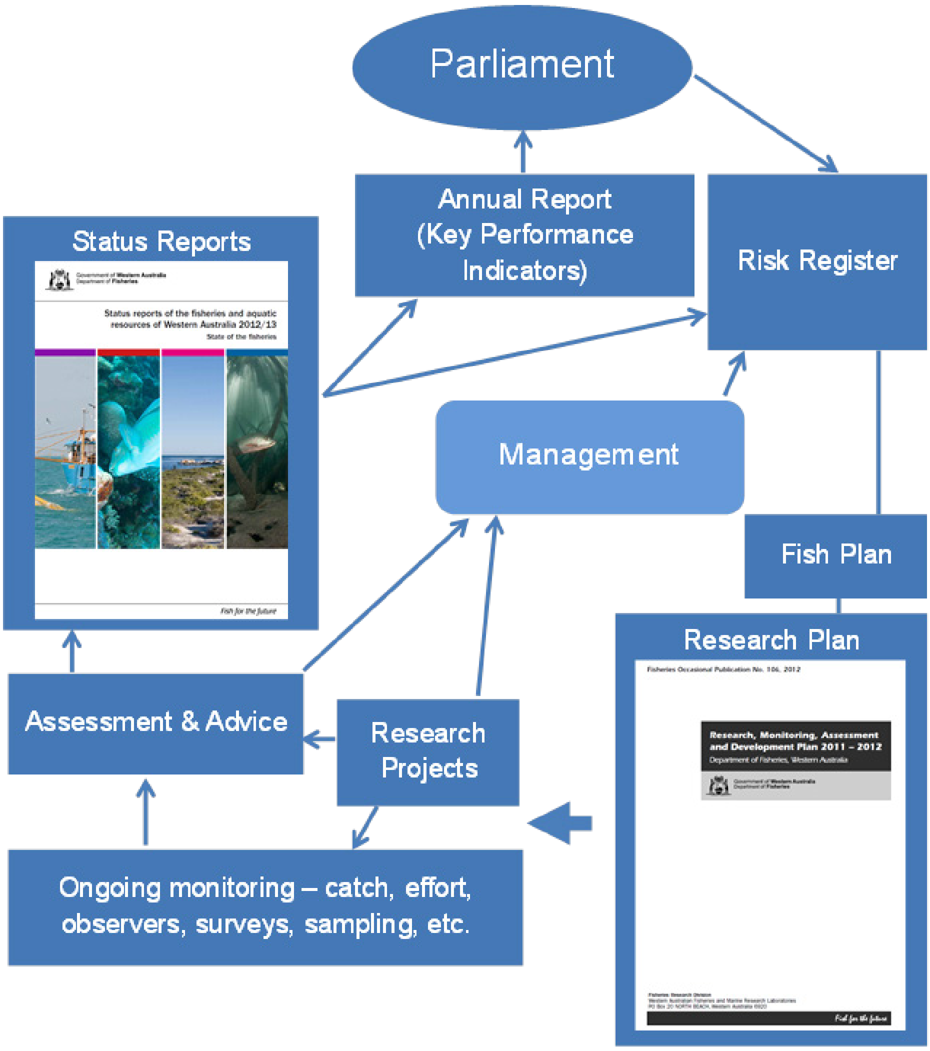

Figure 2-1. An outline of the risk-based planning cycle used for determining Departmental priorities and activities

3 Aquatic Environment

The distributional range of *P. cygnus* sees it restricted to the clear, warm, low- nutrient waters of the west coast of WA, with the majority of catch taken in the West Coast Bioregion (Figure 3-1). These waters are strongly influenced by the Leeuwin Current, a southward flowing warm water current which carries tropical waters along the West Australia coastline (Figure 3-2).

The habitat of *P. cygnus* is dominated by limestone reefs, which can extend seaward for 40 to 60 km on the continental shelf. Within this region there is minimal overlap of other rock lobster species. Changes in sea levels have caused the fringing reefs of sea-level shorelines to be submerged, forming long chains of ledges and banks. The changes have also created a number of mainland remnant islands with fringing reefs. These reefs and banks often contain a matrix of crevices and ledges, which are the primary diurnal habitat of *P. cygnus*.

Water depth, light and wave exposure influence the flora and fauna on these limestone reefs and banks. The reefs are typically covered by seagrass (*Amphibolis*) and large algae. At greater depths, and up to 50 m, large brown algae (*Ecklonia* and *Sargassum*) create “kelp” gardens covering the hard limestone bottom, while crevices, which have poor light penetration, are often covered with sea-squirts, sponges and other sessile invertebrates.

For more details on the environment of *P. cygnus* and an ecological assessment of the fishery, please refer to Bellchambers et al. (in press).

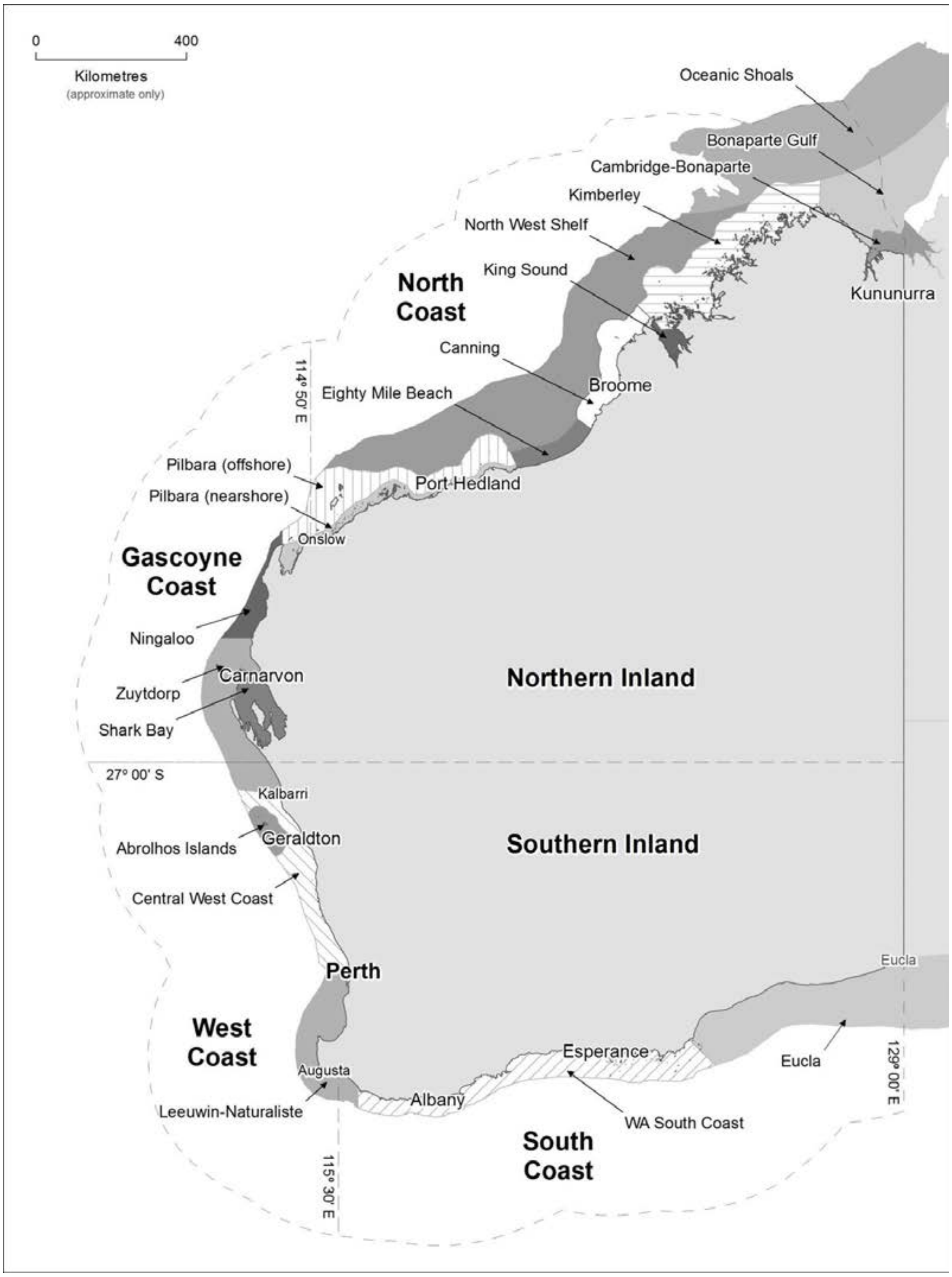

Figure 3-1 Ecosystems within the four marine bioregions in Western Australia based on the Integrated Marine and Coastal Regionalisation for Australia (IMCRA) scheme

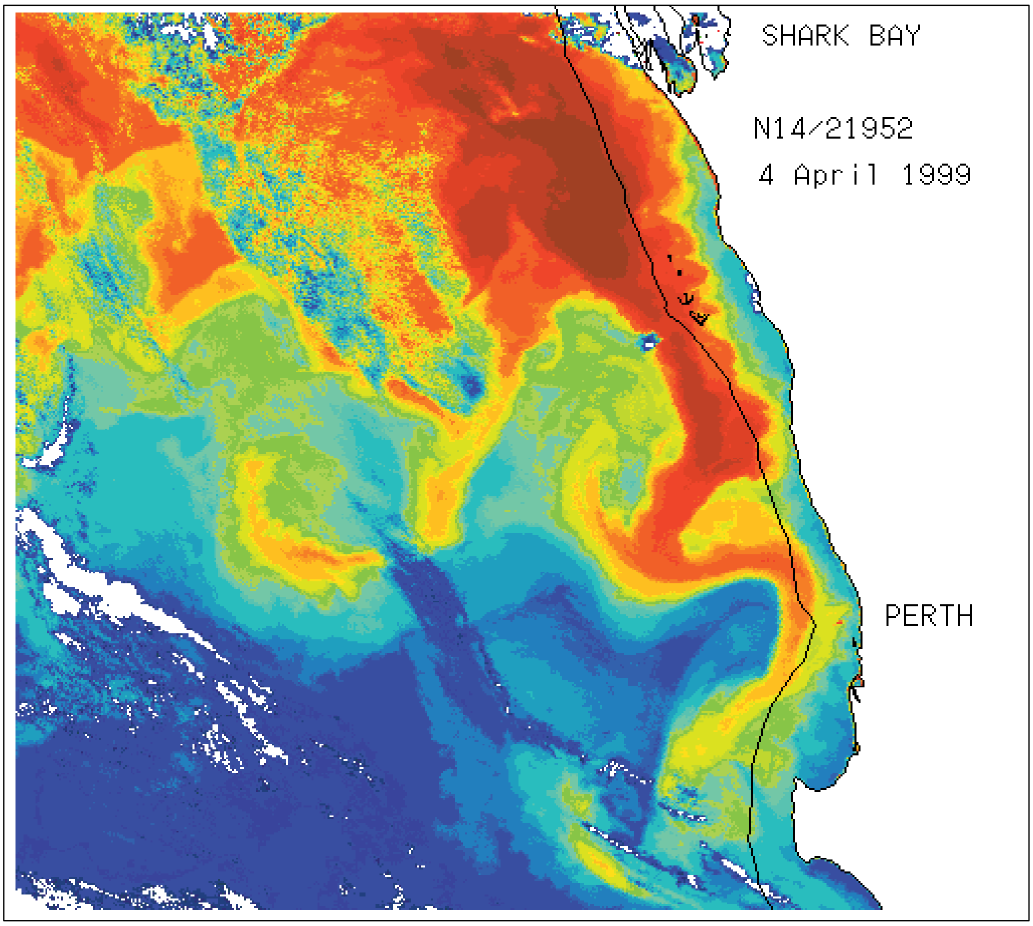

Figure 3-2 Satellite image of the Leeuwin Current (shown in red) in April 1999, from the thermal radiometer on a NOAA satellite. The black line marks the 200 m contour, and the white/blue speckled areas are clouds. Image from Alan Pearce, courtesy of WASTAC

4 Resource Description

4.1 Western Rock Lobster Resource

The western rock lobster resource comprises of *Panulirus cygnus* throughout its distribution. It is targeted by two managed fisheries (Section 6.1), the West Coast Rock Lobster Managed Fishery and the South Coast Crustacean Managed Fishery. Both fisheries have active commercial and recreational fisheries.

4.2 Selection of Indicator Species for Resource

As this resource is restricted to the western rock lobsters, no indicator species are used.

5 Species Description

5.1 Western Rock Lobster (*Panulirus cygnus*)

Figure 5-1. The western rock lobster, *Panulirus cygnus*. Illustration © R. Swainston (www.anima.net.au)

5.1.1 Taxonomy and Distribution

The western rock lobster (Figure 5-1) is a decapod crustacean of the family Palinuridae. The Palinuridae, or spiny lobsters, are found throughout tropical, subtropical and temperate waters (Lipcius & Cobb 1994). The family comprises 47 species in eight genera.

The distribution of *P. cygnus* extends from the North West Cape in the north to around Albany on the south coast on WA (Figure 5-2). It is the dominant lobster throughout its range, with minimal overlap with tropical species (e.g. *P. ornatus*, *P. versicolor*) in the north and *Jasus edwardsii* in the south. Adult western rock lobsters exhibit sexual dimorphism, with mature males having a longer merus on their second pereiopods and gonopods for sperm transfer, while female lobsters possess endopodites for the attachment of fertilised eggs (Figure 5-3).

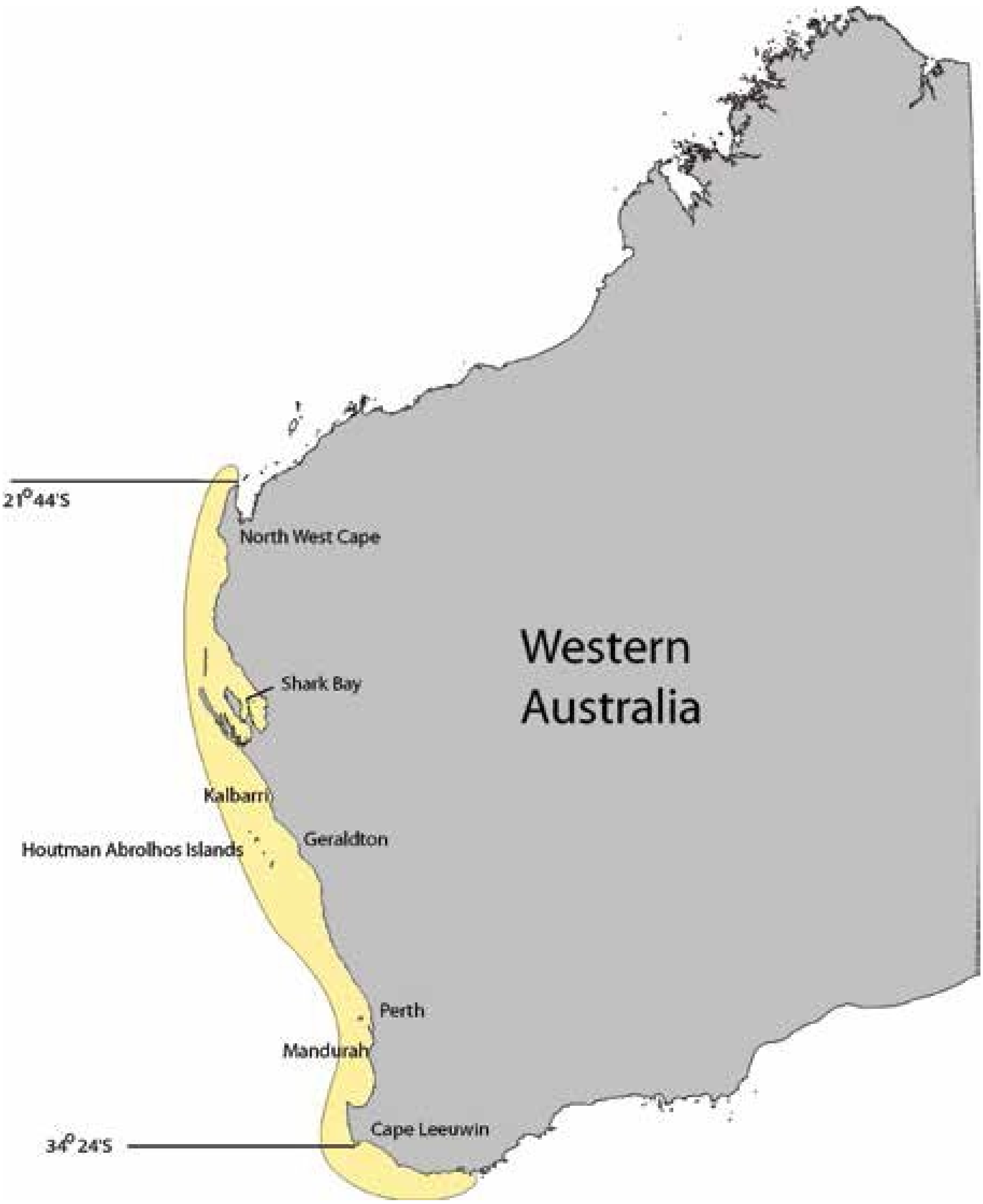

Figure 5-2. Distribution of the western rock lobster *Panulirus cygnus*

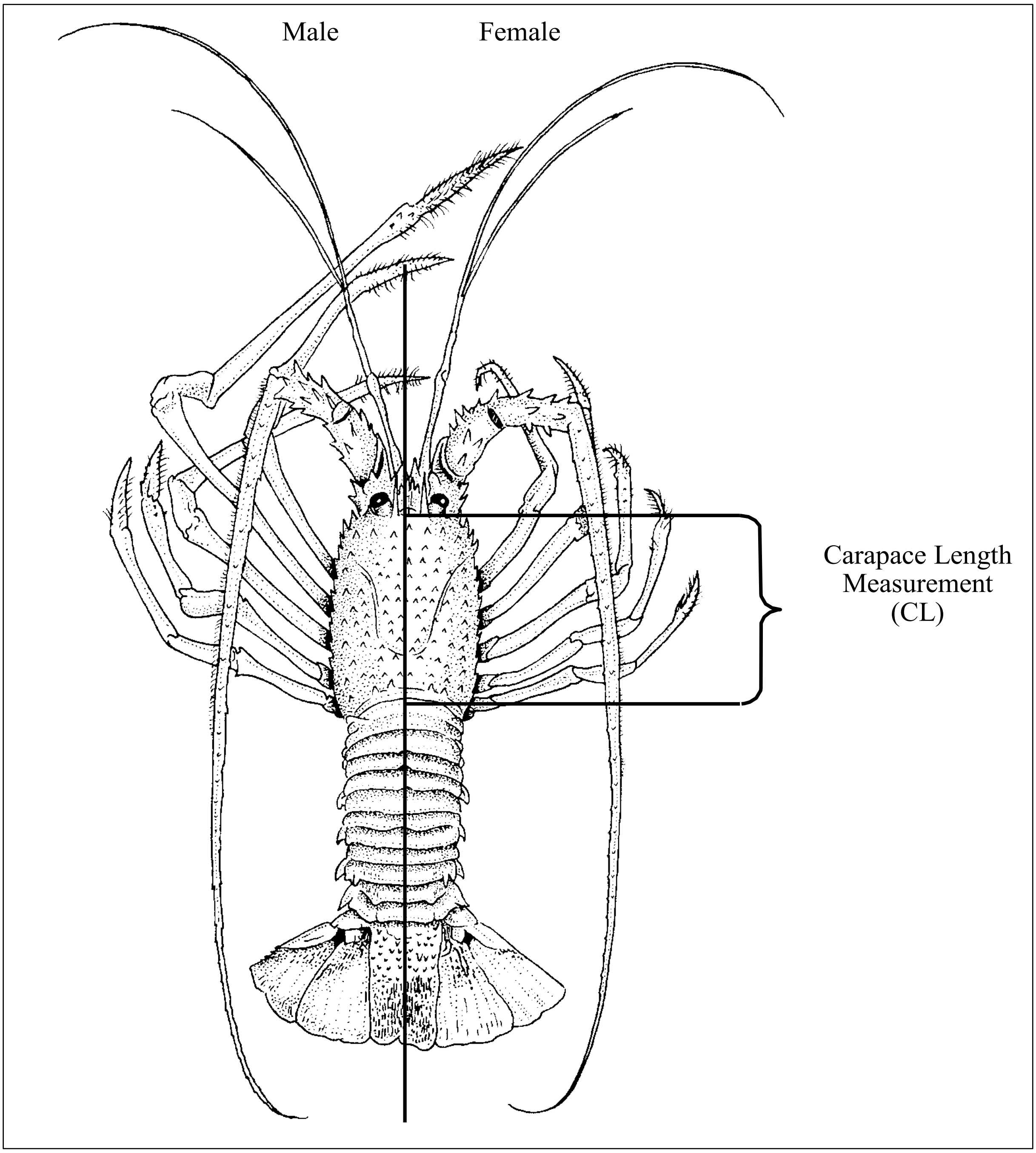

Figure 5-3. Morphology of male (left) and female (right) *Panulirus cygnus* showing how carapace length (CL) is measured from the anterior edge of the carapace between the preorbital spines down the mid-dorsal line to the posterior edge

5.1.2 Stock Structure

Western rock lobster (WRL) is considered a single management unit in the West Coast Bioregion and the same genetic stock extends into the South Coast Bioregion (Figure 3-1 Ecosystems within the four marine bioregions in Western Australia based on the Integrated Marine and Coastal Regionalisation for Australia (IMCRA) scheme).

The stock structure of WRL has been examined genetically through allozyme electrophoresis (Thompson et al. 1996, Johnson 1999). Samples of legal-sized lobster from 1980 (Thompson et al. 1996) and puerulus from 1995 to 1998 (Johnson 1999) showed some latitudinal and temporal variation in allelic frequencies in polymorphic loci. However, the 1994 sample of Thompson et al. (1996) showed that this latitudinal variation did not persist through years. Both studies concluded that the western rock lobster is a single panmictic population, with ephemeral genetic patchiness between cohorts (Thompson et al. 1996, Johnson 1999).

A recent study examined microsatellite and mitochondrial sequences of western rock lobster to examine possible changes in genetic variation (Kennington et. al. 2013). The lobsters high fecundity (Figure 5-19) and extended larval phase (Section 5.1.3.1) leading to variable reproductive success make it a strong candidate for loss of genetic variation. Samples covering a 14 year time span and 960 km of coastline found no loss of genetic variation or significant population structuring (Kennington et. al. 2013). This again confirms the previous assertions of a single panmictic population (Thompson et al. 1996, Johnson 1999).

Although the genetic structure of WRLs has not changed over recent time, there has been variation in the reproductive biology (Section 5.1.3.6) and growth (Section 5.1.3.4) of this species. At this stage there is uncertainty as to whether these observed changes in life history parameters are the result of changes in environmental conditions, a response to selective fishing practices or a combination of possibilities (Melville-Smith & de Lestang 2006). However, they do necessitate the assessment and management of the fishery in zones, so as to account for this biological variation and tailor management accordingly (Section 6.5).

5.1.3 Life History

The sub-sections below provide an overview of the life history characteristics of the western rock lobster, with a summary of the relevant biological parameters used in stock assessments presented in Table 5-1.

Table 5-1. Summary of biological parameters for *Panulirus cygnus*

Parameter	Value(s)	Comments / Source(s)
Growth parameters (average) Double Logistic form:		$\Delta L_{s,a} = \frac{1}{1+e^{\left(\frac{L_{s,a}}{\alpha_{s,a}}\right)}} \frac{(\beta_{s,a}-\delta_{s,a})}{1+e^{\left(\frac{L_{s,a}-\varphi_{s,a}}{\gamma_{s,a}}\right)}} + \delta_{s,a},$
α	F=-28.5, M=-23.3	
β	F=2.34, M=2.43	
δ	F=0.11, M=0.61	
φ	F=71.5, M=60.6	
γ	F=10.2, M=20.8	
Maximum age (years)	25 +	Based on longevity in Aquaria
Maximum size (mm)	186 mm CL	State record 2014 K. Rushworth
Natural mortality, M (year^{-1})	0.23 ± 0.105 (se)	Morgan, 1977
Length-weight parameters		$W = aL^b$ (W gm and L mm)
a	F=1.6086E-06, M=2.5053E-06	
b	F=2.8682, M=2.778	
Reproduction	Gonochoristic, promiscuous mating and highly fecund.	
Maturity parameters		$M = 1/(1+\exp((L-L_{50})/\phi)$
A_{50} (years)	F=~7, M= ~7	No direct aging is currently conducted.
A_{95} (years)	F=unknown, M=unknown	
L_{50} (mm)	Females 65.0-87.5, Males 72.2 – 95.3	Melville-Smith & de Lestang 2006 Size depends on the location
L_{95} (mm)	Females TBA, Males TBA	
Sex change parameters		Not applicable (N/A)
A_{50} (years)	F=(N/A), M=(N/A)	
A_{95} (years)	F=(N/A), M=(N/A)	
L_{50} (mm)	F=(N/A), M=(N/A)	
L_{95} (mm)	F=(N/A), M=(N/A)	
Fecundity measure	Batch / Annual fecundity	
Size-fecundity parameters		$BF = a\ CL^b$
A	1.92	
B	2.69	
Spawning frequency *L50 (mm)*	Multiple spawners 78.7 – 96.6	de Lestang & Melville-Smith 2006 Larger female double spawn Size depends on the location

5.1.3.1 Life Cycle

Although *Panulirus cygnus* can live for over 20 years and weigh of up to 5.5 kg, more typically they live for 10 to 15 years and weigh less than 3 kg. When lobsters mate, the male attaches a package of sperm, which resembles a blob of tar, to the underside of the female. This spermatophore, colloquially called a "tar-spot", remains there until the female is ready to spawn her eggs (Figure 5-4c). At spawning, the female releases eggs from gonophores located at the base of her third pereiopods. At the same time the female releases sperm by scratching the spermatophore with a small hook on the tip of either fifth pereiopod. The eggs are fertilised as they are swept backwards over the opened spermatophore before becoming attached to setae along the endopodite pleopods (Figure 5-5). Females with eggs attached under their abdomen (ovigerous) are also known as "berried" females (Figure 5-4d).

The eggs hatch in 5 to 8 weeks, depending upon water temperature as demonstrated by the following equation:

$$Incubation.time = 4412.4\exp^{0.217*\mathrm{Water.temp}};$$ Chittleborough 1976a

Upon hatching tiny larvae called phyllosoma are released (Figure 5-6a) into the water column.

The phyllosoma larvae spend 9 – 11 months as plankton, are carried offshore by ocean currents (Figure 5-7). The decline in puerulus settlement from 2007 saw a decoupling of the environmental recruitment relationship. This resulted in a suite of research examining the potential of reduced phyllosoma which may have led to the reduced settlement levels. Considerable research was undertaken on the diet, prey fields and nutritional state of phyllosoma from oceanographic features off the West Australian coast. Feeding trials of phyllosoma with abundant potential prey items found that chaetognaths were consumed in higher numbers than the other preys of salps and krill. The rate of chaetognaths consumption also increased with increasing chaetognath density (Sunders et. al. 2012). Their preference for transparent gelatinous zooplankton prey was confirmed through high-throughput amplicon sequencing of DNA from the phyllosoma hepatopancreas (O'Rorke et. al. 2012). These prey were found to result in a significant accumulation of lipid and energy storage fatty acids with larval development. Phyllosoma caught within cyclonic eddies had more lipid and fatty acids associated with their energy storage than those from anti-cyclonic eddies (Wang et. al. 2014). The better condition of cyclonic eddy phyllosoma was also demonstrated by their greater mass, protein and lipid levels (Wang et. al. 2015). These difference are likely a result of water temperature in the eddies reducing the phyllosoma condition directly, or through reducing the productivity of these water bodies (O'Rouke et. al. 2015).

To move from outside the continental shelf where phyllosoma develop to suitable inshore reef systems preferred by juvenile lobsters, the larva has to change into a puerulus (Figure 5-6b) at the right time to benefit from favourable onshore currents before it swims the remaining distance to the inshore reefs. The subsurface currents can return the phyllosoma to the edge of the continental shelf; it is at this point the phyllosoma changes to a puerulus. As pueruli are capable of swimming at speeds of nearly 0.5 metres per second (Phillips & Olson 1975), they could make the 40 – 60 km swim from the shelf edge to inshore reefs in a few days.

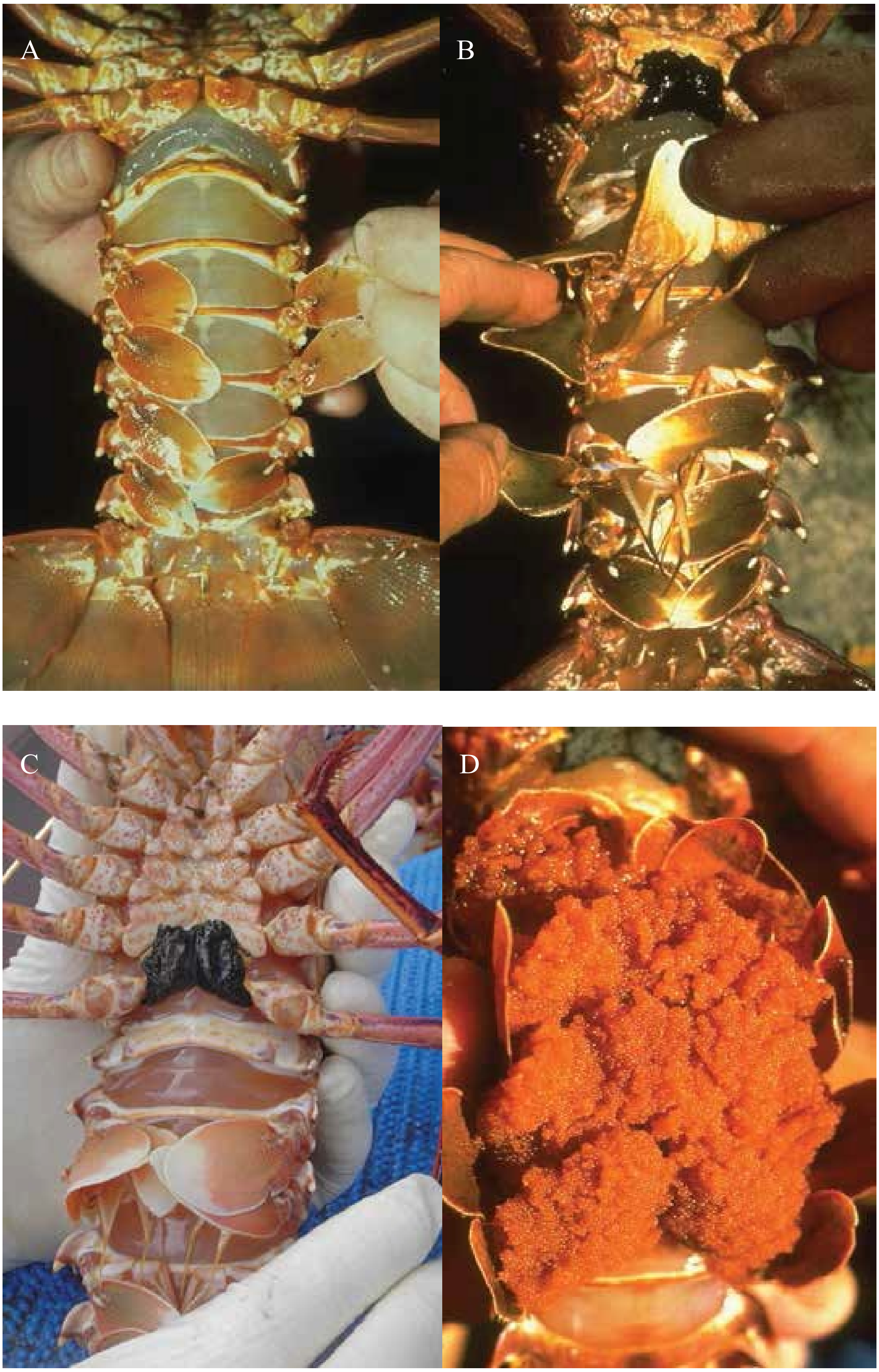

Figure 5-4. Ventral views of a) male, b) female, c) tar-spotted female and d) berried female western rock lobsters (Department of Fisheries, WA)

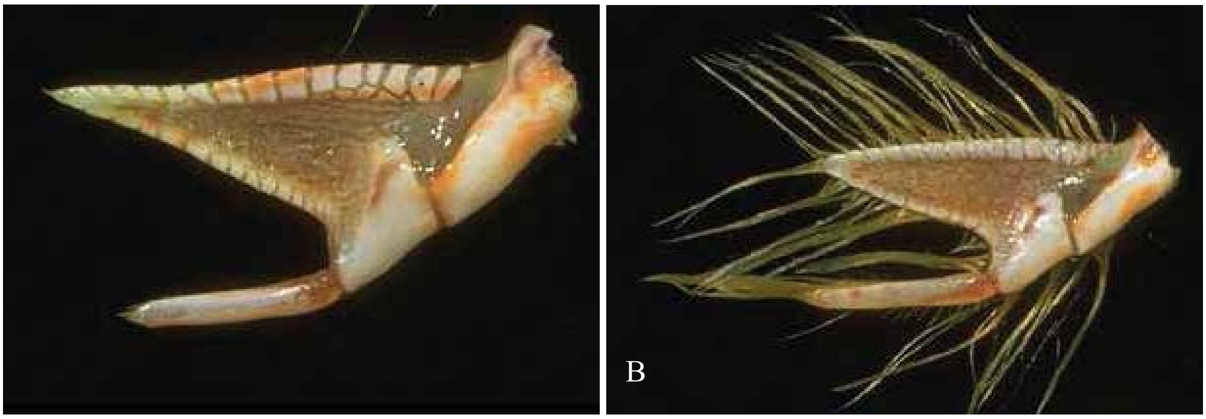

Figure 5-5 Endopodites with a) no setae and b) mature setae

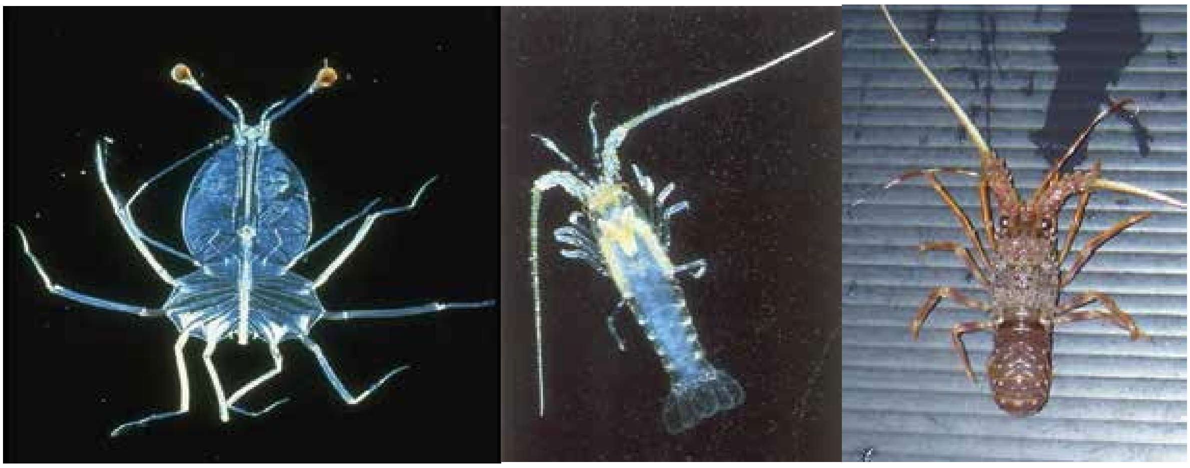

Figure 5-6. Life phases of the *Panulirus cygnus* a) phyllosoma (TL 20 mm); b) puerulus (CL 7-9 mm); c) juvenile (CL 9+ mm)

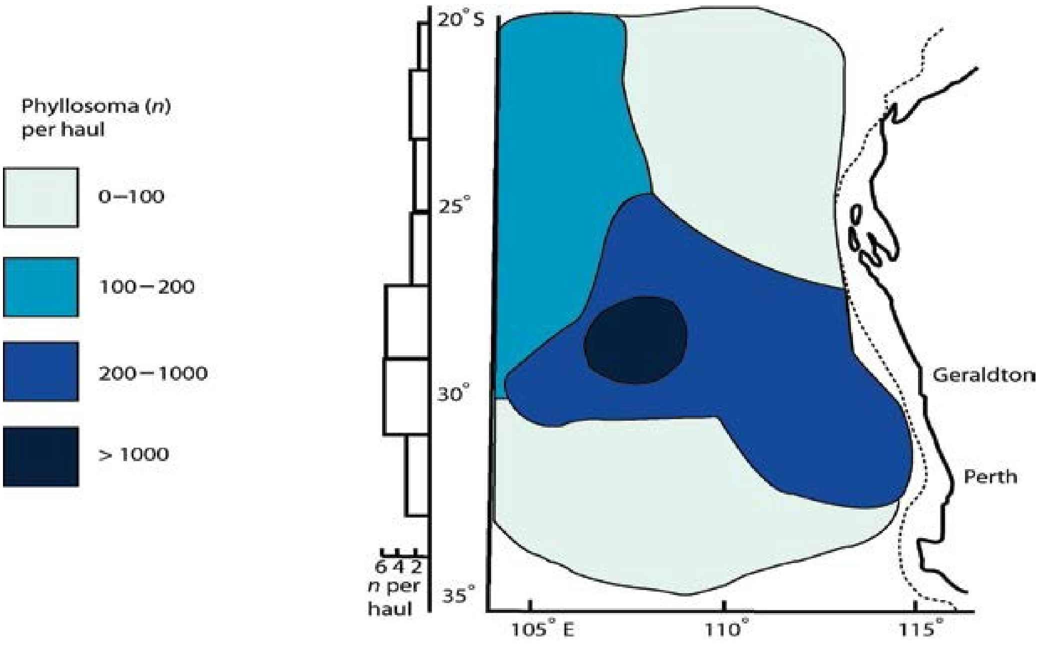

Figure 5-7. Distribution of western rock lobster phyllosoma larvae. The dotted line represents the Continental shelf (from Phillips 1981)

Phillips and MacMillan (1987) theorised that pueruli detect the coast by using their antennae as vibration receptors, detecting ocean swell noise on the coasts or offshore reefs.

Pueruli that successfully return to the coast settle in near shore areas, generally associated with seagrass beds and algal meadows, before they moult into the juvenile stage (Figure 5-6c). For details of juvenile recruitment to inshore areas, see Section 8.2.4.1.

The juveniles feed and grow on the shallow inshore reefs for the next three or four years, by which time they can achieve CLs up to 80 mm. Three to four years after settlement, in late spring, many lobsters undergo a synchronised moult from their normal red shell colour into a paler colour. These are known as "white" lobsters until they progressively return to their normal red colour over the subsequent few months. The "white" phase of a rock lobster's life is the migratory phase (Section 5.1.3.3.1). At this time (summer) they leave the coastal reefs and form a mass migration across pale white sands to their breeding grounds in deeper water, where they become sedentary again on the deeper reefs. A percentage make the far longer migration off the edge of the continental shelf down to depths between 100 and 200 m, before they change direction and follow the shelf in a northerly direction. At some point, generally above the Abrolhos Islands, the northern deeper water migrating lobsters move inshore and settle on offshore reefs. This deeper offshore reefs is where the majority of the spawning stock resides (Figure 5-8).

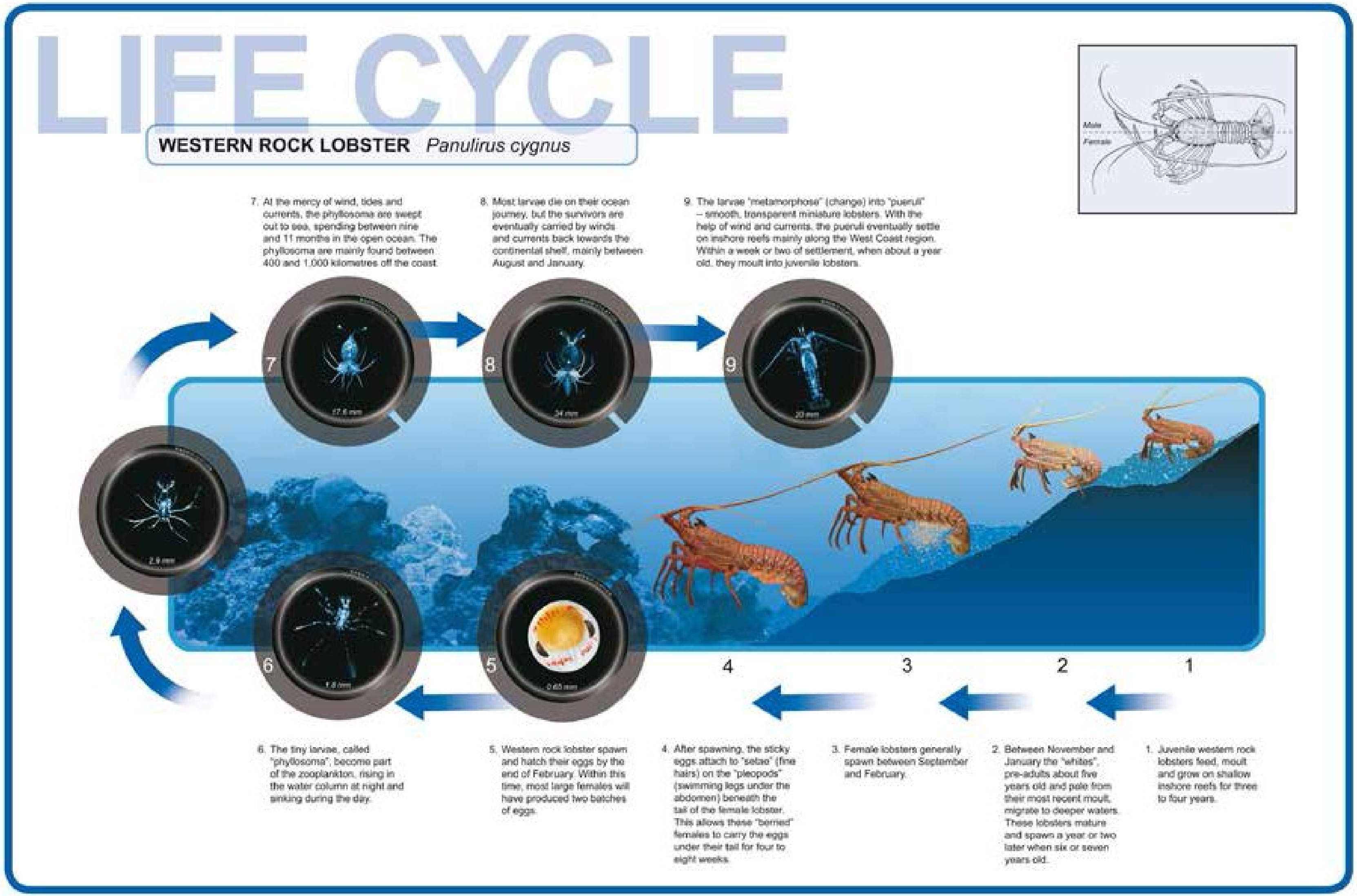

Figure 5-8 Life history of *Panulirus cygnus* (from Community Education Branch, Department of Fisheries, WA)

5.1.3.2 Habitats

The influence of the Leeuwin Current, the dominant oceanographic feature of the West Coast Bioregion creates a range of habitats within the distribution of *P. cygnus*. While the limestone reefs and pavements dominate, there are some coral reefs, particularly at the Houtman Abrolhos Islands, which are important rock lobster habitats.

For detailed information on the aquatic environment of the western rock lobster resource please refer to Bellchambers et al. (in press).

5.1.3.3 Movements

The movement patterns of *P. cygnus* have been and continue to be studied extensively. Research has primarily focused on two aspects of the lobster's movement: the "whites" migration and small-scale foraging movements.

5.1.3.3.1 Migration

The large-scale "whites" migration is a feature of this lobster's life history. Tagging studies (based mainly on external "T-bar" anchor tags) have been undertaken to assess this aspect of the lobster's life history (Melville-Smith et al. 1998, Chubb et al. 1999, de Lestang 2014, de Lestang and Caputi, 2015), as well as to provide growth information (Section 5.1.3.4).

To date (May 2016) 161,833 lobsters have been tagged and released since 1988. Although some of these tagged lobsters were used to examine handling practices and subsequent survival, the majority of lobsters were handled properly and returned in peak condition. It is this majority of lobsters that have been used for growth, mortality and movement studies. The majority (75%) of all recaptures have occurred during the first 12 months at liberty, with around 20% the following season, though there have been some recaptures up to 16 years after release.

In general *P. cygnus* have been shown to move as juveniles from nursery areas into deeper offshore breeding grounds. It has been shown that *P. cygnus* migration is associated with body size and water depth, and that magnetism and oceanic currents appear to be the most likely guideposts used for orientation. Size at migration varied in a constant fashion along the coast, being larger towards the southern end of the fishery and smallest at the offshore Abrolhos Islands. During the migration period, up to 50% of lobsters at their mean size of migration moved from coastal areas out towards deeper waters (>40 m), whereas, 15% of those in deeper water at the same size moved significant distances northward. This behaviour appears to be contranatant, counteracting the downstream redistribution of larvae after their 9–11 month larval life (de Lestang 2014).

Lobsters from as far south as Jurien Bay have been found to migrate over 600 km into the Big Bank region. However, not all lobsters migrate northwards and into the Big Bank region, in fact there is substantial inter-annual variation in the north-ward movement (between latitudes 27° and 30° S) of migrating lobsters in deep water. This variation was found to be highly correlated with the sea-floor meridional current strength in January and mean latitude and abundance of puerulus (post-larvae) settlement 3–4 years previously. Combined, these indices explain 92 % of the annual variation in the latitude of migration, and the majority of the variation in commercial catches towards the north of the fishery. These indices are all either directly or indirectly impacted by the south-flowing Leeuwin Current (de Lestang and Caputi, 2015).

The timing of the initiation of migration appears to be related to water temperatures, the lunar cycle and the total sea swell levels. To date the best single predictor of the start of the migration is the lunar cycle (migration taking place close to a new or full moon). Water temperature seemed to add further power for predicting the start of migration (warmer water temperature encouraged migration). To this stage the lobster migration prediction model has been hampered by the lack of fine spatial- temporal-scaled data (both water temperature and catch rates). With a recent move to better catch recording systems (daily catch disposal records) and hourly water temperature loggers, this work will be re-examined in the near future.

5.1.3.3.2 Foraging Movements

Small-scale foraging movement patterns of juvenile *P. cygnus* have been studied by tag recapture (Chittleborough 1974a), and electromagnetic tracking (Jernakoff 1987, Jernakoff et al. 1987, Jernakoff & Phillips 1988). Jernakoff & Phillips (1988) estimated foraging distances of ~150 m radius from dens. Jernakoff et al. (1987) also showed movements to be very variable, with distances between 72.5 and 585 m accounting for 95% of all foraging distances in the study. One individual moved 803 m in a night within the tracking area.

These results demonstrate that juvenile *P. cygnus* forage over small areas, though the extent of movement is variable.

Recently technological advances have allowed automated tracking of juveniles with acoustic tags (MacArthur et al. 2008). These data will provide further information on foraging distances, home ranges and habitat use of adult and juvenile *P. cygnus* which, from preliminary analysis, appears to be relatively small (<60 m).

5.1.3.4 Age and Growth

For *Panulirus cygnus*, the first examinations of growth were made under controlled aquaria conditions (Chittleborough 1974, 1976), focusing on the impact of such factors as temperature, photoperiod, oxygen, food supply, crowding, autonomy of limbs, and size at maturity. Comparisons were also made between laboratory-reared and wild populations (Chittleborough 1975), with wild populations being studied through tag-recapture (Chittleborough 1975; Morgan 1977) and length-cohort analysis techniques (Chittleborough, 1970; Jernakoff et. al. 1994). Throughout the 1990s the novel use of lipofuscin accumulation in the central nervous system has been trialled to estimate age (Sheehy et al. 1998). More recently a nation-wide FRDC project has examined the viability of ageing *P. cygnus* (and a number of other crustaceans) through the presence of banding in stomach ossicles (senso otolith based ageing in teleosts).

The use of such a large range of techniques to examine the growth of *P. cygnus* (and other crustaceans) is due to the lack of a single robust method that is suited to the full size/age range of the population. Thus unlike in the case of finfish, where aging via otoliths is the standard, there is no single preferred method for crustaceans.

Aquaria studies have been used extensively to examine growth of crustaceans and, although labour intensive, have the capacity to examine growth across the entire life span of a species. A limitation to these studies however is their inability to accurately represent the growth of a wild population due to strong links between growth rates and feeding, stocking densities and water temperature regimes (Chittleborough 1976; Phillips et al. 1983; Johnston et al. 2008).

Length-cohort analysis, i.e. tracking the temporal change in the size composition of a cohort (assumed to represent mainly one age class) of animals with similar lengths, can provide a direct measure of natural growth. This analysis is however only applicable for life stages where growth rates are fast and age cohorts are easily distinguishable based on separations between their size compositions. Length-cohort analysis also requires the population to have minimal immigration or emigration from the sample area. Although this technique has been applied to entire populations of some short-lived fast growing crustaceans (MacDonald and Pitcher 1979; Wang and Somers 1996; Xu and Mohammed 1996; de Lestang et al. 2003), in general it can only be used successfully in long-lived species when applied to the first few juvenile age classes (Chittleborough 1970; Jernakoff et al. 1994; Sainte-Marie et al. 1996; Tuck et al. 1997).

Mark-recapture is the most common method used to examine the growth rates of crustaceans, including lobsters (Morgan 1977; Wang 1997; Comeau and Savoie 2001; Frisch 2007; Erhardt 2008; Haddon et al. 2008; O'Malley and MacDonald 2009, Linnane et al. 2012). Mark-recapture requires the marking of animals with unique identifiers that can be used to identify when, where and at what size the animal was released. In practice this limits its applicability to larger individuals because marks need to be large to be easily detected, yet not proportionally too large as to impact subsequent survival and growth (Montgomery and Brett 1996; Dubula et al. 2005). Mark-recapture techniques are therefore generally better suited for examining the growth rates of larger individuals.

Measuring the accumulation of age-based pigments has recently become more popular as a direct method for determining the age of crustaceans, i.e. used in a similar fashion to the otoliths of finfish (Sheehy 1990a; Sheehy et al. 1998, 1999; Doubleday and Semmins 2011). Lipofuscin is deposited in a range of tissues with concentrations being highly correlated with age. Quantities of lipofuscin are determined via image analysis and compared to standard assays from conspecifics of known-age. This comparison is the biggest limitation of the method as it requires the known-age and wild-caught lobsters to both experience the same water temperatures and metabolic rates throughout their life history (Sheehy 1990b).

Irrespective of the method(s) used to collect growth data, once obtained it is useful to describe these data with an equation to produce a continuous relationship between size and age or size and growth, i.e. into a form useful for stock modelling. The most common group of equations used in fisheries science for relating size and age are based on the von Bertalanffy equation (Wang and Somers 1996; de Lestang et al. 2003; Frisch 2007; Montgomery et al. 2009; O'Malley and MacDonald 2009). If direct age information is unknown (eg. data is from tag recaptures) then the method described by Fabens (1965) is generally employed to derive von Bertalanffy parameters (Phillips et al. 1992; Wang 1997; Cheng and Kuk 2002; Montgomery et al. 2009; Linnane et al. 2012). von Bertalanffy based equations have been shown to accurately describe discrete sections (either juvenile or adult phases) of invertebrate growth (Chittleborough 1976; Cheng and Kuk 2002; Frisch 2007; O'Malley and MacDonald 2009). However relatively few studies have examined their applicability for replicating growth over an entire life span (i.e. early juvenile through to late adult). Of those that have undertaken this comparison most have found that the use of such equations are inappropriate since the relationship between body size and growth rate do not fit a requirement of this equation, i.e. they do not remain linear throughout life. Rather the relationship between these parameters has been reported to be more similar to that described by a Gompertz or inverse logistic equation (Hernandez-Llamas and Ratkowsky 2004; Rogers-Bennett et al. 2007; Ehrhardt 2008; Haddon et al. 2008, Starr et al. 2009; Helidoniotis et al. 2011).

The growth of *Panulirus cygnus* was examined using a model that integrates tag-recapture and length-cohort data with an equation capable of representing a range of typical growth-at-size relationships. Basing growth studies on multiple data sets is shown to produce more robust estimates of growth parameters, reducing the biases normally associated with the extrapolation of data ranges. This technique is applied to data from five regions of the Western Rock Lobster fishery in Western Australia. The growth of *P. cygnus* was well described by a non-linear function similar to that of a Gompertz equation, a form that is capable of accommodating changes in growth in concert with the attainment of maturity. Growth rates for *P. cygnus* were found to vary markedly between sexes and between the various regions of the fishery. Male lobsters maintained higher growth rates for longer and attained greater body sizes than females (Figure 5-9). In warmer waters lobsters exhibited initial faster growth and earlier declines to slower, presumably adult growth rates, than in cooler water locations (de Lestang *et al*., 2014).

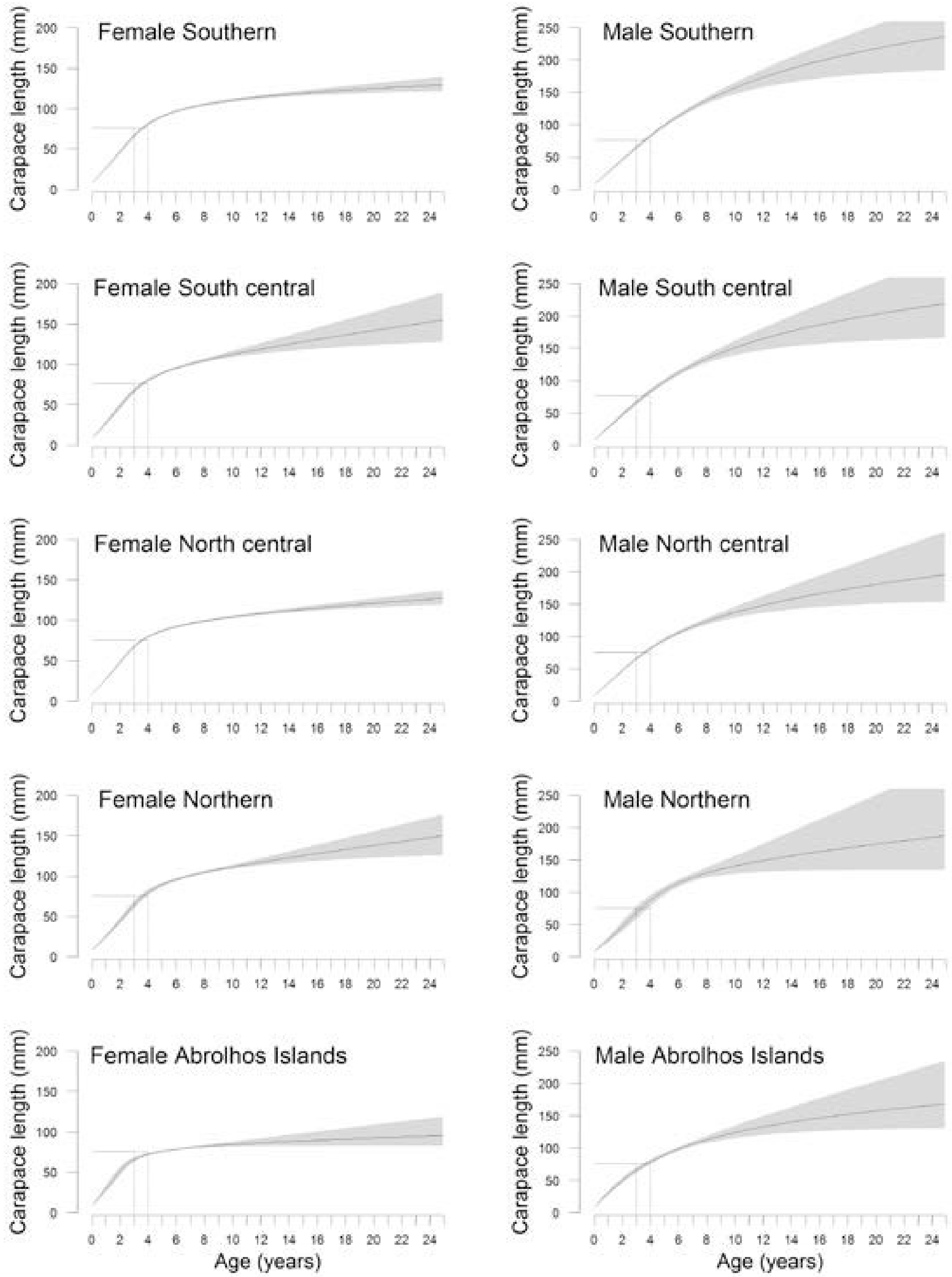

Figure 5-9 Mean and 95 confidence bounds (grey) growth curves for female and male lobsters in five areas of the fishery, Dotted lines represent the intersection of ages three and four with the minial legal size of 76 mm CL.

5.1.3.4.1 Weight-Length Relationships

The length-weight relationship is currently being re-examined using recreational caught western rock lobster. The preliminary relationship is $weight = 0.007 * length^{2.534}$ and $weight = 0.002 * length^{2.799}$ for females and males, respectively (Figure 5-10).

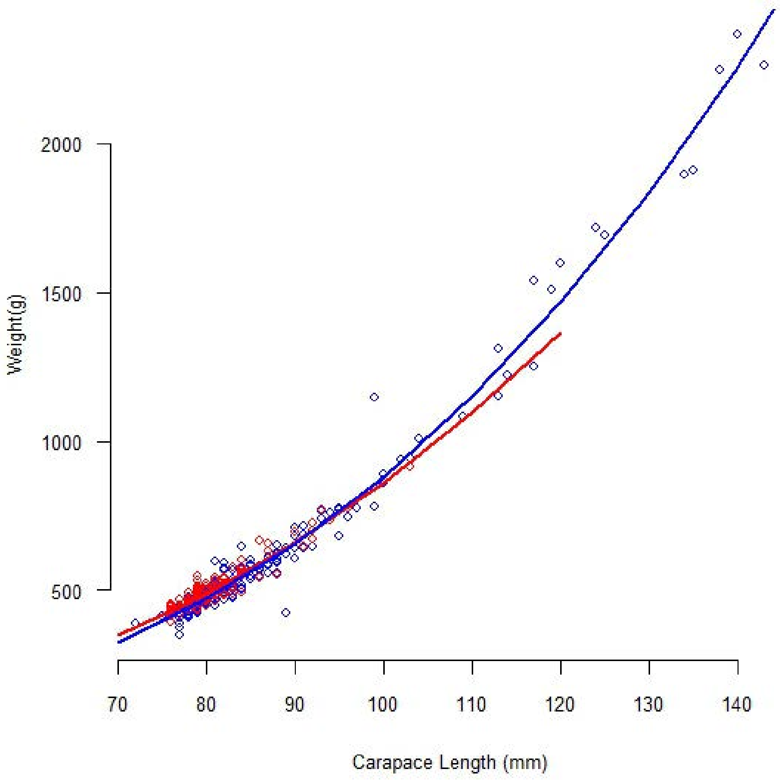

Figure 5-10 Carapace length (mm) and weight (g) relationship for legal male (blue) and female (red) lobsters sampled as part of a recreational fishing survey

Length weight information is also available for each of the grade categories of lobsters (Table 8-2). Seasonal changes in the grade information are presented in Section 8.2.1.2.

5.1.3.5 Natural Mortality

Morgan (1977) conducted the only work that has thoroughly examined the instantaneous rate of natural mortality (*M*) in this species (Table 5-1). This work used a number of methods to estimate *M*, with only one method being considered relatively robust to biases. He used a technique described by Beverton and Holt (1956) and Gulland (1969), which produces an estimate of *M* based on the relationship between the instantaneous rate of total mortality and associated effort levels. The equation used was:

$$Z = qE + M \quad ,$$

where *Z* is the instantaneous rate of total mortality over one year, *q* is catchability (estimated) and *E* is the effort. Estimates of *Z* were first derived from Von Bertalanffy growth parameters and the average length of grades B – E lobsters landed each season ($\bar{L}$) using the equation;

$$Z = K\left(\frac{\left(L_\infty - \bar{L}\right)}{\left(\bar{L} - L_c\right)}\right),$$

where K = 0.565, L_∞ = 110 and L_c = 79.7 (minimum length of exploited lobsters, i.e. B grade).

5.1.3.6 Reproduction

The attainment of sexual maturity begins around June when females moult and develop ovigerous setae on their endopodites [referred to as being setose] (Figure 5-5). At this time a female lobster is considered fully matured (setose), being able to successfully produce and fertilise viable eggs. Once becoming setose females must mate with males before they can produce viable offspring. Mating begins in June and continues until as late as January the following year, and consists of a male grasping a female in his legs, abdomen to abdomen, and placing a sperm packet (referred to as a tar-spot) onto the lower abdomen of the female with his paired gonopods which are located at the base of his fifth pair of legs. The female is then free to fertilise her eggs at any point months into the future. To fertilise and incubate her eggs, females curl their tail inwards towards their mouth and extrude unfertilised, sticky eggs from her paired gonopores located at the base of her fourth pair of legs. At the same time she scratches open the tar-spot on her abdomen and releases the sperm to fertilise her eggs. The eggs then stick to the setae under her tail where they remain to incubate and develop. Once developed the free swimming larvae (phyllosoma) are released directly from the egg still attached to the tail.

5.1.3.6.1 Size at Maturity

There is considerable variation in the size at which lobsters have the ability to reproduce (carapace length of 50% maturity - CL_{50}) for both female (Figure 5-11) and male (Figure 5-12) *P. cygnus* throughout the fishery. Size at maturity has been estimated from lobsters' in deep water in coastal locations and from all depths at the Abrolhos Islands as this represents the areas of breeding. Males were found to have consistently larger CL_{50}s than females at the corresponding locations. The size at maturity for both sexes varied similarly with latitude, being larger in the south of the fishery (Fremantle CL_{50} = 87.5 mm for females in 2002) and becoming progressively smaller further north along the coast of the fishery (Dongara CL_{50} = 74.9 mm for females in 2002). The offshore site of the Abrolhos Islands had the smallest CL_{50} [65.0 mm for females in 2002] (Melville-Smith & de Lestang 2006).

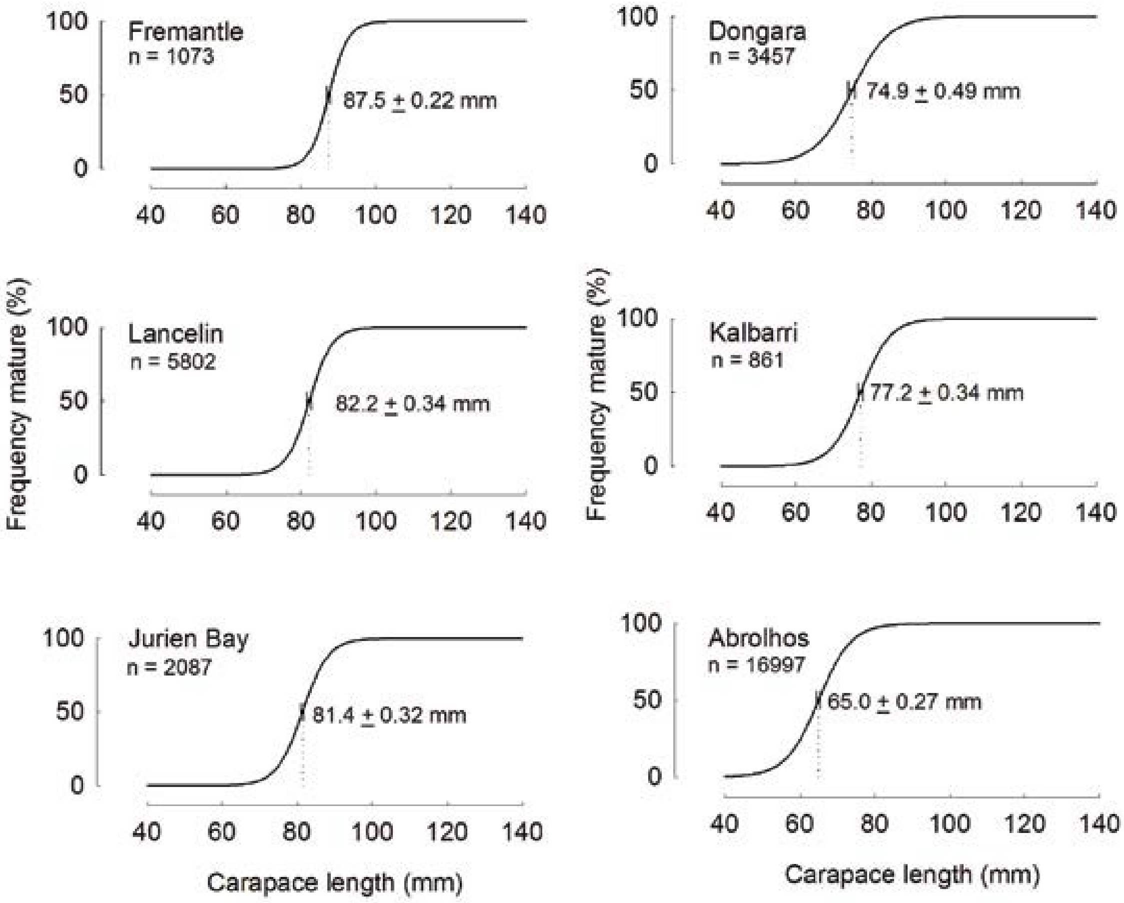

Figure 5-11 Logistic regressions fitted to the percentage of mature female *Panulirus cygnus* at different carapace lengths in six locations in Western Australia, based on data collected during the 2002 Independent Breeding Stock Survey. CL_{50} ±1 SE denotes the size at which 50% of the assemblage is mature and n the sample size (Melville- Smith & de Lestang 2006)

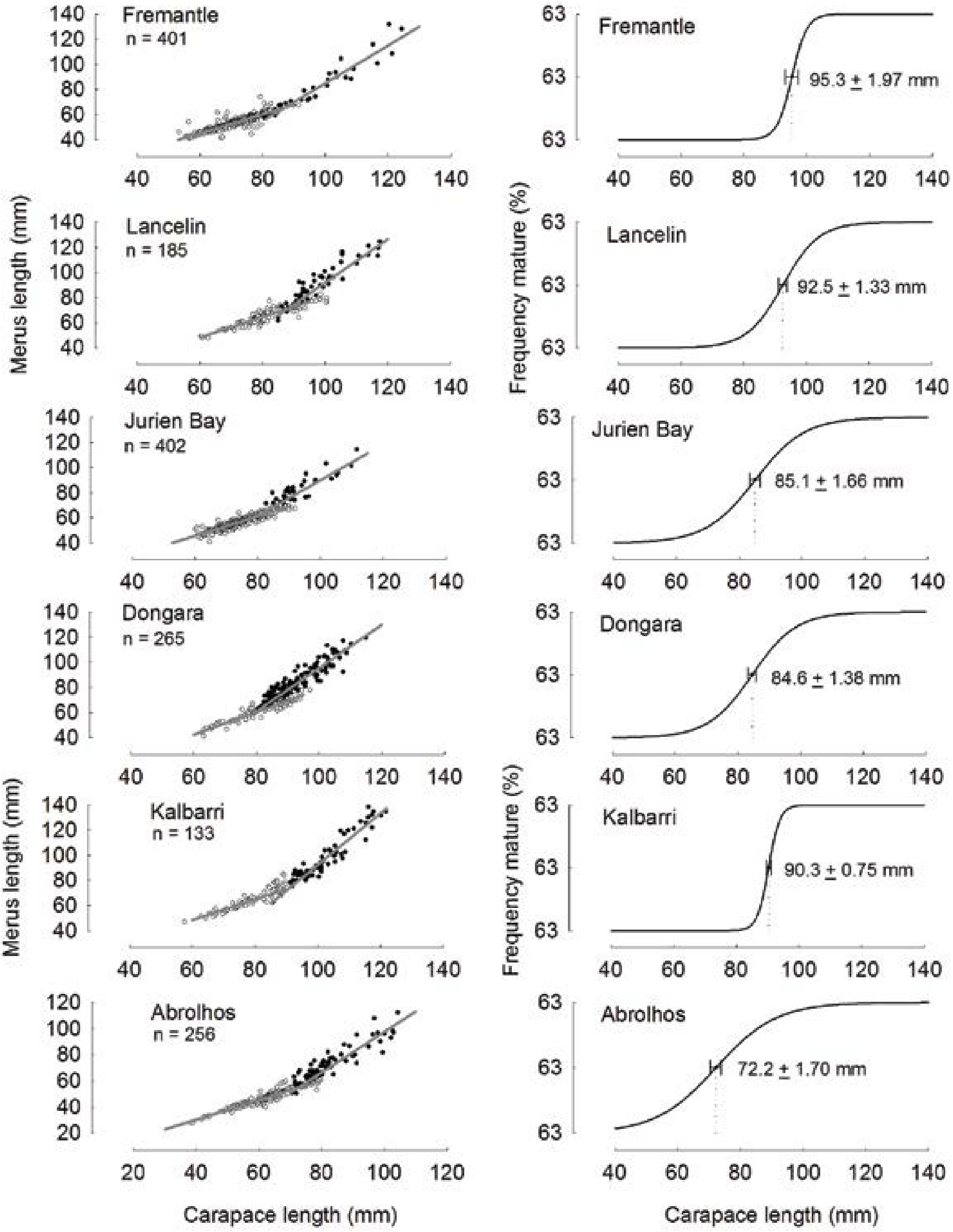

Figure 5-12 Relationship between the merus length of the second pereiopod and carapace length of immature (open circle) and mature (filled circle) male *Panulirus cygnus* (left) and logistic regressions fitted to the percentage of morphometrically mature males at different carapace lengths (right) in six locations in Western Australia, based on data collected during the 2002 Independent Breeding Stock Survey. CL_{50}±1 SE denotes the size at which 50% of the assemblage is mature and n the sample size (Melville- Smith & de Lestang 2006).

Size at double breeding

Mature female lobsters increase the number of batches of eggs they produce each spawning season from one to two, with larger lobsters producing a second batch. The size at which females start to produce a second batch was found to be consistently ~ 10% larger than the size they first attain maturity at all sites along the coast (Table 5-2and Figure 5-13).

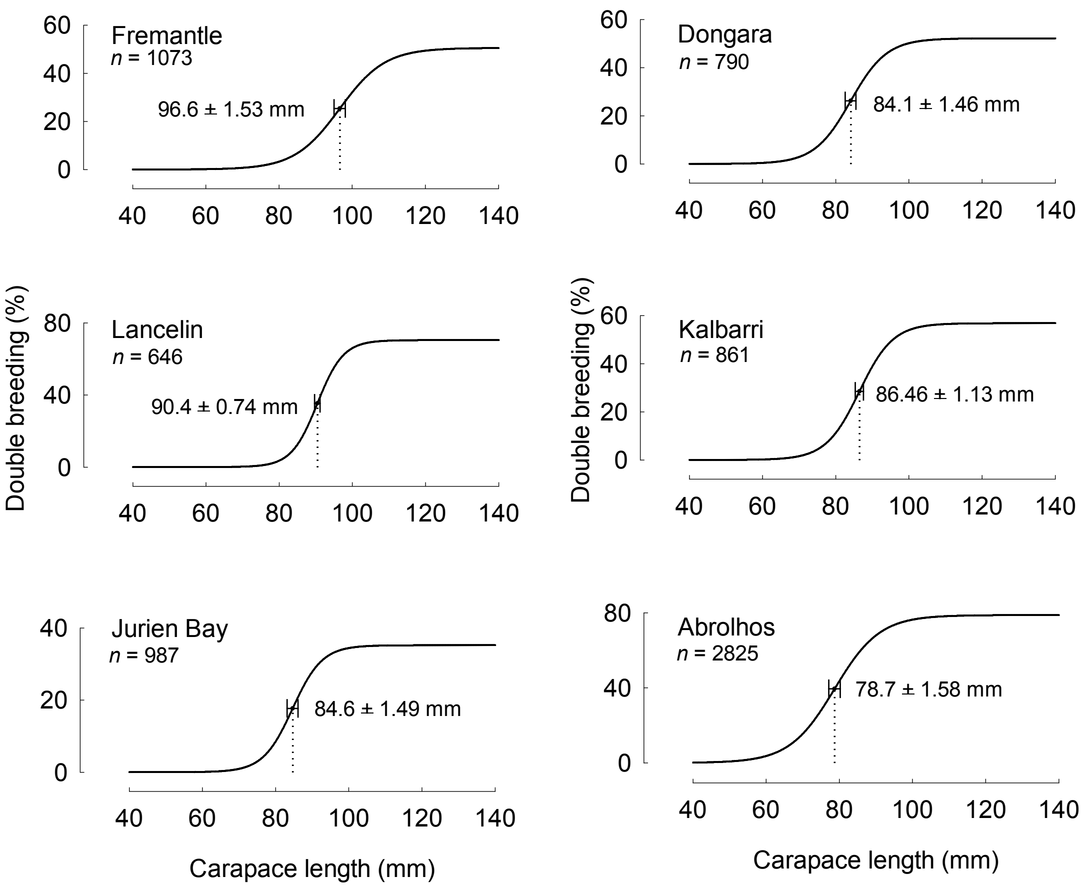

Figure 5-13 Logistic regressions fitted to the percentage of double breeding female *Panulirus cygnus* at different carapace lengths in six locations in Western Australia, based on data collected during the 2002 Independent Breeding Stock Survey (Melville- Smith & de Lestang 2006).

Table 5-2 The sizes of 50% maturity and double breeding female lobsters in 2002 (de Lestang et al., 2006).

	Abrolhos	Kalbarri	Dongara	Jurien	Lancelin	Fremantle
50% Maturity	65.0	77.2	74.9	81.4	82.2	87.5
50% Double Breeding	78.7	86.5	84.1	84.6	90.4	96.6
Scaling factor	1.21	1.12	1.12	1.04	1.10	1.10

Variation in size at maturity

Much of the spatial variation in size at maturity is explained by regional patterns in water temperature (Figure 5-14), with lobster caught in warmer waters maturing at a smaller size than their colder water counterparts (Melville-Smith & de Lestang 2006).

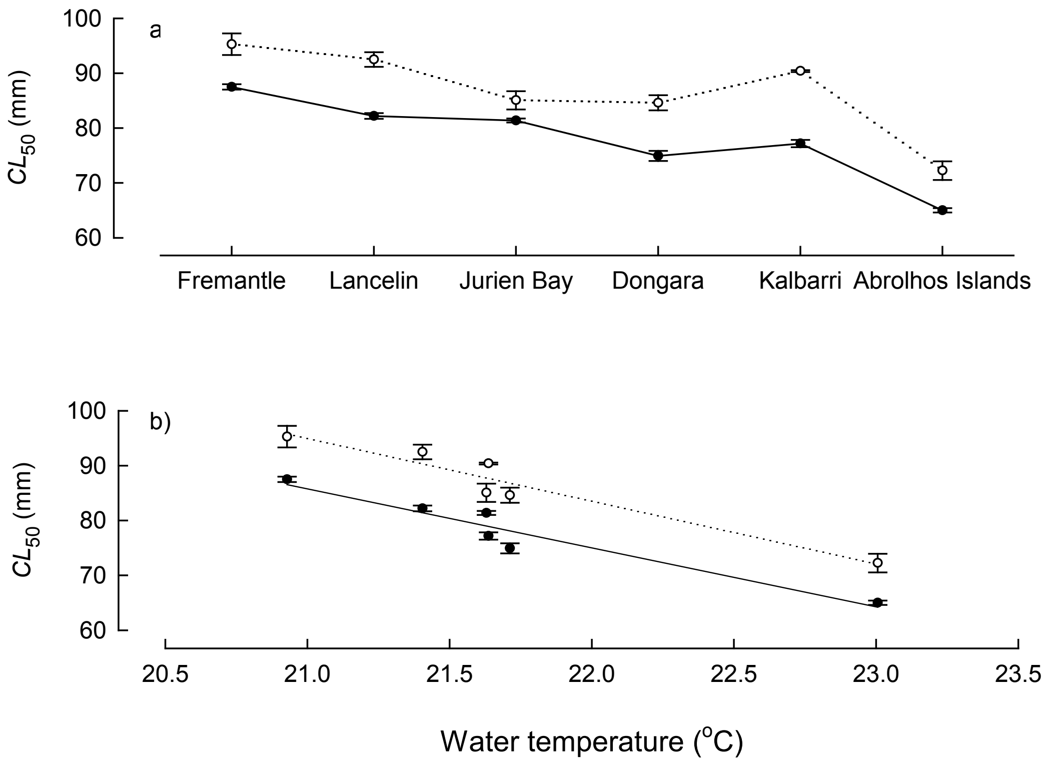

Figure 5-14 a) Size at maturity (CL_{50}) ±1 SE of female (filled circle) and male (open circle) *Panulirus cygnus* at six locations and b) linear regressions fitted to the relationships between female (filled circle) or male (open circle) CL_{50}s at each location and the corresponding mean annual water temperature at that location (Melville-Smith & de Lestang 2006).

There is also a temporal variation in the female size at maturity (*CL_{50}*) at all sites from Fremantle to Kalbarri and offshore at the Abrolhos Islands from the early 1990s to the present [May 2016] (Figure 5-15). This reduction in the size at maturity is most likely due to a combination of changes in water temperatures, exploitation rates and management practices. The return of setose females which was regulated in 1993/94 (Section 2.2), would have resulted in an increase in the number of females likely to spawn in any given size class, thus biasing the proportion-based estimate of size at maturity estimates. These "biased" measures however represent the actual proportions of mature females-at-size in the deep-water breeding grounds and are therefore appropriate for use in developing measures of breeding biomass (i.e. for use in population dynamic models etc.).

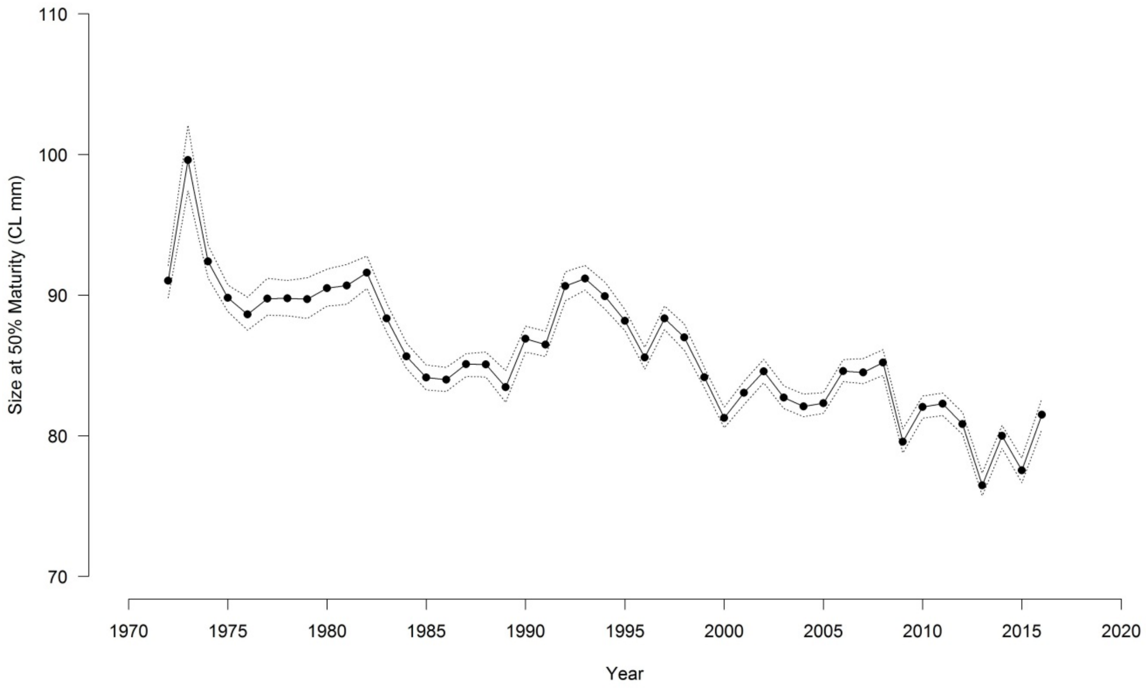

Figure 5-15 Size at female maturity (*CL_{50}*) ± 95% CI standardised for location and month of sampling using a binomial Generalised Linear Model (GLM) with a logit link, based on data collected during monitoring on board commercial fishing vessels.

The temporal change in size at maturity reported for males, which was similar to that of females, would have been unaffected by this altered management regime (“setose rule”). The lower CL_{50} for males in the study of Melville-Smith & de Lestang (2006) compared with Grey (1979) (i.e. 105 *vs.* 95.3 mm at Fremantle and 98 *vs.* 84.6 mm at Dongara/Geraldton) implies that there must be biological or environmental factors (such as changing water temperatures), responsible for altering the CL_{50} over this time period.

5.1.3.6.2 Spawning Season

The average spawning cycle (Figure 5-16) shows the proportion of female lobsters that are mature, but not spawning is very high in May and June, i.e. prior to mating. This proportion then declines in July – September as mating occurs and females are found with newly formed tar-spots on their abdomen. The proportion of newly mated females peaks in September before declining as females begin to scratch their tar-spots to fertilize their recently extruded eggs from September – November. Spawning females are found from September to February with a peak occurring in October and November. As the proportion of spawning females declines from December to February, the proportion of females with eroded (used) tar-spots increases, peaking in February. These females then decline in the catches as mature females begin to moult into a non-setose state, thus losing their eroded tar-spot so that by May of the following year most lobsters have no ovigerous setae and no eroded tar-spots are present (Figure 5-16).

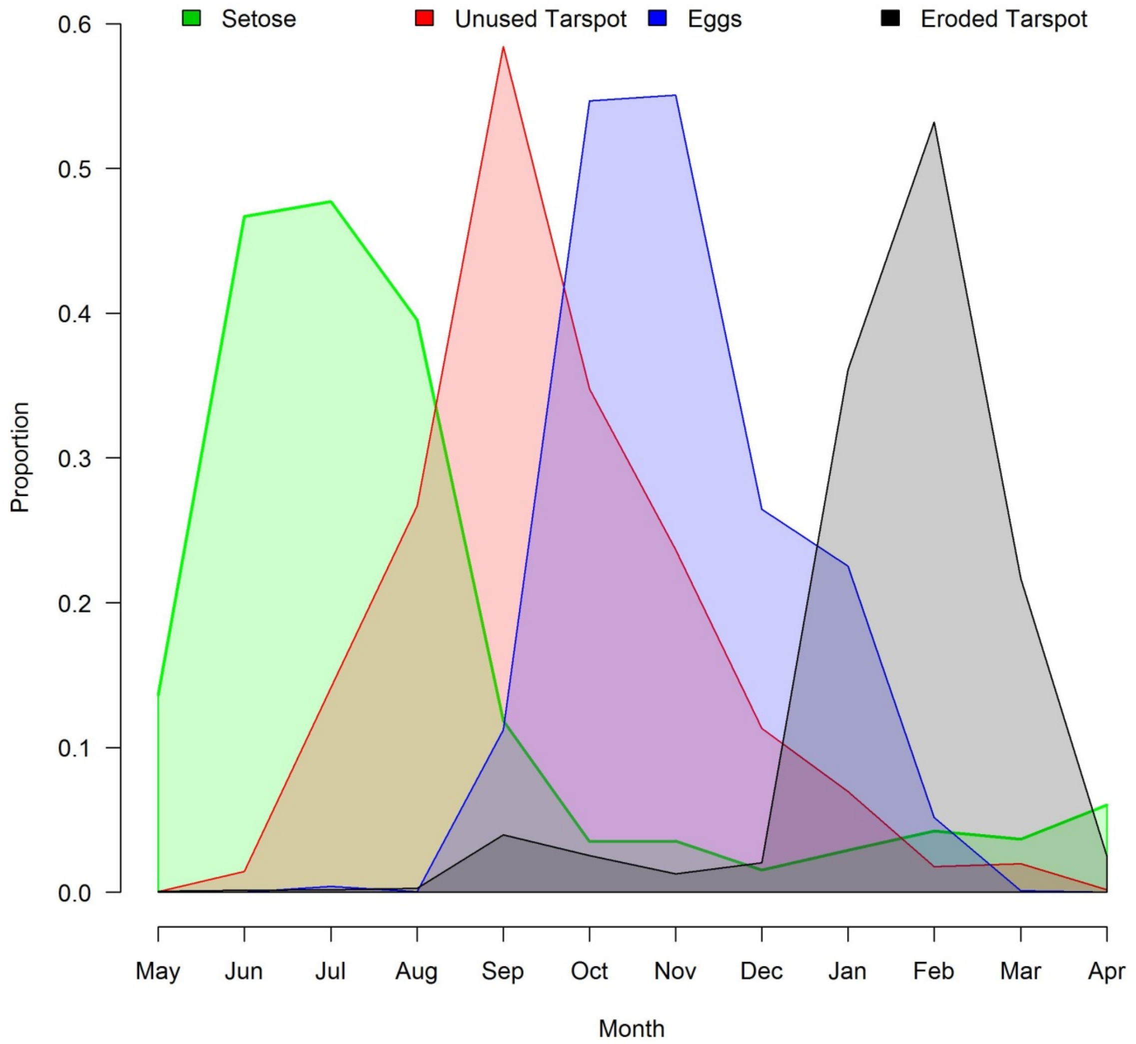

Figure 5-16 Monthly proportions of mature female lobsters that are setose, newly mated (new tar-spot), spawning (eggs) and having a spent spermatophoric mass (eroded tar-spot), based on DCCM and IBSS data between 2011 and 2016

The reproductive pattern shown above is averaged and based on data over a five year period. There is however substantial inter-annual variation in these patterns with the timing of mating, spawning and the moult back into an immature (non-setose) state all varying markedly between years.

The timing of mating and spawning both appear to follow a similar pattern and are therefore presumably related (Figure 5-16). Work has shown that their inter-annual variation is correlated with water temperatures during the start of the spawning season (September and October) (de Lestang et al., 2014). Warm water temperatures during these months' results in spawning occurring earlier and being completed by January, whereas in years following cool September and October temperatures many females are still ovigerous in February.

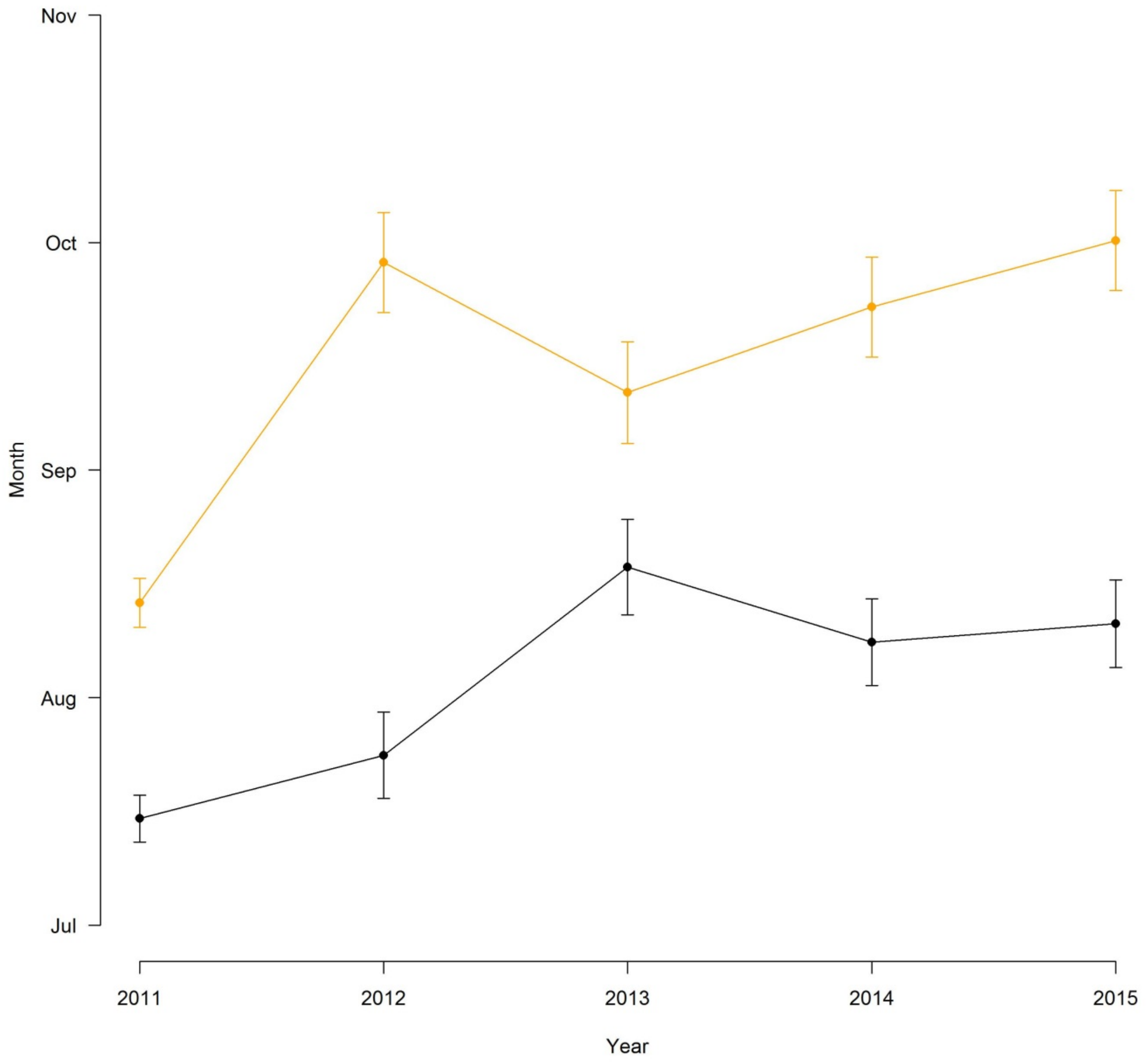

Figure 5-17 Timing at which 50% of mature female lobsters, standardised for location along the coast, are mated and produce eggs. Monthly proportions of mature female lobsters that are setose, newly mated (new tar-spot), spawning (Eggs) and having a spent spermatophoric mass (eroded tar-spot), based on DCCM and IBSS data between 2011 and 2016

The timing of moulting back into a non-setose condition at the end of the spawning season (around March) differs from that associated with the start of spawning and appears more related to water temperatures during the spawning season. Warmer water temperatures during spawning increase the development rate of incubating eggs under the female's tail. Therefore, in years with warm water temperatures during spawning the batches of eggs produced are finished earlier and females moult into a non-setose state earlier (i.e. February). However, in cooler years, when the eggs develop more slowly, some female still have eggs in February, and the mature lobsters delay their moult until March/April and under this scenario, many females do not moult into a non-setose state, rather they moult straight into setose again ready for the next spawning season (Figure 5-18, de Lestang and Melville-Smith, 2006).

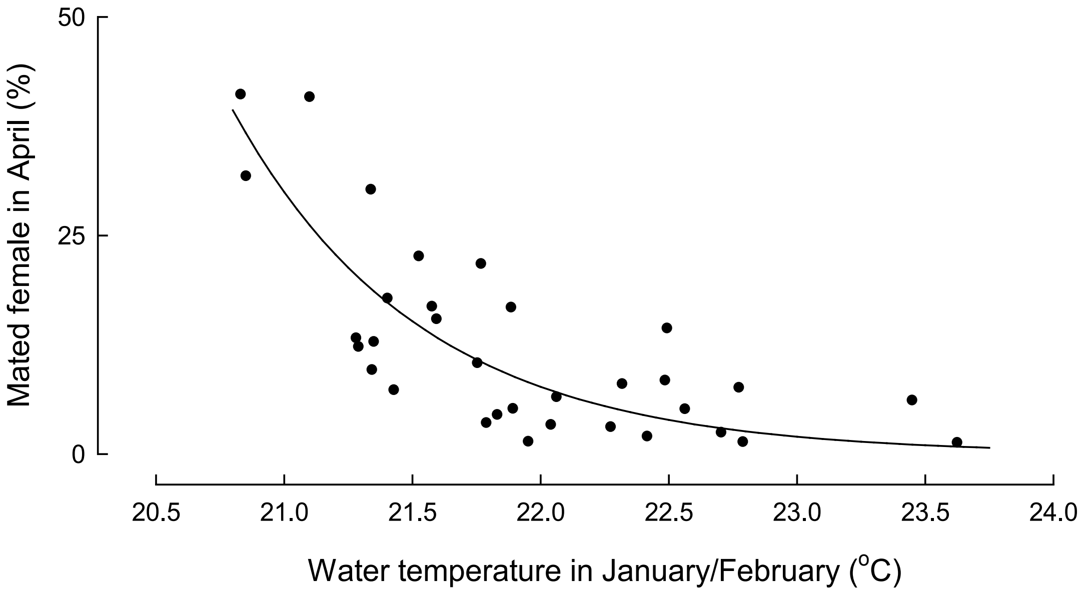

Figure 5-18 Exponential decay regression between the annual incidence of large (≥ 95 mm) mated female *Panulirus cygnus* in April and the annual standardised mean bottom water temperature for January and February (combined) of that year.

5.1.3.7 Size-Fecundity Relationships

The number of eggs produced by a particular female during a spawning period depends on the size of the individual ($Fecundity = 1.92 \cdot CL^{2.69}$) (Chubb 1991). Hence larger females produce more eggs than smaller females, with large females capable of producing over a million eggs (Figure 5-19), almost all of which are successfully fertilised (Morgan 1972).

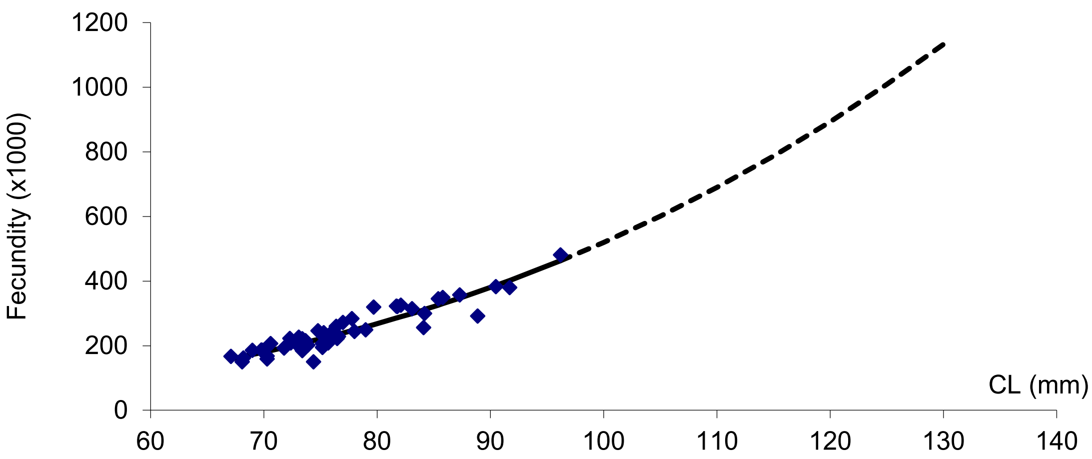

Figure 5-19 Fecundity of *Panulirus cygnus* in relation to carapace length (CL) Dotted line represents extrapolation of relationship

5.1.3.8 Factors Affecting Year Class Strength and Other Biological Parameters

Most lobster larvae do not survive their larval phase. Many are eaten by predators or are not carried close enough to the coast by the ocean currents to enable them to metamorphose and settle. Therefore, the number successfully surviving their larval phase and settling can vary greatly from year to year, largely as a result of changes in environmental factors (Caputi et al. 2000). When the Leeuwin Current is flowing strongly, the settlement of puerulus is generally higher (Caputi et. al. 1995b) as presumably a higher proportion of larval lobsters return to the coast. Possibly the warmer oceanic waters may increase the development rate and survival of phyllosoma larvae. Westerly winds at the time of year when the puerulus are ready to settle may also help more of them to reach the shallow reefs along the coast. The strength of the Leeuwin Current is weakened by El Niño events.

More recently these above relationships decayed, with extremely low levels of settlement occurring during strong Leeuwin Current years with associated warm water temperatures (e.g. 2008/09 settlement). Examination of the timing of the start of spawning using fishery-independent data since the mid-2000s indicated that spawning has recently been occurring earlier. The low settlement appears to be related to higher water temperatures at the time of the onset of spawning (October) since the mid-2000s. Statistical analysis shows that the majority (71%) of the variation in puerulus settlement was explained by the timing of spawning, storm activity during mid-autumn to mid-spring (measured by rainfall between May and October) and offshore water temperatures in February. It is possible that earlier spawning causes a mismatch with other environmental factors such as peaks in ocean productivity and/or storms (westerly winds) that assist the larvae return to the coast, offshore water temperatures help the early stage larval growth, and storm activity assists late stage larvae to be transported back to the coast. These variables produced a plausible hypothesis to explain the decline in puerulus settlement for these 7 years, including the recruitment failure of 2008/09. They also predicted the substantial improvement in settlement for 2013/14 based on a later start to spawning in 2012 and above-average rainfall and water temperature in 2013. Egg production levels did not appear to have a significant relationship with puerulus settlement levels after taking environmental variables into account.

Although large fluctuations in puerulus settlement occur between years (Section 8.2.4.1), the impact of this on recruitment to the fishable biomass is far less dynamic. This is due to the high levels of density-dependent mortality that occur during the juvenile phase of *P. cygnus*. Examination of relationships between recruitment level of puerulus and subsequent commercial catches three-four years later identified very high levels of density dependent mortality at a number of sites including the Abrolhos Islands (Figure 5-20) (Caputi et al., 1995; de Lestang et al., 2009).

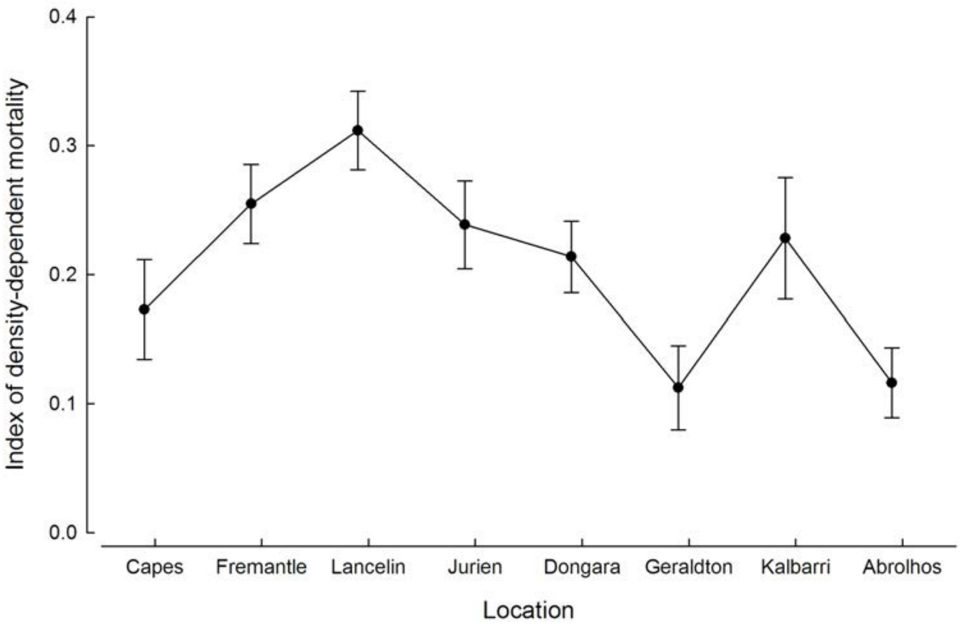

Figure 5-20 Index of density dependent mortality (mean + 1SE) over the period from settlement to fishery-recruitment (3–4 years) for *Panulirus cygnus* at eight locations spanning the western rock lobster fishery. Note the index is the power term in the relationship and therefore a lower value represents a rgeater rate of change and thus greater level of density dependence.

5.1.3.9 Diet and Predators

The western rock lobster is an opportunistic omnivore, feeding on a wide range of food items from coralline algae to molluscan and crustacean fauna (Joll & Phillips 1984, Edgar 1990). The major predators of western rock lobster are octopus, with less mortalities being associated with finfish and in certain areas, Australian sea lions. For full details on the diet and predators of western rock lobster see Bellchambers et al. (in press).

5.1.3.10 Parasites and Diseases

"In spiny lobsters, *Panulirus cygnus*, *P. argus* and *Jasus edwardsii*, a form of shell disease occurs. It is known as ''tail fan necrosis", an aptly named syndrome because the uropod and telson appear melanized and partly or fully eroded away (Porter et al., 2001)." The main impact of this disease is a reduction in marketability of the lobster, however this only occurs in more extreme cases, which are fairly rare.

Shields (2011) also stated that "Lobsters serve as the second intermediate host to digenetic trematodes. They bear the metacercaria, or the encysted stage. The metacercarial cysts are usually quite small (<1 mm) and can be detected using microscopy. As the name implies, the microphallid trematodes are known for their small phallus. Several species use crustaceans as intermediate hosts. While the metacercariae of most trematodes are difficult to identify to the species level, the microphallids develop sexual characteristics as metacercariae making it possible to identify and describe them. *Thulakiotrema genitale* is a microphallid found encysted as metacercaraie in the gonads of *Panulirus cygnus* (Deblock et al., 1990). The prevalence in Western Australia was quite high, ranging from 47% to 87%." This trematode, in large infestations, can cause the lobster to become sterile, however infestations of this magnitude are not often reported.

5.1.4 Inherent Vulnerability

The biology and behaviour of lobsters makes them low to moderately vulnerable to fishing. Temperate lobsters are a moderately fast growing group, with most reaching spawning age and exploitation size by 4-5 years but with potential longevities in excess of 20 years. They are highly fecund with a long planktonic larval stage (approx. 12 months) usually with broad dispersal. Whilst individuals of many species undergo size / age related migrations there is often limited mixing amongst regions. They do not form spawning aggregations.

The most common method of capture is by baited pots / traps positioned close to reefs or other structures. There is only a low risk of hyper-stability in catch rates. Successful long-term management has been recorded for many fisheries. The stock declines that have occurred in some lobster fisheries have following extended periods of high exploitation, these can, however, recover in a relatively short (< 10 years) period once corrective actions are implemented. There is evidence that recruitment levels are maintained even following significant reductions in spawning biomass. Further, whilst the level of recruitment often varies annually, associated with environmental conditions, there is generally some recruitment in most years.

6 Fishery Information

6.1 Fisheries / Sectors Capturing Resource

Panulirus cygnus is fished by two commercial fisheries; the WCRLMF and the South Coast Crustacean Managed Fishery (SCCMF). These fisheries extend over the whole of the lobster's range.

The WCRLMF is the largest fishery encompassing most of the western rock lobster's (WRL) geographic range, including the most productive regions. The fishery is the most valuable single- species wild-capture fishery in Australia (with the catch worth between $A200 and $A400 million annually), representing about twenty per cent of the total value of Australia's wild-capture fisheries.

Catches of *P. cygnus* in the SCCMF are small compared to those in the WCRLMF. Catches periodically increase and are associated with increased puerulus settlement in the south of the WCRLMF (Figure 6-1).

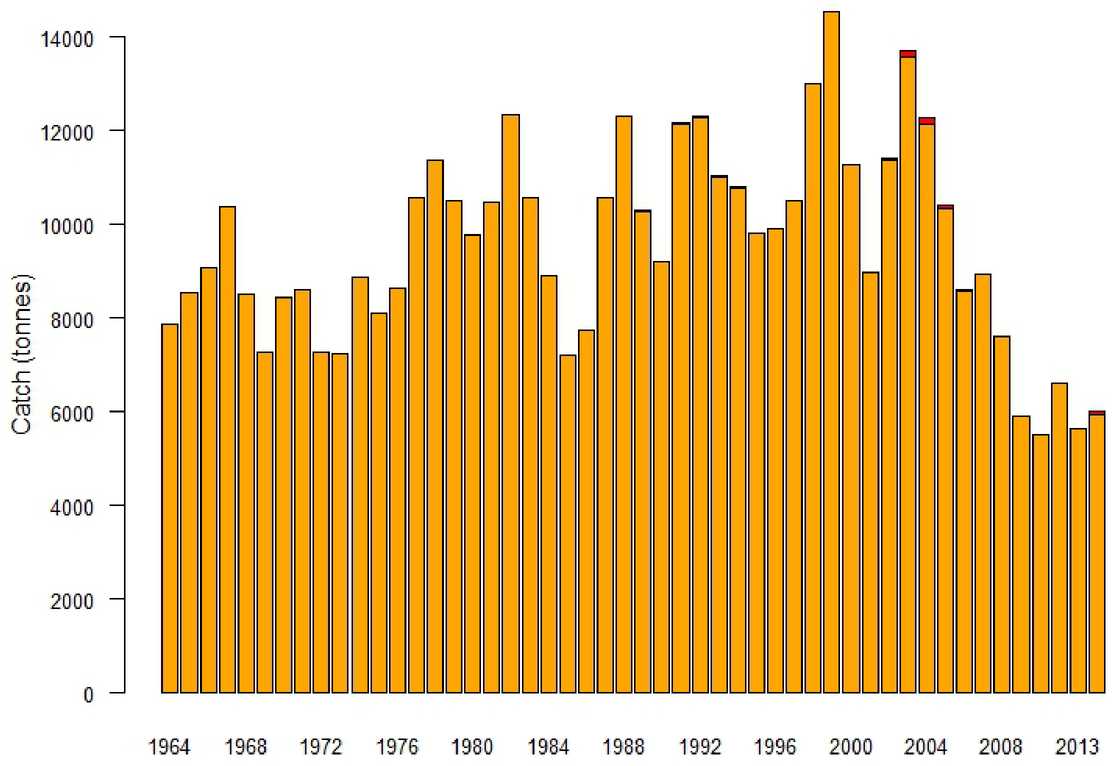

Figure 6-1 Catches of western rock lobster from the West Coast Rock Lobster Managed Fishery (orange) and South Coast Crustacean Managed Fishery (red)

The recreational rock lobster fishery primarily targets western rock lobster but also takes southern and tropical rock lobster species using pots (traps) or by diving. Most of the fishing effort is focused on western rock lobster and is concentrated on the coasts adjacent to Perth and Geraldton.

The sections below provide more detailed information about the main fisheries / sectors that target the Western Rock Lobster Resource, i.e. the WCRLMF and the recreational fishery.

6.2 West Coast Rock Lobster Managed Fishery

Table 6-1. Summary of key attributes of the commercial West Coast Rock Lobster Managed Fishery for 2015

Attribute	
Fishing methods	Pots (baton or beehive)
Fishing capacity	28,606 pots, which is 82.5 % of total allowed (69,291 pots at a usage rate of 0.5)
Number of (fishing boat) licences	233
Number of vessels	231 (actively fishing)
Size of vessels	17 – 25 m
Number of people employed	Unknown
Value of fishery	$417 million ($359 million in 2014)

6.2.1 History of Development

The small WCRLMF fishery expanded rapidly in the 1940s: by the mid-1950s the annual catches were over of 8 million kg. Management introduced total allowable effort limits in 1963. Since the 1980s the annual catch has averaged approximately 11 million kg, although it has varied from 5.8 to 14 million kg (Figure 6-2). Recent years have seen a decline in catch and effort through a range of management measures. This culminated in a catch limit for the 2009/10 season of 5,500 tonnes (± 10%) and this TACC was maintained for the 2010/11 season using individual catch limits. The season length and start and end dates were progressively changed between 2011 and 2013, with the new season structure spanning 12 months (Table 6-2). This started on the 15th January 2013. From this point on all seasons have started on 15th January and finished on the following 14th January (in the next year) and are referred to as the season they began in. For example the season that ran from 15th January 2013 to 14th January 2014 is referred to as the 2013 season. Recent TACC levels have increased slightly to 6000 tonnes in the 2015 season. The TACC for the current (2016) season is again 6000 t.

The rock lobster fishery was declared limited entry in March 1963 when licence and pot numbers were frozen. Since 1963, boat numbers have declined due to management changes (pot reductions etc.) and consolidation from 836 to 231 (2015) (Figure 6-3). There was a significant drop in vessel numbers in 2008/09 and 2009/10 associated with the effort reductions. In 2015 vessels were operating an average of 123 pots. Since 1965 commercial catches have ranged from 5.5 (2010/11) to 14.5 million kg (1999/20) with this maximum catch being the second largest catch of any single species of rock lobster after *Panulirus argus*.

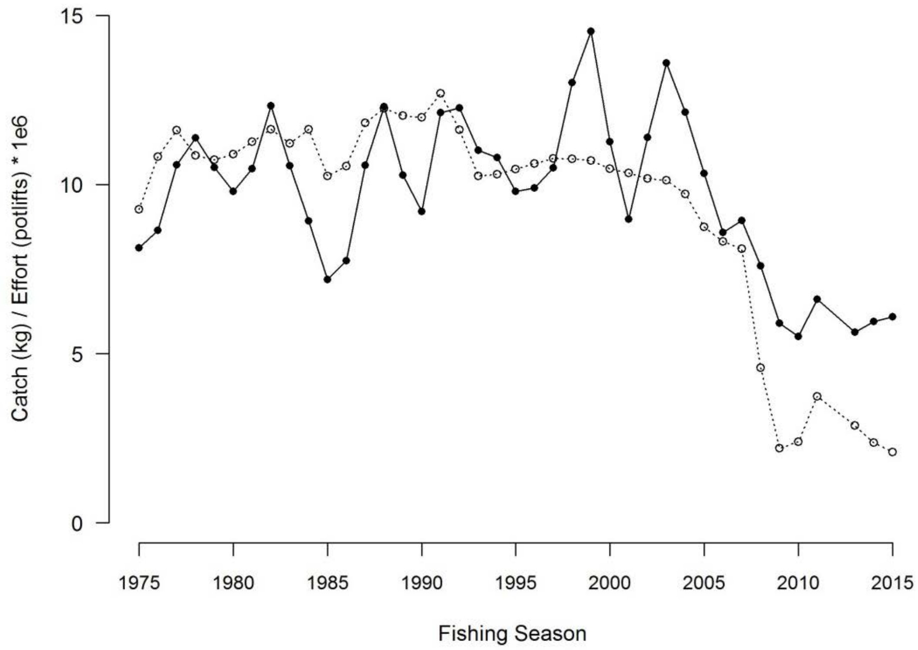

Figure 6-2 Annual catch (solid cirlces) and effort (open circles) for *Panulirus cygnus* in the WCRLMF.

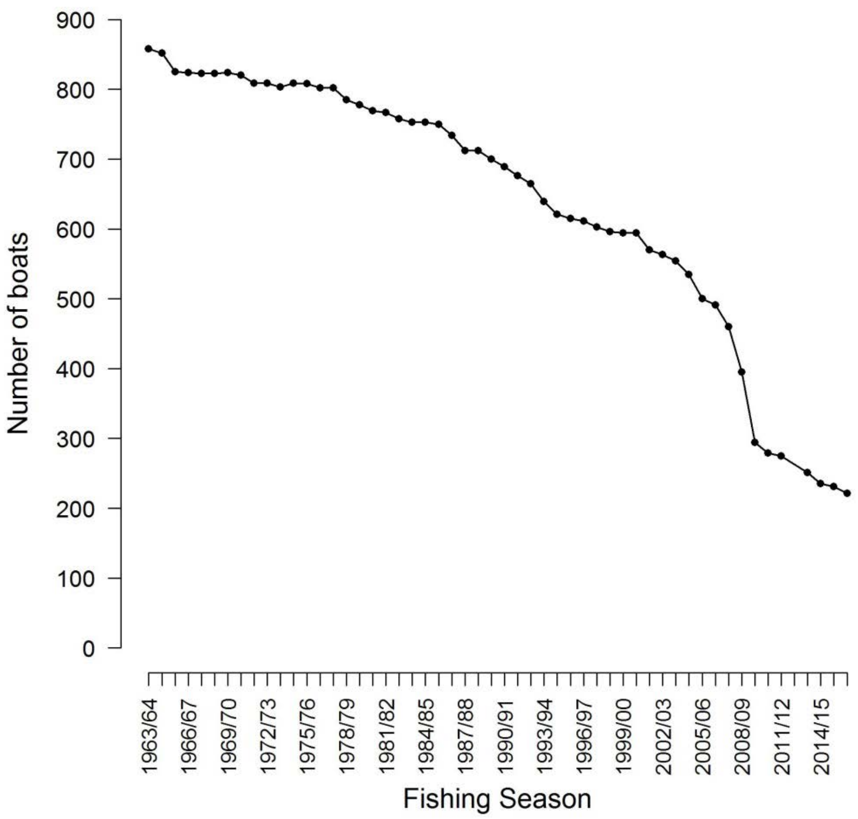

Figure 6-3 Number of commercial rock lobster boats actively fishing in the fishery since 1963/64 season.

6.2.2 Current Fishing Activities

The WCRLMF encompasses the waters "*situated on the west coast of the State bounded by a line commencing at the intersection of the high water mark and 21°44' south latitude drawn due west to the intersection of 21°44' south latitude and the boundary of the Australian Fishing Zone; thence southwards along the boundary to its intersection with 34°24' south latitude; thence due east along 34°24' south latitude to the intersection of 115°08' east longitude; thence due north along 115°08' east longitude to the high water mark; thence along the high water mark to the commencing point and divided into zones*" (Figure 6-4).

The fishery is managed in three zones: south of latitude 30° S (Zone C), north of latitude 30° S (Zone B) and, within the Abrolhos Islands area (Zone A) (Figure 6-4). This distributes effort across the entire fishery, and allows for the implementation of management controls aimed at addressing zone-specific issues, which has previously included different maximum size restrictions in the northern and southern regions of the fishery.

Throughout the document the fishery may be described according to a zone (A, B and C), or area (northern or southern). The latter refers to the northern zones of A and B and the southern zone of Zone C, respectively. Reference may also be made in regard to the breeding stock management areas (BSMA) which are used in the assessment (Section 9) and harvest strategy (Section 7.2) for the fishery. These broadly align with the management zones but do differ slightly to better reflect the biology of the western rock lobster (Figure 6-4).

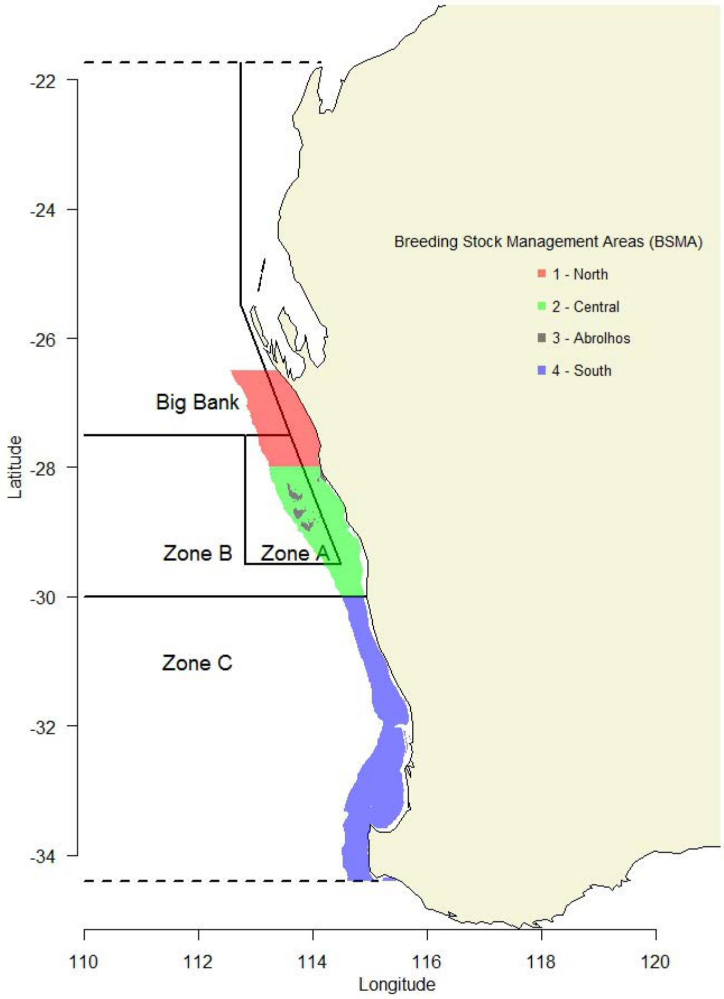

Figure 6-4. Boundaries of the commercial West Coast Rock Lobster Managed Fishery (dotted lines) and the three management zones (A, B and C). The northern 'Big Bank' part of the fishery is shown with the four breeding stock management areas

The season for Zones B and C have typically been open from 15 November to 30 June annually; the Abrolhos Islands zone (Zone A) operating from 15 March to 30 June. Starting in the 2010/11 fishing season there was a progressive increase in season length until year-round fishing occurred in 2013 (Table 6-2). The season start date is now 15 January.

Table 6-2 Season opening and closing dates for all zones unless otherwise stated

Season	Season Start	Closure	Season End
Prior to 2008/09	15 November		30 June
2009/10	15 November		Zone A – 17 May Zone B – 15 June Zone C – 10 May
2010/11	15 November		31 August
2011/13	15 November	1 October – 14 November	14 January
2013 onwards	15 January		14 January

6.2.3 Fishing Methods and Gear

The commercial fishery for western rock lobster is a "potting" fishery. This activity occurs from inshore regions in shallow waters out to the edge of the continental shelf (~200 m depth) with the only allowable method of capture being by the use of pots of either a batten design made of wood slats or plastic (Figure 6-5a), or beehive pots made of cane (Figure 6-5b).

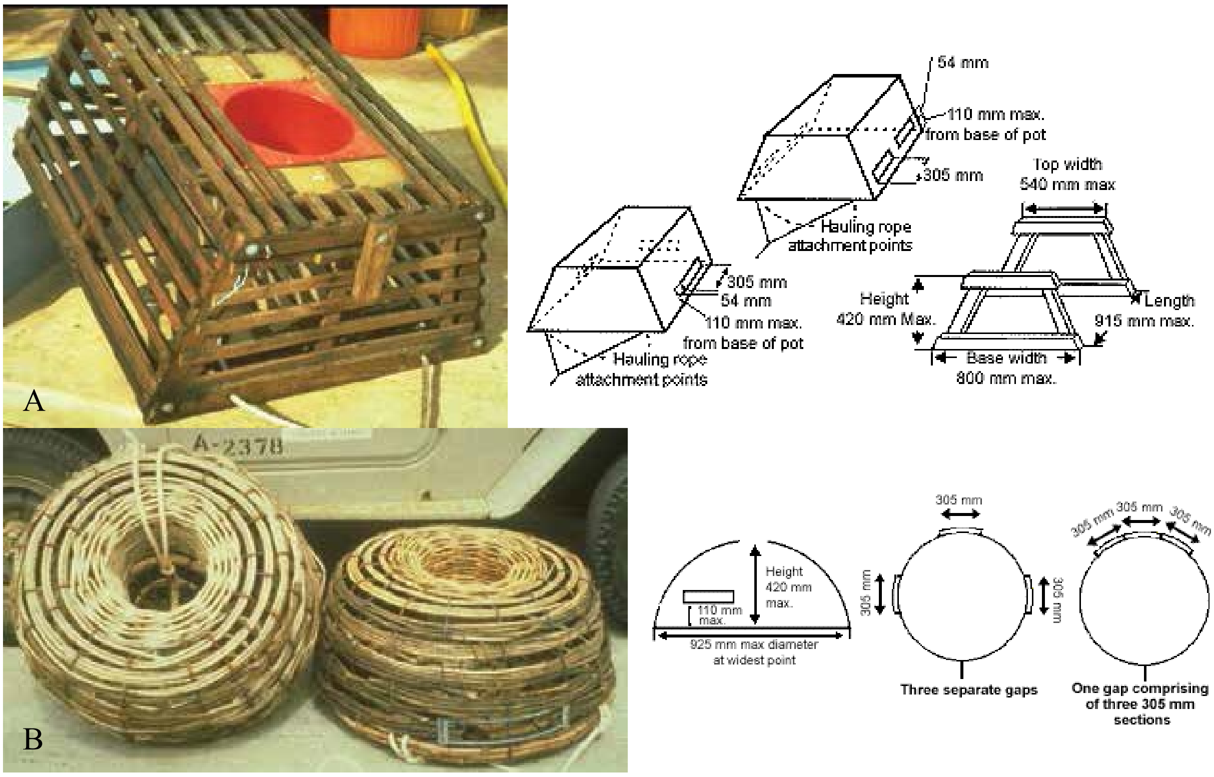

Figure 6-5 Two main trap types used by fishers and their regulated measurements for; **(a)** batten design (made of wood); **(b)** cane beehive pot

Baited pots are released (set) from boats either near reefs where the lobsters usually live or in regions (usually with a sandy bottom) thought to be on migration paths. The setting of pots is based on a combination of information gained from depth sounders, GPS systems, previous experience and recent catch rates in the area. The pots are left overnight to attract the nocturnally active lobsters to the baits, which are in the pots. The pots are generally retrieved (pulled) the following morning, though sets of two or more days often occur, particularly when catch rates are low. Captured lobsters of legal size and of appropriate reproductive status (e.g. not setose) are placed into holding tanks and taken to on-shore processing plants, where most are prepared for overseas markets, many as live shipments.

A range of bait types are used depending on the type of fishing and soak times. These are generally "oily" fish with blue mackerel (*Scomber australasicus*) being a preferred bait type. Detailed information on bait usage and sources can be found in Bellchambers et al. (in press).

6.2.4 Susceptibility

The majority of the geographic distribution of western rock lobster is commercially fished. In some areas where commercial fishing is generally low (e.g. between Cape Naturalist and Cape Leeuwin) or absent (e.g. Ningaloo Marine Park) this species is either fished recreationally and/or found only in very low numbers. The encounterability of western rock lobster to fishing gear is high. This species lives on the sea floor and fished directly using pots that also sit on the sea floor. The foraging activity of this species varies throughout it life stages, thus affecting its catchability to pots. Small individuals are highly catchable, with their catchability declining with size after sexual maturity is reached. Large individuals of both sexes show significant declines in catchability through much of the year, presumably in relation to moulting and reproduction.

The fishing pots used in the fishery are highly selective to legal size individuals, having a minimum of three escape gaps that allow for the escapement of undersize individuals. The gaps are large enough to allow the escapement of a certain proportion of just legal-sized individuals as well. There is well documented survival of lobsters returned to the sea, with the process of returning unwanted catch having been documented in a "Code of Practice" and regulations placed around having to return lobsters immediately to the water before fishing re-commences.

6.3 Recreational / Charter Fishery

6.3.1 History of Development

Recreational fishing for rock lobsters in Western Australia occurs state-wide with an annual licence giving fishers access to four species: western rock lobster (WRL) (*Panulirus cygnus*), southern rock lobster (*Jasus edwardsii*) and tropical lobsters (*Panulirus ornatus* and *P. versicolour*). A general amateur licence was introduced in 1932, but was replaced in 1986 with the current fishery-specific rock lobster licence (Melville-Smith and Anderton 2000). An umbrella licence, which collectively endorsed fishing for lobster, abalone, netting, marron and freshwater angling, was also in effect from 1986 to 2010. The recreational fishery is managed by gear restrictions, size limits, protection of reproductive females, seasonal closures, daily bag and boat limits and possession limits (for the latest arrangements see: http://www.fish.wa.gov.au/Documents/recreational_fishing/licences/rec_licence_rock_lobster.pdf).

Prior to 2008/09, when recreational catches were not limited by allocation between sectors, the recreational catch was less than 4% of the commercial catch. This 'best estimate' of recreational catch and the potential for long-term growth in catch from the recreational sector was considered in determining allocation of 95% to the commercial and 5% to the recreational sectors (DOF, 2005). Implementation of the *West Coast Rock Lobster Managed Fishery Management Plan 2012* in 2011/12 finalised the transition of the commercial fishery from effort-based management controls to a catch quota based fishery and the determination of the TACC and Total Allowable Recreational Catch (TARC) for monitoring resource allocations between the commercial and recreational sectors, respectively (de Lestang *et al.* 2012, Reid *et al.* 2013). The TACC was set according to the Maximum Economic Yield (MEY) with a TARC based on 5% of the upper limit of MEY.

The total catch and effort from charter boat-based recreational fishers have been monitored with mandatory Tour Operator Returns (charter logbooks) since 2001. Charter fishing effort is mainly directed at scale-fish and catches of lobster are minimal.

6.3.2 Current Fishing Activities

The recreational fishing season is the 9 month period from 16th October to 30th June. For the 2014/15 season, 50,734 lobster recreational fishing licences were issued. Concentrated in inshore regions from Exmouth (latitude 21°47′S) to Augusta (latitude 34°24′S), with the majority of recreational fishing occurring in waters off Perth (31°57′S) and Geraldton (28°46′S). Recreational fishing activity is highest during November–January (Christmas holidays) when 'whites' are easily accessible.

6.3.3 Fishing Methods and Gear

Recreational fishing for WRL can occur from a boat and from the shore. Recreational fishers can target WRL with pots (limit of two pots per licence), by diving (using a loop, shepherds hook, or blunt hook and dive gear such as scuba, snorkelling or hookah), and by hand collecting in the intertidal zone. Pots have size and shape restrictions and require escape gaps (refer to Section 7.1).

6.3.4 Susceptibility

The majority of the geographic distribution of western rock lobster is not recreationally fished. There is minimal fishing in deeper water (>20 fathoms) where the bulk of the breeding stock reside, and hence are not accessed by recreational fishers. The encounterability of western rock lobster to fishing gear is high. Pots used recreationally are very similar to those used commercially so the same rationale for their encounterability (Section 6.3.4) applies to the recreational fishery. As recreational fishers are able to dive for rock lobsters, this further increases the encounterability of the species to fishing methods as diving is directly targeted at the habitats occupied by lobsters.

6.4 Customary Fishing

Although there are no records required for indigenous fishers taking lobster under customary take, the catch is thought to be very low. In the assessment of the fishery (Section 9), customary take is arbitrarily assigned as one tonne. This is in line with the integrated fisheries management (IFM) of the stock (Section 0).

6.5 Illegal, Unreported or Unregulated Fishing

During the 10–15 years after limited entry was introduced (1963 to the early1970s) some fishers adopted a cavalier approach to the regulations protecting undersize and spawning animals and to the number of traps they used. There are, for example, anecdotal reports from the early 1960s of large numbers of undersize rock lobsters being transported out of Western Australia, under the guise of "frozen chickens". Fishers breaching regulations were possibly encouraged by the relaxed approach to enforcement during the early 1960s and by the limited resources available to fisheries enforcement officers at that time. In the early 1970s, better resourced fisheries enforcement officers became more innovative and, backed by harsher penalties, were able to enforce the regulations. By the mid-1970s the regulations were generally accepted by the industry; since that time few serious breaches have been detected. Such illegal activities in the early years of the fishery obviously affected the integrity of the data reported by fishers. Undersize rock lobsters were either not delivered to processing establishments or, if they were, were not recorded by the processors or reported in the fishers' mandatory monthly returns. The reported catch landings, therefore, were understated. Egg-bearing females were landed to processing establishments after the eggs had been removed (scrubbed) from the tails. While the females that had their eggs removed were included in the reported landings and in the monthly returns, it is of value to note the quantities landed so that models of the fishery make appropriate use of the data.

Levels of effort were also understated on monthly returns by fishers using more traps than they were legally entitled to. To assess the impact of these activities, fishers who had fished during this period were interviewed in 1985 or asked to complete a questionnaire anonymously. Analysis of the responses is shown in Table 6-3. The time series of recorded catch and effort figures were subsequently adjusted using these estimates and the records of prosecutions, under the Fisheries Act, for relevant offences during this period.

Table 6-3 Estimate of undersize rock lobsters as a percentage of the annual catch, the percentage of spawning rock lobsters in the annual catch and the percentage of traps used in excess of the licensed numbers of traps (NA: Not Available, NR: No Restriction (on trap numbers) (Caputi et al. 2000)

Fishing Season	Undersized	Spawners	Traps
1957/58	NA	NA	NR
1958/59	NA	1.2	NR
1959/60	NA	1.1	NR
1960/61	NA	1.0	NR
1961/62	NA	0.4	NR
1962/63	3.6	0.4	19.4
1963/64	4.4	0.4	17.0
1964/65	4.3	0.4	21.5
1965/66	4.3	0.0	19.6
1966/67	7.6	0.0	23.8
1967/68	7.1	0.0	19.1
1968/69	7.3	0.0	14.2
1969/70	6.7	0.0	7.3
1970/71	6.4	0.0	4.7
1971/72	5.8	0.0	2.9
1972/73	5.0	0.0	1.8
1973/74	5.7	0.0	1.0
1974/75	5.4	0.0	0.0
1975/76	4.0	0.0	0.0
1976/77	2.5	0.0	0.0
1977/78	1.5	0.0	0.0
1978/79	0.7	0.0	0.0
1979/80	0.6	0.0	0.0
1980/81	0.4	0.0	0.0
1981/82	0.4	0.0	0.0
1982/83	0.3	0.0	0.0
1983/84	0.3	0.0	0.0
1984/85	0.1	0.0	0.0
1984/85	0.1	0.0	0.0
1985/86	0.0	0.0	0.0

Another source of bias has also resulted from an understatement of catch on fishers' compulsory monthly catch and effort returns, in an attempt by fishers to minimise taxation. This bias is believed to affect only the catch component of the monthly return, not the fishing effort. However, these unreported catches have been reported by most processors as cash sales, although not as a catch attributed to a particular vessel, and therefore do not result in a biased measure of the total catch from this source. On average, the difference between the processors' total catch and total catch declared by fishers has been about 5%. Correction of the fishers' monthly return data for cash sales to processors has been achieved by using the ratio of landings received by processors to the total catch recorded by all licence holders.

An unquantifiable but insignificant proportion of the catch goes unrecorded through the very small local market by way of direct sales to retail outlets and consumers.

Since the early 1990s, processors have been required by the Australian Tax Office to record the vessel details for all lobster received, which has significantly reduced the number of unreported cash sales.

In 2015, there were a total of 19,492 consignments inspected which resulted in a total of 226,844 containers inspected. This resulted in a total of 31 brief offences (prosecutions), 32 infringements and 97 warnings. As there is currently very little illegal or understated catches in the fishery, and there is good information on the number and degree of over-quota offences, the catch reported by fishers in believed to be reflective of the actual catch retained.

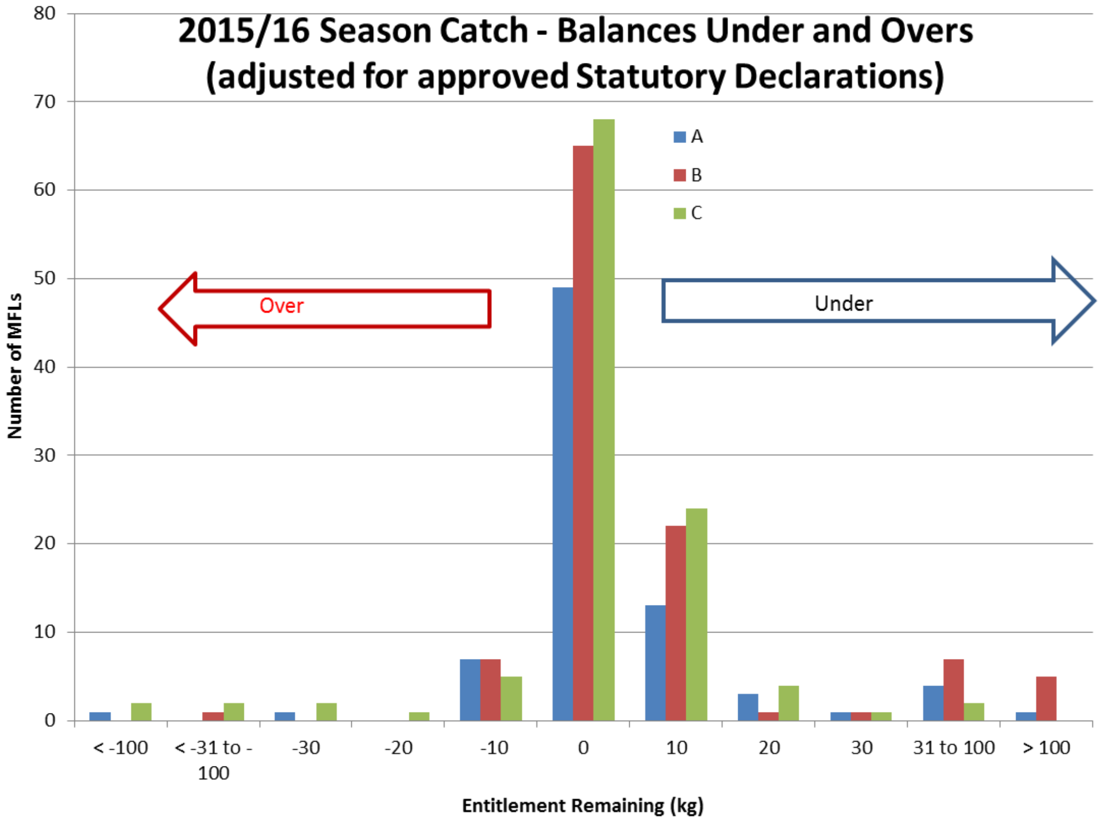

Figure 6-6 Frequency of managed fishing license (MFLs) and their remaining quota entitlement by zone for the 2015 season.

7 Fishery Management

The WCRLMF was one of the first limited entry fisheries in the world and utilised a sophisticated Individual Transferrable Effort based system for over 20 years. In 2009/10 a notional TACC was introduced. The transition to an Individually Transferable Quota (ITQ) fishery, which began in 2010/11, is now complete.

The fishery has historically been Australia's most valuable single species wild capture fishery and was the first fishery in the world to achieve Marine Stewardship Council (MSC) Certification. In early 2012 the fishery was certified by MSC for the third time.

Box 7-1 Timeline of major management regulatory changes introduced into the WCRLMF.

Year / Season	Regulation
1897	Minimum legal whole weight of 12 oz (340 g). This measurement is equivalent to, and eventually evolved into, the 76 mm carapace length minimum size currently in force in the fishery (Figure 5-3 for measurement detail).
1899	Females carrying spawn were given full protection by requiring them to be returned to the sea.
1962	Closed seasons: coastal fishery 16 August–14 November; Abrolhos Islands fishery 16 August–14 March.
1963	Limited entry introduced: boat numbers were fixed (858) and the number of traps per boat was limited to three traps per foot (0.3 m) of boat length.
1965	Boat replacement policy required a boat to be replaced with one of exactly the same length. This stopped fishers replacing a boat with a larger one and hence obtaining additional traps to use under the three traps/foot of boat length regulation. This froze the number of traps in the industry at 76 623.
1966	A 51 x 305 mm escape gap was introduced into all traps to allow sub-legal size lobsters to escape before the trap is brought to the surface.
1971/72	Escape gap increased to 54 x 305 mm.
1973	Multiple entrance traps were banned.
1977/78	Fishing season was shortened by 6 weeks from (15 November–15 August to 15 November–30 June) to protect newly mated females and to constrain fishing effort.
1979	Boat replacement policy was changed to allow a boat's trap quota (entitlement) to vary from seven to ten traps per metre of boat length. This gave fishers the flexibility in the size of replacement boats that they could have for a given trap quota.
1984	Maximum size of traps was established; based on a maximum volume of $0.257m^3$
1986	Number of escape gaps (54 x 305 mm) in traps was increased (from one) to three or four (depending on the positions of the gaps).
1986	Trap numbers of all licence holders were reduced temporarily by 10% for the 1986/7 season. Total trap numbers were reduced from 76 623 to 68 961 for one season.
1987–1991	Trap numbers were reduced permanently by 10%, at 2% per year for 5 years.
1992/93	10% reduction in traps in Zone B (15 November–9 January) Closure of Zone B (10 January–9 February) Return of setose females required (November–February) Maximum size for females of 115 mm (Zone C) and 105 mm (Zones A&B) introduced. Home porting in Zone C.

1993/94	18% reduction in traps Minimum size increased to 77 mm in November–January Required return of females that are setose or above a maximum size (105 mm Zone A and B; 115 mm Zone C) Home porting in Zone C restriction lifted
2000/01	Unitisation of the fishery to more explicitly incorporate the 18% pot reduction in the current pot entitlements Individual numbering of pot entitlements The ability of those with access to 63 or more pot entitlements and a fishing boat licence to apply for a new managed fishery licence The ability of fishers to retain an inactive managed fishery licence by retaining an inactive fishing boat licence and one or more inactive pot entitlements Provision for temporary pot transfers
2001/02	Use of animal hide as bait prohibited
2003/04	Removal of the maximum entitlement of 150 pots per vessel
2005/06	Three-year effort reduction package 15% effort reduction in Zone B 10% pot reduction 15 November–15 March 10% pot reduction in Zone A 15 March–15 April Summer closure in Zone B 15 January–9 February Sundays off in Zone B 15 March–30 June Closed Christmas and New Year's day 5% effort reduction in Zone C Closed 15 November–24 November Five three-day moon closures 1 February–30 June Closed Christmas and New Year's day
2006/07	A and B Zone fishers who nominate to fish the Big Bank from 10 February must remain in Big Bank until midday on the last day of February of the season. Big Bank then becomes part of the B Zone fishery and any Zone A or B fisher can go there or leave it as they please.
2007/08	Effort reduction: unit values (number of pots per unit) of Zone A – 0.74 from 15 November to 15 April then 0.82 until season end Zone B – 0.74 from 15 November to 15 March then 0.82 until season end Zone C – 0.82

2008/09	15 November - Effort reduction: unit values (number of pots per unit) of Zone A – 0.66 Zone B – 0.66 Zone C – 0.74 Sunday closure for all zones and all season with the exception of the first two weeks in Zone A 30 November - Effort reduction: unit values (number of pots per unit) of Zone A – 0.54 Zone B – 0.54 Zone C – 0.62 24 February - Closure of Big Bank for the remainder of the season 1 March - Effort reduction: unit values (number of pots per unit) of Zone A – 0.42 Zone B – 0. 42 Zone C – 0.50 6 March – Saturday and Monday closures for all zones and all season Sunday closure for the first two weeks of Zone A continuing all season Removal of Zone C moon closures 15 March - Maximum size of female lobsters in Zone A and B reduced to 95mm Minimum size in Zone C increased to 77mm 1 May - back to 5 fishing days per week (Saturday and Sunday closures)

2009/10	Effort reduction: unit values (number of pots per unit) of: Zone A – 0. 36 Zone B – 0.40 Zone C – 0.44 Temporal closures: Zone A – 4 days a week all season Zone B & C – 4 days a week during "whites" and "reds" peaks (December 1 to December 31 and March 15 to April 14) Zone B & C – 5 days a week for rest of the season Changes in maximum female size: Zone C – 115 mm to 105 mm Minimum size of 77 mm all season All pots must have at least three escape gaps 55 mm high and 305 mm wide Nominal TACC of 5,500 tonnes set for the 2009/10 season. Removal of soaking periods prior to the start of the season (provision made to load and bait pots and move in the Fishery 7 days before the start of the season) Big Bank to remain closed Rock Lobster processors to submit weekly catch (only) returns, to be received by the Department no later than COB Tuesday, each week of the season (in addition to monthly reporting requirements) Carrier boats permitted to carry more than 4 rock lobster pots. December 2009 Prohibit fishing in Zone B between 25 December 2009 and 10 January 2010 inclusive; Continue the prohibition on fishing on Friday, Saturday and Sunday each week throughout the remainder of the first half of the season in Zone B; Prohibit fishing in Zone C between 25 December 2009 and 3 January 2010 inclusive; and B Zone summer closures removed. January 2010 Closure in Zone B extended to 25 January; and Prohibit fishing in Zone C between 16 January and Prohibit fishing on Fridays in Zone C from 1 Feb to end of season. February 2010 Prohibit fishing in Zone C between 12 March and 21 March Change unit value to 0.30 for Zone C effective 21 March; Zone A prohibited from fishing in Zone B for the remainder of the season as of 15 February 2010; and Prohibit fishing in Zone B between 12 March and 11 April. 17 February 2010 Zone B permitted to fish Friday's for the remainder of the season. May 2010 Zone C closed for the remainder of the season – effective 10 May; Zone A closed for the remainder of the season – effective 17 May. June 2010 Zone B closed for the remainder of the season – effective 15 June

2010/11	Total Allowable Commercial Catch (TACC) of 5,500 tonnes set for the 2010/11 season. Individual catch limits introduced with the following number of kilograms per unit: Zone A – 36kg from 15 November to 14 March Zone A – 51kg from 15 March to end of season Zone B – 81kg for entire season Zone C – 75kg for entire season Pot usage set at 0.5 pots per unit for all zones. Fishing prohibited weekends Big Bank to remain closed Season extended to 31 August Zone C start date moved from 25 November to 15 November The restriction on AB concession vessels to fish deeper than 20 fathoms for the first 14 days of March removed Implementation of Sea Lion Exclusion Devices at the Pelsaert and Easter Groups of the Abrolhos Islands Introduction of crate tags catch and disposal records (Appendix A), authorised receivers, holding over book and catch weighing procedures to monitor fishers' catch. Limited "within-season" transferability of licenses and entitlement
2011/13	TACC of 6938 tonnes. Extended 14 month season 15 November 2011 to 14 January 2013 with closure between 1 October and 14 November
2013	TACC of 5554 tonnes (Zones = 1076, B = 1921, C = 2557 t). Changes to the Harvest Strategy such that there is a 50:50 share of catch between the north (A&B Zones) and the south (C Zone)
2014	TACC of 5859 tonnes (Zones A = 1076, B = 1921, C = 2862 t). Gear modifications for whale entanglement reduction introduced (see Bellchambers et al. in press)
2015	TACC of 6000 tonnes (Zones A = 1076, B = 1921, C = 2997 t). TARC of 404 t (2014/15 season).
2016	TACC of 6000 tonnes (Zones A = 1076, B = 1921, C = 2997 t). TARC of 422 t (2015/16 season). Restriction on the retention of maximum size females removed Pot usage increased to 100% for the periods 15 January -30 April and 1 November-14 January

7.1 Management System

In 2014, the Department implemented a Harvest Strategy and Control Rules (HSCR) for the fishery following extensive consultation with the Western Rock Lobster Council, broader industry stakeholders and Recfishwest.

The HSCR is now used as the basis for setting the TACC and the Total Allowable Recreational Catch (TARC). A copy of the HSCR can be found at the following link: http://www.fish.wa.gov.au/Documents/management_papers/fmp264.pdf

The HSCR is based around managing rock lobster stock sustainably in accordance with Maximum Economic Yield (MEY). The HSCR also established fixes TACC proportions between each fishing zone. The catch share between the northern zones (Zone A and Zone B) and Zone C is now split at a ratio of 50:50. With the 50% share allocated to the northern zones being split 36% to Zone A and 64% to Zone B.

In 2013 an increase in interactions with migrating humpback whales resulted in the fishery's export approval being reduced from a five year exemption to a two year Wildlife Trade Operation. To reduce interactions with whales a number of measures, including gear modifications, were introduced in 2014. These measures were developed in consultation with industry and relevant Government agencies and included: restrictions on the amount of surface rope, number of surface floats and length of pot rope that could be used by fishers when operating in deep water areas of the fishery. In addition, other mitigation measures such as negatively buoyant rope requirements and pot retrieval restrictions were implemented.

For full details of the management of the fishery please refer to the West Coast Rock Lobster Managed Fishery Management Plan 2012 (https://www.slp.wa.gov.au/statutes/subsiduary.nsf/0/2B3A7C7BF6ED718D48257FBD00218A24/$file/43.8+wcrlmfmp+2012+-+24.05.16.pdf)

The recreational component of the western rock lobster fishery is managed under fisheries regulations. A combination of input and output controls are used to ensure that the recreational sector enjoys the amenity of its access to the rock lobster resource, while fishing to their 5% allocated share.

7.1.1 Integrated Fisheries Management (IFM)

Integrated Fisheries Management (IFM) is a recent management development in Western Australia fisheries. It is designed to ensure that all sectors that access resource are taken into account in the management of the state's fisheries. A core objective is to determine how to share the available fishery resource between competing users, while maintaining the fishery stock at an ecologically sustainable level. To do this requires

- setting an ecologically sustainable harvest level for the whole fishery
- allocating shares of the sustainable harvest level between indigenous, commercial and recreational users
- monitoring the catch of each sector
- managing each sector remains within its catch allocation
- developing processes to enable re-allocation of catch shares between sectors.

The West Coast Rock Lobster Fishery was the first fishery in the state to go through the IFM process. Currently the IFM process for the WCRLMF has resulted in an allocation report (IFAAC 2007). In this, the Minister's proposed position is that the recreational and commercial allocations should be 5 % and 95 % respectively, and that there should be a customary fishing initial allocation of one tonne. The Minister has proposed that the allocations be implemented starting in the 2009/10 fishing season.

7.2 Harvest Strategy

A Harvest Strategy and Decision Rules (HSDR) for the West Coast Rock Lobster Fishery outlines the long- and short-term objectives for management (DoF, 2014; http://www.fish.wa.gov.au/Documents/management_papers/fmp264.pdf). It also provide a description of the performance indicators used to measure performance against these objectives, reference levels for each performance indicator, and associated control rules that articulate pre-defined, specific management actions designed to maintain the resource at target levels. The HS contains two main objectives, key management principals and a process for setting the TAC.

7.2.1 Sustainability Objective

The Sustainability Objective is the primary objective of the HS, and must be met irrespective of other principles or objectives in the HSCR. This objective is: "To ensure that the egg production in Breeding Stock Management Areas of the Fishery remains above its threshold value for the next five years with a probability greater than 75%." There are four Breeding Stock Management Areas (BSMAs) which will be used to assess the status of the fishery (DoF, 2014).

7.2.2 Harvest Objective

The Harvest Objective is to be used to determine the maximum harvest rate (HR) for the Fishery based on Maximum Economic Yield (MEY) analysis. The maximum HR is used to determine the allowable harvest level for the resource. This objective is described as: "Once the Sustainability Objective has been satisfied, TACCs for the Fishery shall use MEY to determine an optimal range of HRs that would optimise the economic performance of the Fishery by achieving optimal stock abundance and catch rates, and thereby providing high economic returns and greater amenity to the Fishery and the WA community."

7.2.3 Key Management Principals

The key principles that underpin the HS are:

1. The TACC will be equal in the northern Zones (i.e. Zones A and B) and Zone C (50% Zones A and B and 50% to Zone C). This principle will be applied after the allowable HR for the Fishery has been set under both the Harvest and Sustainability Objectives.

2. The proportional allocation of the TACC between Zone A and Zone B will continue to be fixed at the ratio of 0.36 to Zone A and 0.64 to Zone B. This is consistent with the historic 10-year average between the 1998/99 and 2007/08 seasons and has been used as the basis for setting catch allocations since TACCs were introduced for each Zone.

3. Given there is some uncertainty regarding the stock abundance and the preliminary threshold and limit that have been set for BSMA 1 (Big Bank), the abundance of lobsters in BSMA 1 will not contribute to the TAC setting process even if Big Bank is re-opened. This ensures that a precautionary approach to managing breeding stocks in the northern part of the fishery is maintained. This will be re-examined when the HS is reviewed.

7.2.4 TAC Setting Process

The process for setting TACs is set out below:

1. Determine the optimal Legal Proportion Harvested (LPH) range through the Harvest Objective;

2. Ensure Sustainability Objective is met in all BSMAs;

3. If Sustainability Objective is not met in a BSMA, reduce the LPH in the relevant Zone or Zones until the Sustainability Objective is met;

4. The highest HR within the optimal range that results from the Harvest Objective (or through the reduced HR if the Sustainability Objective is not met) will determine the Upper TACC limit for the commercial Fishery. This is then used to determine the allowable harvest level (AHL) though the following formula: • AHL = Commercial Upper TACC Limit/0.95 Therefore the allowable catch for each sector is determined by: • Allowable Recreational Catch = AHL x 0.05; and • Allowable Commercial Catch = AHL x 0.95

5. The WRLC will provide TACC recommendations based on an equal TACC for Zones A/B and Zone C taking into account the catch ranges derived in step 3 above;

6. The TACC for Zones A/B will then be proportioned 0.36 to Zone A and 0.64 to Zone B; and

7. The resulting TACC recommendations will then be provided to the Minister for consideration, and the Management Plan will be amended accordingly

Table 7-1. Summary of the performance indicators, reference levels, control rules and tolerance levels for Western Rock Lobster in the West Coast Rock Lobster Fishery

Management Objective	Performance Indicator(s)	Reference Levels	Control Rules	Tolerance Levels
To ensure that the egg production in Breeding Stock Management Areas of the Fishery remains above its threshold value for the next five years with a probability greater than 75%.	Annual estimates of egg production in four Breeding Stock management areas (BMSA)	**Threshold:** BSMA 1: average of level in 1994-1996. BSMAs 2-4: average of level in 1984-1986. **Limit:** 80% of Threshold levels.	If ≥ Threshold ++, no management action is required. If < Threshold and > Limit ++, Adjust the TACC down and if necessary, take other management action to bring the egg production indicator above the threshold value ++ If < Limit ++, significantly reduce the TACC and or implement large scale area closures until the egg production indicator is projected to be back above the threshold ++ ++ = 75% certainty over projected five years	No tolerance is allowed as the uncertainty is provided by using the 75% confidence level of the subsequent five years
Once the Sustainability Objective has been satisfied, MEY shall be used to determine an optimal range of HRs	Net Present value average over five subsequent years	**Target:** Range of MEY ± 1%	If projected to be within Target range, no management action is required. If projected to be > Target range, reduce TACC If projected to be < Target range, increase TACC unless justified for other reasons (e.g. market issues)	No tolerance is allowed as the uncertainty is provided by using the 75% confidence level of the subsequent five years

7.3 External Influences

External influences include other activities and factors that occur within the aquatic environment that may or may not impact on the productivity and sustainability of fisheries resources and their ecosystems. The main external influences included here are environmental and market related.

7.3.1 Environmental Factors

There are a variety of environmental impacts on the biology of *P. cygnus*. These include but are not limited to spawning timing and size at maturity (Section 5.1.3.6), growth (Section 5.1.3.4) and recruitment (Section 5.1.3.1). These impacts are discussed in the relevant sections.

7.3.1.1 Climate Change

Two FRDC research projects, conducted by Department of Fisheries, have been completed; 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 was 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 Caputi et al. 2014).

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 (Caputi et al. 2015). 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).

Most of the impacts associated with climate change, particularly those associated with increasing water temperatures are addressed in the associated biological sections (e.g. Reproduction (Section 5.1.3.6) and Growth (Section 5.1.3.4)).

7.3.2 Market Influences

The products from the WCRLMF are currently mainly exported live to China. With the fishery now under a quota system, fishers are highly influenced by the market, with market preferences translated into differential beach prices for different grades of lobster, resulting in targeting of specific grades by fishers to maximise their profitability. Due to the inherent nature of an export market, there are considerable external economic considerations which can influence the fishery such as the value of the Australian dollar, Chinese demand and border access.

8 Information and Monitoring

8.1 Range of Information

There is a range of information available to support the assessment and harvest strategy for western rock lobster in the West Coast Rock Lobster Fishery (see Table 8-1).

8.2 Monitoring

The collection of data from the all components assessing the stock is comprehensive. Catch and effort data as well as a range of ancillary data is mandatorily reported by all commercial fishers at a fine spatial scale for each trip (Section 8.2.1.1). The composition (demography) of this catch is also well understood through on-board commercial monitoring (Section 8.2.3.1). These catch rates and demography measures are also assessed independently to account for any efficiency changes through an Independent Breeding Stock Survey (IBSS) which covers the extent of the grounds of the fishery in the deep water breeding areas (Section 8.2.4.2). Finally, with regard to the biological components of the fishery, there is a good understanding of the recruitment levels which are likely to enter the fishery (Section 8.2.4.1). This provides a 3-4 year indication of future catch levels that allows management actions to be implemented prior to any variations from average levels of recruitment.

The other major sector accessing the western rock lobster resource is the recreational sector (Section 8.2.2). The licencing of this sector allows an understanding of the number of people who access the resource, with a number of monitoring programs aimed specifically at better understanding the composition and magnitude of the catch. It should be noted, that while these data sets are not as comprehensive as for the commercial sector, under IFM (Section 6.1) the recreational component is relatively small (<5%), resulting in a very comprehensive understanding of the vast majority of lobster removals.

In addition to the coverage of extractive use, there are also monitoring programs which provide information on the environmental and economic impacts which affect the fishery (Sections 8.2.5 and 8.2.6).

Table 8-1. Summary of information available for assessing the West Coast Rock Lobster Fishery

Data type	Fishery-dependent / independent	Purpose / Use	Area of collection	Frequency of collection	History of collection
Commercial catch and effort statistics (CAES returns)	Dependent	Monitoring of commercial catch and effort trends, calculation of catch rates and the area fished	CAES 1^o x 1^o block	Monthly	1964 - 2011
RLQMS	Dependent	Monitoring of commercial catch and effort trends, calculation of catch rates and the area fished	10' x 10' blocks	Daily	2011 - 2013
Catch Disposal Records (CDRs)	Dependent	Monitoring of commercial catch and effort trends, calculation of catch rates and the area fished	10' x 10' blocks	Daily	Since 2013
Volunteer log books	Dependent	Monitoring of commercial catch and effort trends, calculation of catch rates and the area fished	10' x 60' blocks	Daily	1971 - 2015
Processor unloads	Dependent	Validation of catch returns Size composition of the catch	Fishery wide	Monthly	Since 1964
Processor unloads	Dependent	Validation of catch returns	By fisher	Daily	Since 2011
Recreational catch and effort estimates	Dependent	Monitoring of recreational catch and effort trends	Fishery wide	Annual – mail survey	Since 1986
Charter catch and effort statistics	Dependent	Monitoring of charter catch and effort trends	5' x 5' blocks	Daily	Since 2002
Biological data (size, maturity)	Dependent	Size composition and reproductive parameters for Stock Assessment Model	5 sites	Monthly	Since 1971
Recruitment survey data (Puerulus)	Independent	Puerulus settlement rates used to predict catches in 3-4 years	9 sites	Monthly	Since 1968
Spawning stock survey data (IBSS)	Independent	Catch rates provide an index of spawning stock abundance. Also provides information on sex ratios and the reproductive stage of females	4 - 6 sites	Annually	Since 1992

8.2.1 Commercial Catch and Effort

8.2.1.1 Catch and Effort Returns

Commercial catch and effort information were only sporadically collected prior to 1941, when the Chief Inspector instigated a fishery statistics collection system based on 1^o latitude and longitude blocks to record fishing effort and catch. In 1949 a separate cray-fisherman return was introduced to provide more information on the fishery, including gear used and the weight of the catch. This system was used until 1964, when a standardised Commonwealth statistic collection system was introduced by the Commonwealth Bureau of Census and Statistics (ABS). Since 1992, all aspects of reporting and the Catch and Effort Statistics (CAES) database have been the responsibility of the Department of Fisheries.

For seasons up to and including 2009/10, catch and effort returns from fishers were received monthly, with a deadline of 15 days after the end of the month. Fishers who were in arrears with their returns were contacted every month by the CAE returns officer, requesting their return. Once a year, a written reminder is sent to fishers that it is a licensing requirement to provide a return. By the end of the financial year, the annual return rate was approximately 98%. With the move from input to output management in 2010/11 fishers have been required to return a trip specific Catch Disposal Record (CDR) every time they land a commercial catch. This is rigorously enforced, with a 100% return rate; fishers cannot resume fishing unless their last CDR has been submitted. As well as the increased temporal resolution of catch and effort data (from monthly to by-trip), spatial resolution also increased with the 1^o x 1^o blocks replaced by 10 minute by 10 minute blocks.

Each month, processors of western rock lobster must complete forms for the Department as part of their licensing requirements. The collated information provides the most accurate measure of the total catch of the fishery. Under the quota system, processors are also required to provide CDR returns stating the weight of the catch. The higher of this weight or the weight from the fishers' CDRs is used to determine the weight of the catch for that fisher on that trip.

The data collected in the CAES and CDR returns are vetted upon receipt. After data entry is completed, data are compared to processors' returns and to details from the Fisheries Licensing system. This includes looking at irregularities in the number of days fished (if greater than is allowed), incorrect block numbers (fishing in a block outside the zone they are licensed for) and unrealistic records (e.g. extremely high catch rates). When catches do not match that provided by lobster processors, both datasets are interrogated and often the fisher is contacted by phone to determine the inconsistencies and correct where necessary. This provides a comprehensive, and largely accurate, database as a baseline for comparing data between blocks, zones and seasons.

8.2.1.1.1 Analysis

Commercial catch rates of western rock lobster in the WCRLMF are derived from CAES, RLQMS and CDRs, depending on the recorded system at the time (see above). When the fishery was under input management the raw catch rates were a good relative measure for stock density. Since the implementation of quota in 2010 and the development of split-pricing for lobsters of different quality and grade, fishers have started to change their fishing behaviour and raw catch rates are no longer comparable between input and quota fishing periods. The main changes in fisher's behaviour have been the increase in high-grading (returning lower value legal lobsters to the water), the fishing of areas to target certain lobsters and the fishing at specific times in response to market prices. To develop a temporally and spatially comparative index of catch rates the raw catch rates are now standardised for year, month, latitude and depth of fishing as well as high-grading. The model used is:

$$\log(U+1) = Y + M + Z + D + H + Y*Z + D*Z + M*Z ,$$

where the catch rate (*U*; kg pot-lift^{-1}) is a function of month (*M*), management zone (*Z*), depth (*D*) and high-grading (*H*).

The standardised catch rate should only be used as an indicative proxy for biomass as, even though it has been standardised for a range of factors, other factors such as variable catchability between years/lobster densities and between lobster sizes/sexes are not standardised against and can also impact this measure. Furthermore, the standardised catch rates have not been adjusted for efficiency creep, which was a significant factor when the fishery was under input controls. It is assumed that under quota management, efficiency creep is less of a concern since the drive to increase efficiency in catch rates has become less of a focus as many fishers aim rather to increase their economic efficiency (e.g. bait usage has declined under quota, whilst fishing two-pots off one float line has increased).

8.2.1.2 Processor Returns

Processing factories deal with almost 100% of the commercial catch landed, with only occasional small domestic sales. Traditionally, at times of low prices and high catches around Easter and Christmas (E. Barker pers. comm.) large sales are made throughout Australia, primarily to large supermarket chains. However, with a shift to quota management, the restricted landings have resulted in an increase beach price for lobsters and a smoothing of the catch throughout the year. As a result, the vast majority of the landed product is exported, primarily to China. Five companies deal with the export (unrestricted) processing of WRL.

There are different reporting requirements for the processor licence holders. Unrestricted processors are required to fill out a monthly return log, CDR and monthly breakdown of product lines (e.g. green tails, whole cooked, whole green and live) by grade (A – H) (Table 8-2) and market (export or local). Restricted processors (domestic sales only) are required to submit only a monthly return log and a CDR.

Table 8-2 Processor grades for *P. cygnus* showing the weight and carapace length (CL) ranges.

Lobster Grade	Tail Weight (g)	Female CL (mm)	Male CL (mm)
A	140–179	76–77	76–79
B	180–239	78–85	80–88
C	240–279	86–90	89–94
D	280–359	91–98	95–103
E	360–479	99–108	104–115
F	480–599	109–117	116–126
G	600–667	118–121	127–131
H	668 +	122 +	132 +

8.2.1.3 Volunteer Research Logbooks

Fisheries Research Log books were issued to about 60% of commercial fishers each year, from 1963 until 2011. Returns from fishers varies between years, but generally between 30 – 40% of fishers completed the log book. With a move to quota management, the increase resolution of the catch return (CDR) and its mandatory reporting greatly increased the information available on fishing activities. There remained a voluntary research section on the CDR to record discard rates. From the 2016 season, the level of high grading was made compulsory and all other voluntary reporting removed and estimated through other monitoring programs.

8.2.2 Recreational / Charter Catch and Effort

Mail and telephone-diary surveys

As recreational fishing for western rock lobster occurs over large spatial and temporal scales, the most cost-effective survey method historically was mail surveys (Melville-Smith and Anderton 2000). Mail surveys have been undertaken on an annual basis since the close of the 1986/87 season, totalling 29 surveys inclusive of 2014/15. Survey respondents are asked to recall effort (in days) and retained catch (in numbers) by fishing method (potting, diving and other) for the previous season. Approximately 10% of licence holders are randomly selected at the end of the fishing season and sent a written questionnaire (Thomson 2013) with a reply paid envelope, and a follow-up reminder is sent a month later. Both the fishery-specific and umbrella licence holders were included in the sampling frame from 1986 to 2010 when the umbrella licence was available (de Lestang *et al.* 2014). The annual response rates have ranged from 40 to 60% and non-response includes refusals, non-contacts and sample loss, which is unknown because incorrect contact details may or may not be identified as 'return to sender'. Mail surveys are also prone to non-response bias where non-respondents are more likely to have not fished and recall bias where respondents cannot recall exact details of their fishing activity.

Supplementary longitudinal, phone-diary surveys of WRL recreational fishers to assess the accuracy of estimates from the mail survey have been conducted in 2000/01, 2001/02, and annually from 2004/05–2008/09. For each survey, approximately 500 licence holders were randomly selected from the licence database, with stratification by licence type (western rock lobster or umbrella) and fisher residence (Perth metropolitan or country) (Baharthah 2007). These phone-diary surveys are considered to provide less biased estimates because response rates are generally greater than 90% and recall periods are minimised by sending fishers a personal fishing diary and maintaining regular contact throughout the fishing season.

Unadjusted estimates of recreational catch from the mail survey were more than double the estimates from the phone-diary surveys during the same time frame (Thomson 2013). Raw data from the mail survey is expanded to the total population of licence holders, adjusted for bias by multiplying the raw estimate from the mail survey with a correction factor to improve the accuracy. As these surveys estimate total catch by numbers, an average weight of 0.5 kg has been used to estimate total catch by weight (Melville-Smith and Anderton 2000). Current work is examining the appropriateness of using a constant value of 0.5 kg.

8.2.3 Fishery-Dependent Monitoring

8.2.3.1 Commercial Catch Monitoring

On-board monitoring of commercial catches by Department of Fisheries staff was initiated in 1971. Members of the Research Division make regular and detailed records of the target catch (retained and returned to the sea) and by-catch landings, as well as environmental conditions and fishing activities. This program provides vital information on a broad temporal and spatial scale on the abundance of juvenile (undersize) and spawning stocks and on size at maturity.

Monitoring has occurred every month throughout the fishing season (traditionally: November–June, currently: year-round) in Dongara, Jurien, Lancelin and Fremantle since 1971, and in Kalbarri and the Abrolhos Islands since 1985. Opportunistic monitoring also occurs in other localities, such as Mandurah and the Capes region (Figure 8-1). At each locality, monitoring is conducted only on-board vessels fishing within 15 nautical miles north or south of the target port.

During each month, at each site, monitoring is spread across four depth categories: < 18, 18 – 36, 36 – 54 and > 54 m (i.e. < 10, 10 – 20, 20 – 30 and > 30 fathoms). A minimum sample of 300 individuals is sought in each depth range. In some location–depth combinations in some months, there was no sampling because vessels did not fish in that depth-range due to either poor catches or weather conditions.

Information is recorded on each lobster: carapace length to the nearest 1 mm, sex, breeding condition and colour (migratory white or sedentary red). Information is also collected on the skipper and crew, the fishing vessel, fishing techniques and interactions with non-target species (see Bellchambers et al. in press for specifics).

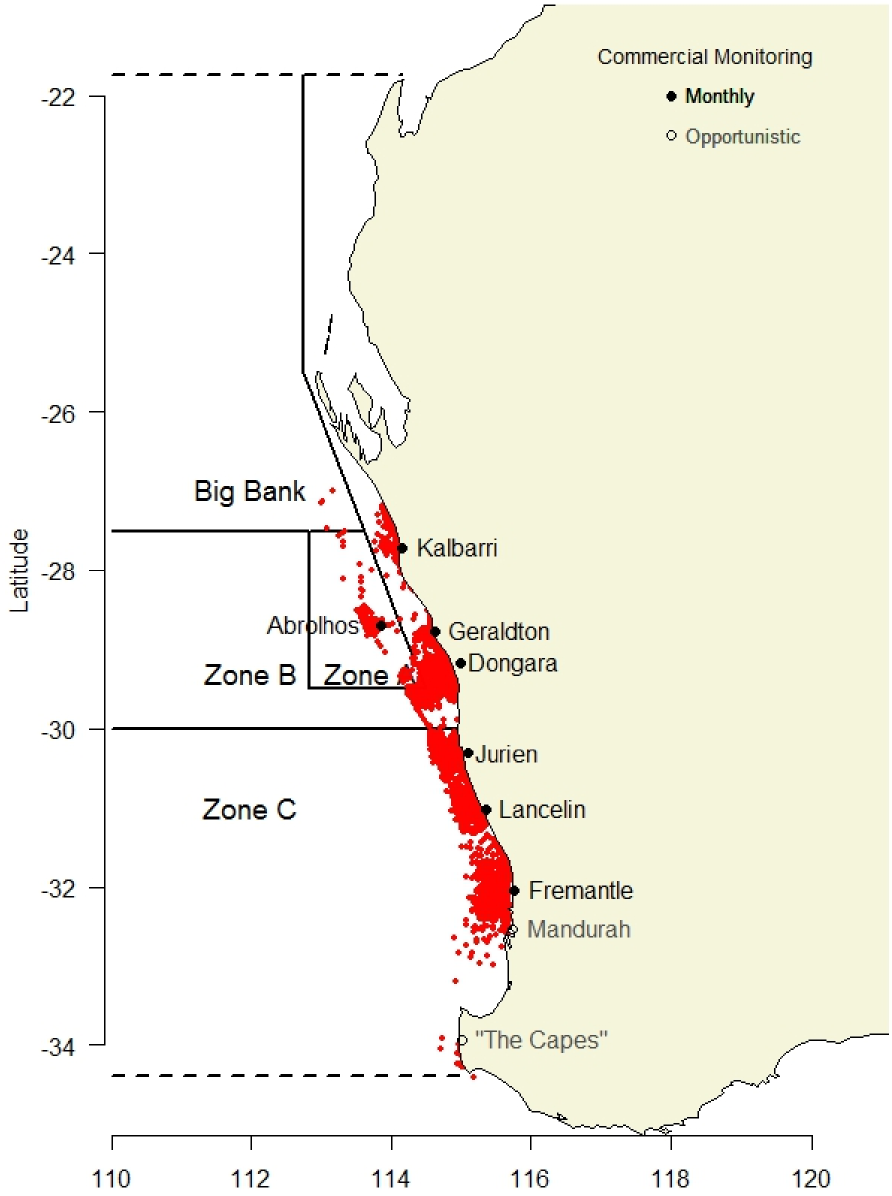

Figure 8-1 Locations of commercial catch-monitoring sites

8.2.3.2 Meshed Pot Surveys

Since 2007, a number of commercial fishers have fished, as part of their normal operations, a pot modified to catch small lobsters. This project was initiated to monitor the abundance and size composition of undersize lobster cohorts in shallow (≤20 fm) and deep-water (>20 fm) regions of the fishery. Since its inception it has provided additional valuable datasets for the assessment of the fishery including for growth analysis (Section 5.1.3.4).

Commercial fishers were approached to fish an additional pot to their normal unit entitlement, which was modified to increase the catch rates of smaller lobsters. They are asked to provide data on the catch of this pot, and since the 2009/10 season, an additional non-modified commercial pot adjacent to the meshed pot. Incentives for participation in the survey were initially the ability to retain the catch from an additional pot, which was outside of their normal pot entitlement under an input controlled fishery. With the advent of catch limits for the 2010/11 season, incentives moved to supplying fishers with two boxes of bait per month.

Data is similar to that collected as part of the commercial monitoring program (Section 8.2.3.1), with each pot recording the number of lobsters in each 1 mm size category for all combinations of red or white and male or female. Red females are further categorised as berried, tar-spotted or setose. Datasheets also record boat name and registration, date, position (latitude and longitude), depth, evidence of octopus as well as noting if it is the open or closed (meshed) pot.

8.2.3.2.1 Results

The program has resulted in almost 95,000 lobsters measured from over 5,400 potlifts throughout the fishery (Figure 8-1). Recorded lobsters have ranged in size from 16 – 158 mm CL. The meshed pot has consistently produced better catches for the undersize component of the population than the open pot, with both pots having a similar representation of the legal component (Figure 8-3).

The initial intent of the program was to examine the size composition of lobsters from different depth categories to examine the likelihood of deep-water settlement. All the data collected indicates that the bulk of the settlement occurs in the shallow water (<20 fathoms). While small lobsters (below the size at migration (Section 5.1.3.3.1) were captured in deeper water (>20 fathoms), the undersize component of the lobster population is greatest in the 0-10 fathom depth range (Figure 8-4).

The dataset while providing distribution of small lobsters as it was additionally designed to also provide another valuable monitoring tool to examine the composition of the stock not normally captured in the commercial monitoring programs (Section 8.2.3.1). Examination of the composition of meshed pots catches from the shallows through seasons has permitted an examination of the impacts of the low puerulus settlement on the stock as it recruits to the fishery. The low puerulus recruitment (Section 8.2.4.1) which occurred in 2007/08 and 2008/09 is evident in the catch composition from 2009/10 and 2010/11, with very few juvenile (<65 mm CL) lobster captured (Figure 8-5). There was an increase in the abundance of juvenile lobsters during the extended 2011/13, which resulted from the improved settlement in 2010/11 (Figure 8-5). The low number of juvenile lobster in the most recent season is reflective of the small number of samples which have occurred recently.

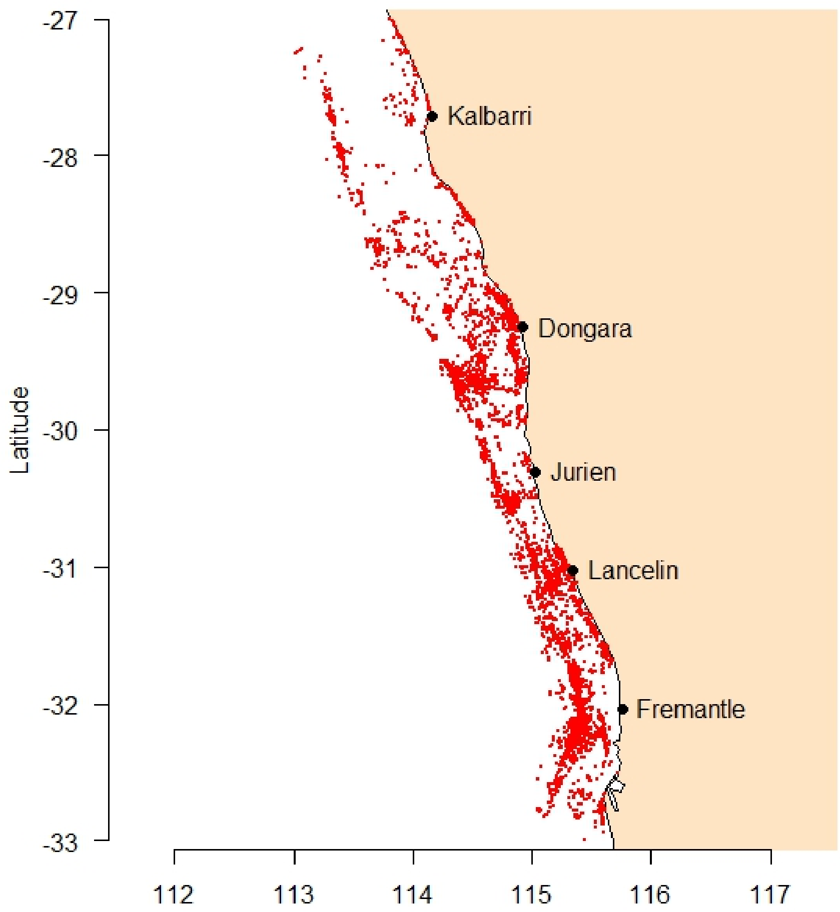

Figure 8-2 Location of meshed pot potlifts from 2007/08 season to current (2015)

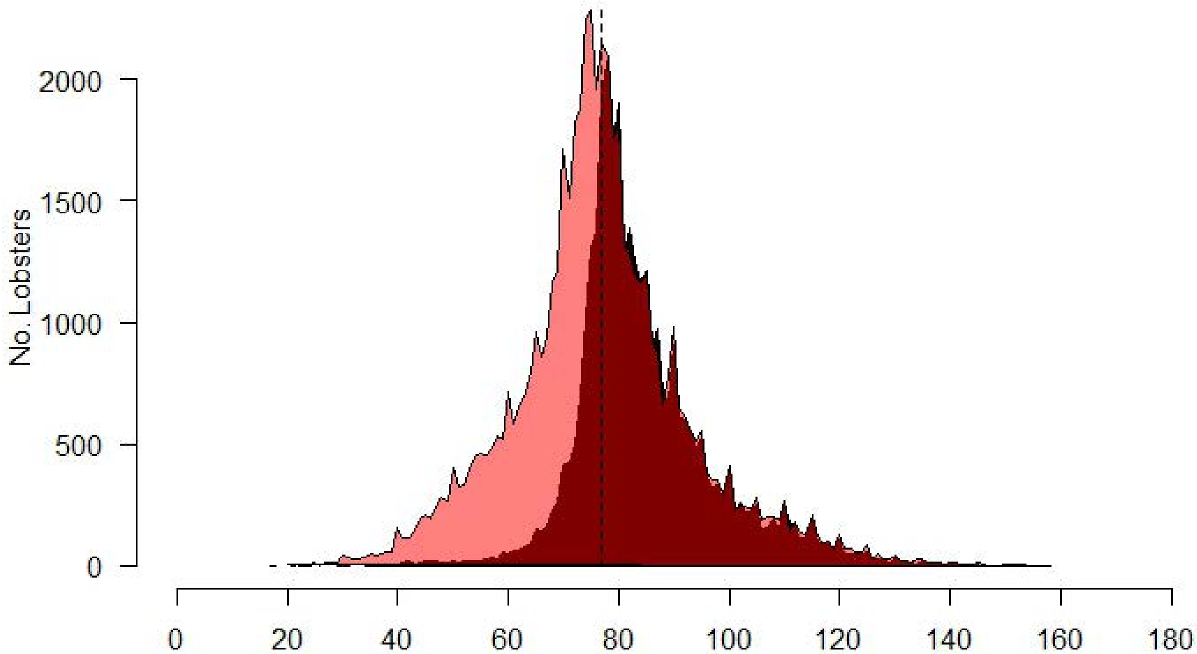

Figure 8-3 Length frequency for all lobsters captured in meshed (red) and open (dark red) pots from 2007 to current (2015).

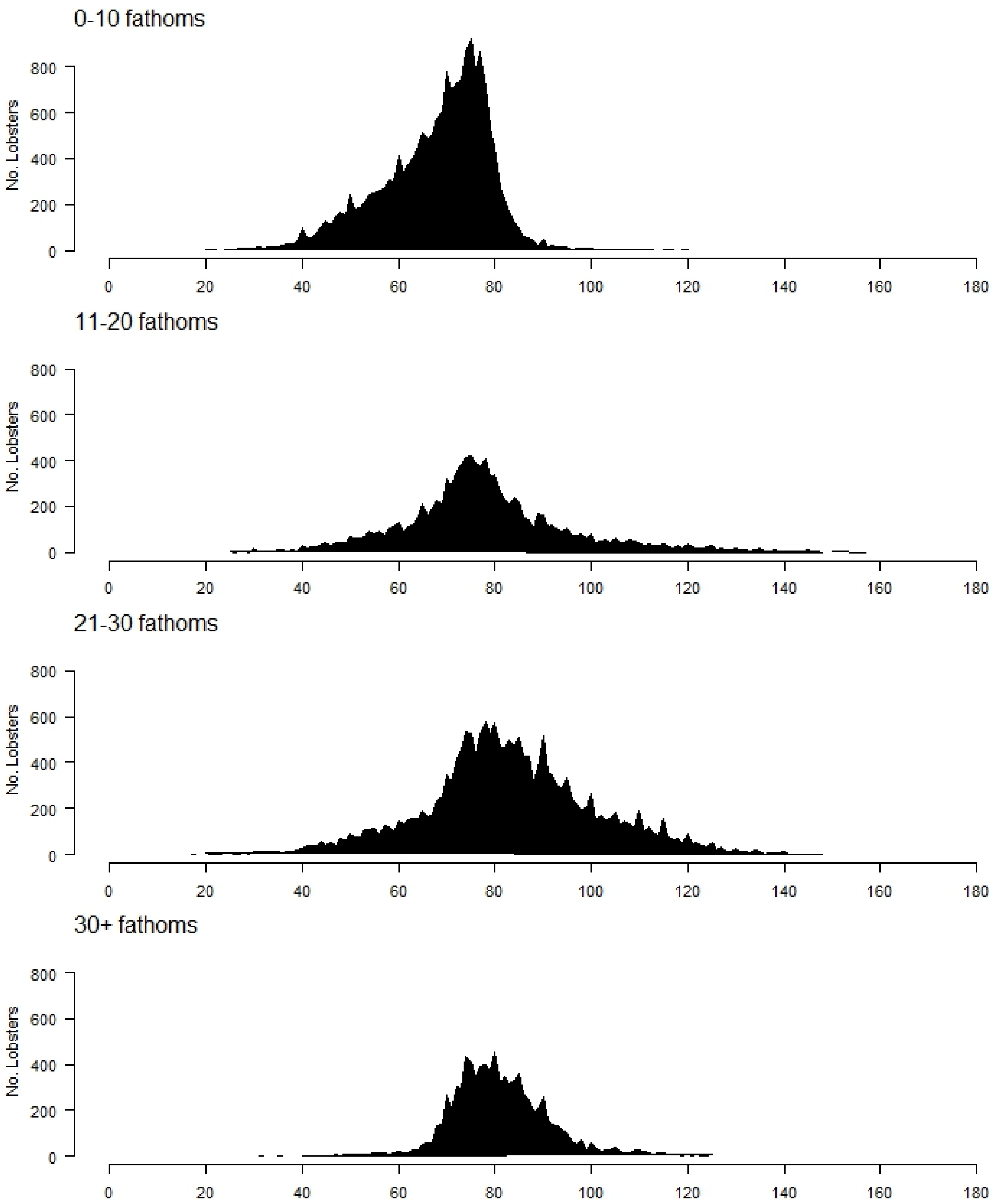

Figure 8-4 Number of lobsters from the mesh potting program by 10 fathom water depth categories

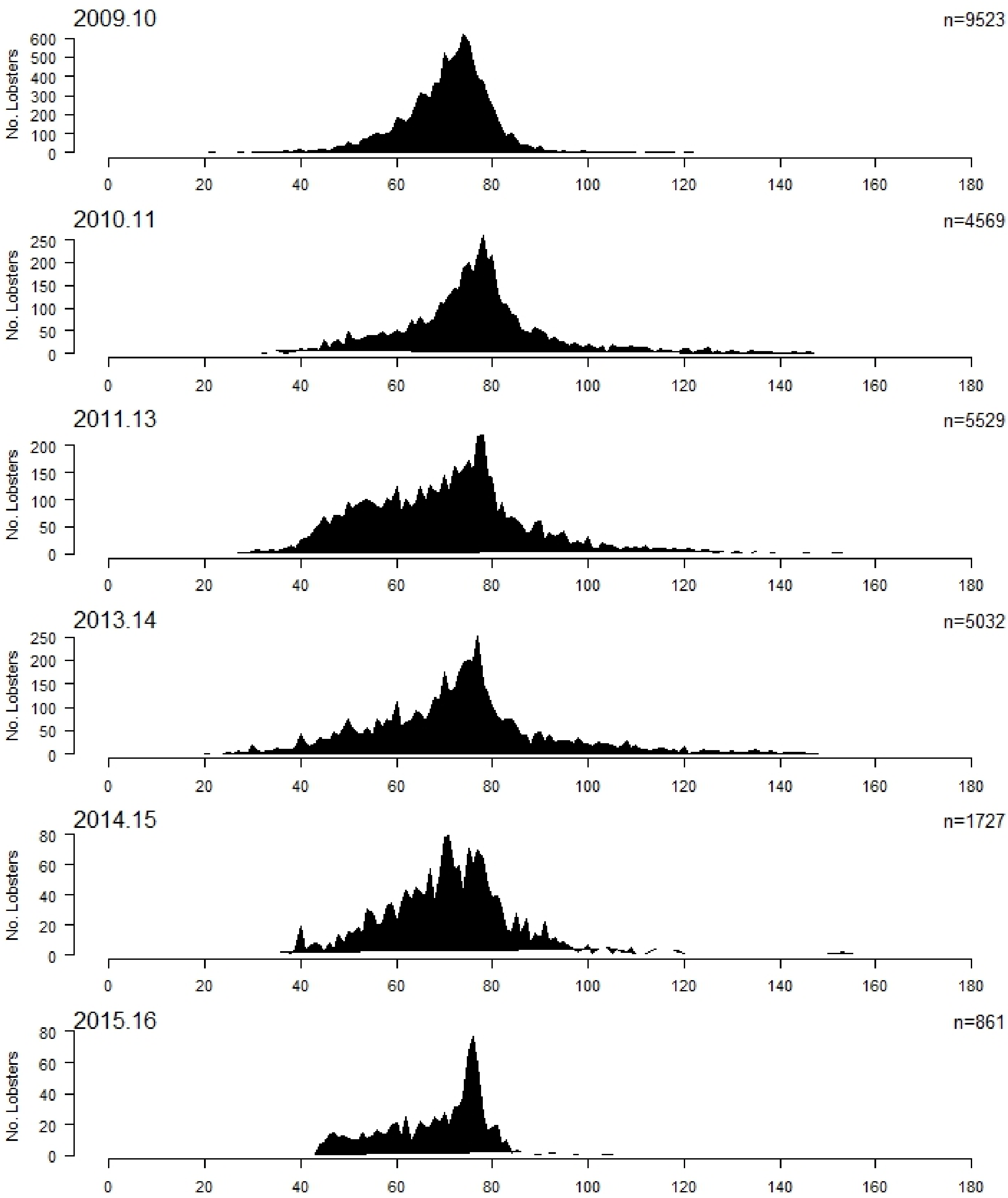

Figure 8-5 Catches of the lobsters from meshed pots in shallow water (<20 fathoms) by season. Numbers of lobster measured in each season is shown top left of each graph

8.2.4 Fishery-Independent Monitoring

8.2.4.1 Puerulus Surveys

The puerulus stage of *P. cygnus* settles naturally in nearshore seagrass areas and are commonly found on reef structures with attached seagrass. This behaviour is exploited by artificial collectors, which mimic this habitat and thus provide a mechanism for measuring relative settlement rates of puerulus throughout the fishery. Annual puerulus settlement data are used to predict future catches throughout this fishery.

The first collectors were deployed in near-shore shallow waters (<5 m) in 1968 and 1969 at Seven Mile Beach (north of Dongara), and Jurien Bay and Garden Island, as part of a CSIRO study. The first two of these sites have been monitored on a continual basis since then, with additional sites being added and removed over the years (Table 8-3 and Figure 8-6)

Table 8-3 Location of historical and current puerulus collector sites and the number of collectors at each site. Current (2015) collector sites are denoted by bold type.

Site	Initiated	Collectors (n)	Status
Abrolhos Is. (Rat Is.)	**1971**	**5**	**1971–1978; 1984 to current**
Alkimos	**1982**	**5**	**Current**
Cape Mentelle	**1984**	**5**	**Current**
Cervantes	1984	5	Stopped in 1992
Coral Bay	**2009**	**5**	**Current**
Cowaramup	2005	2	Stopped in 2008
Dongara (Seven Mile)	**1968**	**6**	**Current**
Dunsborough	1984	5	Stopped in 1985
Garden Island	1969	4	Stopped in 1984
Horrocks	1984	5	Stopped in 1991
Jurien Bay	**1969**	**5**	**Current**
Marmion	1984	6	Stopped in 1992
Lancelin	**1990**	**5**	**Current**
Point Quobba	2006	5	Stopped in 2009
Port Gregory	**1995**	**5**	**Current**
Shark Bay	1984	5	Stopped in 2004
Warnbro Sound	**1984**	**6**	**Current**

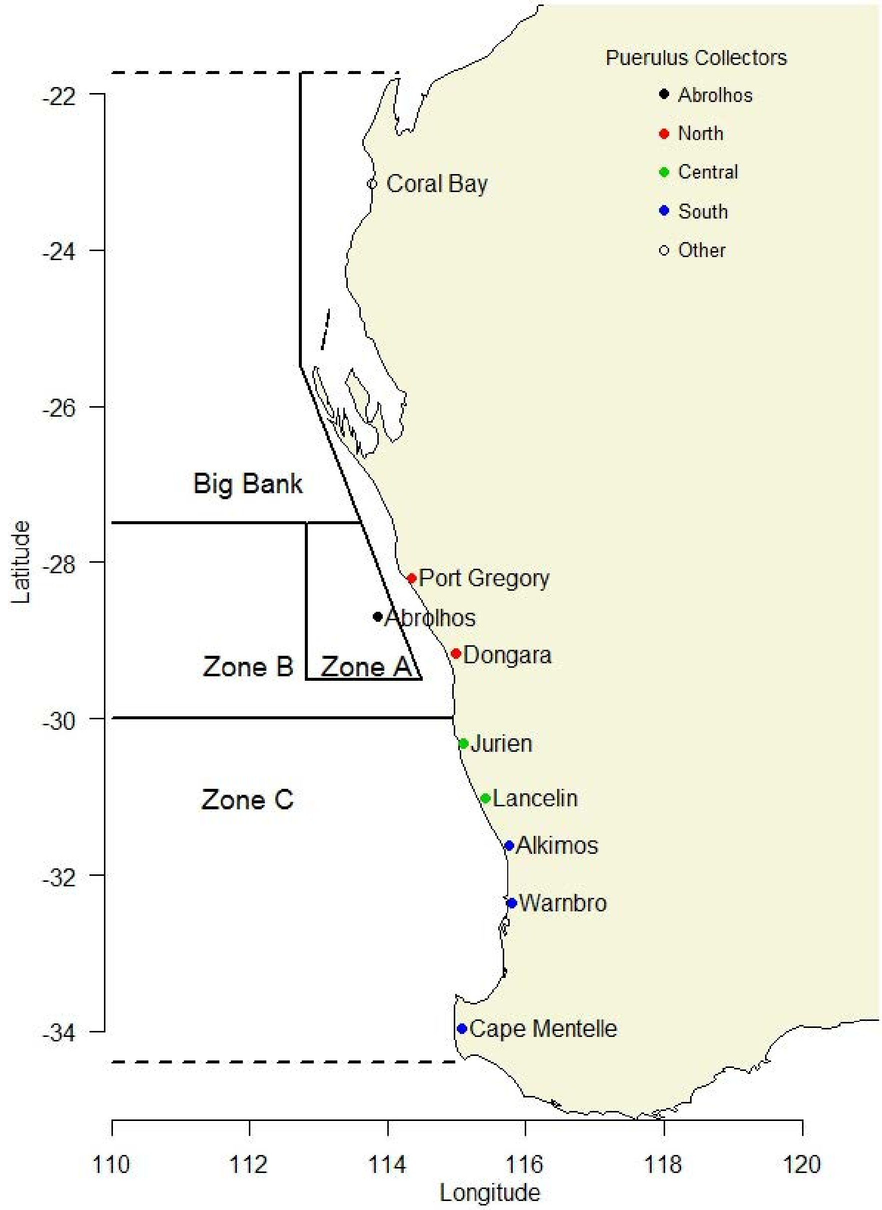

Figure 8-6 Location of current (2015) puerulus collector sites coloured according to the region they represent (see Figure 9-8)

The original puerulus collectors consisted of three panels, each with Tanikalon tassels and a brown mesh-backing sheet (synthetic fibre) (Phillips 1972). These three panels were affixed to a stainless steel frame with two 20 cm floats in the centre and two 20 cm floats on the top of a central pole. The frame and tassels were moored to the seabed by a stainless steel chain and anchored to a large concrete block (Figure 8-7a).

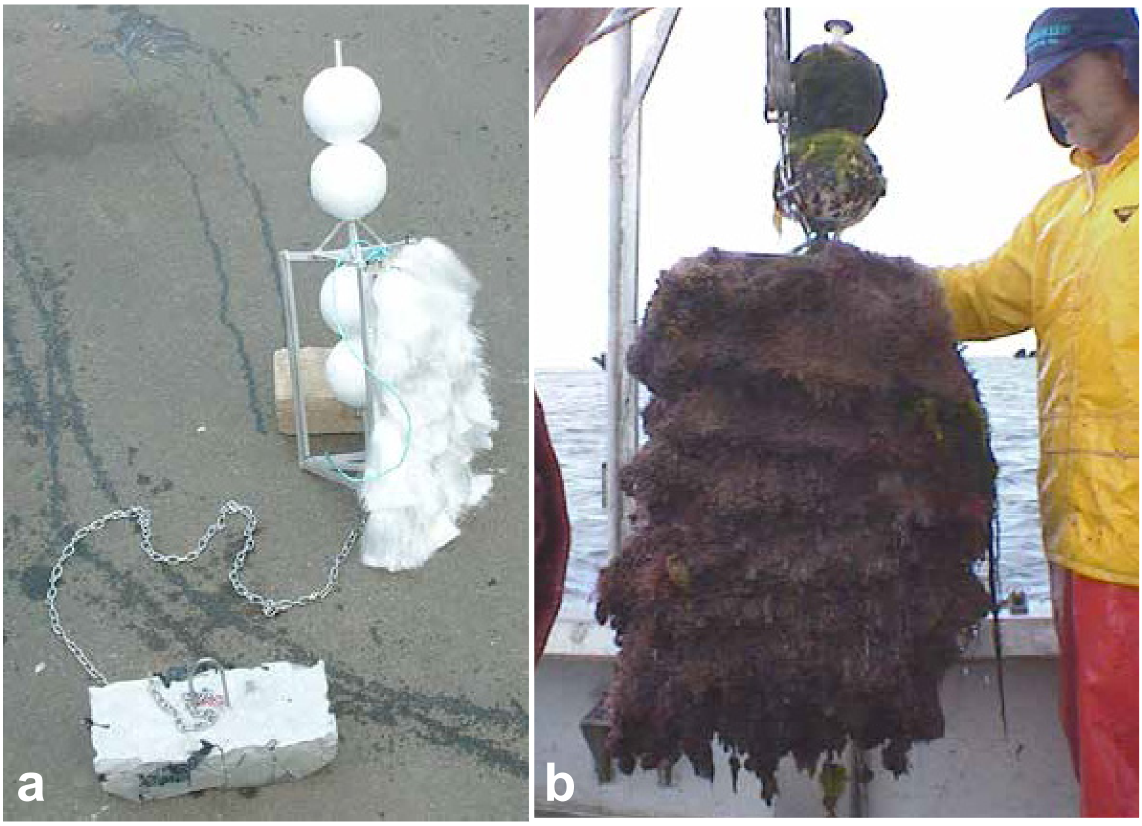

Figure 8-7 Puerulus collectors a) design with two panels removed to show internal construction and, b) retrieved from site before being "banged"

The manufacture of Tanikalon stopped during the late 1980s and a replacement fibre had to be sourced and its efficiency for collecting puerulus compared to that of Tanikalon. The replacement fibre chosen is produced by Boral Kinnears (subsequently referred to as BK). From 1992 – 2006, collectors containing either Tanikalon or BK were deployed in nearby "tandem" locations at the Rat Island, Seven Mile Beach and Jurien Bay sites to compare the fibre types. As of 2007, BK fibre has replaced Tanikalon in all collectors used for catch prediction. The material used on the backing sheets, which originally was a brown material glued onto the external side of the plastic backing sheets to provide additional surfaces for puerulus to cling to, also stopped being manufactured during the early 1990s, and a replacement for this also had to be sourced.

To further examine the catchability differences between the two tassel types and various backing materials, additional studies were developed, one at Lancelin and another at Seven Mile Beach. At Lancelin, three puerulus collectors were deployed in October 2004. The three panels on each collector contained different backing materials, one sheet using the traditional brown material, a second sheet using the new white material and the third sheet having no backing material. Analysis of these data indicate that the puerulus catches on sheets with BK fibre tassels and no backing are not significantly different ($p > 0.05$) from those backed with the traditional brown backing. Catches produced by sheets covered with the new white material were significantly lower ($p < 0.001$) than the other two treatments.

The second study, set up at Seven Mile Beach in July 2005, focused on both tassel types and backing material. Six Phillips collectors were set in pairs of two (making three groups). Of the six collectors, two were entirely fitted with Tanikalon fibres and brown backing, two with BK fibres and brown backing, and the final two with BK fibres and no backing material. Each month the position of each collector was randomly re-assigned to one of these six locations to provide multiple pair-wise comparisons between different collectors with different fibres in different locations. Analyses of these data indicate that tassel type ($p < 0.001$) and not backing material ($p > 0.05$) (traditional brown or no backing) significantly affects puerulus settlement rates. A conversion rate determined from this analysis suggests that Tanikalon is ~ 18% more efficient than BK. This data set is preliminary and this conversion factor may change with the addition of additional data.

Collectors are sampled every full moon period (five days either side of the full moon) of the settlement season, which runs from May to the following April. During each sample, the collectors are removed from the water onto a boat, where each of the three sheets is removed one at a time and placed face down in a rack for shaking over a collection tray. The aluminium shaker frame is slid over the P.V.C. backing board and, holding the shaker by the handles, the operators give 20 "shakes" before being placed on the deck, fibre side down (Figure 8-8). The contents of the shaking tray are poured through a sieve, before the sheet is shaken another 10 times over the tray. If any more pueruli appear in the tray after the second set of shaking, then the panel is given another ten shakes until no further pueruli appear. The sheet is then removed from the frame and the process repeated for the remaining two sheets.

Figure 8-8 Collection of puerulus from collectors by a) shaking puerulus collector and b) sieving contents

After all three sheets have been shaken, the number of puerulus and post-puerulus (similar in size to puerulus but pigmented) are counted. Any specimens that are substantially larger than post-puerulus, and may not have been shaken out during the previous collection, are counted and clearly identified as having settled in the previous month. Puerulus that are returned to the water are released at some distance from the collectors to prevent contaminating the data.

Once all three panels have been shaken, the collector is reassembled, cleaned of marine growth and checked for wear and tear. All maintenance on each collector, such as replacement of sheets, is also recorded. Department of Fisheries staff currently services the collectors from Warnbro Sound to Port Gregory, with the collectors at Cape Mentelle serviced by local contractors, with staff from the Department of Environment and Conservation assisting in servicing the collectors at Coral Bay.

At each site, the surface water temperatures at the southern and northern ends of the collectors for that site are measured, and salinity is recorded. One collector at each site is also fitted with an archival data storage logger that records the water temperature every hour. It is replaced with a new logger every second month.

8.2.4.1.1 Analysis

Puerulus settlement indices in each management zone are based on one or more puerulus collection sites (Table 8-4). The settlement index for each collector site is each full moon period's average number of puerulus sampled per collector, summed over the settlement season (May to the following April). These indices are standardized to having been sampled by Boral-Kinnear collectors by multiplying puerulus averages from Tanikalon collectors by 0.759. When settlement index uses data from more than one puerulus location, a least-squares mean estimate (Russel, 2016), standardised for location, is determined by GLM with location, season and month as factors. If a location was not serviced for a month(s), usually due to bad weather, settlement is estimated from the proportion that month contributes on average to the overall season. This proportion is determined for each location by using a GLM to model that locations monthly settlement overtime, in terms of the main effects of season and month. Using this model, seasonally standardized monthly effects were extracted and from these, the average contribution of each month to that locations annual puerulus index could be measured. If for a particular season, a group of "missing" months would normally contribute x%, then the sum of the "non-missing" collection of observed months was multiplied by a factor of 100/(1 - x). At some locations, additional collectors have been added over the years for various reasons. To maintain the consistency over time of the indices produced from these sites use only the original collectors (see Table 8-4).

Table 8-4 Sites and numbers of collectors used to calculate puerulus settlement indices for the three management zones.

Site	Collectors Used
Port Gregory	All (1–5)
Rat Island	1–4 (not 5)
Seven Mile Beach	All (1–6)
Jurien Bay	1–5 (not 6)
Lancelin	All (1–5)
Alkimos	All (1–5)
Warnbro Sound	All (1–5)

8.2.4.1.2 Results

Since 2007 there has been a significant shift in the magnitude of puerulus settlement, as well as temporal and spatial trends in puerulus settlement (Figure 8-9 - Figure 8-11). The causes of these are related to changes in water temperature affecting the timing of spawning and the ultimate success of recruitment back to the coast. For more details see Section 5.1.3.8.

Temporal trends in puerulus settlement

The puerulus settlement season runs from May to April the following year, with peak settlement historically in late winter to spring for coastal locations (Figure 8-9). Prior to 2007, coastal locations such as Dongara and Lancelin's peak settlement occurred in September and October, although Lancelin seemed to have a plateau of settlement from August through to December (Figure 8-9). Settlement at the offshore Abrolhos Islands occurs later, peaking in December.

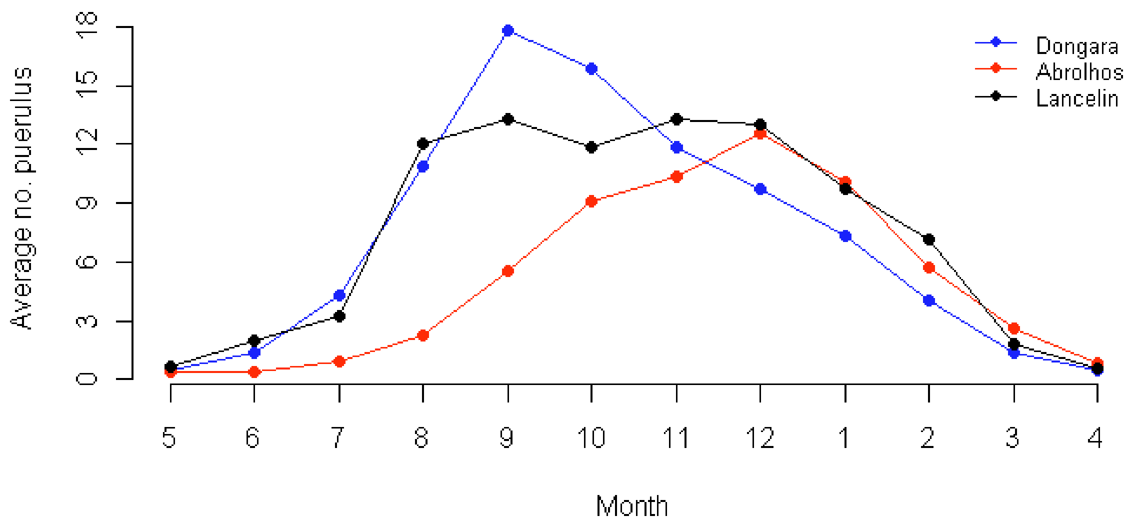

Figure 8-9 Average long-term (per 2007) puerulus settlement by month for sites in the northern (Dongara), southern (Lancelin) and offshore (Abrolhos Islands) zones of the WRL fishery.

Coincident with the reduction in puerulus settlement which began in 2007, there has been a change in the timing of puerulus settlement. As a likely result of the later timing of spawning (Figure 8-15), the initial part of the settlement season (August – October) is considerably reduced compared with the historic pattern (Figure 8-10). The later portion of the settlement season appears to return to this historically pattern, though there are recent examples of higher than average settlements in these later months (Figure 8-10).

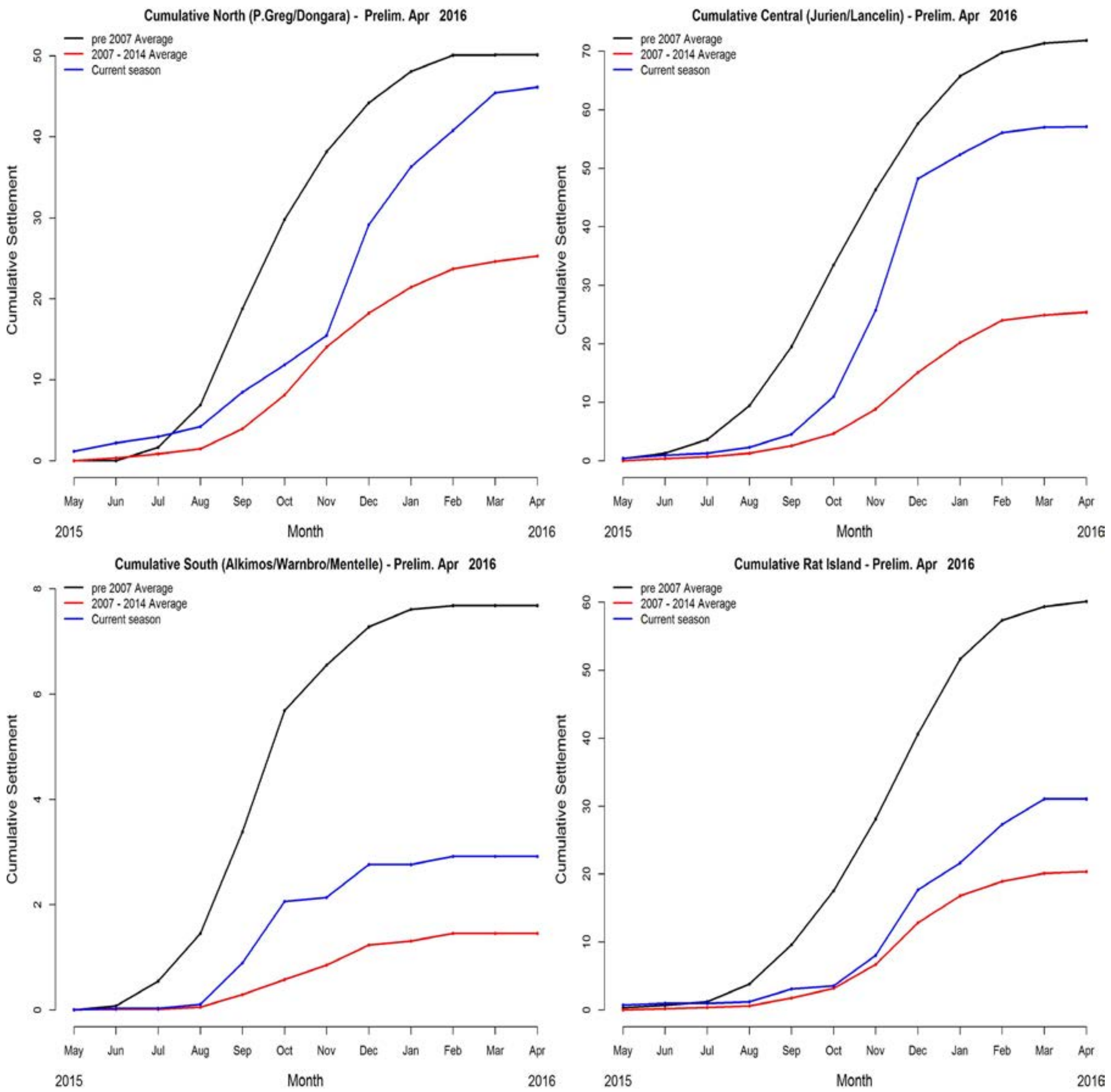

Figure 8-10 Historic (black) and recent (red) averages in cumulative puerulus settlement with the current (2015) season (blues) for the four settlement regions**.**

Spatial trends in puerulus settlement

The timing, spatial location and magnitude of puerulus settlement varies between years, presumably in response to environmental drivers. Prior to 2007 settlement, the water temperatures in February proceeding the settlement season in a block offshore of the coast, which was in the larval pool, combined with the intensity of winter storms crossing the coast and the strength of the Leeuwin Current, correlated very well with variations in puerulus settlement (Caputi et al. 1995b). In years of water temperatures, frequent winter storms and a strong flowing Leeuwin Current, puerulus catches were greater and they occurred slightly earlier and slightly further south. This relationship however broke down in 2007.

With the change to puerulus settlement, the mean latitude of settlement has also changed. The strength of the Leeuwin Current between June and September has also been shown to affect the spatial distribution of puerulus settlement, with the mean latitude of puerulus settlement occurring further south in years of strong Leeuwin Current as indicated by a higher mean sea level in Fremantle (FSL, which has been de-trended to remove the long-term increase in FSL; Caputi et al. 2001 and Caputi 2008). Recently the mean latitude of settlement has maintained the same relationship of lower latitudes of settlement following strong Leeuwin Currents. However, this pattern has shifted north by approximately half a degree (Figure 8-11).

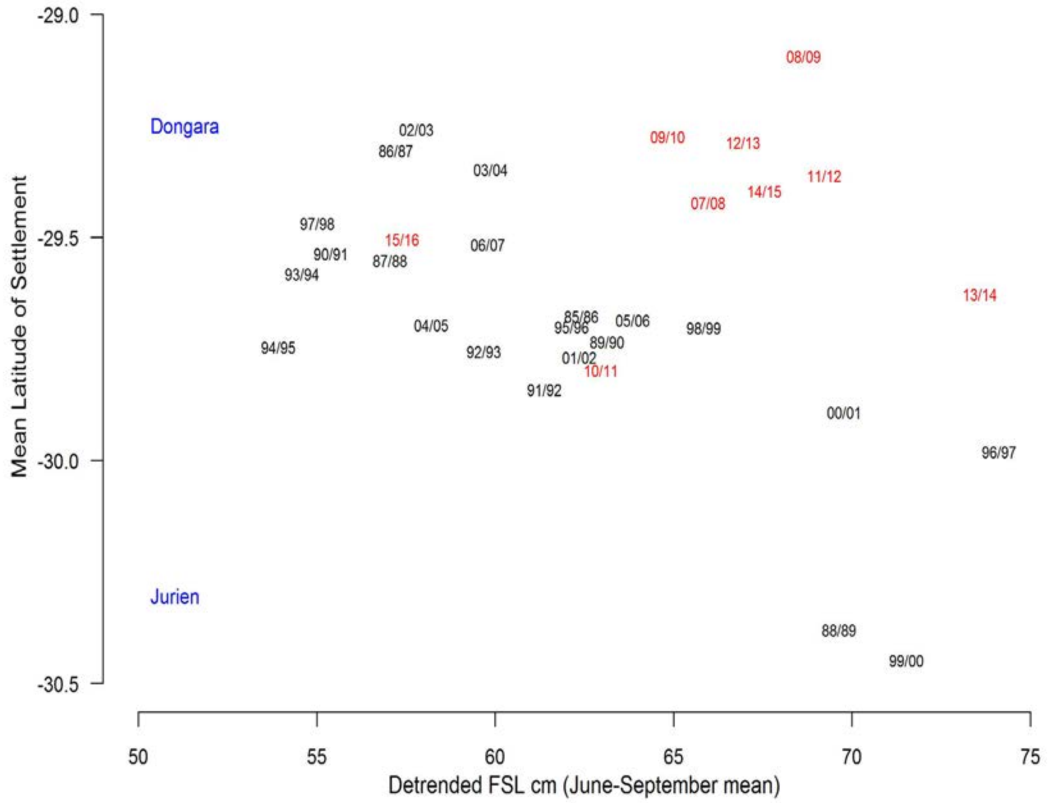

Figure 8-11 Mean latitude of settlement for each puerulus settlement season against the de-trended mean Fremantle sea level with recent puerulus settlement seasons (red) and those period to 2007 (black)

8.2.4.2 Breeding Stock Surveys

The Independent Breeding Stock Survey (IBSS) is conducted over about ten days during the last new moon before the start of the fishing season (15 November). This period is also close to the annual peak of egg production, which occurs in October/November (Chubb 1991; see Section 5.1.3.6.2).

The IBSS involves the setting of standard fishing pots in up to six coastal sites as well as the Abrolhos Islands, using the same locations each year. The survey is made annually at Dongara, Lancelin and the Abrolhos Islands, and at least every five years at Fremantle, Jurien and Kalbarri (Figure 8-12). As of 2008 surveys are now conducted annually at Leeman and in the Big-Bank region north of the Abrolhos Islands to monitor the effect of the area closures. Commercial WRL boats are now chartered for all locations. For the coastal sites, the surveys are made in depths from 25 – 70 m, while at the Abrolhos Islands and Big-Bank the depth ranges surveyed are 10 – 60 m and 100 – 150 m, respectively. These correspond to the depths at which most breeding lobsters are found in these areas (Chubb 1991).

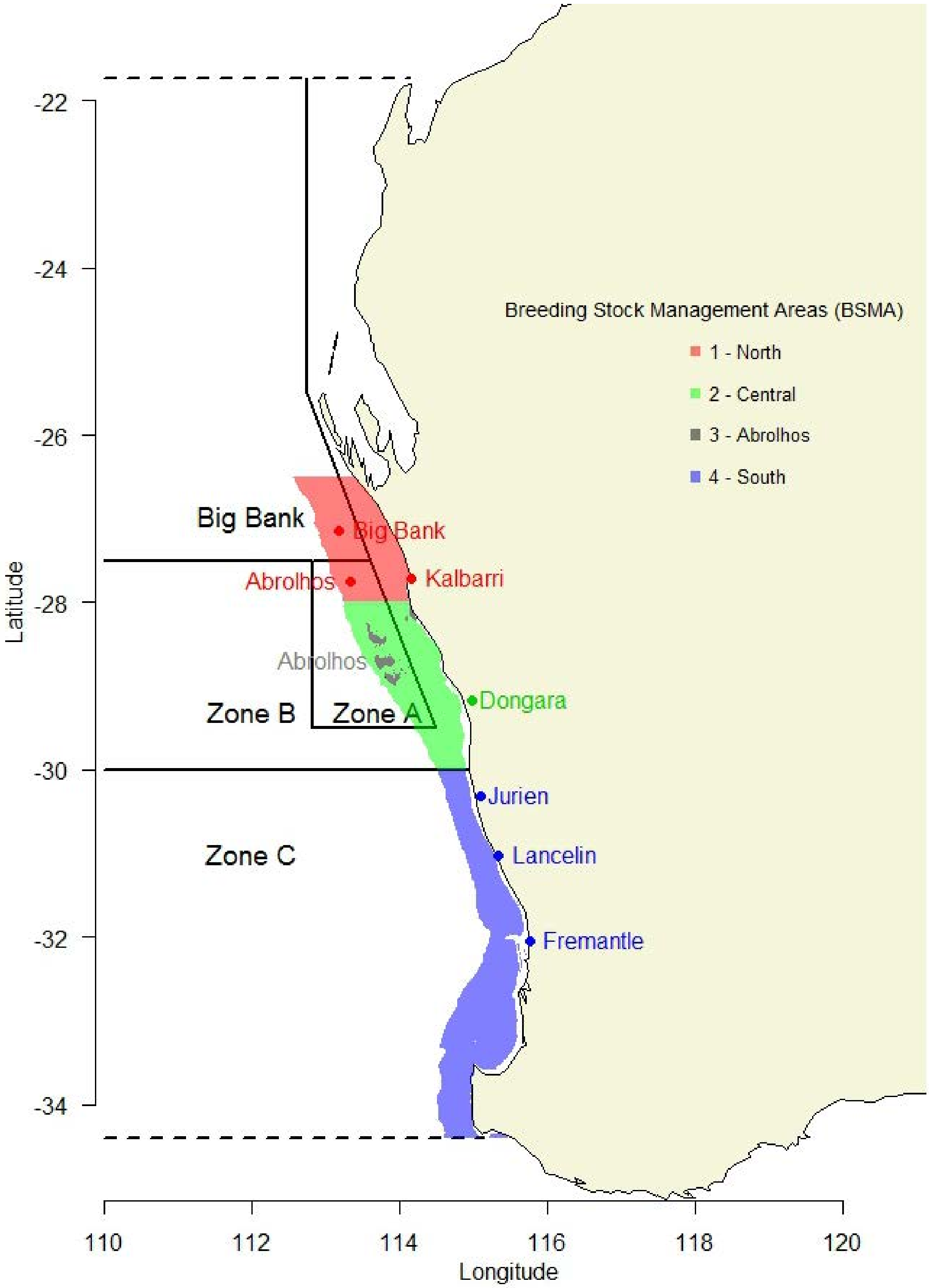

Figure 8-12 Location of independent breeding stock survey (IBSS) coloured according the breeding stock management area they are used assess

At the coastal sites and Big Bank, each year 160 commercial-sized batten pots, with no escape gaps, are used. These are set up for a two-day pull, with 80 pots being sampled each day during the 10-day sampling period. At the Abrolhos Islands, 51 pots are used with one-day pulls because greater quantities of lobsters are caught. Standard baits are used in standard amounts. Due to recent changes in Australian Quarantine regulations, the North Sea Herring has been substituted with local scaly mackerel, with a quantitative assessment showing that the two baits do not significant impact catch rates ($p > 0.05$).

After the completion of the IBSS sampling, an additional two days are spent in the shallows (< 36 m) tagging lobster for growth and movement information. The tagging protocol is outlined below; the results in terms of movement and growth are detailed in Section 5.1.3.3.1. Lobsters without missing appendages, are tagged with a Hallprint ™ "standard T-bar anchor tag" dorsally or ventrally between the first and second abdominal segments (Figure 8-13).

Figure 8-13 Tagged lobster showing location and type of tag

Ventral tagging reduces the likelihood of damage to the tag, thus increasing returns and preserves identification information (Melville-Smith & Chubb 1997) it also results in better tag retention (M. Pember pers comm.). Detailed information on each lobster is also recorded as during the IBSS (above) and each lobster is returned to its approximate location after being tagged.

8.2.4.2.1 Analyses

Data from these surveys is used for a number of purposes including the development of empirical indices on, egg production (Figure 9-9), lobster damage from handling (Figure 8-14) and timing of spawning (Figure 8-15), as well as some important inputs into the integrated size-structures model (catch rate of female and male lobsters >= 76 mm; Figure 9-15).

One of the key benefits of the IBSS data is its standardised nature, and therefore its resilience to efficiency creep, which is present in commercially derived catch rates. A limitation of this independent data source is the presence of inter-annual variability in lobster catchability, which can markedly impact certain years. The survey is especially sensitive to this because of its close proximity to the spawning season (female catchability varies dramatically with egg development stage) and its short time span (only 10 days). In the construction of the indices the catch rates are attempted to be standardised for water temperature and swell, however this technique does not remove all influences of catchability. As such general trends should be focussed on more that specific points.

To develop a standardised index of egg production individual mature female lobsters are first converted to a potential egg production using a size-fecundity relationship which takes into account the number of batches a female could produce in a spawning season. A female is considered mature during the survey if she possesses either a tarspot (has mated), mature ovaries or external eggs. The equation used to estimate the egg potential of a female is:

$$G_{La} = F_L B_{La} \ ,$$

where the egg potential of a female (G_{la}) of size L in area a is a function its fecundity (F_L) and the number of batches that female would produce in a single spawning season (B_{La}). The fecundity relationship used is consistent across the fishery and is:

$$F_L = 1.96L^{2.69} \ ,$$

where L is the carapace length of the lobster in mm. The number of batches produced per season is area specific and is described by the equations:

$$B_{La} = \begin{matrix} 1 + \left(1 \big/ \left(1 + e^{4.075\text{-}0.0495L+0.484} \right) \right) & a = 1 \\ 1 + \left(1 \big/ \left(1 + e^{4.075\text{-}0.0495L\text{-}0.484} \right) \right) & a = 2 \\ 1 + \left(1 \big/ \left(1 + e^{6.675\text{-}0.1063L\text{-}0.484} \right) \right) & a = 3 \end{matrix} \ ,$$

where B_{La} is the number of batches produced per spawning season and a is the lobster capture area where 1 = Fremantle and Lancelin, 2 = Leeman, Jurien, Dongara, Kalbarri and Big Bank and 3 = Abrolhos Islands.

In an attempt to remove the influence of water temperature and swell from the IBSS data the catch rates of "potential eggs" are standardised. The model used is:

$$\log\left(U_G + 50000\right) = Y + M + A + P + T + S \ ,$$

where the catch rate (U_G; eggs pot-lift^{-1}) is a function of year (Y), month (M), sub-area (A), pot-soak time (P), water temperature (T) and swell index (S).

A second index that is produced from the IBSS is the proportion of the catch that possesses damaged appendages (legs and antennae). This provides an independent measure of the damage that is being caused to the stock through the capture and handling of lobsters that are returned to the sea (i.e. return as they are illegal or high-graded). As this index is a proportion of the landed catch it does not have to be standardised for catchability.

Lobsters captured during the IBSS have their appendages examined and damage can be attributed to three time periods based on the appearance of the appendages. Missing appendages with a clear-coloured wound indicates a very recent (< day) injury, whereas a darkened/black wound indicates an injury that occurred > one day previously but since the animal last moulted. A smaller appendage with a greenish tinge indicates a regenerated appendage that has been re-grown after a moult but has not reached its full size. Lobsters with "old damage" (blackened wound or regenerated limbs) are considered to have received the impact from interactions with predators or fishers, with variation in the proportion assumed to be due to fisher's behaviour (assumes predator interactions are constant).

Despite an increase in high-grading, resulting in additional handling of legal lobsters, there has been a decline in the incidence of 'old' damage in recent years (Figure 8-14). Despite an increase in 'old' damage initially after the move to output controls, this level was still below that experienced during the mid-2000s when high-grading did not occur.

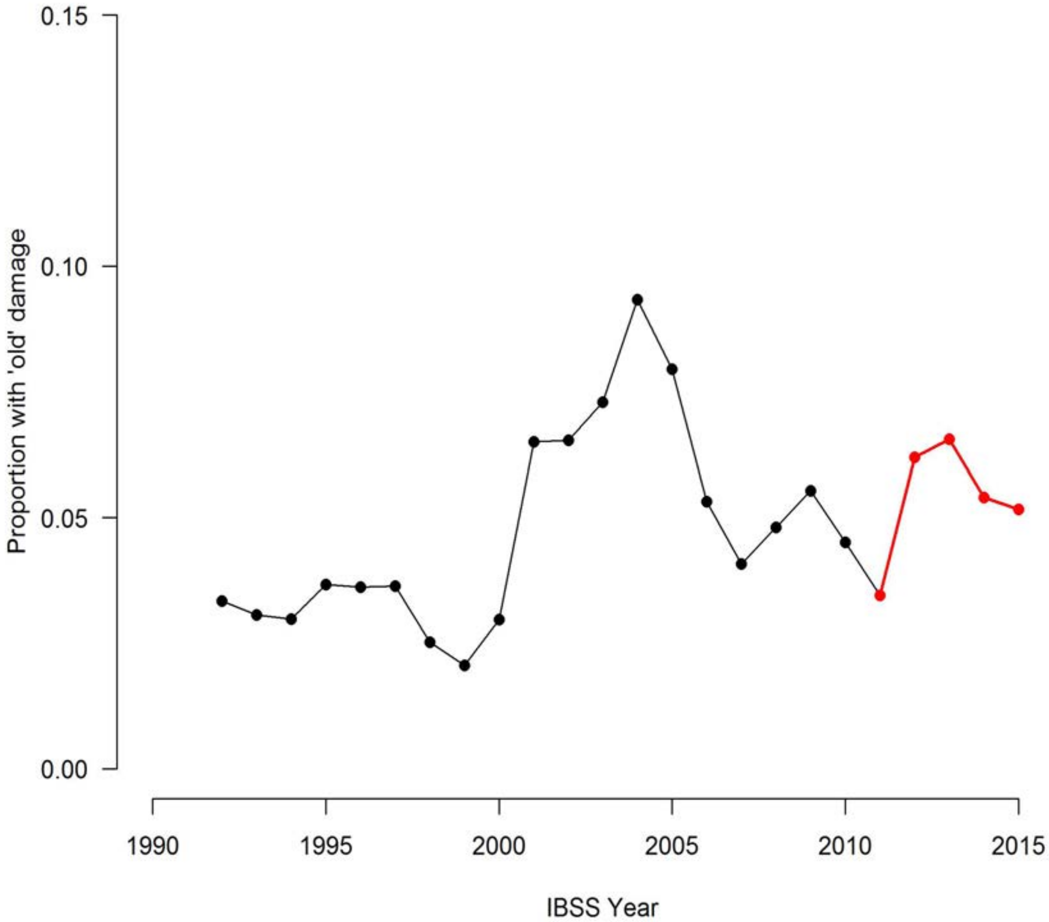

Figure 8-14 Proportion of lobsters recorded with ‘old’ damage during independent breeding stock surveys during input (black) and output (red) management regimes

The timing of spawning is derived from a combination of data sources, the IBSS and commercial monitoring. Initially the only data that was collected during the onset of spawning each year was that collected during the IBSS. However, in 2011 the commercial fishery expanded the months that it could fish, which then provided an opportunity for the commercial monitoring program to collect data on the reproductive state of females in all months of the year. As such two indices for the onset of spawning have been developed.

The IBBS only index is based on the reproductive condition of female lobsters sampled in October and November and compares how the average standardised stage varies between years. This provides a relative index, for example at what point within the reproductive process (e.g most lobsters with 1. no eggs, 2. new eggs, 3. old eggs, 4. eggs have been released and second batch is starting representing a late – early start across this range, respectively),

The IBSS and commercial monitoring datasets combined allows the proportion of females spawning across the months of June to November to be described by a logistic equation which can provide a more precise estimate of the timing at which 50% of the population has been mated and has also become ovigerous (produced external eggs). This measure is therefore considered more robust than that produced only by the IBSS survey.

The timing of spawning dramatically increased in 2007 making it the latest spawning period recorded for western rock lobsters (Figure 8-15). It was this spawning season which preceded the record low puerulus settlement which occurred in 2008/09 (Figure 9-8). Since then the timing of spawning has moved earlier, with the current season (2015) returning to the average spawning timing from 1990-2006 (Figure 8-15) which resulted in a normal puerulus settlement season (Figure 8-9).

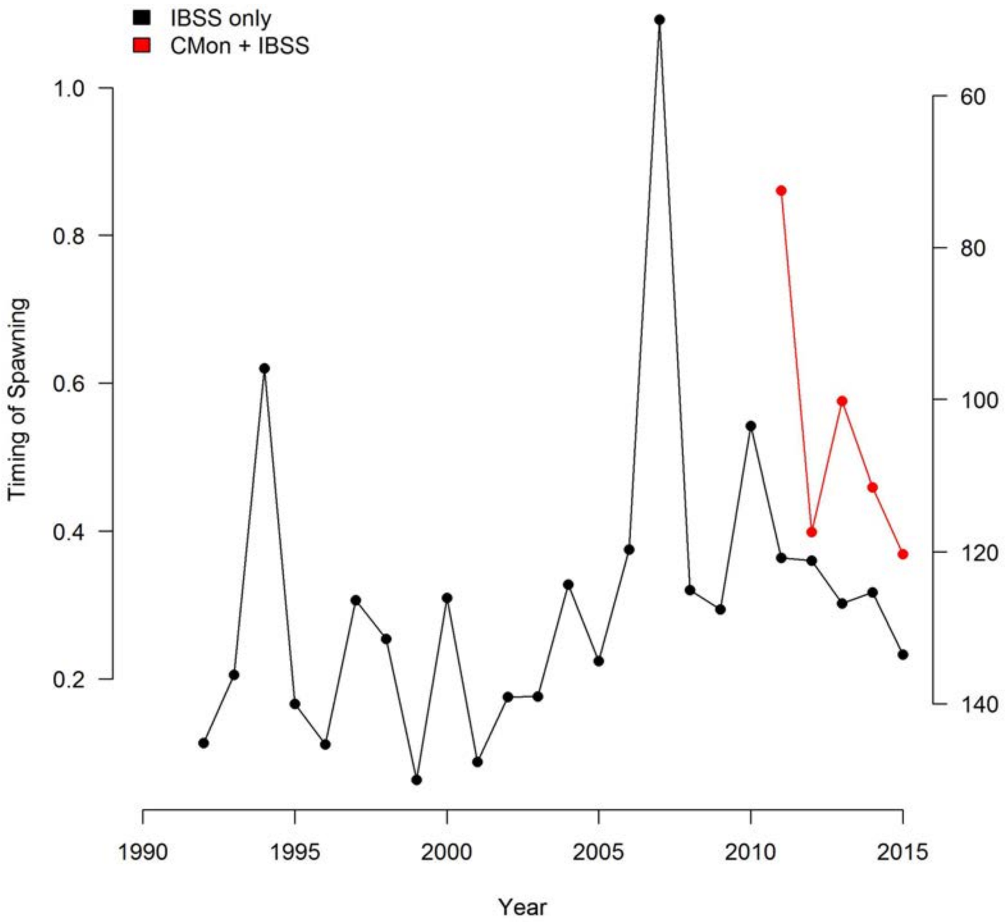

Figure 8-15 Timing of spawning as determined by the independent breeding stock surveys (IBSS; black) and combined IBSS and commercial monitoring (red)

8.2.5 Environmental Monitoring

Environmental conditions such as water temperatures and oceanic currents greatly influence the survival and behaviour of larval *P. cygnus*. The Department of Fisheries sources a number of environmental variables to determine what effects variations in climatic conditions have on the fishery. Most of the data described below are gathered from the Australian Government's Bureau of Meteorology (BOM), CSIRO and NOAA. These data complement environmental data collected by the Department of Fisheries during monitoring programs (Sections 8.2).

Rainfall

Monthly rainfall data are collated from Bunbury, Mandurah, Rockingham, Fremantle, Rottnest, Lancelin, Jurien, Dongara, Geraldton and Kalbarri (e.g. Bureau of Meteorology 2007). Rainfall is used as a proxy for westerly winds associated with storms crossing the coast in winter and spring.

Sea level

Sea level data for the west coast are obtained from BOM recordings at Hillarys[1], and from the National Tidal Centre for Fremantle sea level. This provides hourly sea-level data as well as data on water temperature, air temperature, barometric pressure, wind direction, wind gust, wind speed. Archived data are available from 1992; current data are updated monthly.

Reynolds Satellite sea-surface temperatures

Obtained monthly from the CSIRO and/or NOAA, the Reynolds Satellite temperatures have provided sea- surface temperatures since January 1982. Temperature is recorded for 1-degree blocks ranging from 10 ^{o} to 50^{o} S and 90 ^{o} to 130 ^{o} E.

Southern Oscillation Index (SOI)

The index is calculated from the monthly air-pressure difference between Tahiti and Darwin (sourced from BOM website[2]). It and provides a monthly value of the SOI, with archived values available from 1876.

The SOI reflects changes in global oceanic conditions and is usually used to denote either El Niño or La Niña weather conditions. A change in the temperature of the eastern and central Pacific Ocean affects the strength of trade winds, rainfall patterns and also oceanic currents. While the impact of these climatic conditions mostly influences the eastern seaboard of Australia (bordering the Pacific Ocean), they also impact the Leeuwin Current off the Western Australia coast, which effects settlement of juvenile western rock lobster (Sections 8.2.4.1).

[1] http://www.bom.gov.au/oceanography/projects/abslmp/abslmp.shtml
[2] http://www.bom.gov.au/climate/current/soi2.shtml

8.2.6 Other Information

8.2.6.1 Gear Information

At the end of each season, a gear survey is sent to all fishers, requesting details of the type of gear used, boat modifications and technology installed. This information, which has been collected since 1989/90, has been used to assess changes in fishing efficiency.

8.2.6.2 Economic Data

The majority of economic data collected for the fishery has been produced from individual projects (Winzer, 2009[3]; ERA 2015[4], collected from the Geraldton Fishermens Co-operative's website[5] or from individual processors at the end of each fishing season. These data include daily beach price information, bait usage and the costs associated with running and maintaining a fishing vessel (e.g. fuel, maintained and pot replacement, boat servicing and insurance).

The annual Gross Value of Production (GVP) is determined by multiplying the annual catch (determined from CDRs) by the weighted average beach price paid to fishermen over the fishing season (provided by individual processors and weighted by the proportion of the commercial catch they process in that season).

[3] http://frdc.com.au/research/Documents/Final_reports/2007-052-DLD.pdf
[4] http://www.fish.wa.gov.au/Documents/rock_lobster/wrl_notice_board/analysis_of_the_demand_for_western_rock_lobster.pdf
[5] http://www.brolos.com.au/beach-prices.html

9 Stock Assessment

9.1 Assessment Principles

The different methods used by the Department to assess the status of aquatic resources in WA have been categorised into five broad levels, ranging from relatively simple analysis of catch levels and standardised catch rates, through to the application of more sophisticated analyses and models that involve estimation of fishing mortality and biomass (Fletcher and Santoro 2015). The level of assessment varies among resources and is determined based on the level of ecological risk, the biology and population dynamics of the relevant species, the characteristics of the fisheries exploiting the species, data availability and historical level of monitoring.

Irrespective of the types of assessment methodologies used, all stock assessments undertaken by the Department take a risk-based, weight of evidence approach (Fletcher 2015). This requires specifically the consideration of each available line of evidence, both individually and collectively, to generate the most appropriate overall assessment conclusion. The lines of evidence include the outputs that are generated from each available quantitative method, plus any qualitative lines of evidence such as biological and fishery information that describe the inherent vulnerability of the species to fishing. For each species, all of the lines of evidence are then combined within the Department's ISO 31000 based risk assessment framework (see Fletcher 2015; Appendix) to determine the most appropriate combinations of consequence and likelihood to determine the overall current risk status.

9.2 Assessment Overview

The assessment model synthesised all the available data necessary to get a better understanding of management actions likely to be required to ensure the sustainability of the fishery in the period of low recruitment. A more comprehensive assessment model than that previously used (Hall and Chubb, 2001) was developed that was length-structured and had greater temporal and spatial detail and incorporated more of the known biological processes of *Panulirus cygnus*.

9.2.1 Peer Review of Assessment

The stock assessment model has been reviewed externally by international experts in 2007[6] and 2010[7]. The second assessment review in 2010 suggested a number of changes to the model, namely:

1. The code be made more efficient to reduce the processing time [completed].
2. The number of time-steps, areas, and length-bins should be reduced to make the model less complex and reduce processing time [completed].
3. The egg production indices should be generated from the model by incorporating the dependent and independent breeding stock survey (DBSS and IBSS) data in the model. These data consist of length frequency data from DBSS and IBSS and the CPUE from the IBSS [completed].

[6] (http://www.fish.wa.gov.au/docs/op/op050/fop050.pdf
[7] (www.fish.wa.gov.au/docs/op/op081/fop81.pdf

4. The growth should be determined by estimating the parameters in the model from tagging data [not completed].
5. The movement parameters, including northward movement should be estimated from tagging data incorporated in the model [completed].
6. Initial conditions be modified [completed].

All changes suggested by the second assessment review team were incorporated into the model with only point four proving not to be a viable option; point four significantly increased the run time of the model making it impracticable for conducting assessments. It was decided to run all growth analysis outside of the model and incorporate the parameter estimates and their uncertainty into the stock assessment model (see Section 9.3.14).

The WCRLMF has undergone third party certification against the Marine Stewardship Council (MSC) standard for sustainable fishing ([V1.3]).

9.3 Analyses and Assessments

9.3.1 Data Used in Assessment

CAES / RLQMS / CDR (tempo-spatial catch, effort, bycatch, behaviour) Processor returns (catch and size compositions) Recreational catch and effort Charter catches Exchange rates / fishing costs / Beach prices Water temperatures Commercial catch monitoring (tempo-spatial catch, effort, bycatch, behaviour) Fishery-independent survey catch, effort and composition Fishery-independent puerulus monitoring Tagging data Volunteer logbooks

9.3.2 Catch and Effort Trends

9.3.2.1 Commercial Catches

Western rock lobsters are taken by the West Coast Rock Lobster Managed fishery (WCRLMF) and the South Coast Crustacean Managed Fishery (SCCMF). The WCRLMF lands the majority (>99.8%) of the catch (Table 9-1) because the fishery spans much of the geographical distribution of this species, while there is minimal overlap of the species distribution with the fishing grounds of the SCCMF. Commercial catches in the WCRLMF have been limited by quotas since 2010, which have been set between 5500 and 6000 t over this period. In the SCCMF catches are not limited by quota, and have therefore varied markedly between years due to variation in larval recruitment.

Recreational catches of Western Rock Lobster have increased in recent years, now contributing almost 5% of the total landings (recreational landings in 2014/15 season were estimated to be 330 t, see section 9.3.2.3 for more details).

Table 9-1. Annual catches retained by the commercial fisheries targeting Western Rock Lobster, calculated as an average for the past 5 years

Species	WCRLMF	SCCMF	Total
Panulirus cygnus	5957	15.7	5973

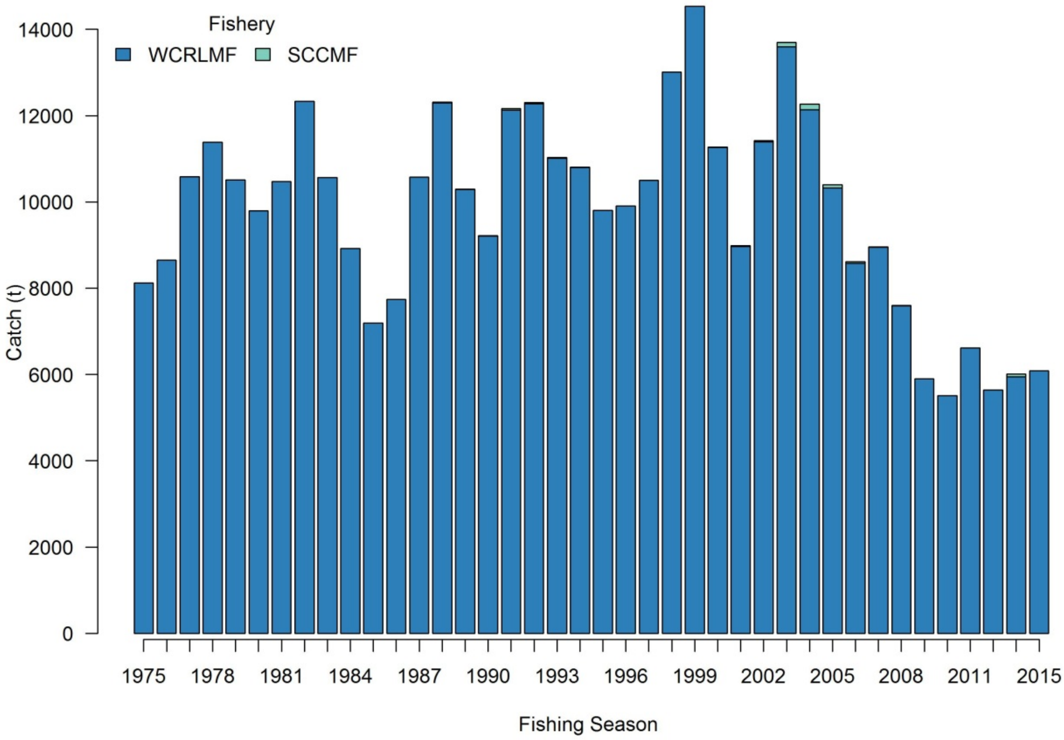

Figure 9-1. Annual total catch (tonnes) of western rock lobster by the West Coast Rock Lobster Managed Fishery (blue) and South Coast Crustacean Fishery (green) between 1975 and 2015

Historically commercial catches in the WCRLMF have always remained relatively stable in Zone A, with considerably more variation in Zone C (Figure 9-2). This is because the recruitment into Zone C is the most variable within the fishery. Since the change to quota controls in the fishery in 2010 and then the adoption of a 50% share between the A and B zone combined with C zone in 2015, variability in catches between zones has been removed.

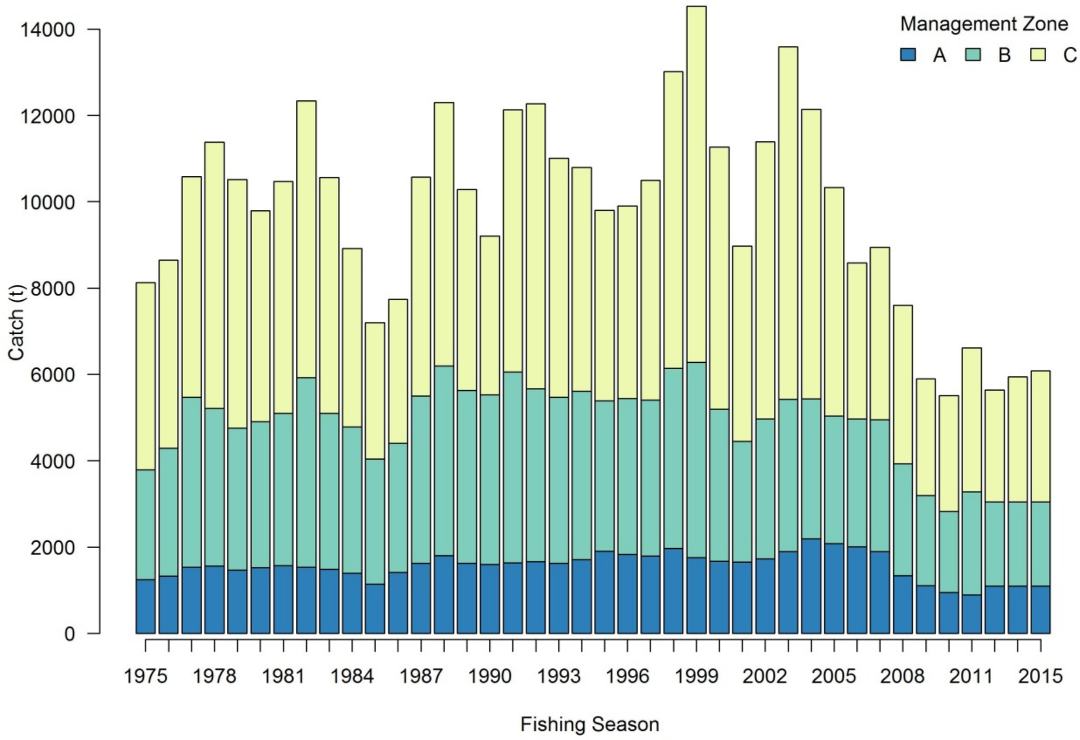

Figure 9-2 Annual catch (tonnes) of Western Rock Lobster from the different management zones of the commercial WCRLMF between 1975 and 2015.

There is a marked temporal variation in commercial catches of western rock lobster. Historically catches were greatest during the whites' phase of the fishery (December/January), due to the moult in November and high catchability of this life stage. Catches again increased in March/April when large numbers of undersize lobsters moult into legal size and are relatively catchable. Although this pattern is still present, it is far less obvious in recent years. The smoothing of temporal peaks in catches has been due to the implementation of quotas, with fishers fishing practices based mainly when beach prices are high. In general high beach prices occur during periods of high demand in China such as during the Chinese New Year celebrations (January/February) and other "lucky" Chinese days/weeks. Catches are generally lower in winter during the cooler months due to a combination of factors including lower demand in China, more rough weather days, lower catchability and many females starting to mate and thus becoming illegal for capture.

9.3.2.2 Commercial Effort

Historically commercial effort in the WCRLMF was relatively stable between about 10 and 12 million pot-lifts per season, and only differed between management zones because of the number of pots licensed in each zone was different (Figure 9-3). Effort reduction had a marked impact on the number of pot-lifts in 1993 (18% pot reduction) and again in the period 2005 until quota was introduced in 2010. Since quota was introduced into this fishery effort levels have remained about 20% of those pre-2000. Note, the increase in effort during the 2011 fishing season was due to this season being extend to 14 months to realign the season start date from 15 November to 15 January. Since the 2013 fishing season, the fishery has operated for 12 months of the year, 15 January to the following 14th January.

Effort within the fishery now varies temporally and spatially for the same reasons described above for catch.

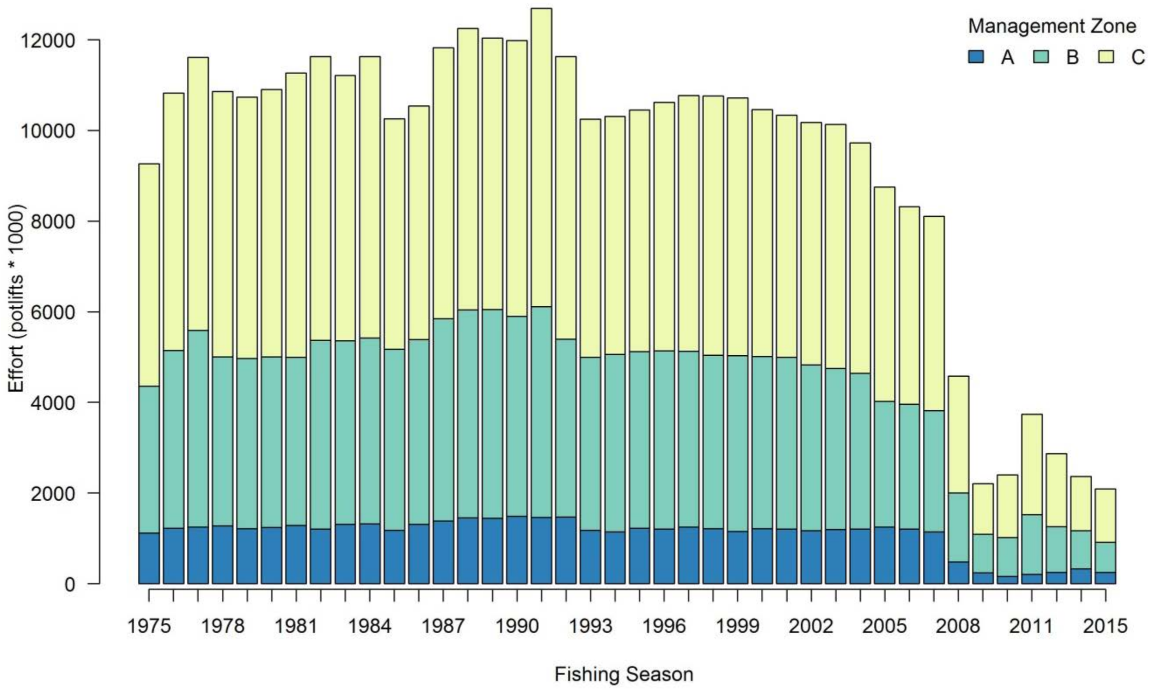

Figure 9-3 Annual effort (potlifts * 1000) in the different management zones of the commercial WCRLMF between 1975 and 2015

9.3.2.3 Recreational Catches

The recreational and charter fisheries run from 14 October to the following 30 June. Recreational fishing estimates are derived from surveys, while those from charter operators are derived from catch return statistics. The recreational fishery takes the majority of the catch from these two sectors. The recreational catch is determined through a range of survey techniques, some run annually (i.e. mail survey) and others intermittently in an attempt to correct for biases.

Recreational catches have increased from less than 100 t in the mid-1980s to peak in the early 2000s at 350 t, following a period of exceptionally good recruitment. They then declined to around 150 t for a number of years until they have recently increased again back to record levels of ~ 350 t (Figure 9-4). There are a number of reasons for their recent increase, including a relaxation of regulations aimed at limiting the quantities landed by recreational fishers and an increase in biomass due to the commercial sector reducing their harvest rates.

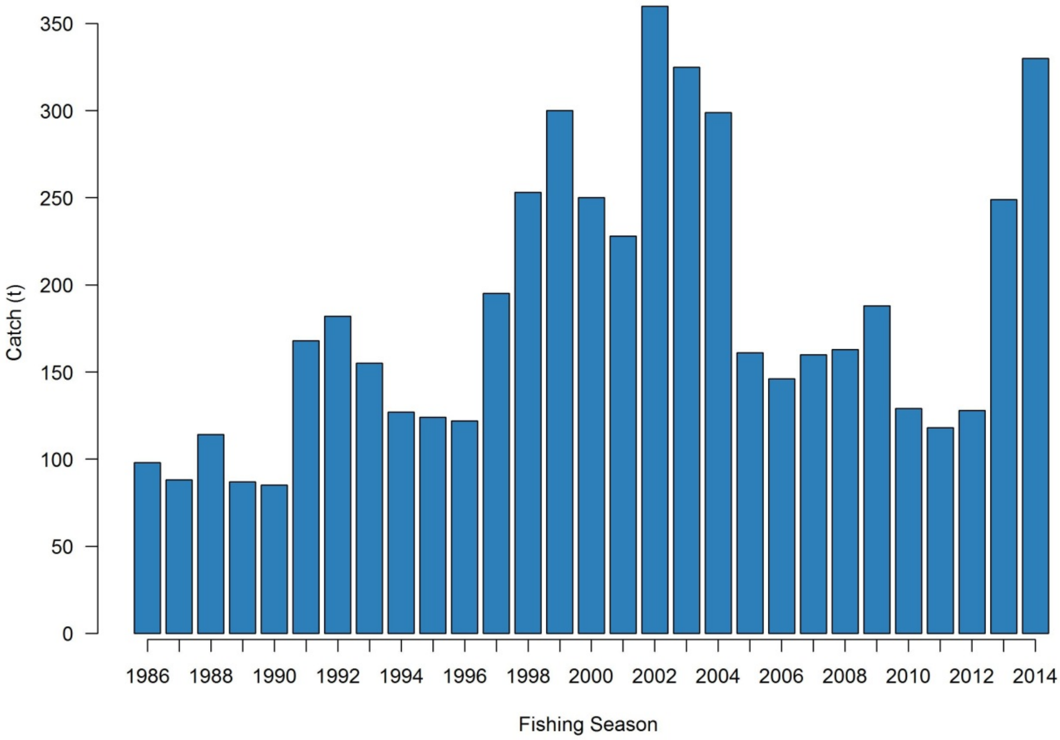

Figure 9-4 Adjusted recreational catch estimates.

9.3.2.4 Recreational Effort

The numbers of fishers involved in the recreational lobster fishery have changed over time in much the same fashion as the catches (Figure 9-5). The number of fishers increase from about 10,000 individuals up to 25,000 fishers in the mid-2000s, declined slightly for the following few years and has now increased again to about 25,000.

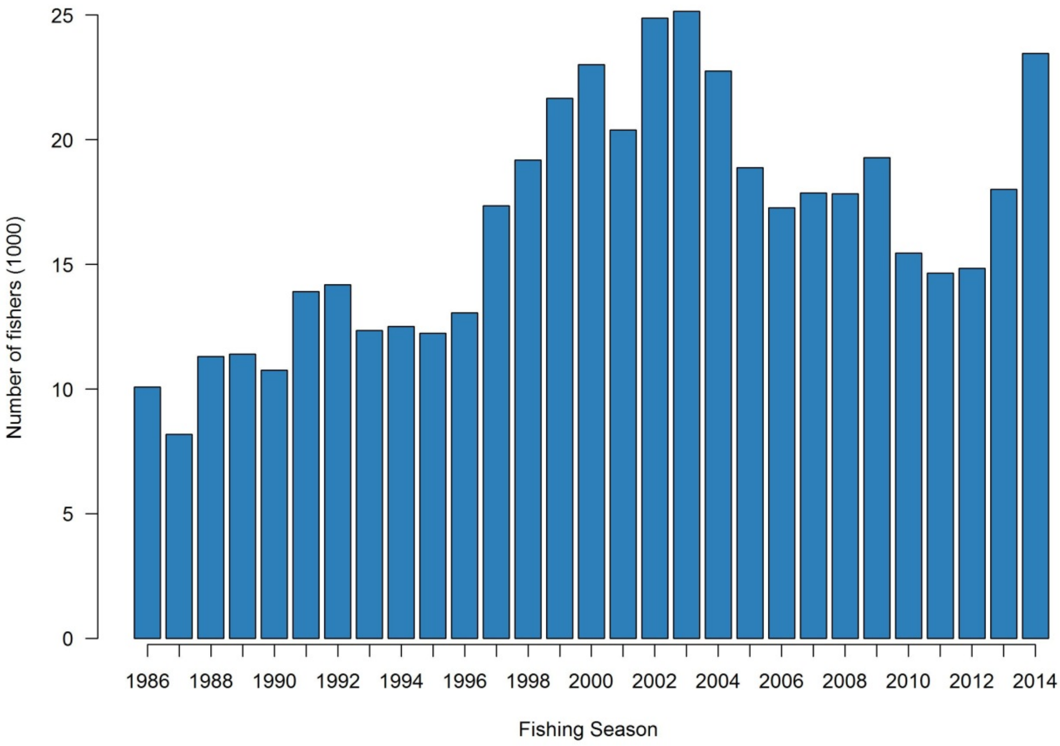

Figure 9-5 Adjusted recreational participation estimates.

9.3.2.5 Conclusion

Catches in the WCRLMF have increased slightly over the past few seasons due to small increases in quota and an increase in recreational catch; however they remain below 55% of the historical average level of catch. The fact that catches are relatively low and quotas have historically been easily obtained indicates that there is a low risk of the stock being over exploited.

9.3.3 Catch Distribution Trends

Historically commercial catch data was reported on a fairly broad spatial scale (1^o blocks), however since the implementation of quota in 2010, catches have been reported on a by-trip basis (generally daily) on a finer 10 x 10' blocks spatial resolution. Recreational catches are reported on a bio-regional scale and charter catches in 1^o blocks.

Catches of western rock lobster are obtained throughout their geographic range (Figure 5-2), however most commercial catch is focussed between Kalbarri and Mandurah and offshore at the Abrolhos Islands (Figure 9-6), whereas most recreation catch is focussed around the Perth area and regional centres (Section 6.3). There has been a slight increase in catch taken in deep-water (whites migration in 100+ m during February/March) over the past three years.

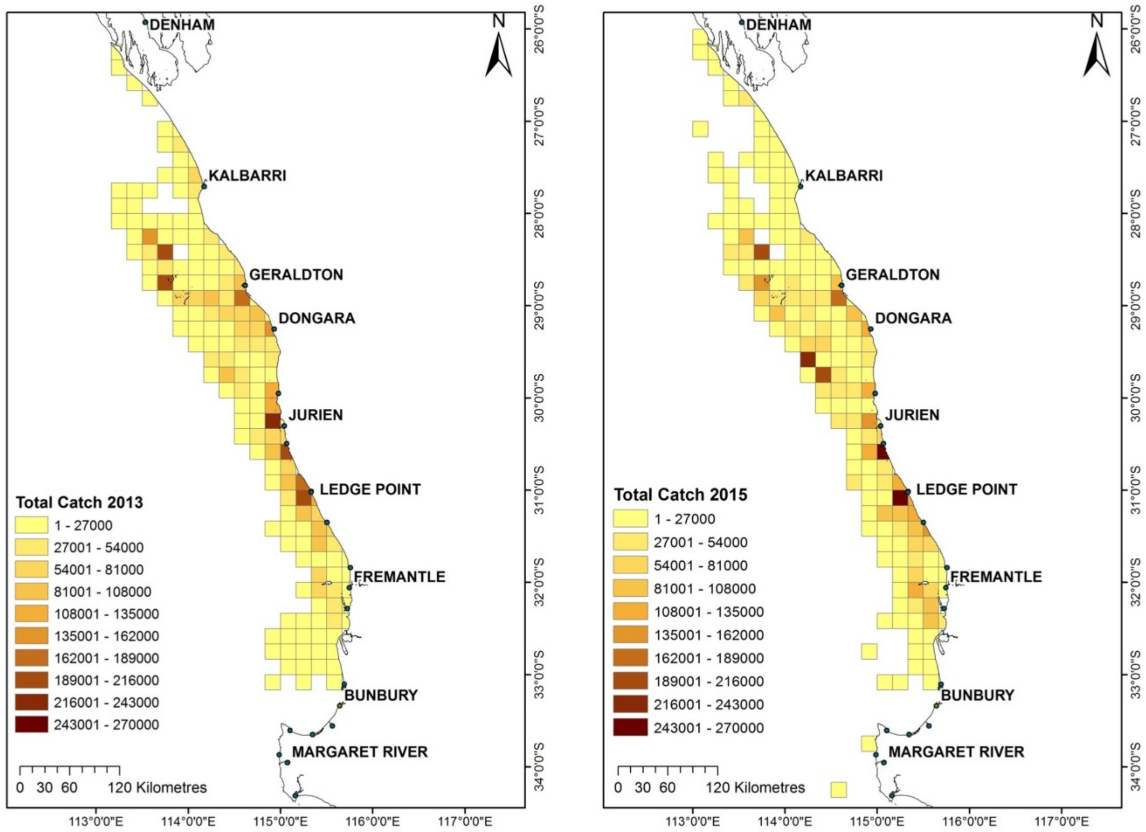

Figure 9-6 Spatial variation in total fishing catch between (left to right) 2013 and 2015

9.3.3.1 Conclusion

The slight change in the spatial distribution of the catch to increase landings in deep-water regions during the white migration has been in response to increased market demand and thus higher beach prices being offered during this period. The data do not represent a spatial shift in effort indicative of serial depletion within the fishery.

9.3.4 Fishery-Dependent Catch Rate Analyses

The standardised commercial catch rates show a similar general pattern in all three zones of the fishery, i.e. all catch rates were around 1 kg pot-lift^{-1} when the fishery was under input management (Figure 9-7). In 2008, when large effort reductions were introduced, catch rates began to increase dramatically, reaching a five-fold peak in A zone and doubling in B and C zones within two seasons (2010). A Zone was also allowed to fish during the migrating period for the first time when quotas were introduced in 2010. Over recent quota managed years the catch rates in B and C zone have continued to progressively increase to about 2.5 kg potlift^{-1} in 2015, whereas in A zone a small decline in catch rates occurred from 2010 until 2014 before an increase in 2015 to just over 3.5 kg pot-lift^{-1} (Figure 9-7).

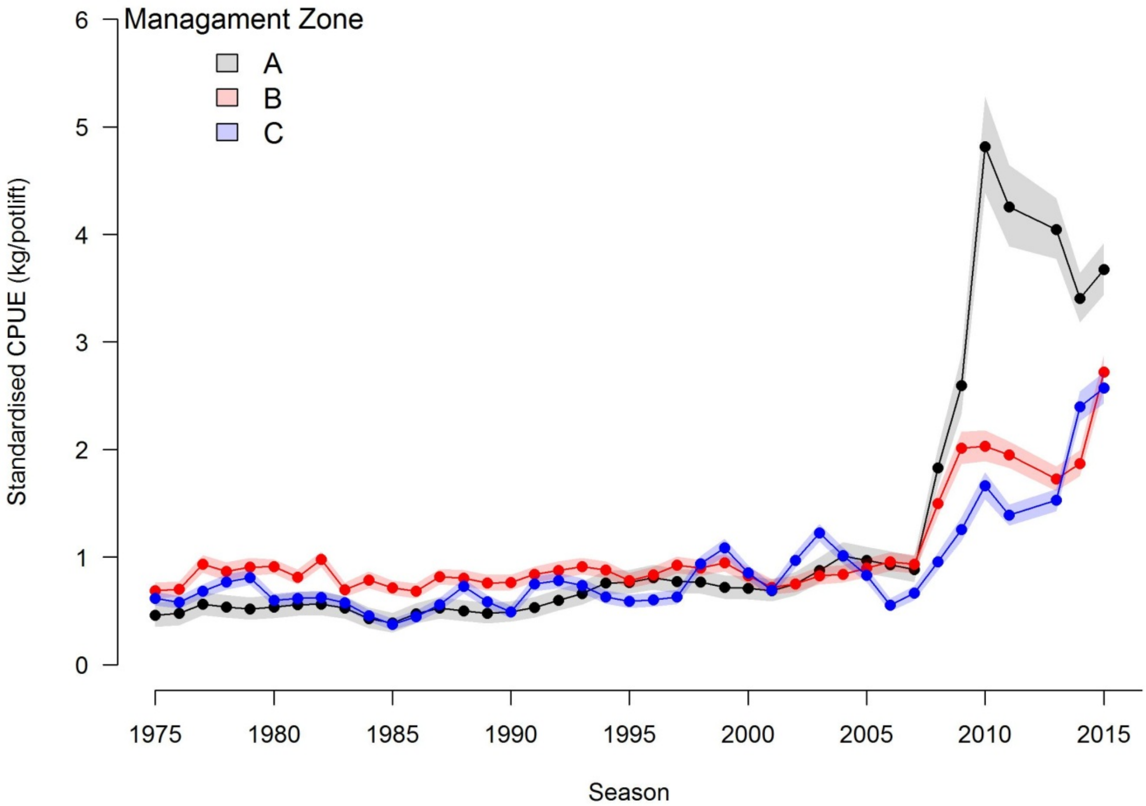

Figure 9-7 Standardised catch rates of legal lobsters by zone. Standardisation accounts for high grading and spatial and temporal changes in fishing effort

9.3.4.1 Conclusion

Standardised catch rates provide an overall measure of lobster biomass. Trends in these indices indicate that biomasses in recent years are over three-times greater than they were under input controls and either remaining stable under current exploitation rates or increasing. These indices suggest that the lobster stock is at low risk of being overfished.

9.3.5 Fishery-Independent Data Analyses

9.3.5.1 Puerulus Settlement

Puerulus are collected monthly at a number of sites along the west coast (see Section 8.2.4.1 for more details). The timing of settlement in 2015/16 season was again delayed compared to the long-term average timing at all locations, with the peak in settlement being recorded two to four months later than traditionally has occurred (Figure 8-9). Despite this, puerulus settlement while below the long term average was above the recent average puerulus settlement levels (Figure 9-8).

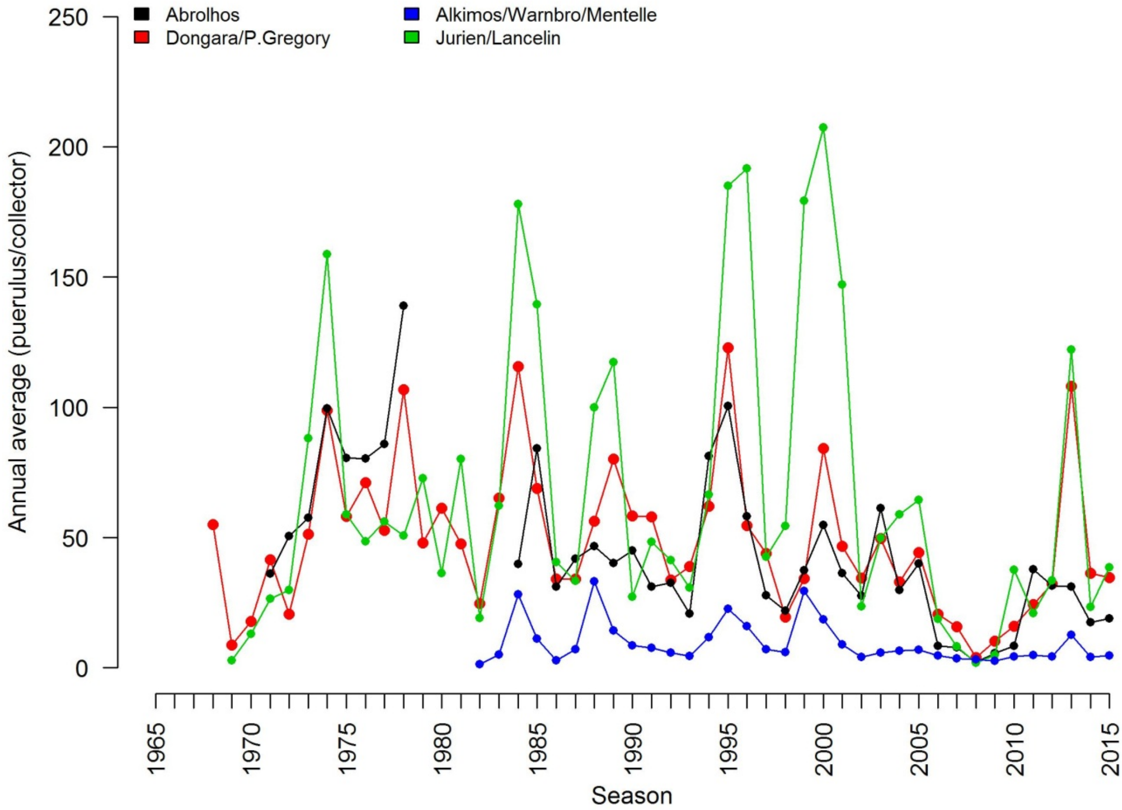

Figure 9-8 Average puerulus numbers per collector per season at the Abrolhos Islands (black), northern coastal sties (7 Mile and Port Gregory; red), central coastal sites (Jurien and Lancelin; green) and southern coastal sites (Alkimos, Warnbro and Cape Mentelle; blue).

9.3.5.2 Breeding Stock Levels

Standardised independent breeding stock survey (IBSS) egg production indices from the seven locations generally show similar patterns, being low at the start of the series, peaking in 1999 and 2000, before declining again until effort reductions were introduced in 2008 and 2009. After these years the egg indices increased to new highs, peaking in either 2012 or 2014. In most areas a small decline from maximum levels occurred in 2015. A decline during 2015 was expected, as new recruits entering into the breeding stock were a combination of lobsters that settled during the 2008 and 2009 settlement seasons. As these were extremely poor settlement seasons, a short-term decline in breeding stock was expected until better recruitment years start to mature and enter this life stage. Model projected breeding stock indices from the integrated population model (Section 9.3.14) also predicted this short term decline in breeding stock, before an increase in 2016 or 2017.

Leeman and Big Bank are far shorter time series and represent areas mainly closed to fishing (a small proportion of the Leeman area is fished). Both areas show an initial increase in egg production, peaking in 2012 and 2011, respectively, before declining and progressively increasing again. This pattern is considered unusual for closed areas as a continued increase and then a levelling off when the area reaches carrying capacity is the expected scenario. The variation from this may represent the impacts of variable catchability remaining even after the standardisation process, which may help explain the saw tooth effect present to some extent in all the egg production indices (Figure 9-9). Peaks were present in both 2012 and 2014, while dips occurred in 2013 and 2015. Irrespective of the variable catchability, egg production indices in all locations (bar the Abrolhos where no marked increase occurred) are well above levels recorded prior to 2010. In the Abrolhos Islands, although no marked increase has occurred at any point throughout the time series, there has been two step-wise increases that have occurred in 1996 and again in 2008 (Figure 9-9).

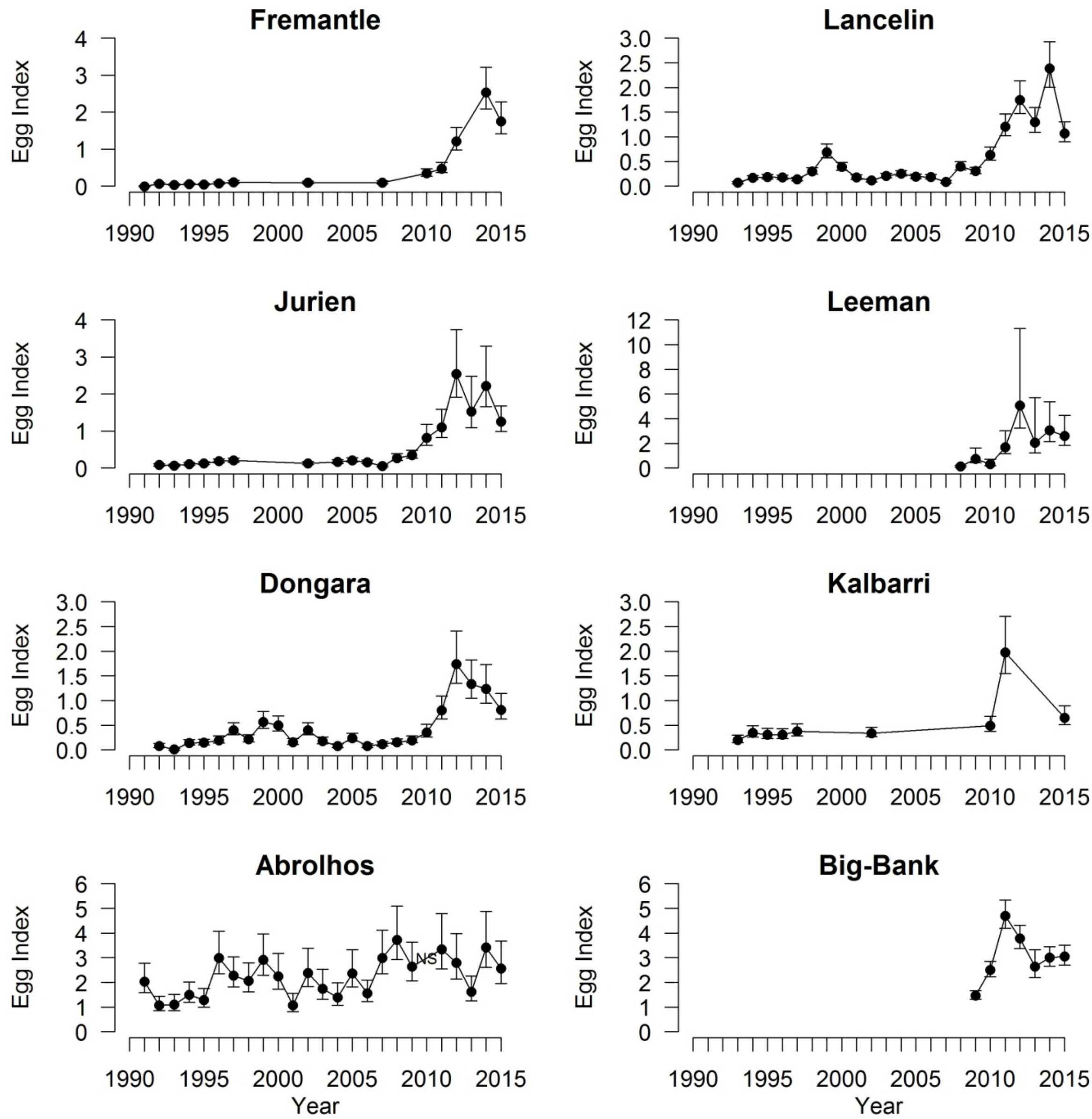

Figure 9-9 Standardised catch rates of egg production by area. Standardisation accounts for water temperature and swell

The damage index shows a substantial increase in 2001 from about 2.5% of the catch to 7% of the catch in one year (Figure 9-10). It then continued to increase over the subsequent three years to almost 10% of the catch in 2004, before declining progressively to 2010. With the implementation of quota in 2010, damage progressively increased over subsequent years, presumably as the incidence of high-grading increased. The proportion of damaged lobsters in the catch now appears to have levelled off at around 5% of the catch, well below peak levels in the mid-2000s (Figure 9-10).

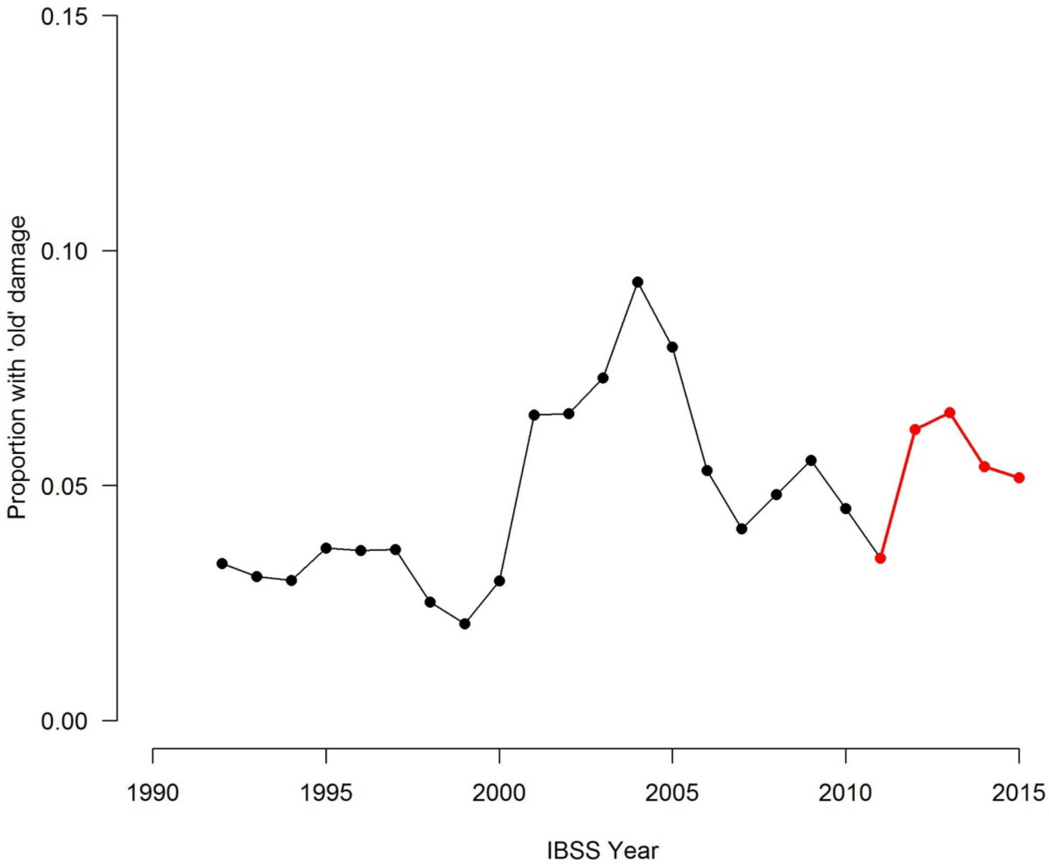

Figure 9-10 Incidence of lobsters with old damaged appendages caught during the IBSS. The change in colour from black to red represents the move from input to output controls in the fishery.

9.3.5.3 Conclusion

Fishery-independent recruitment monitoring indicates that the current puerulus settlement is continuing its recent pattern. Modelling suggests that this current level of settlement is sufficient to maintain/increase stock abundance levels at current harvest levels.

Fishery-independent egg production indices at all sites are well above long-term levels. These indices indicate high levels of spawning stock exist throughout the fishery.

Fishery-independent index on lobster damage indicates that recent increases in high-grading are not leading to increases in the proportion of lobsters in the population with damaged appendages.

9.3.6 Catch Rate Predictions

All catch predictions are produced by the integrated population model (IPM) (See Section 9.3.14).

9.3.6.1 Conclusion

See Section 9.3.14

9.3.7 Empirical Stock-Recruitment Relationships

No empirical stock-recruitment relationships have been developed for this fishery for two main reasons:

1. Puerulus monitoring provides a very accurate and direct method of determining recruitment.
2. Levels of puerulus recruitment are strongly influenced by environmental variates, making stock-recruitment relationships difficult to determine. Spawning stock was not found to be significant in the assessment of the recent decline in puerulus settlement variation after taking environmental factors into account (de Lestang et al. 2014)

An examination of implementing a stock-recruitment relationship into the integrated model is planned for the near future.

9.3.8 Trends in Age / Size Structures

Aging is not carried out on western rock lobsters as there is currently no method with which to conduct this process. Western rock lobster is one of several Australian commercially important crustaceans which are being examined as part of a direct aging project. If the presence of bands within the stomach ossicles of this species proves viable for aging, this assessment will be conducted.

Size trend analysis is not formally carried out for this fishery. Split-pricing of lobsters is used by processors to influence the size composition of the landed catch to meet market expectations. When demand is high for larger lobsters, this demand is easily filled.

9.3.8.1 Conclusion

There is no indication of a reduction in the contribution of large lobsters to the commercial catch.

9.3.9 Productivity Susceptibility Analysis

Productivity Susceptibility Analysis (PSA) is a semi-quantitative risk analysis originally developed for use in Marine Stewardship Council (MSC) assessments to score data-deficient stocks, i.e. where it is not possible to determine status relative to reference points from available information (Hobday et al. 2011; MSC 2014). The PSA approach is based on the assumption that the risk to a stock depends on two characteristics: (1) the productivity of the species, which will determine the capacity of the stock to recover if the population is depleted, and (2) the extent of the impact on the stock due to fishing, which will be determined by the susceptibility of the species to fishing activities (see Appendix 2).

Although a valuable tool for determining the overall inherent vulnerability of a stock to fishing, the PSA is limited in its usefulness for providing stock status advice. This is because of the simplicity and prescriptiveness of the approach, which means that risk scores are very sensitive to input data and there is no ability to consider management measures implemented in fisheries to reduce the risk to a stock (Bellchambers et al. in prep.). Consequently, the PSA is used by the Department to produce a measure of the vulnerability of a stock to fishing, which is then considered within the overall weight of evidence assessment of stock status.

The sections below outline the PSA scores for Western Rock Lobster.

9.3.9.1 Productivity

The average western rock lobster matures at an age of about seven years post settlement (PSA score 2) and is expected to live for at least another seven to ten years. The average maximum age of western rock lobster is therefore expected to be around 15 years (PSA score 2).

Western Rock Lobsters produce between one and two batches of eggs per spawning season with larger females producing over 1 000 000 eggs per batch (PSA score 1). The eggs are fertilized externally but maintained on the tail of the adult female for six to eight weeks before the larvae are released live into the environment. Even though this behaviour is consistent with that of a live bearer, lobsters are considered delayed-broadcast spawners (PSA score 1).

As Western Rock Lobsters feed on many of the small macro-invertebrates such as polychaete worms and small bi-values they are considered to occupy the trophic position of a first-order predator, ranging from 1.90 and 2.18 (PAS score 1) (Waddington et al., 2008).

Strong relationships existed between recruitment levels (puerulus abundance) and subsequent catches three and four years when the fishery was under input controls (Caputi et al., 1995; de Lestang et al., 2009). The relationships showed strong density-dependence at all locations along the coast, with increasing levels of recruitment only marginally increasing subsequent catches (PAS score 1).

Table 9-2. PSA productivity scores the western rock lobster

Productivity attribute	Western Rock Lobster
Average maximum age	2
Average age at maturity	2
Reproductive strategy	1
Fecundity	1
Trophic level	1
Density dependence	1
Total productivity (average)	1.3

9.3.9.2 Susceptibility

The majority of the geographic distribution of western rock lobsters is accessed by the WCRLMF commercial fishery, with only some research closures (e.g. Big Bank and Leeman) as well as ‘fringe’ regions such as the Ningaloo Marine Park, devoid of commercial fishing (PSA score 3). Recreational fishing occurs mainly in shallower waters close to regional centres and the Perth metropolitan region. The recreational sector therefore accesses less than 30% of the distribution of this species (PSA score 2). The southern extreme of this species distribution is relatively erratic in its densities of lobsters as it is highly influenced by recruitment variability. Only following years of strong Leeuwin Current does this region contain significant number of lobsters. This area represents the fishing grounds of the SCCMF, and is only a small fraction of the overall distribution of this species (PSA score 1).

As western rock lobsters are the target species of the WCRLMF, SCCMF and the recreational lobster’s fishery, the fishing methods used directly target this species (PSA score all 3).

All fisheries use pots as their main method to capture lobsters (note the recreational fishing in the only fishery where diving is also permitted). Legalisation requires all lobster pots to be fitted with a minimum of three escape gaps that allow the majority of undersize (<76 mm carapace length) lobster to escape entrapment. Furthermore, research has shown that lobster pots are relatively inefficient, only capturing a small proportion of those that attend a pot each night. In the northern part of the fishery, lobsters below the size at maturity are rarely caught, whereas in the south where the size at maturity is larger, lobsters below the size at maturity can be retained within a pot (PSA score 2). Lobsters that have recently mated or are carrying eggs must be returned directly to the area they were captured within five minutes. Research has shown that if handled with care and returned quickly to the water the survival of lobsters is extremely high (PSA score 1).

Table 9-3. PSA susceptibility scores for the West Coast Rock Lobster Managed Fishery, South Coast Crustacean Managed Fishery and their associated recreational components on western rock lobster.

Susceptibility attribute	WCRLMF	SCCMF	Recreational Fishery
Areal overlap	3	1	2
Vertical overlap	3	3	3
Selectivity	2	2	2
Post-capture mortality	1	1	1
Total susceptibility (weighted average)	1.43	1.13	1.28

9.3.9.3 Conclusion

The total PSA scores was 1.96 for the Western Rock Lobster, with the MSC PSA score being 96 out of 100. This classifies this species as being of low risk to over-exploitation.

9.3.10 Biomass Dynamics Model

9.3.10.1 Overview

A preliminary Biomass Dynamics Model (BDM) has been developed for this fishery. Although the model still needs to be properly reviewed, its outputs have been described here. The BDM has been developed on the platform Template Model Builder (TMB) implemented off the platform “R”. The model is currently projected out five years using likely future TACC levels (e.g. 6300 t).

9.3.10.2 Model Description

The BDM represents the standard Pella–Tomlinson (Pella and Tomlinson, 1969) equation with additional productivity information being provided by the puerulus settlement dataset lagged four years. The model is fitted to two series of catch rate data, commercial and independent catch rates. Commercial catch rates are influenced by four periods of different catchability, the first three represent periods when the fishery was under input controls and as such also contain compounding efficiency creep. The independent catch rates share a single common catchability for all years.

9.3.10.3 Input Data and Parameters

Commercial catch data is used to represent all removals (future development of this model will include recreational catches). This dataset spans 71 years (1944 to 2015). The catch rate data associated with these commercial catches has been, when possible, standardised to account for month and depth of fishing as well as high grading (Figure 9-7). Catch rate data derived from the IBSS (Section 8.2.4) has been standardised to remove the effect of location, water temperature and swell, and spans 24 years (1991 to 2015).

The puerulus time-series (Figure 9-8) used to help inform the BDM on recruitment variability is an index that spans 1944 to 2015 and is a combination of observed data from all locations sampled standardised to remove the effect of location. For years prior to 1968, when puerulus data was not available, estimates of puerulus settlement were derived from the empirical relationship between settlement and catch based on observations collected when the fishery was under input control and fully exploited (i.e. 1975 – 2005). Puerulus levels used in future projections are the lowest 25 percentile of the time series.

The BDM estimates nine parameters: r, Bzero, four commercial catchability parameters, one IBSS catchability parameter, puerulus density dependency and a common variance for the two catch rate data series.

9.3.10.4 Results and Diagnostics

The model is able to replicate both series of catch rates data (Figure 9-11). There is a slight under-estimation of recent catch rates recorded during the IBSS, and possible causes for this discrepancy (such as variable catchability) will be investigated.

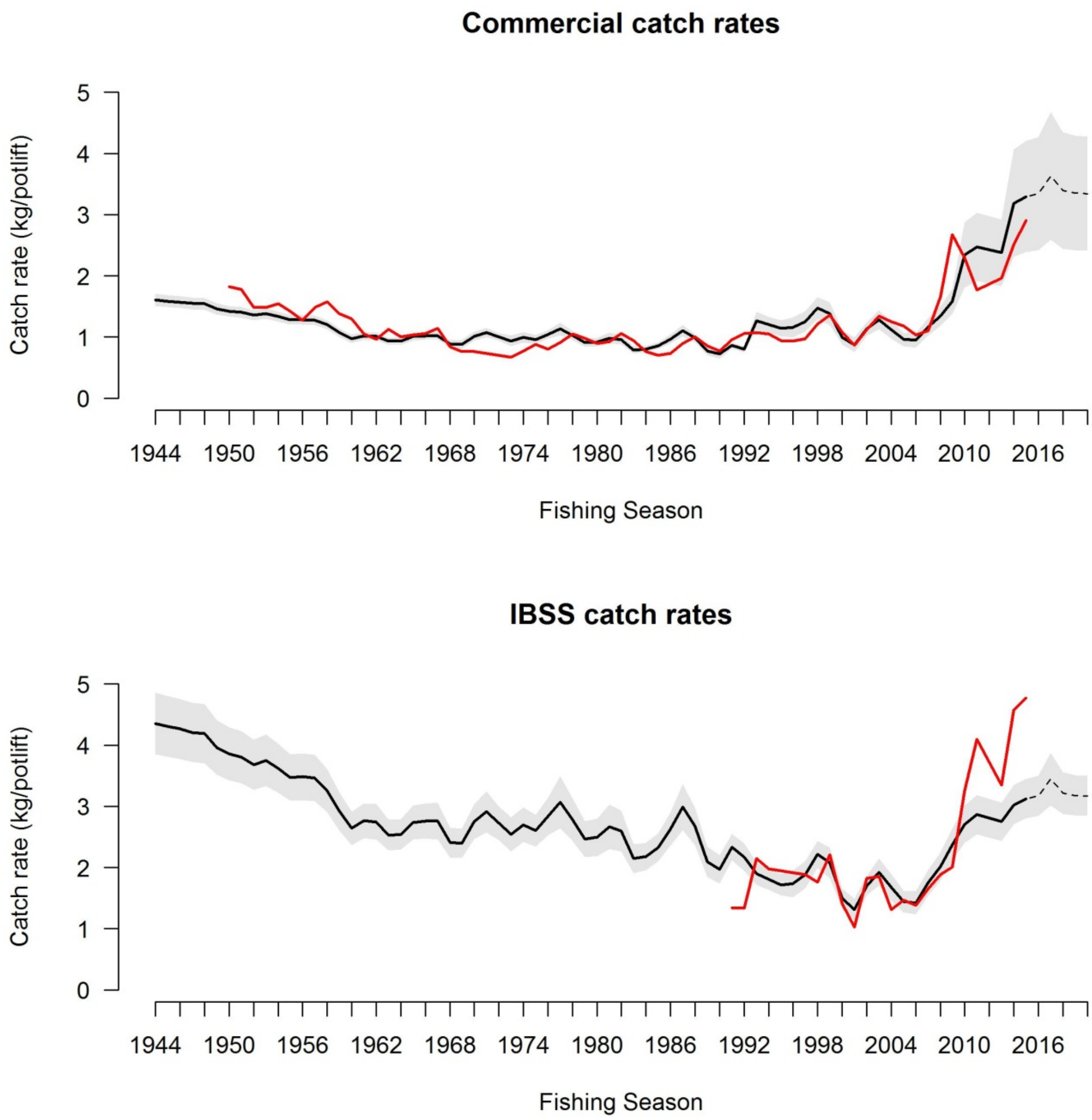

Figure 9-11 BDM fit (black line) with 95% CI (grey) and projections (dotted line) to commercial and IBSS catch rates (red).

The model estimated that the biomass of Western Rock Lobster > 76 mm Cl has slowly declined from about 25 000 t to a low of ~ 10 000 t (40% of virgin biomass) by the early 2000s, before a rapid increase occurred following effort reductions and a change in management to quota (Figure 9-12). Biomass levels are now around 20 000 t or 80% of virgin biomass and predicted to remain at or close to this level under current TACC levels.

The harvest rate followed a similar but reverse trajectory, being low as the fishery developed and peaking at close to 60% of all lobsters >76 mm being captured each year (Figure 9-12). Harvest rates declined markedly following effort reductions and now are just below 30%, where they are expected to remain under projected TACC levels.

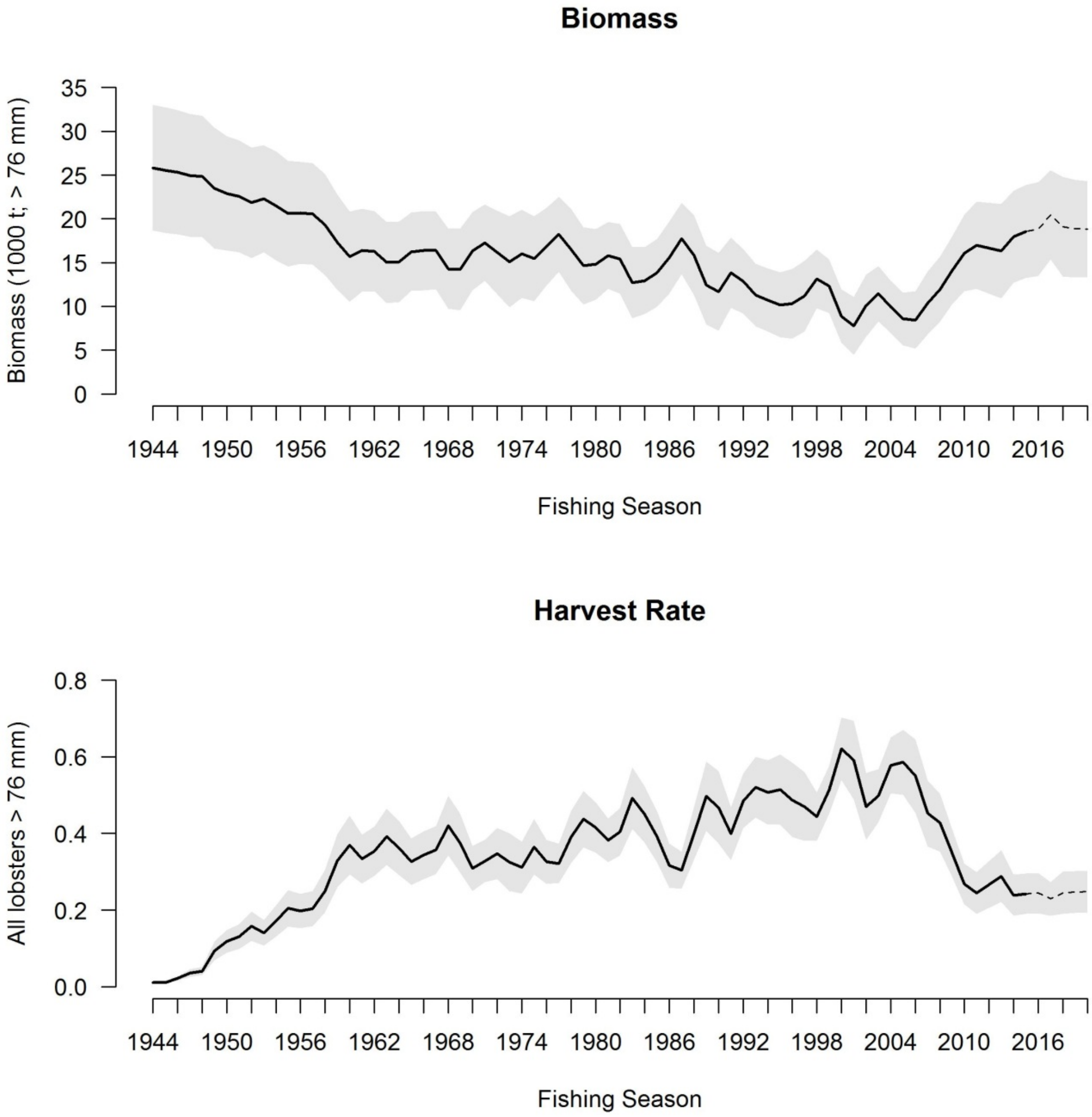

Figure 9-12 BDM estimates (mean and 95% CI) of biomass and harvest rates of all lobsters >76 mm.

9.3.10.5 Accounting for Uncertainty

TMB uses the "delta method" to determine standard deviations of any parameter or derived time series. Uncertainty in both the standardised time series of catch rate and the puerulus settlement data will be included into the likelihood in future versions of the model, rather than being estimated as is currently implemented.

9.3.10.6 Conclusion

The BDM indicates that the stock biomass is currently high, more than double than in the early 2000s and that at slightly increased TACC levels (e.g. 6300 t) the biomass and catch rates will increase slightly or remain steady over the subsequent five seasons. The BDM currently predicts that the fishery is fishing at harvest rates of about 30%. These will remain similar or to decline at current or slightly higher TACCs.

9.3.11 Catch Curve Analysis

Catch curve analysis is not currently conducted on this stock. All of the attributes that are derived from changes in size composition by catch-curve analysis are incorporated into the size-structured integrated model (Section 9.3.14). Even so, a standalone catch curve analysis of this fishery may be conducted in the future to provide a cross check to the other models.

9.3.12 Per Recruit Analysis

Per recruit analysis is not currently conducted on this stock. All of the attributes that are derived from this modelling framework are incorporated into the size-structured integrated model (Section 9.3.14). Even so, a standalone per recruit analysis of this fishery may be conducted in the future to provide a cross check to the other models.

9.3.13 Demographic Analysis

The western rock lobster is unable to be directly aged and as such demographic analysis is not possible. However, there is currently a project investigating if banding which has been seen in the gastric ossicles can be used to age this species. If these bands are validated as being formed annually, a demographic analysis may be undertaken.

9.3.14 Size-Structured Integrated Population Model

9.3.14.1 Overview

Hall and Chubb (1995) developed the initial assessment model for this fishery. This model was updated in 2005 with a more comprehensive integrated population model (IPM) that contained greater temporal and spatial detail and incorporated more of the known biological processes. The models runs on a fine temporal and spatial scale (11 time-steps and 11 areas designed to encompass various biological and management processes that occur within the year and fishery). The model is implemented in ADMB with control via "R". Scenario runs by the model are conducted by simply maximising the combined negative log-likelihood and using the "delta-method" to derive measures of uncertainty, with the final chosen scenario also run using 400 000 MCMC runs saving every 100th iteration with a burn-in of 5000 runs. This process takes approximately six days and subsequent convergence criteria indicate that this protocol is appropriate.

9.3.14.2 Model Description

The model runs on 11 time steps per year from November 1 1975 to October 31 2016 (Table 9-4) in 11 regions, which include inshore and offshore components using the 20-fathom depth contour (Figure 9-13). The regions have a biological basis (i.e. different growth and movement rates) and can be combined into the management zones A, B, and C. Lobsters are tracked in the model by sex in 46 length classes from 45 to 135+ mm with 2 mm bin widths.

Changes in the number of animals of each sex in each length-class and region are due to recruitment, growth, movement and mortality. The orders of events during each time-step are recruitment, growth, movement then mortality (although recruitment, growth and movement do not occur in each time-step).

Table 9-4 List of the parameters of the population dynamics model

Date	Time-step
15 Nov – 31 Nov	1
1 Dec – 14 Dec	2
15 Dec – 31 Dec	3
1 Jan – 14 Jan	4
15 Jan – 14 Mar	5
15 Mar – 31 Mar	6
1 Apr – 30 Apr	7
1 May – 30 Jun	8
1 Jul – 31 Aug	9
1 Sep – 30 Sep	10
1 Oct – 14 Nov	11

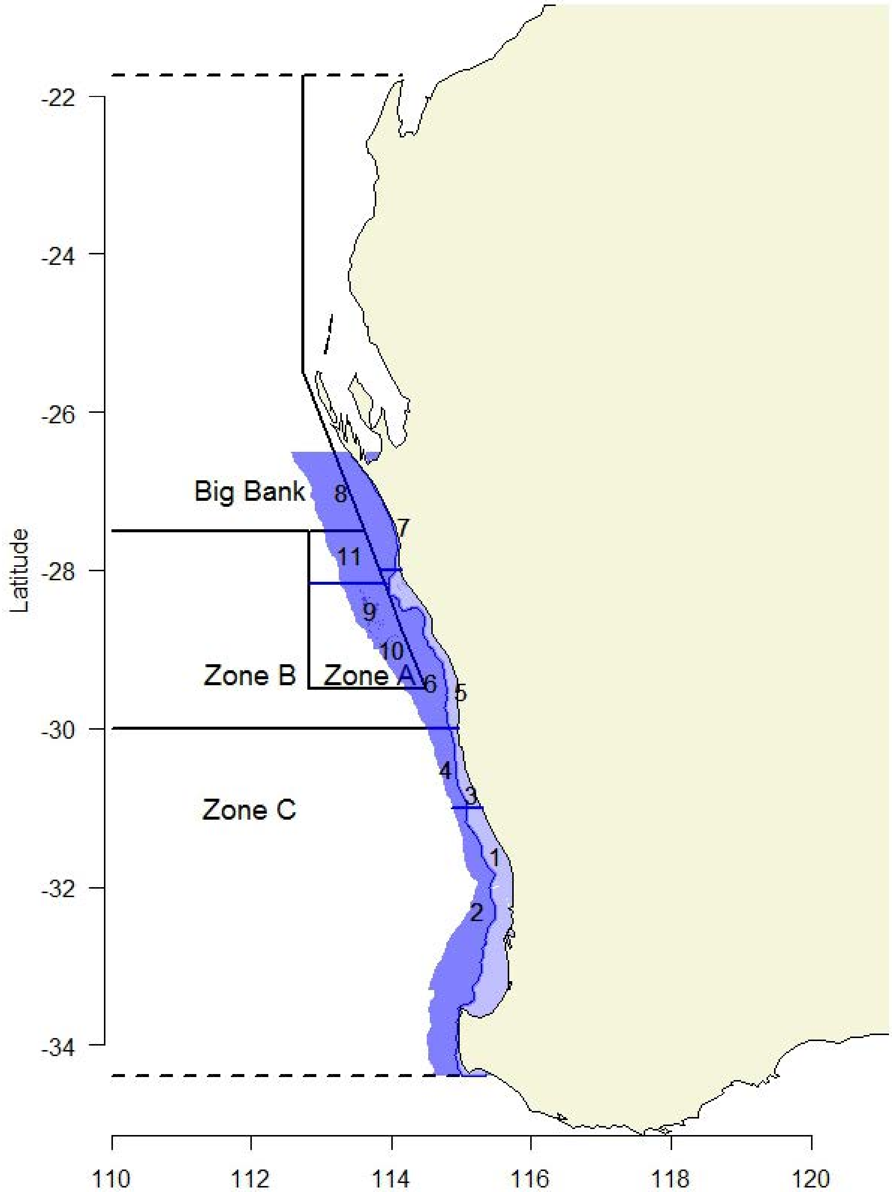

Figure 9-13 Shallow (light blue) and deep (dark blue) areas used in the integrated population model (1-11) and their boundaries (blue) relative to the boundaries and zones of the West Coast Rock Lobster Fishery

9.3.14.3 Input Data and Parameters

The model uses all available data sources from the fishery and fits to six independent data sources using individual objective functions; namely catch, commercial monitoring length-frequency, IBSS catch rates, IBSS length-frequency, growth data, movement data.

The commercial catch and effort and size composition data spans 52 years (1964 to 2015), pooled into 11 different time-steps and locations. The IBSS data spans 24 years (1991 to 2015) and is representative of six of the offshore regions in the model. The growth and movement data are based on the tagging (> 50 000) and recapture (>3000) of lobsters since 1992. Other data sources included in the model are monthly and site specific high-grading rates, monthly and site specific water temperatures derived from commercial monitoring, standardised for water depth and location, year-specific size at maturity, size at migration, size at egg bearing and size at setose relationships derived from IBSS and tag-recapture data, respectively.

Most of the parameters of the population dynamics model are estimated by fitting the model to the available data although some are pre-specified (Table 9-5). Overall 1555 parameters are estimated but a large number of these (1394) are deviations that are restricted in some form (e.g. summed to one) and are only implemented after the first stage of parameters have been estimated based on the fits to the available data.

Table 9-5 List of the parameters of the population dynamics model

Parameter	Treatment	
Population dynamics model		
Initial fishing mortality, F_r^I	Estimated (one per region)	
Growth increment parameter $\hat{M}_{s,r}^I$	Pre-specified	1.492 1.492 1.444 1.444 1.426 1.426 1.426 1.426 3.381 1.426 1.426 1.492 1.492 1.444 1.444 1.426 1.426 1.426 1.426 3.381 1.426 1.426
Growth increment parameter $\hat{I}_{s,r}^{50}$	Pre-specified	90.72 90.72 86.64 86.64 89.08 89.08 89.08 89.08 61.94 89.08 89.08 125.60 125.60 142.66 142.66 118.49 118.49 118.49 118.49 49.81 118.49 118.49
Growth increment parameter $\hat{S}_{s,r}^I$	Pre-specified	10.21 10.21 10.59 10.59 7.52 7.52 7.52 7.52 4.82 7.52 7.52 18.89 18.89 22.55 22.55 16.60 16.60 16.60 16.60 25.83 16.60 16.60
Normal distribution for whites, $K_{r,y,L}$, $P_{r,y}^{\Lambda}$, $\sigma_{r,y}^{\Lambda}$	Pre-specified	Appendix J in de Lestang et al., 2014
Egg production – length parameters, $L_{50,y}, L_{95,y}, D_{50,y}, D_{95,y}$,	Pre-specified	Appendix K in de Lestang et al., 2014
Annual natural mortality, M^τ	Pre-specified	0.30 0.22
Proportion of ovigerous females, $O_{r,t}$	Pre-specified	Appendix L in de Lestang et al., 2014
Average recruitment, R_r	Estimated (one per region)	
Proportion of setose females, $S_{r,t}$	Pre-specified	Appendix M in de Lestang et al., 2014
Availability to capture, $V_{r,y,t,L}^{\tau,s}$	Pre-specified	Appendix N in de Lestang et al., 2014
Weight-at-length $W_L^s = a_s L^{b_s}$	Pre-specified	a_f=1.6086E-06 a_m=2.5053E-06 b_f=2.8682 b_m=2.778
Catchability for reds, q_r^R	Estimated (one per region)	
Catchability for whites, q_r^1, q_r^2	Estimated (two per region)	
Discard mortality, δ	Pre-specified	0.03
Proportion of catch high graded ϖ	Pre-specified	0.1
Recruitment deviations, $\varepsilon_{\tilde{r},y}$	Estimated (one per year and transect)	
Temperature-catchability parameters, $\gamma_1, \gamma_2, \gamma_3$	Pre specified (three parameters)	-1.68 87.46 -1032.68
Movement rate, λ_r	Pre-specified	0.33 0.1 0.33 0.1 0.33 0.1 0.28 0.1 0.05 0.1 0.1
Impact of escape gaps, $\eta_{y,L}$	Pre-specified	Appendix N in de Lestang et al., 2014
Proportion recruiting by length, ϕ_L	Pre-specified	CV=0.05
Efficiency increase, $\theta_{r,y,t}^\tau$	Estimated	
Observation model		
Proportionality for the puerulus data, $\alpha_{\tilde{r}}$	Estimated	
IBSS selectivity, $\tilde{L}_{50}, \tilde{L}_{95}$	Estimated (two parameters)	
Catchability coefficient for the IBSS survey, $q_{r,t}^{IBSS}$	Estimated	
Puerulus count uncertainty, φ	Pre-specified	0.2
Catch measurement variation, σ_r^C	Estimated	
Extent of sampling error for the IBSS survey, $\sigma_{r,t}^{IBSS}$	Estimated	

9.3.14.4 Diagnostics

The model fits to six main data sources, with the main fits shown below (Figure 9-14 - Figure 9-21). The model reproduced the inter-annual pattern of commercial catch landings for the fishery as a whole and by management zone (Figure 9-14). A good fit also occurred with the catch rates of female and male lobsters recorded during the IBSS at all sites (Figure 9-15).

The size-compositions of female and male lobsters sampled during commercial monitoring (Figure 9-16;Figure 9-17), and the IBSS (Figure 9-18;Figure 9-19), all showed a generally good fit with the only obvious residuals occurring in the first length bin in a number of regions/areas. This suggests growth rates used in the model could be improved (albeit the fit is still very close). Further model development will have growth rates as a priority focus.

The model reproduced the viability measured in the puerulus indices very well as shown in the recruitment deviation plots (Figure 9-20). Observed puerulus settlement levels are converted into recruitment deviations by applying the model-estimated density dependency parameter for each respective area to the settlement in that area and then normalising the estimate of recruitment in each location (difference of each value from the time-series mean). The migration behaviour displayed by tagged lobsters was also well replicated by the model (Figure 9-21).

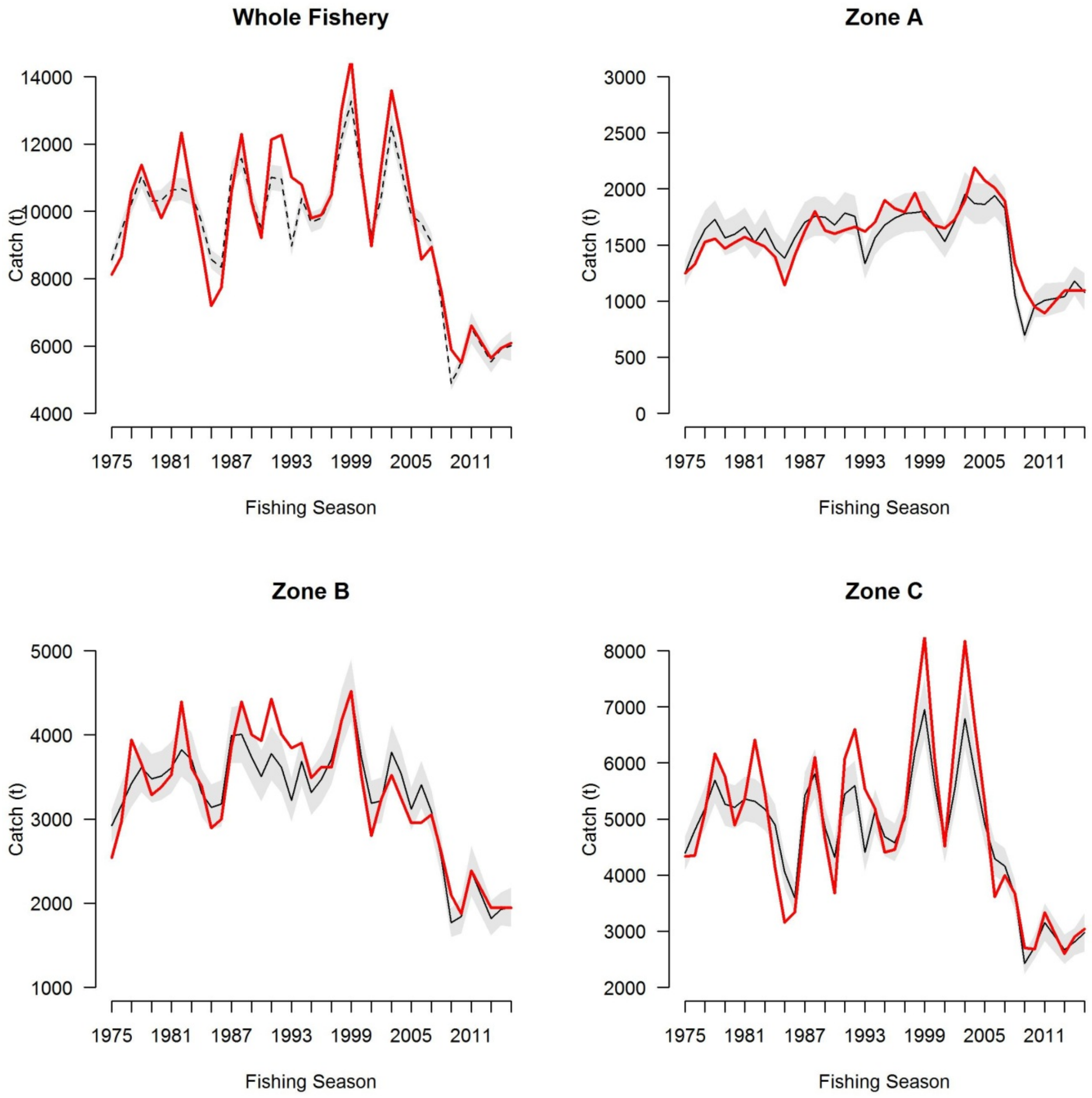

Figure 9-14 Actual (red line) and modelled catches (black line) with 95% CIs from the model (grey) for the whole fishery, and by management zone

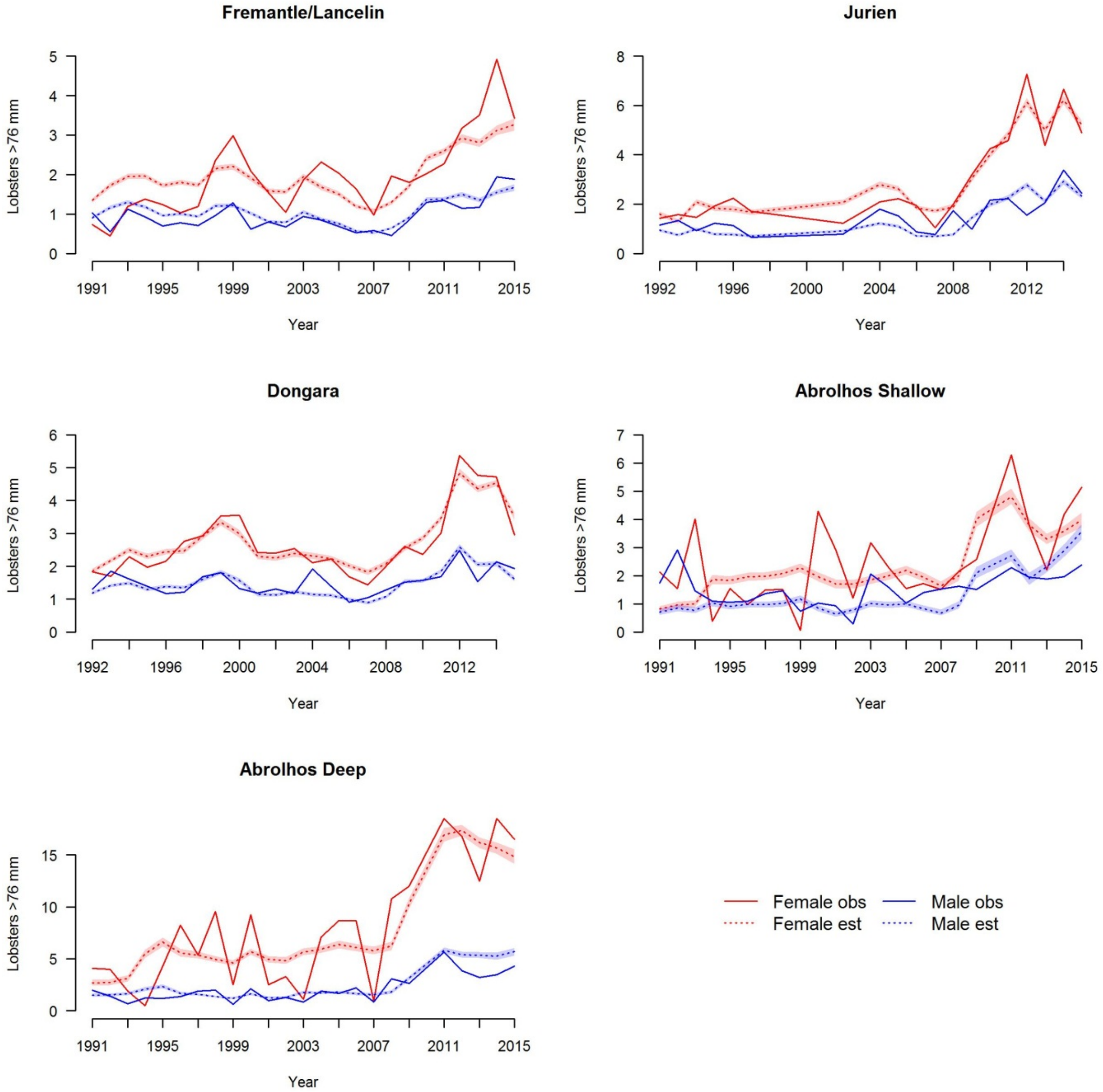

Figure 9-15 Actual (solid line) and estimated (dotted line) catch rates of legal male (blue) and female (red) lobsters from independent breeding stock surveys. Model estimated 95% CIs for each sex are shown by the shaded region

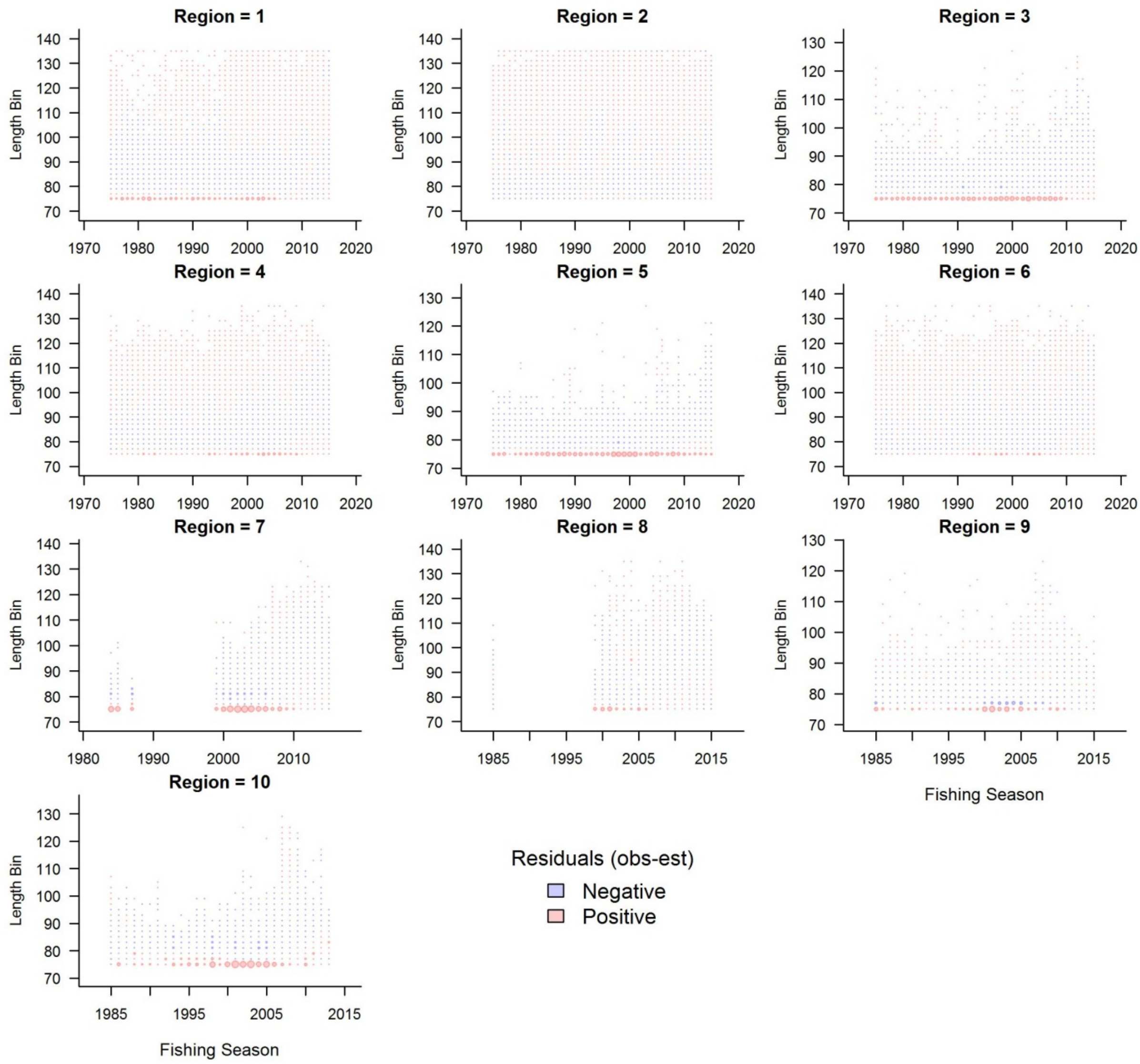

Figure 9-16 Size frequency residual plots of female lobsters in each region of the fishery where substantial length-composition data is collected on-board commercial fishing vessels.

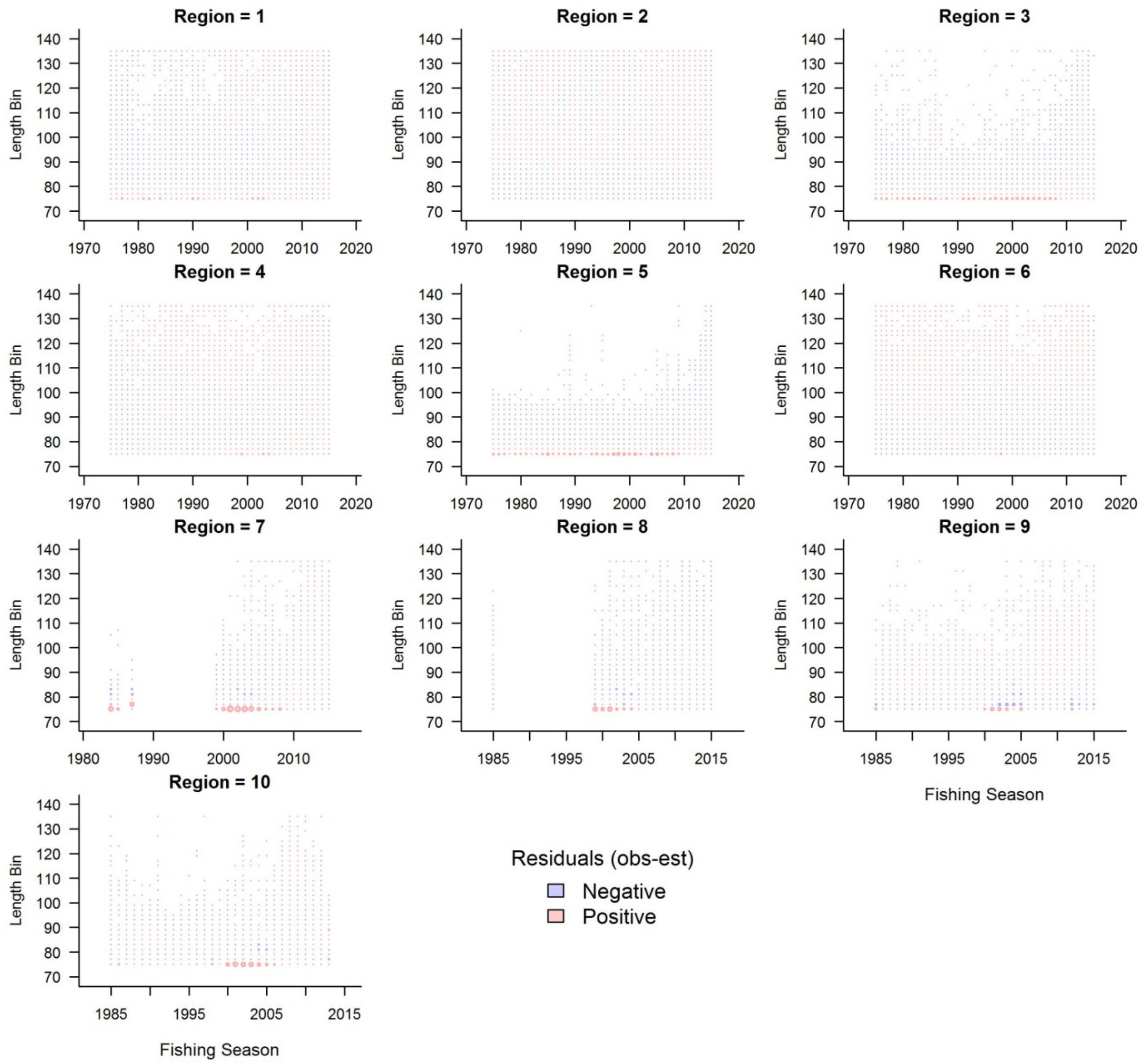

Figure 9-17 Size frequency residual plots of male lobsters in each region of the fishery where substantial length-composition data is collected on-board commercial fishing vessels.

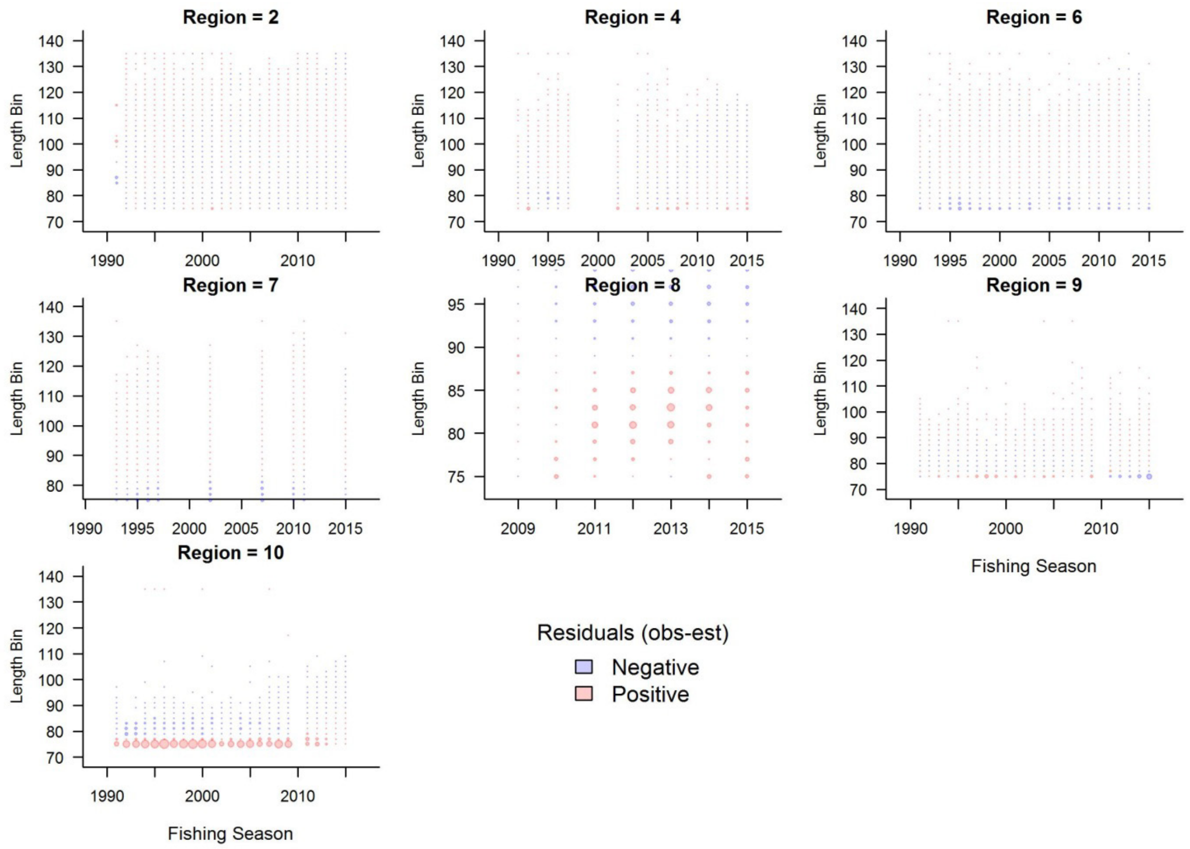

Figure 9-18 Size frequency residual plots of female lobsters at each IBSS location.

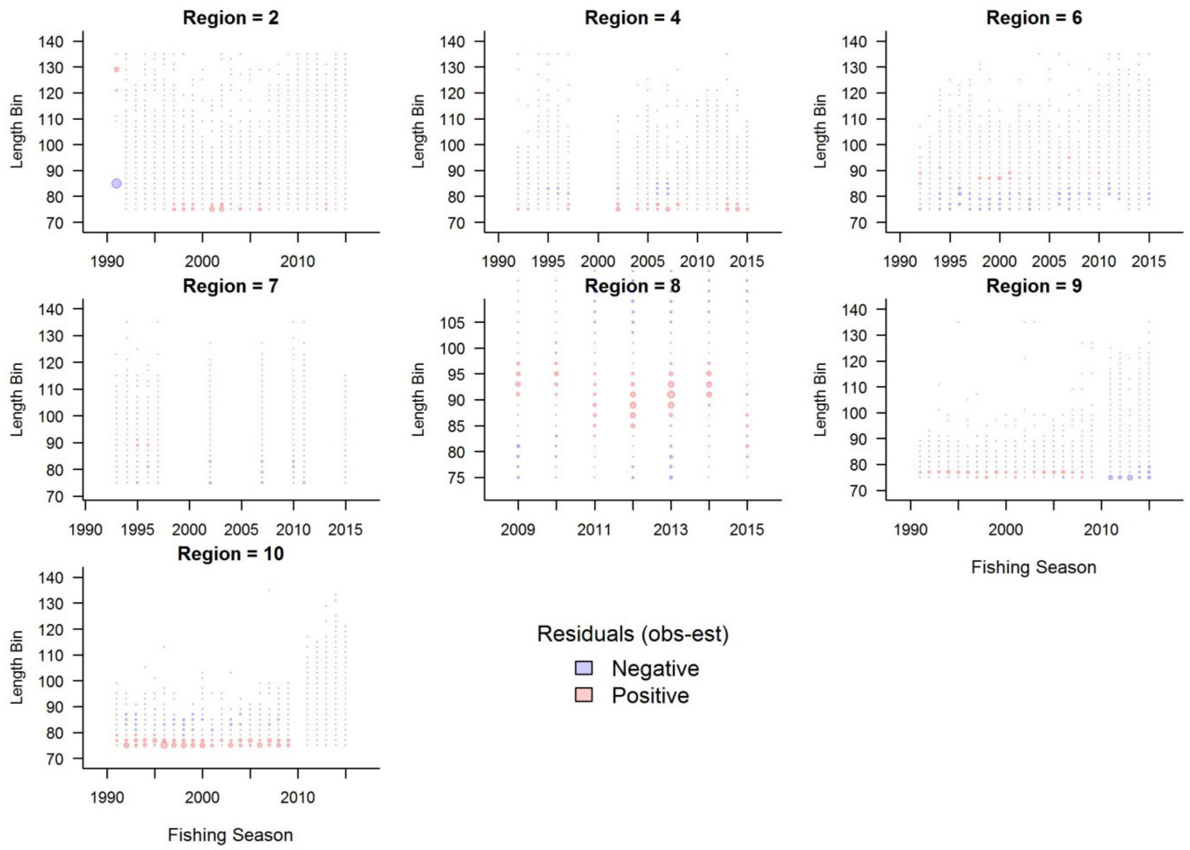

Figure 9-19 Size frequency residual plots of male lobsters at each IBSS location.

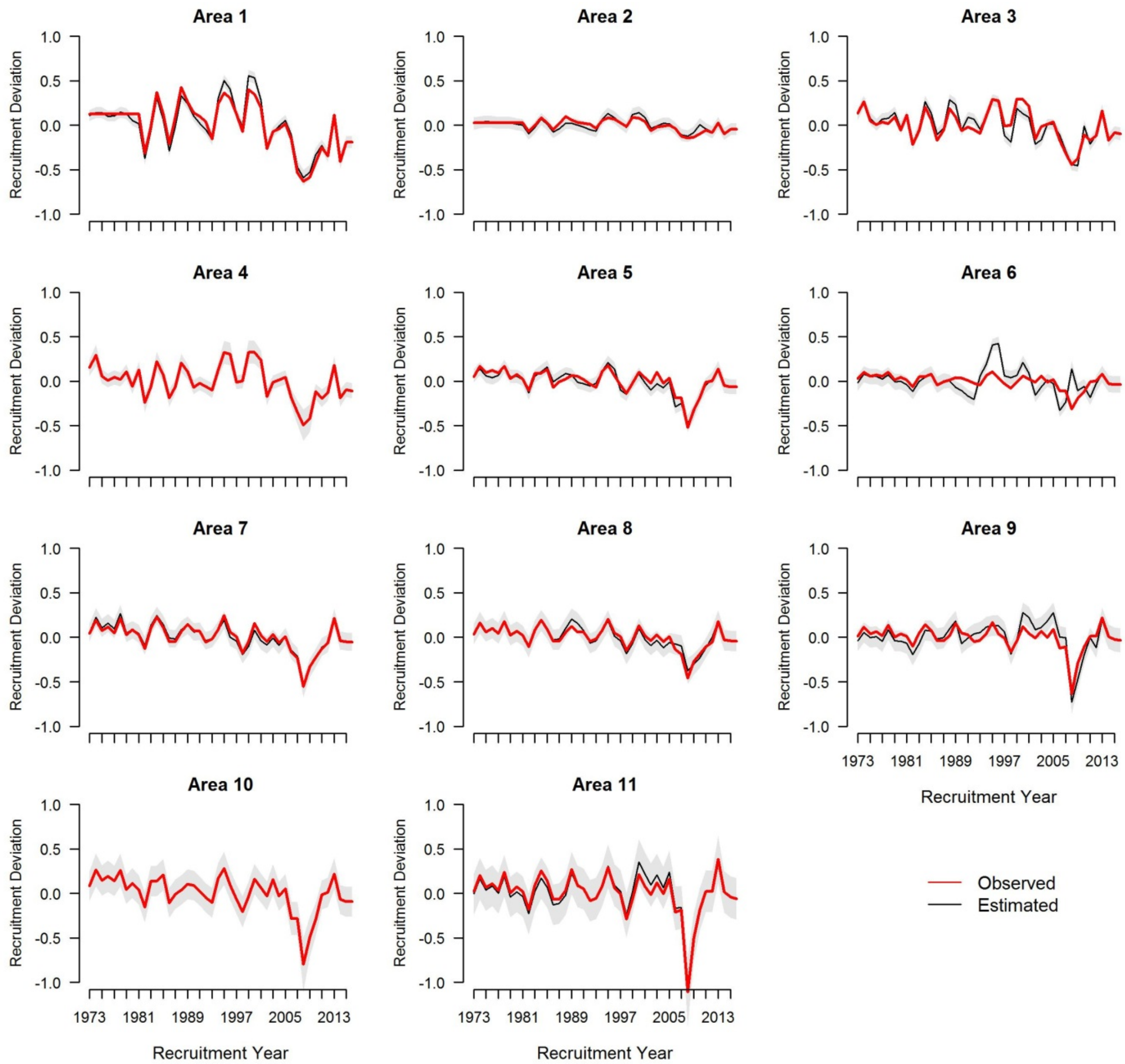

Figure 9-20 Actual (solid red line) and estimated (black line) recruitment deviations, with estimated 95% CIs shaded grey. Model estimated deviations are parameters estimates of the difference from average recruitment. Observed recruitment deviations are the respective areas puerulus settlement levels converted to a recruitment index using a model estimated density-dependence parameter (see text).

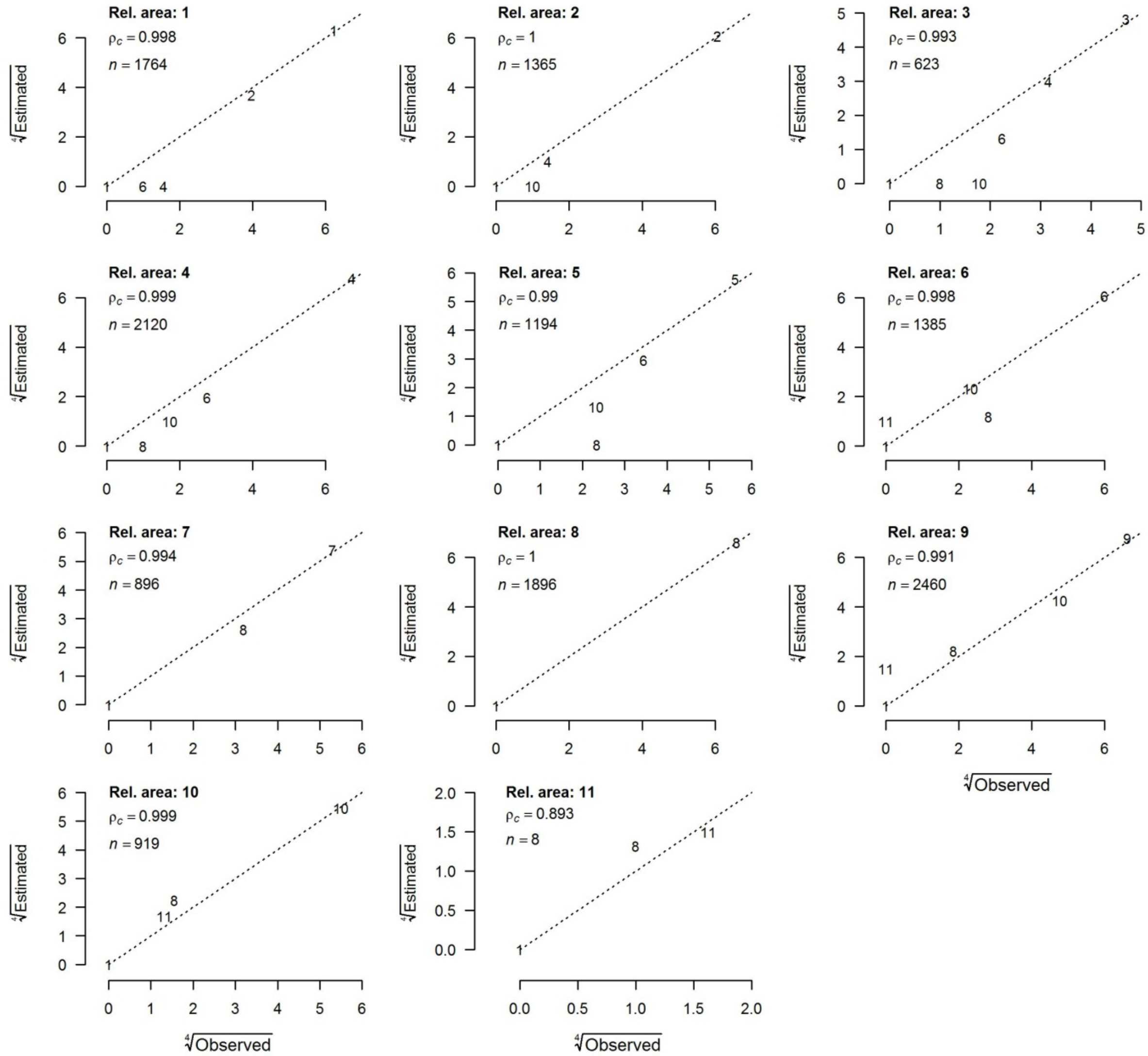

Figure 9-21 Comparisons of observed (x-axes) and estimated (y-axes) recapture location of tagged lobsters released in each of the 11 areas used in the model. For each release area the numbers on the plot represent the area number of their recapture location and their position along the axes are the fourth-root of the number of lobsters the point represents. The diagonal dotted is the identity line, ρ_c is the concordance correlation coefficient and *n* represents the sample size of all lobsters released and recaptured in that area.

9.3.14.5 Results

The model estimates of lobster biomass (all legal lobsters) follows the same pattern as those produced by the BDM (Figure 9-12), decreasing progressively until the late 2000s before increasing markedly to about 25 000 t, and predicted to increase or remain steady at this level with current harvest rates (Figure 9-22).

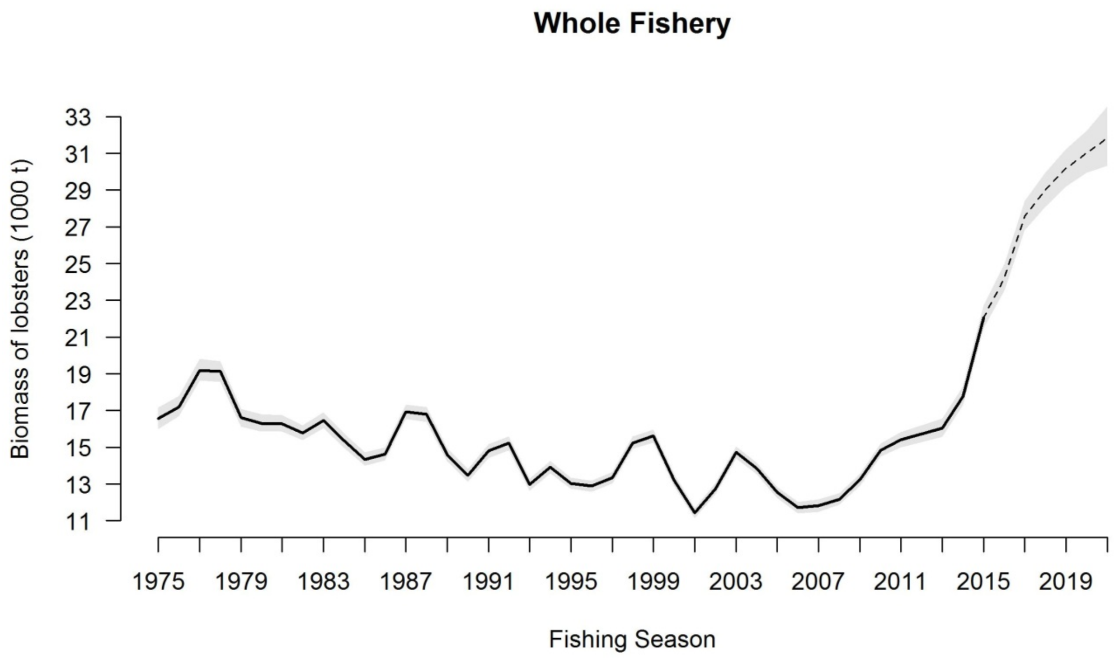

Figure 9-22 Model estimate (black) and associated 95% CIs (grey) biomass of legal size lobsters (>76 mm CL) for the whole fishery

Harvest rate estimates for the northern and southern regions of the western rock lobster fishery each follow the same trajectory, which were similar to that produced by the BDM, albeit these harvest rates are the proportion of the legal biomass caught, whereas those produced by the BDM are the proportion of all lobster > 76 mm caught by the fishery. As such the indicies are on a slightly different scale for much of the time series. The point where they are most comparable is 2015 onwards since many of the protections historically provided to female lobsters have now been removed and there is similarity between all lobsters > 76 mm and all legal lobsters. The IPM estimates that curent harvest rates in the two zones are between 25% and 30% of the legal biomass, and projected to remain steady or decline at current TACCs (Figure 9-23).

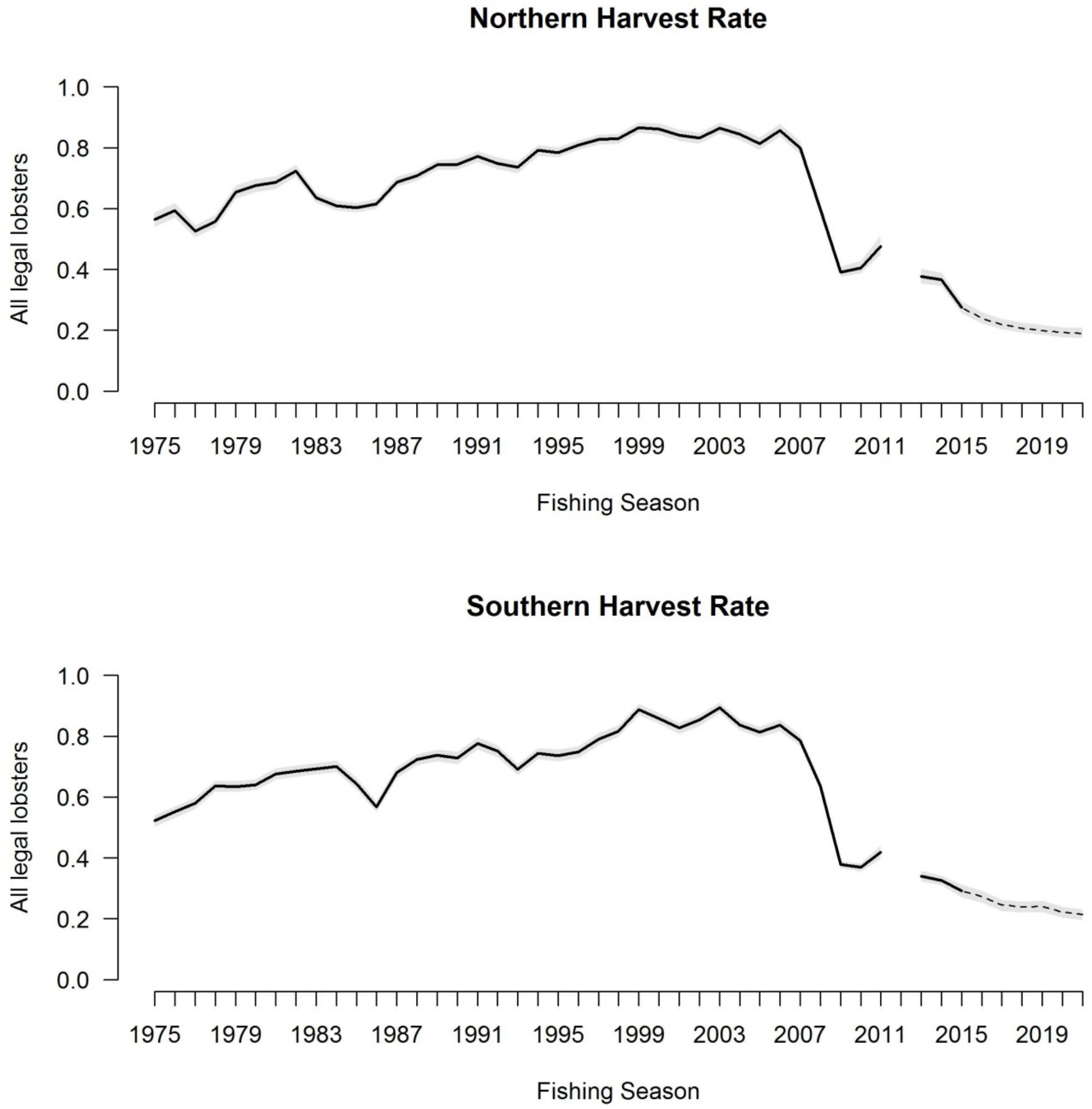

Figure 9-23 Model estimate (black) and 95% CIs (grey) of harvest rate of legal size lobsters (>76 mm CL) for the northern (A& B zones) and southern (C zone) regions of the fishery

Model projections of expected catch rates under a constant future TACC of 6300 t for seasons 2017 – 2020, show a progressive rise over the period, generally with a marked increase associated with 2017 (Figure 9-24). This is due to the recruitment into the fishery of a large number of lobsters following a good puerulus settlement in 2013/14.

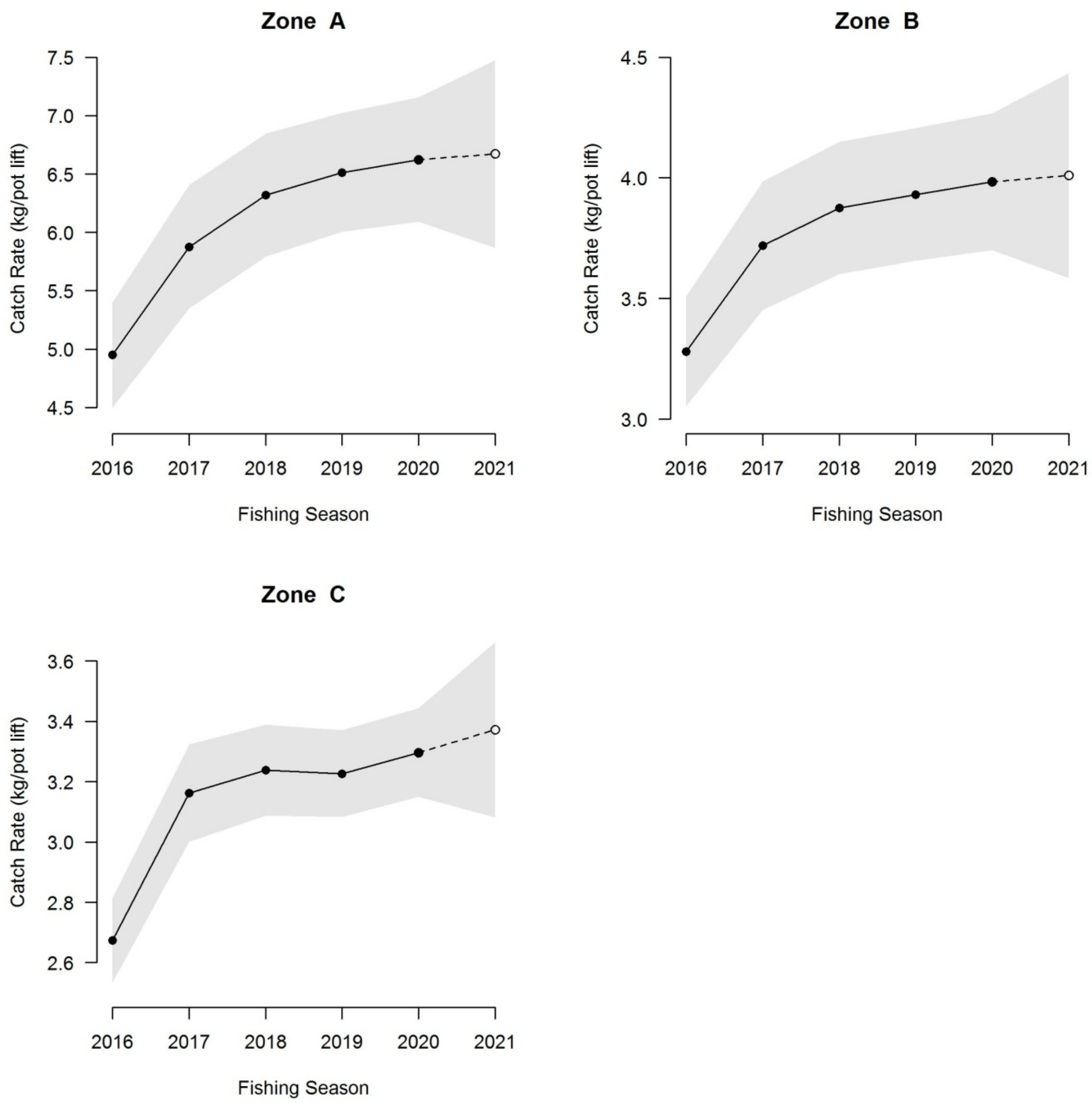

Figure 9-24 Model estimate (black) and 95% CIs (grey) of catch rates in the three management zones of the fishery assuming a constant future catch of 6300 t.

Estimates of egg production from the IM show steady levels in the Shallow Abrolhos before an increase after the late 2000s, whereas the other three regions show progressive declines during the early years followed by a small increase in the mid-1990, a time when strict regulations were introduced to protect breeding female lobsters. Egg production then declined somewhat into the 2000s before a rapid increase was seen in all locations to current record levels. This is a similar pattern to those shown by the IBSS. The IPM projects that egg production will remain high and increase further under current harvest rates and will remain above its respective threshold levels with 75% certainty over the projected five fishing seasons (Table 9-6; Figure 9-25).

Table 9-6 Model estimates for median (and lower 25 percentile) egg production index in the four Breeding Stock Management Areas and the respective values of their threshold and limit reference points.

	Breeding Stock Management Area			
Season	Abrolhos	Northern	Central	Southern
2016	410.4 (391.5)	381.4 (366.4)	374.4 (358.1)	608.5 (583.8)
2017	419.7 (399.9)	418.0 (402.6)	405.4 (387.0)	668.6 (639.8)
2018	422.0 (402.0)	443.8 (427.6)	429.8 (409.5)	752.3 (718.8)
2019	457.5 (428.6)	499.0 (482.2)	548.9 (526.8)	854.7 (819.5)
2020	457.1 (416.7)	510.1 (491.6)	559.6 (532.7)	886.8 (848.1)
Threshold	235.6	175.0	99.7	112.6
Limit	188.5	140.0	79.8	90.1

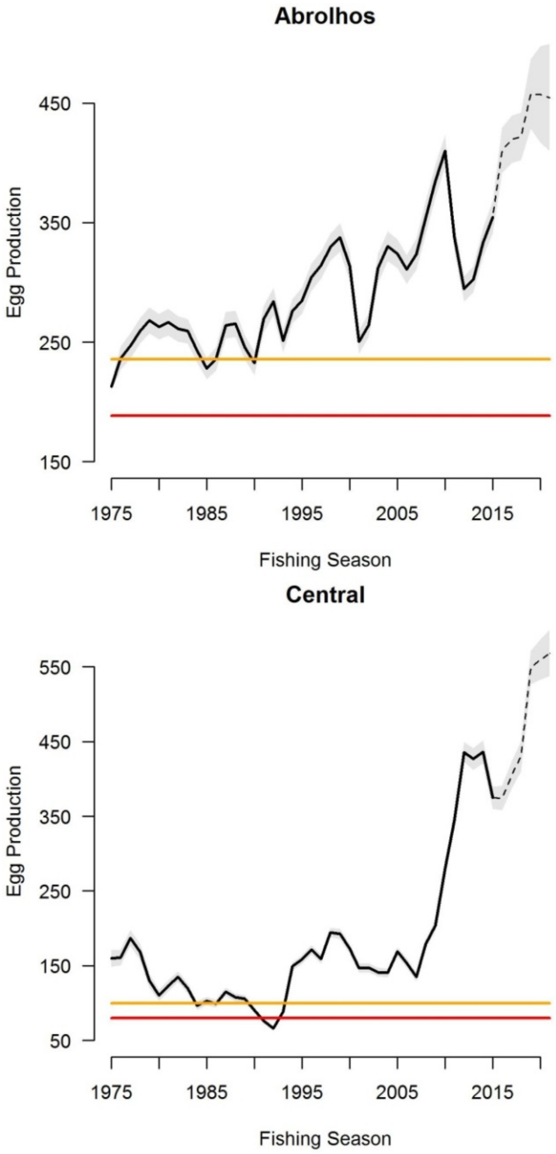

Figure 9-25 Modelled estimates (black) and projections (dotted line) of egg production for the four breeding stock management areas. The 75% CI is denoted in grey. Horizontal lines represent the threshold (orange) and limit (red) reference point for breeding stock levels in each breeding stock management area

9.3.14.6 Accounting for Uncertainty

Uncertainty associated with all data sources is included where possible, i.e. into the likelihood calculations. ADMB uses the "delta method" to determine standard deviations of any parameter or derived time series. MCMC is run on the final model fit to develop better estimates of uncertainty around projections. 400 000 MCMC runs are conducted, saving every 100th iteration with a burn-in of 5000. Convergence criteria indicate that this protocol is appropriate. Many of the predetermined parameters are implemented into the model as estimated parameters with penalties based on their variance to tie them "appropriately" to their previously-determined value.

9.3.14.7 Conclusion

The IPM indicates that the biomass and egg production in all locations of the fishery is at record high levels since the mid-1970s, and that a continuation of fishing at similar or slightly higher TACCs (e.g. 6300 t) will continue to result in increasing biomass and catch rates. The IPM currently predicts that the fishery is fishing at harvest rates of between 25 and 30%. These will continue to decline at current or slightly higher TACCs.

9.3.15 Bio-Economic Assessment

9.3.15.1 Overview

An economic function has been added onto the biological IPM. This is implemented in R in conjunction with scenario runs of different harvest rates of fishing in the IPM. This bio-economic modelling is used to help determine in what direction the fishery should move to fish closer to Maximum Economic Yield (Caputi et al. 2015b).

9.3.15.2 Model Description

The model uses the changes in effort projected to be required by the fishery to fish at a range of harvest rates to determine the change in costs associated with fishing at each of those harvest rates. The variations in cost are then compared to changes in production value and the impacts this production has on the price of lobsters. These variations in changes in cost include direct changes in pot lifts (i.e. fuel and bait) as well as the number of vessels required (and their associated costs such as insurance, maintenance and storage).

9.3.15.3 Input Data and Parameters

The model uses cost information derived from an FRDC report (Winzer, 2008), updated with phone surveys in 2014. The number of vessels – pot lift relationship is based on historical data and an assumption that a vessel will only work 250 days / season and pull a maximum of 150 pots. The catch-price relationship is derived from commercial catch landings and processor reported beach prices during the last 45 days of the fishing season. This period is chosen as fisher's quotas are almost extinguished and the market begins to show a marked price response to a decline in supply.

9.3.15.4 Results and Diagnostics

It is not currently possible for the bio-economic model to predict the actual TACC or harvest rate that would be associated with MEY because this point is too far from the fisheries current position. As the fishery moves closer to MEY a better estimate of its general location can be achieved. Current bio-economic modelling suggests that increasing the TACC would move the fishery closer to MEY (Figure 9-26).

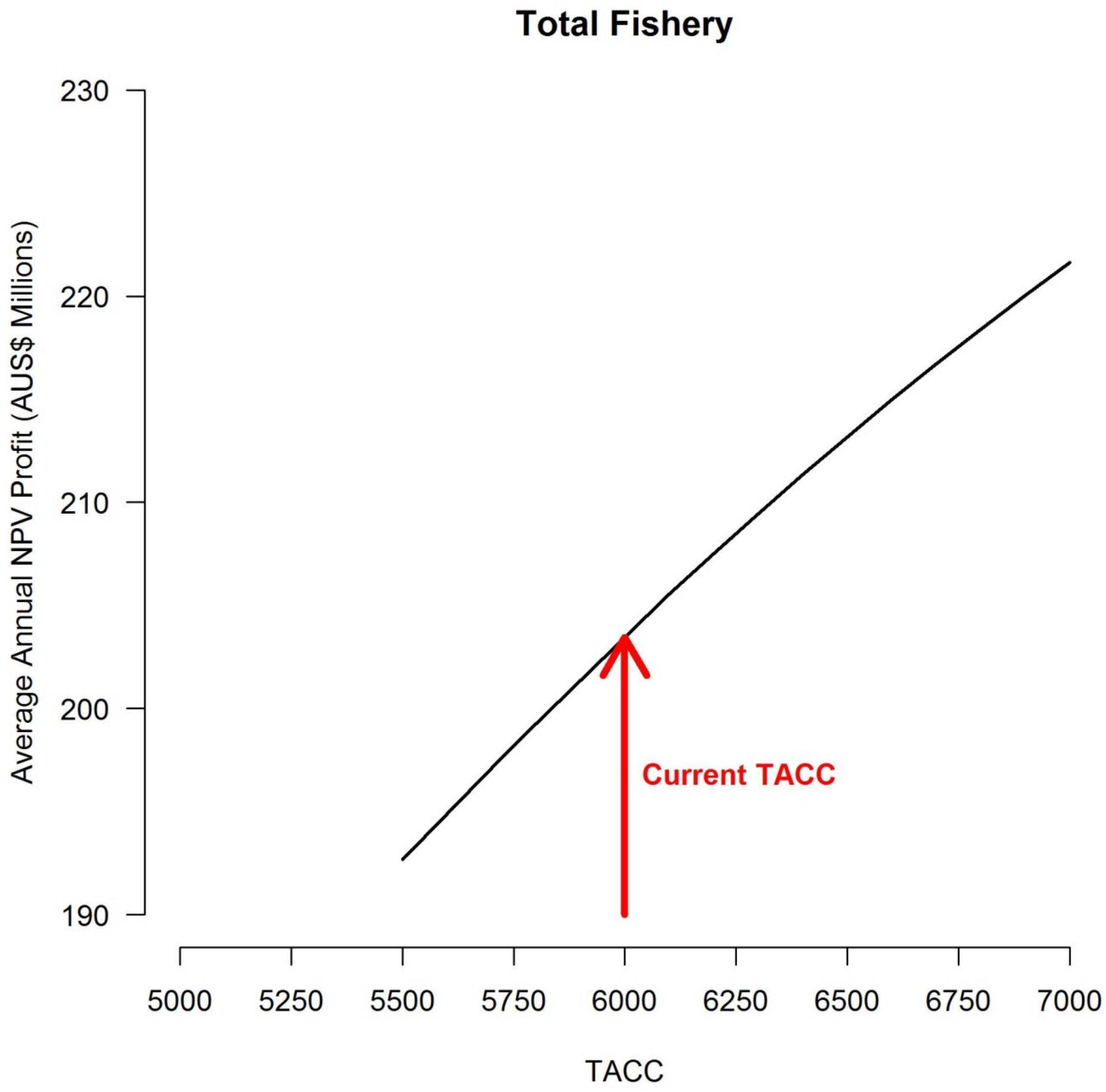

Figure 9-26 MEY analysis of the Western Rock Lobster fishery indicating that an increase in TACC would move the fishery towards maximising its economic yield. The Current TACC is shown in red.

9.3.15.5 Accounting for Uncertainty

Sensitivity analyses have been conducted on all of the main inputs into the bio-economic model; namely variation in costs (± 5%), exchange rate and the catch-price relationship. The only input which had a significant impact on the estimates of MEY was the catch-price relationship. The model was found to be very sensitive to this value. As such the relationship used in the modelling to estimate the direction of MEY was far more conservative than suggested by economic experts (Economic Research Associates 2015).

9.3.15.6 Conclusion

Bio-economic modelling indicates that the fishery should increase its quota if it were to fish closer to the levels associated with MEY.

9.3.16 Other Modelling / Methods

Not applicable.

9.4 Stock Status Summary

9.4.1 Weight of Evidence Risk Assessment

Presented below is a summary of each line of evidence considered in the overall weight of evidence assessment of the stocks that comprise the western rock lobster.

Table 9-7 Weight of evidence table for western rock lobster

Category	Lines of evidence (Consequence / Status)
Catch	Catches in the WCRLMF have increased slightly over the past few seasons due to small increases in quota and an increase in recreational catch; however they remain below 55% of the historical average level of catch. The catches being relatively low and quotas having historically been easily obtained, indicates that there is a low risk of the stock being over exploited.
Catch distribution	The slight change in the spatial distribution of the catch to increased landings in deep-water regions during the whites migration has been in response to increased market demand and thus higher beach prices being offered during this period. The data do not represent a spatial shift in effort indicative of serial depletion within the fishery.
Catch rates	Standardised catch rates provide an overall measure of lobster biomass. Trends in these indices indicate that biomasses in recent years are over three-times greater than they were under input controls and are either remaining stable under current harvest rates or increasing. These indices suggest that the lobster stock is at low risk of being overfished. The Biomass Dynamics Model (BDM) indicates that at slightly increased TACC levels (e.g. 6300 t) the catch rates will increase slightly or remain steady over the subsequent five seasons. The Integrated Population Model (IPM) indicates that catch rates in all locations of the fishery will continue to increase with a continuation of fishing at similar or slightly higher TACCs (e.g. 6300 t).

Fishery-independent monitoring	Fishery-independent recruitment (puerulus) monitoring indicates that the current puerulus settlement is continuing its recent pattern. The IPM suggests that this current level of settlement is sufficient to maintain/increase stock abundance levels at current harvest levels. Fishery-independent index on lobster damage indicates that recent increases in high-grading are not leading to increases in the proportion of lobsters in the population with damaged appendages.
Vulnerability (PSA)	The total PSA scores was 1.96 for the Western Rock Lobster, with the MSC PSA score being 96 out of 100. This classifies this species as being of low risk to over-exploitation.
Age and / or size composition	There is no indication of a reduction in the contribution of large lobsters to the commercial catch.
Fishing mortality (*F*)	The BDM currently predicts that the fishery is fishing at harvest rates of about 30%. These will remain similar or to decline at current or slightly higher TACCs. The IPM currently predicts that the fishery is fishing at harvest rates of between 25 and 30%. These will continue to decline at current or slightly higher TACCs.
Spawning biomass (*B*)	Fishery-independent egg production indices at all sites are well above long-term levels. These indices indicate high levels of spawning stock exist throughout the fishery. The BDM indicates that the stock biomass is currently high, more than double that in the early 2000s and that at slightly increased TACC levels (e.g. 6300 t) the biomass will increase slightly or remain steady over the subsequent five seasons. The IPM indicates that the biomass and egg production in all locations of the fishery is at record high levels since the mid-1970s, and that a continuation of fishing at similar or slightly higher TACCs (e.g. 6300 t) will continue to result in increasing biomass and catch rates.

Table 9-8. Western Rock Lobster risk matrix. The maximum risk score is highlighted in bold

Consequence (Stock Depletion) Level	Likelihood					**Risk Score**
	L1 Remote (<5%)	L2 Unlikely (5-30%)	L3 Possible (30-50%)	L4 Likely (50-90%)	L5 Certain (90-100%)	
C1 Minimal				■		**4**
C2 Moderate		■				**4**
C3 High	■					3
C4 Major	NA					NA
C5 Catastrophic	NA					NA

C1 (Minimal Depletion – Above Target): **L4** - Based on the catch history, current catch rates and model estimate and projections it is very likely that the level of current stock depletion is minimal and the stock biomass is above its target as it is being harvested below its MEY level. Model projections indicate that this scenario will become more certain over time if harvest rates stay as low as they are currently.

C2 (Maximum Acceptable Depletion – Above Threshold): **L2** - All of the lines of evidence indicate that the level of stock depletion is well below threshold levels. Most notably the three biomass indicators all suggest biomass are two – three time greater than they were in the mid-2000s and increasing at current harvest rates.

C3 (Unacceptable Depletion – Below Threshold): **L1** – There is no evidence of the stock has been depleted unacceptably. It is therefore remote that the biomass is in this condition.

C4 (Unacceptable – Below Limit): Not plausible.

C5 (Catastrophic): Not plausible.

9.4.2 Management Advice

The maximum risk score for Western Rock Lobster in the West Coast Bioregion is 4 and was generated by the combination of C1 and L4. This constitutes a Low Risk which is the minimum acceptable risk level.

This score assumes the total catch will be maintained within a 5% increase per season over the following two seasons. TACC scenarios outside of this range will require a re-assessment.

9.4.3 Previous Assessments

This assessment has come to the same conclusion as the last. The stock is in a very healthy state and possibly being exploited below that which would represent MEY.

9.4.4 Future Monitoring

Additional work needs to be focussed on catchability issues associated with the catch rates of lobsters under the current scenario of very high biomass levels. Work into the productivity of the stock under high biomass levels and how this may be related to carrying capacity / density dependent mortality is essential to implement the correct relationships in the IPM.

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Appendix 1

Consequence, Likelihood and Risk Levels (based on AS 4360 / ISO 31000) considered in the Department's Risk Assessment Framework

CONSEQUENCE LEVELS

1. Minimal – Measurable but minor levels of depletion of fish stock
2. Moderate – Maximum acceptable level of depletion of stock
3. High – Level of depletion of stock unacceptable but still not affecting recruitment level of the stock
4. Major – Level of depletion of stock are already (or will definitely) affect future recruitment potential level of the stock
5. Catastrophic – Permanent or widespread and long-term depletion of key fish stock, close to extinction levels

LIKELIHOOD LEVELS

1. Remote – Never heard of but not impossible here (< 5 % probability)
2. Unlikely – May occur here but only in exceptional circumstances (> 5 %)
3. Possible – Clear evidence to suggest this is possible in this situation (> 30 %)
4. Likely – It is likely, but not certain, to occur here (> 50 %)
5. Certain – It is almost certain to occur here (> 90 %)

Consequence × Likelihood Risk Matrix		Likelihood				
		Remote (1)	Unlikely (2)	Possible (3)	Likely (4)	Certain (5)
Consequence	Minimal (1)	1	2	3	4	5
	Moderate (2)	2	4	6	8	10
	High (3)	3	6	9	12	15
	Major (4)	4	8	12	16	20
	Catastrophic (5)	5	10	15	20	25

Risk Levels	Description	Likely Reporting & Monitoring Requirements	Likely Management Action
1 Negligible	Acceptable; Not an issue	Brief justification – no monitoring	Nil
2 Low	Acceptable; No specific control measures needed	Full justification needed – periodic monitoring	None specific
3 Medium	Acceptable; With current risk control measures in place (no new management required)	Full Performance Report – regular monitoring	Specific management and/or monitoring required
4 High	Not desirable; Continue strong management actions OR new / further risk control measures to be introduced in the near future	Full Performance Report – regular monitoring	Increased management activities needed
5 Severe	Unacceptable; Major changes required to management in immediate future	Recovery strategy and detailed monitoring	Increased management activities needed urgently

Appendix 2

Productivity Susceptibility Analysis (PSA) Scoring Tables

Productivity attribute	High productivity Low risk Score = 1	Medium productivity Medium risk Score = 2	Low productivity High risk Score = 3)
Average maximum age	<10 years	10-25 years	>25 years
Average age at maturity	<5 years	5-15 years	>15 years
Average maximum size (not to be used when scoring invertebrates)	<1000 mm	1000-3000 mm	>3000 mm
Average size at maturity (not to be used when scoring invertebrates)	<400 mm	400-2000 mm	>2000 mm
Reproductive strategy	Broadcast spawner	Demersal egg layer	Live bearer
Fecundity	>20,000 eggs per year	100-20,000 eggs per year	<100 eggs per year
Trophic level	<2.75	2.75-3.25	>3.25
Density dependence (only to be used when scoring invertebrates)	Compensatory dynamics at low population size demonstrated or likely	No depensatory or compensatory dynamics demonstrated or likely	Depensatory dynamics at low population sizes (Allele effects) demonstrated or likely

Susceptibility attribute	Low susceptibility Low risk Score = 1	Medium susceptibility Medium risk Score = 2	High susceptibility High risk Score = 3)
Areal overlap (availability) i.e. overlap of fishing effort with stock distribution	<10% overlap	10-30% overlap	>30% overlap
Encounterability i.e. the position of the species / stock within the water column / habitat relative to the position of the fishing gear	Low encounterability / overlap with fishing gear	Medium overlap with fishing gear	High encounterability / overlap with fishing gear (Default score for target species in a fishery)
Selectivity of gear type Potential of gear to retain species	a) Individual < size at maturity are rarely caught	a) Individual < size at maturity are regularly caught	a) Individual < size at maturity are frequently caught
	b) Individual < size can escape or avoid gear	b) Individual < half the size can escape or avoid gear	b) Individual < half the size are retained by gear
Post-capture mortality i.e. the chance that, if captures, a species would be released and that it would be in a condition permitting subsequent survival	Evidence of majority released post-capture and survival	Evidence of some released post-capture and survival	Retained species or majority dead when released