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Stock Assessment for the West Coast Rock Lobster Fishery

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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, worth $200 – 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. 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 accounts for about 3 – 4% 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. 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%." (http://www.fish.wa.gov.au/Documents/management_papers/fmp239.pdf). The commercial fishery was managed by a total allowable effort (TAE) up to the 2008/09 season as well as associated biological controls (eg. size limits). Subsequently, overall commercial catch limits were introduced, with individual catch limits operating since the 2010/11 fishing season.

Department of Fisheries researchers have an ongoing program to monitor settlement of puerulus, catches of the commercial fleet (through on-board sampling and logbooks), the breeding stock, recreational catches, and environmental conditions. This information is used to assess changes in the stocks of the western rock lobster and input into a population dynamics 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 have been subject to independent, external review by stock assessment experts (see: http://www.fish.wa.gov.au/Documents/occasional_publications/fop050.pdf & http://www.fish.wa.gov.au/Documents/occasional_publications/fop081.pdf). These indices include:

- Trends in puerulus settlement which are affected by environmental factors (e.g. Leeuwin Current); puerulus settlement has been used to predict catches 3 – 4 year ahead
- Trends in fishery-dependent breeding stock indices (basis of original threshold BRP);
- Trends in fishery-independent breeding stock indices;
- Stock modelling of the fishery that integrates information on recruitment, catch rates of legal and sub-legal lobsters, the size composition of lobsters, migration patterns, tag-recaptured lobsters and breeding stock catch compositions.

There are three fishery management zones. The status of egg production in each of these zones in 2011 was as follows:

- Modelled egg production in **Zone A** (Abrolhos Islands), **Zone B** (Northern Coastal) and **Zone C** (Southern Coastal) at the end of the 2010/11 fishing season were all above respective threshold reference points and are predicted to remain above these levels with 75% certainty in five years time under the current level of commercial catch of 5500 t per season. Breeding stock surveys on coastal sites have recorded improved egg production (historic maximum or near maximum levels) in recent years.
- Levels of recruitment in all zones have been well below average levels since 2006/07 (five consecutive seasons). Low levels in 2006/07 were likely linked to poor water temperatures during early larval life. The following three settlements 2007/08, 2008/09 (lowest level of record) and 2009/10 do not appear solely related to cool water temperatures during early larval life. The cause of these low levels is currently the focus of a number of research projects. The most recent completed settlement year (2010/11), although again below average, was significantly greater than the three previous years at most sites. The fact that this settlement was again below average may be explained by the below average water temperatures during early larval life and weak storm fronts during spring. Offshore water temperatures in 2011, which have historically positively influenced the subsequent settlement (2011/12), were well above average.
- The fishery has historically been an input controlled fishery, however a nominal Total Allowable Commercial Catch (TACCs) limit was imposed on the fishery in 2008/09 and 2009/10 fishing seasons with individual catch limits set in 2010/11. Each zone is allocated a portion of the TACC and biological controls (e.g. female maximum size and protection of setose females) have remained to ensure the protection of the breeding stock. The TACC for the 2010/11 fishing season was set at 5500 t.
- Proactive management measures were introduced in 2008/09 and 2009/10 as a result of the low puerulus settlement. This resulted in nominal fishing effort reductions of 44 and 72% (compared to 2007/08) and ensured a carryover of legal-size lobsters to assist in maintaining

the breeding stock above threshold levels over the five year period. This resulted in catches of 7600 and 5900 t in 2008/09 and 2009/10, respectively, compared to the catch predictions based on historic (2007/08) levels of fishing effort of 9200 and 8700 t, respectively. These large reductions in catch (up to 4400 t) resulted in significant increases in the residual biomass during these two years which flowed into the predicted low recruitment years commencing in 2010/11.

Background to this Report

Note that this report does not deal with either the social aspects of the fishery or its ecological interactions. Ecological issues relating to the fishery are dealt with in Department of Fisheries (2011).

This document is a "living" document, with a synopsis of available biological information on *Panulirus cygnus*, a guide to the on-going monitoring undertaken by the Department of Fisheries, and an indication of the analyses used by management to make decisions.

This document will be amended to reflect changes to procedures, and updated regularly. As such, the following table outlines the point in time to which the current document is updated for each data sources or sections.

Table (i) The periods to which the various data sources and/or sections are updated to in this document.

Section / data source	Current to
Catch and Effort Statistics	2010/11 season
Management Arrangements	July 2011
Puerulus indices	2010/11 settlement
Commercial Monitoring data	2010/11 season
Independent Monitoring data	2010 survey
Environmental data	2010
Recreational survey data	2010/11 season
Meshed pot survey data	July 2011
Fishing Efficiency	2009/10 season
Biological Stock Assessment Model	July 2011
Stock Status	July 2011

1.0 The Fishery

The western rock lobster (*Panulirus cygnus*) is fished by three managed fisheries; West Coast Rock Lobster Managed Fishery (WCRLMF), Augusta–Windy Harbour Managed Fishery and the South Coast Crustacean Fisheries. These fisheries extend over the whole of the lobster's range (Figure 1.0–1). The WCRLMF is the largest fishery encompassing most of the western rock lobster's (WRL) geographic range (Figure 2.3–1), including the most productive regions. The resource in this fishery is the focus of this report.

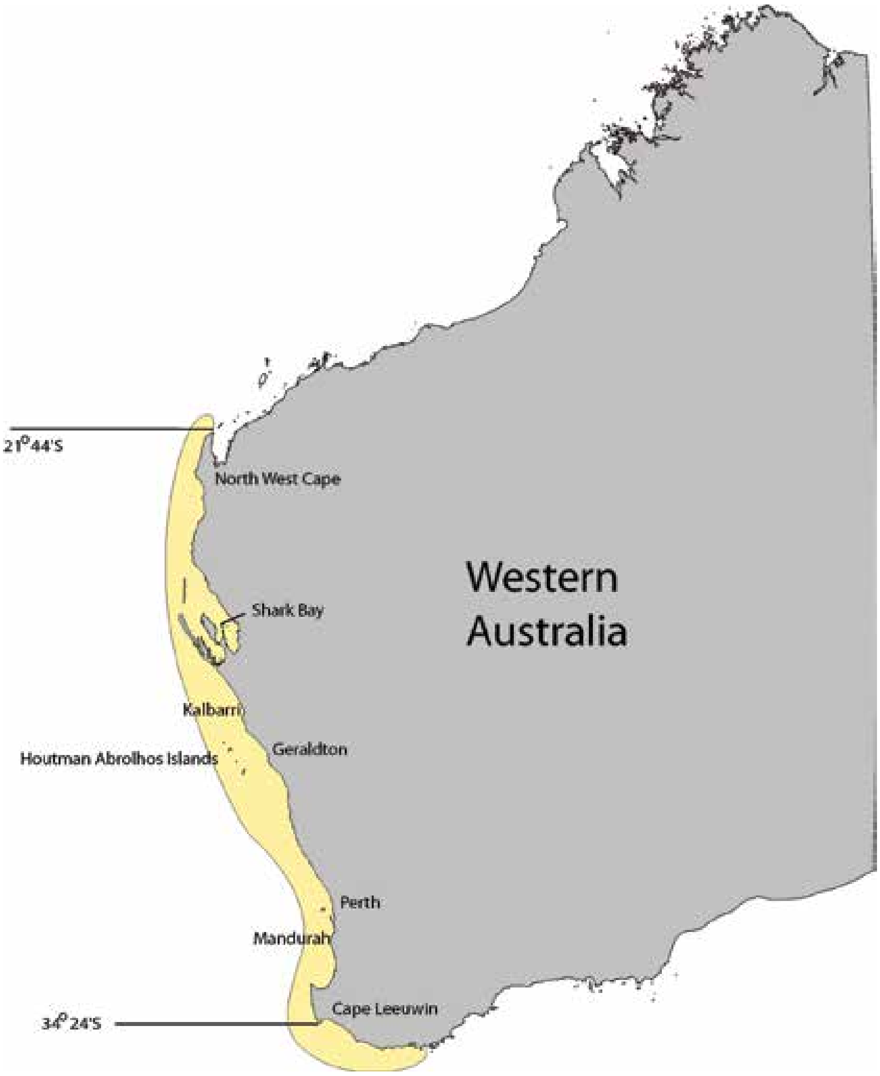


Figure 1.0–1 Distribution of the western rock lobster *Panulirus cygnus*

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 1.0–2). 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 5.5 million kg (± 10%) and this TACC was maintained for the 2010/11 using individual catch limits.

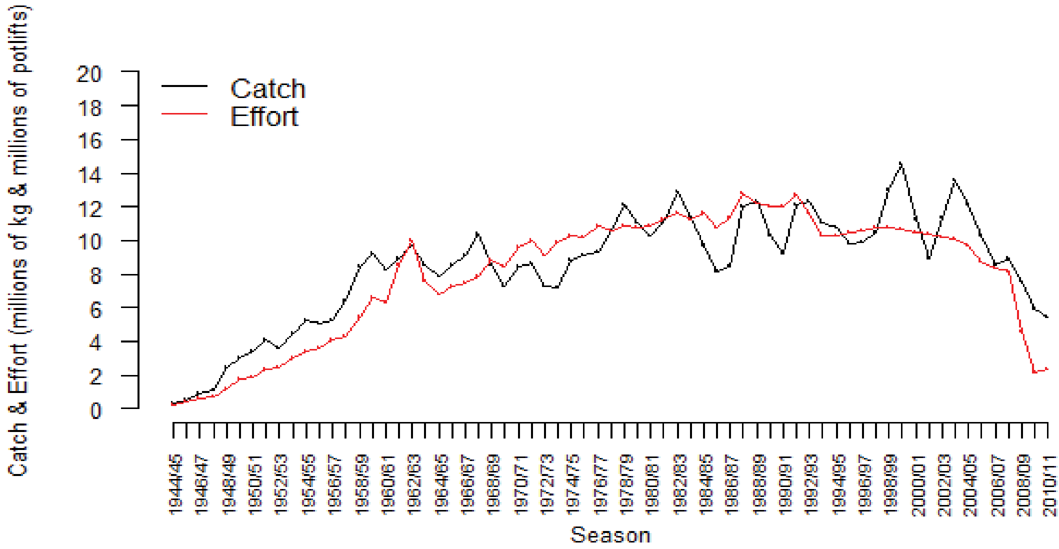


Figure 1.0–2 Annual catch and effort for *Panulirus cygnus* in the WCRLMF.

1.1 Commercial Fishery

The West Coast Rock Lobster Managed Fishery (WCRLMF) 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.

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 1.1–1a), or beehive pots made of cane (Figure 1.1–1b).

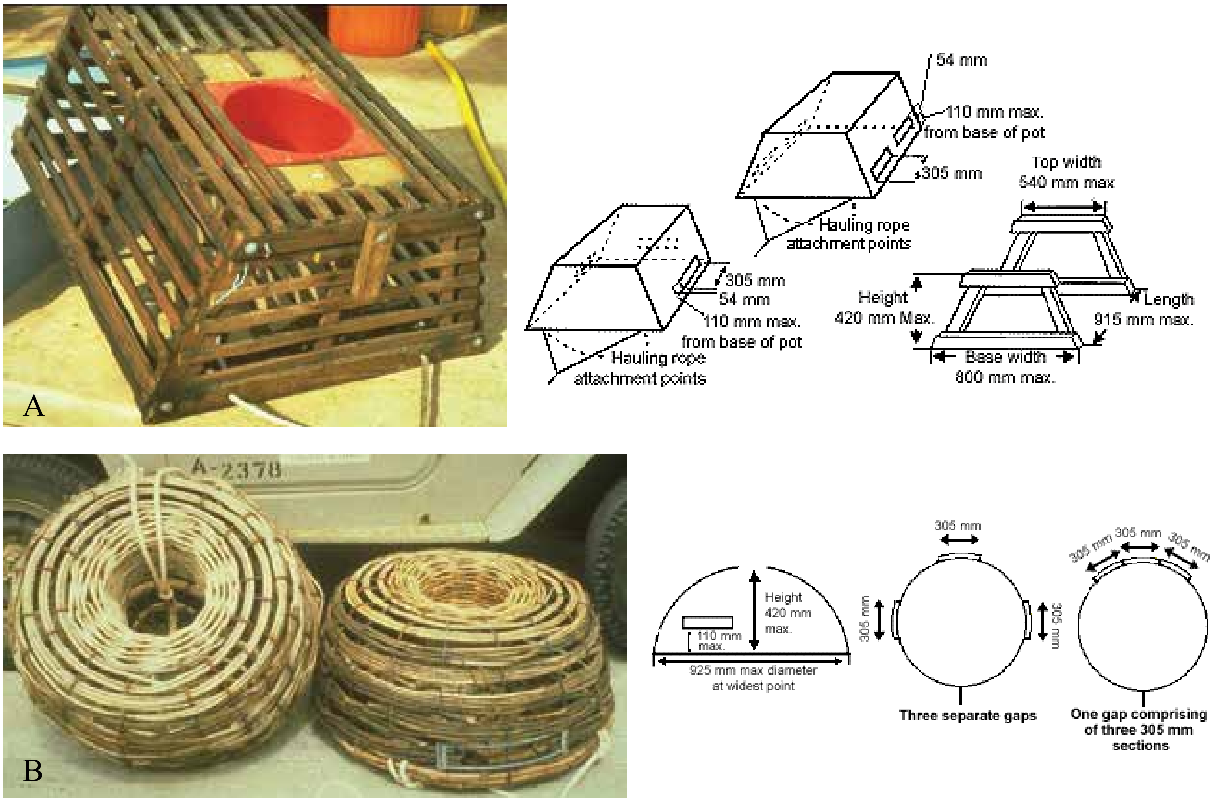


Figure 1.1–1 Two main trap types used by fishers and their regulated measurements for; (A) batten design (made of wood); (B) cane beehive pot

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.

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.) from 836 to 273 (December 2011) (Figure 1.1–2). There was a significant drop in vessel numbers in 2008/09 and 2009/10 associated with the effort reductions. In 2011/12 vessels were operating an average of 126 pots (2011/12). Since 1965 commercial catches have ranged from 5.6 (2009/10) 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*.

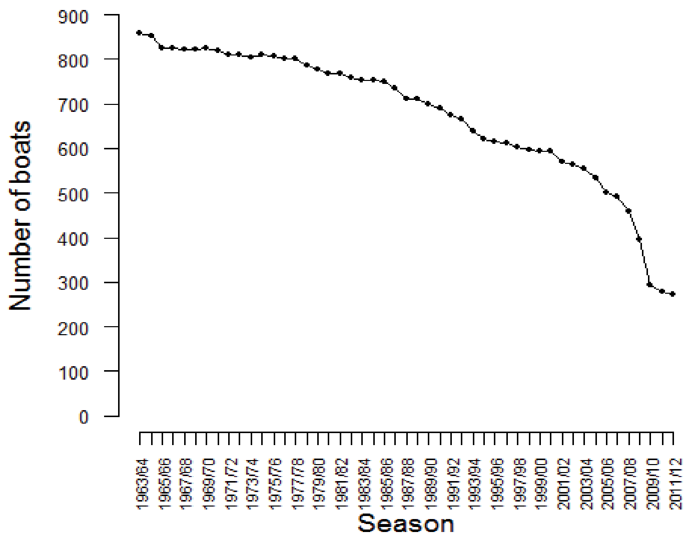


Figure 1.1–2 Number of commercial rock lobster boats actively fishing in the fishery since 1963/64 season.

1.2 Recreational Fishery

The WCRLMF also supports a significant recreational fishery with about 45 000 rock lobster licences issued annually, of which around 80% are utilised. The catch of approximately 400 tonnes per year is ~3% of the total commercial and recreational catch (Section 4.8). Recreational fishers can catch WRL with pots (limit of two pots per licence) or by diving, using a loop or blunt hook. Other restrictions such as bag and boat limits are outlined in Section 2.4.1.

1.3 Illegal Catch

1.3.1 Illegal fishing activities

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 1.3–1. 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 1.3–1 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

1.3.2 Understating catch

A 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.

Figure 1.3–1 compares the catch from the original database, as obtained from fishers' monthly returns, to the catch adjusted for the illegal take of undersize rock lobsters and understated catches. 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.

Currently there is considered to be very little illegal or understated catches in the fishery, therefore the catch reported in Figure 1.0–2 is equivalent to that for the applicable season in Figure 1.3–1.

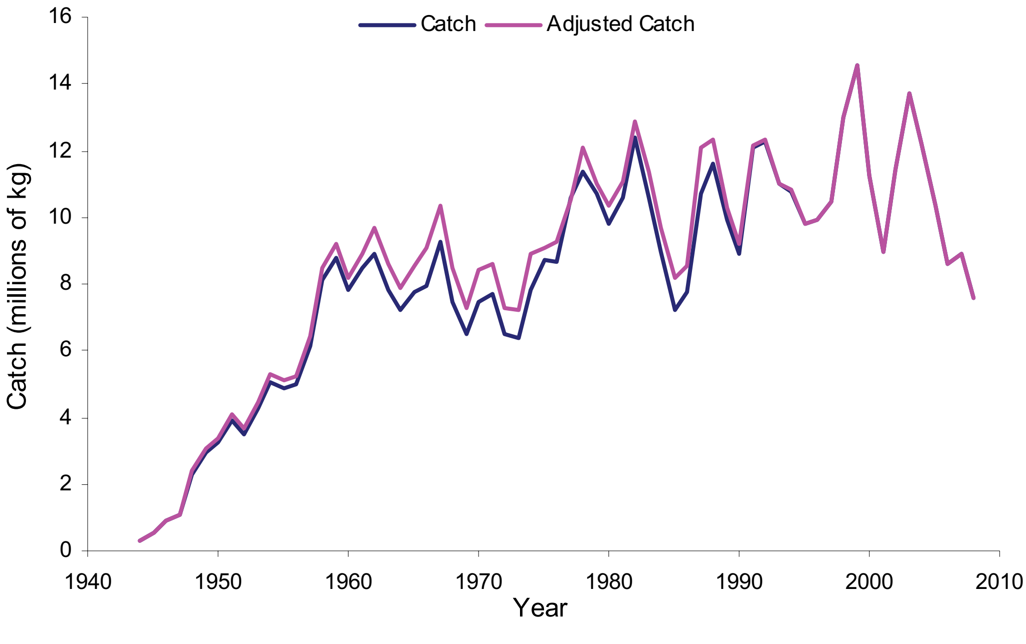


Figure 1.3–1 Catch of the western rock lobster fishery from fishers' monthly returns, and catch adjusted for illegal activities and underreporting (adapted from Caputi et al. 2000).

2.0 Management

This sections deals with the management of the fishery as it pertains to the assessment of the stock. Details regarding governance, and the Marine Stewardship Council's Principle 3, Effective Management can be found in Brown (2011).

2.1 Management Objective

The management regulations for the WCRLMF are aimed primarily at protecting the breeding stock. The regulations are continually reviewed to ensure the breeding stock is maintained at a sustainable level, i.e. above a threshold Biological Reference Point (BRP).

Currently the proposed management objective is: *"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%."* the threshold BRP for a sustainable breeding stock is deemed to be the egg production in the early 1980s for coast al regions and the mid-1980s in A zone. Egg production in the late 1970s and early 1980s was estimated from a length-based assessment model to be around 20% of the unfished level (Hall and Chubb 2001). This level was considered appropriate for the sustainability many other invertebrate fisheries (Hall & Chubb 2001).

2.2 History of Commercial Management Regulations

When the legal whole weight at which a western rock lobster could be kept by a fisherman was introduced in 1897, the WCRLMF became one of the first managed fisheries in Western Australia (and the world). A timeline of the management regulations to 2007/08 is outlined below (Box 2.2–1).

Box 2.2–1 Timeline of major management regulatory changes introduced into the WCRLMF. See Box 2.4–1 for current management arrangements.

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 3.2 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 per foot (0.9 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.

Year / Season	Regulation
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 0.257m3
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 changed to 115 mm 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 fishermen 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 150 pot rule
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 til season end - Zone B – 0.74 from 15 November to 15 March then 0.82 til season end - Zone C – 0.82

Year / Season	Regulation
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)

Year / Season	Regulation
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 A & B – 105 mm to 95 mm 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 Total Allowable Commercial Catch (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.

2.3 Boundaries and Zoning

The boundaries of the WCRLMF are:

"*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*".

The fishery is managed in three zones: south of latitude 30° S (Zone C), north of latitude 30° S (Zone B) and, within this northern area, a third offshore zone (Zone A) around the Abrolhos Islands (Figure 2.3–1). This distributes effort across the entire fishery, and allows for the implementation of management controls aimed at addressing zone-specific issues, including different maximum size restrictions in the northern and southern regions of the fishery. 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 fishing season, all fishing zones will remain open until 31st August.

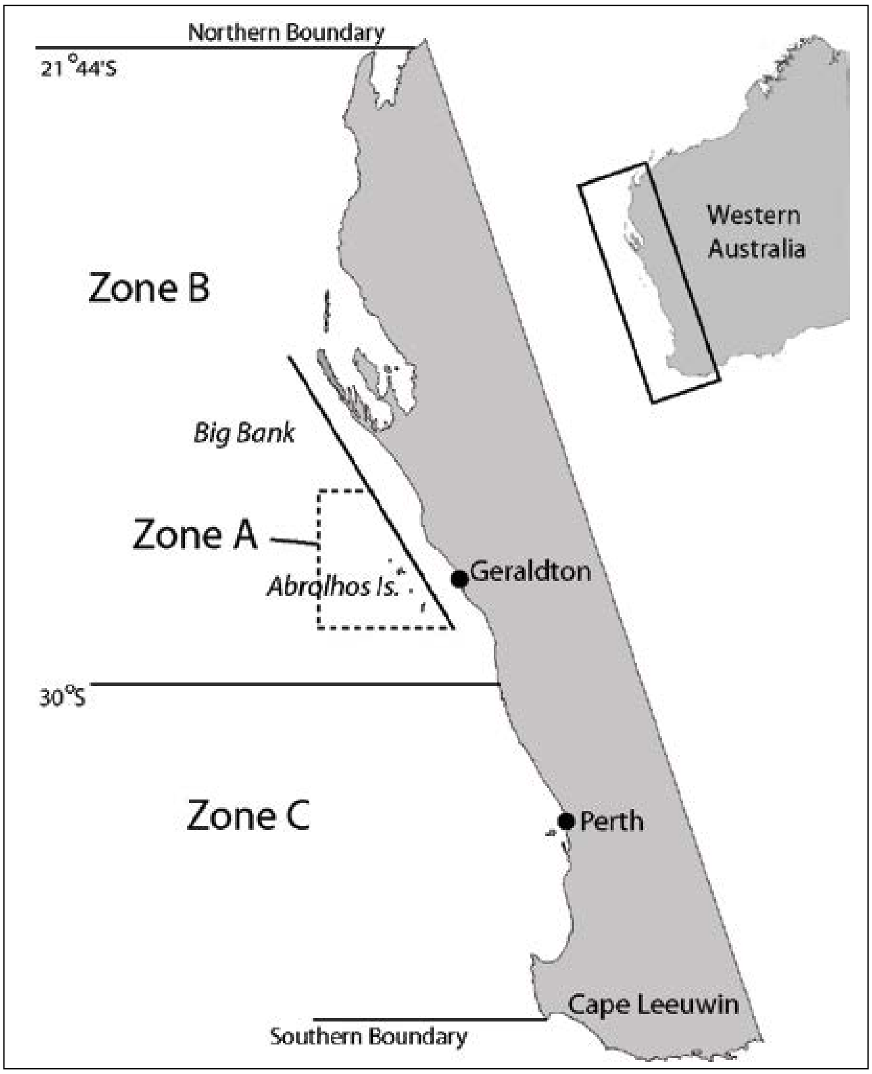


Figure 2.3–1 Western Rock Lobster Fishery Management Zones

2.4 Current Management Strategies

The fishery has been managed by a total allowable effort (TAE) system and associated input controls until 2009/10. The main control mechanism is the number of units (pots) for the fishery, together with a proportional usage rate, which creates the TAE in pot lifts (i.e. number of pots in the fishery multiplied by the usage rate and the number of days in the season). Classifying pots as units and allowing transfers between fishers allows market forces to determine what is the most efficient use of licences and pot entitlements. This is known as an individually transferable effort (ITE) management system. The number of units allowed in the fishery was set at 69 000 in the early 1990s, and since 1993/94 a usage rate of 82% has operated to keep the TAE at a sustainable level. In 2005/06 and 2007/08 further reductions in the usage rate was introduced in Zones A and B (Box 2.2–1).

Management arrangements also include the protection of females in breeding condition, a variable minimum carapace length and a maximum female carapace length. Gear controls, including escape gaps and a limit on the volume of pots are also significant in controlling harvest rates (Box 2.4–1)

Box 2.4–1 Summary of WRL management arrangements for the 2010/11 season

- Closed season 1 September–14 November (Coastal Zones), 1 September–14 March (Abrolhos Island)
- Licensees can only operate in the zone for which they are licensed.
- Minimum size of 77mm
- Maximum female size of 105mm in zone C and 95mm in zones A and B
- It is illegal to take females with setose pleopods.
- Pots types have maximum size and configuration regulations (see Figure 1.1–1).
- To operate in the managed fishery, a licensee must have at least 63 units of pot entitlement.
- Units have been allocated a catch limit depending on which zone they are attached to.

2010/11 Season specific management arrangements

- 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
- 20 fathom rule 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 licences and entitlement

There are several marine parks or fish habitat protection areas throughout the state where fishing for western rock lobster are prohibited. None of these areas where specifically implemented as a direct management strategy by the Department of Fisheries, however represent another management restriction on fishers, both commercial and recreational. A lobster specific research closure has also just been gazetted. For more details see Department of Fisheries (2011).

2.4.1 Management strategies specific to Recreational Fishing

The recreational component of the western rock lobster fishery is managed under fisheries regulations that impose a mix of input and output controls on individual recreational fishers. These arrangements are designed to complement the management plan for the commercial fishery.

Input controls include the requirement for a recreational fishing licence. Fishers are restricted to two pots per licence holder, although the total number of licences is not restricted. The pots must meet the specific size requirements, which are smaller than those for commercial fishers, and must have gaps to allow under-size rock lobsters to escape, For specific details on recreational pot dimensions see web site http://www.fish.wa.gov.au/docs/pub/FishingRockLobsters/FishingforRockLobstersPage06.php?0102. Divers are also restricted to catching by hand, snare or blunt crook in order that lobsters are not damaged. Fishing for rock lobsters at the Abrolhos Islands is restricted to potting only.

The recreational fishing season runs from 15 November to 30 June each year, with a shorter season (15 March to 30 June) at the Abrolhos Islands. Night-time fishing for lobsters by diving prohibited, and diving for lobsters in not permitted in Zone A.

Recreational fishers comply with the same legislation as the commercial fishers with regard to the size and condition of lobsters they can take and when, except there is a daily bag limit of 6 lobsters per fisher per day. Where there are three or more people fishing from the same boat, a daily boat limit of 12 lobsters provides further control on high individual catches. These individual and boat limits were introduced on 1 December 2008, down from the previous limits of 8 and 16. At the same time a possession limit was also introduced of 24 lobsters in response to forecast low catch years of 2011/12 and 2012/13. In the North coast region (Pilbara / Kimberly; east of 114°50'E and north of 21°46'), and Ningaloo Marine Park the daily bag limit is 4 and the boat limit 8 lobsters. There is also a requirement for recreationally caught lobsters to be tail-clipped in order to stop these animals from being sold illegally.

2.5 Marine Stewardship Council Certification

In 2000, the West Coast Rock Lobster Managed Fishery became the world's first fishery to receive Marine Stewardship Council (MSC) certification on the basis of demonstrating the sustainability of its fishing and management operations. To achieve this, the fishery was assessed by an international group of experts against the criteria set out in the MSC guidelines (see web site http://www.msc.org/ for details). To continue this accreditation a number of ongoing requirements have had to be met, including an ecological risk assessment and the development and implementation of an Environmental Management Strategy (EMS; Brown and How 2011). Ecological Risk Assessment (ERA) workshops have been conducted to provide a register of the potential ecological risks arising from the various activities carried out by the WCRLMF. The fishery was re-certified in December 2006 and under consideration for re-certification during 2011/12.

2.6 Integrated Fisheries Management

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 it 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. The recreational and commercial allocations has been determined as 5 % and 95 % respectively, with an additional customary fishing initial allocation of one tonne.

3.0 Biology

3.1 Taxonomy

The western rock lobster, *Panulirus cygnus* (George 1962), 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 the Australian genera is shown below (Figure 3.1–1). In adults there is sexual dimorphism with males having a longer merus (Figure 3.1–2).

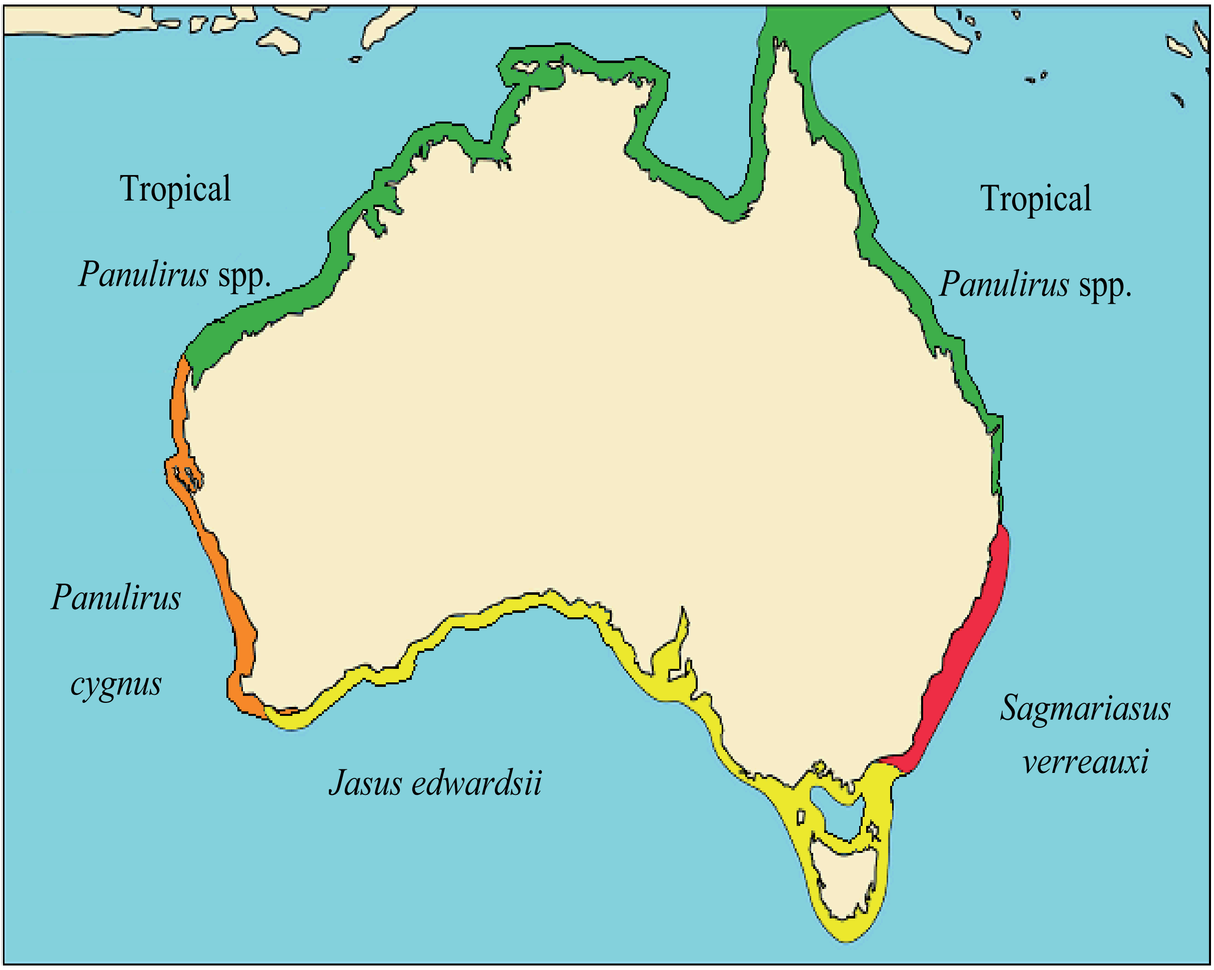


Figure 3.1–1 Distribution of Palinuridae (spiny) lobsters around Australia

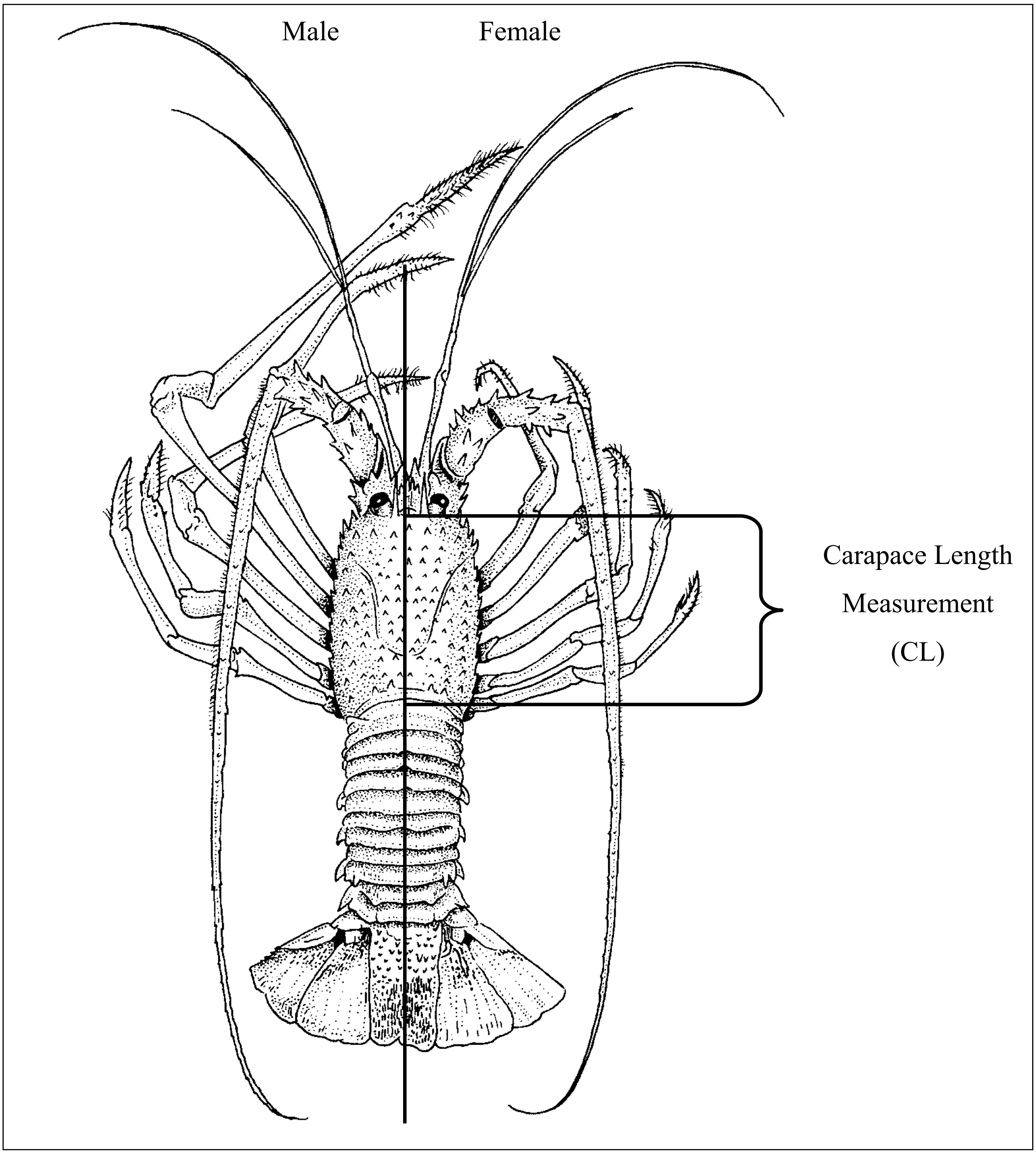


Figure 3.1–2 Morphology of male and female *Panulirus cygnus* showing how carapace length (CL) is measured from the anterior edge of the carapace between the preorbital spines down the mid-dorsal line to the posterior edge.

3.2 Stock Structure

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).

However, there is variation in reproductive biology (Section 3.6) and growth (Section 3.8). 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 2).

Currently the structure of the stock is being re-addressed through the use of more advanced genetic techniques (microsatellite markers). See section 7.1.2 for more details

3.3 Habitats

3.3.1 Oceanography

The distributional range of *P. cygnus* (Figure 1.0–1) sees it restricted to the clear, warm, low-nutrient waters of the west coast of Western Australia. These oceanic conditions are markedly different from those on the eastern edge of other ocean systems (Atlantic and Pacific) in the southern hemisphere. Those coasts have cold, northward-flowing currents (Humbolt and Benguela) that produce nutrient-rich upwellings near the coast. In contrast the eastern coast of the Indian Ocean is dominated by the warm southward-flowing, tropical water of the Leeuwin Current (Plate 3.3–1).

The Leeuwin Current is strongest during the southern autumn and winter (March to October) when it flows from the north-west of Australia, along the coast and around into the Great Australian Bight. Between North West Cape and Shark Bay (Figure 1.0–1) it approaches the coast, where its flow becomes broad and shallow before narrowing and deepening to about 150 – 200 m and 30 km wide along the continental shelf. When it nears Cape Leeuwin it moves up onto the continental shelf and flows into the Great Australian Bight. As the current skirts the coastline it forms gyres or eddies; offshoots of the main current. These are highly variable in terms of their duration (days to months), size (some may be over 100 km in diameter), and are usually consistent in their location (Plate 3.3–1).

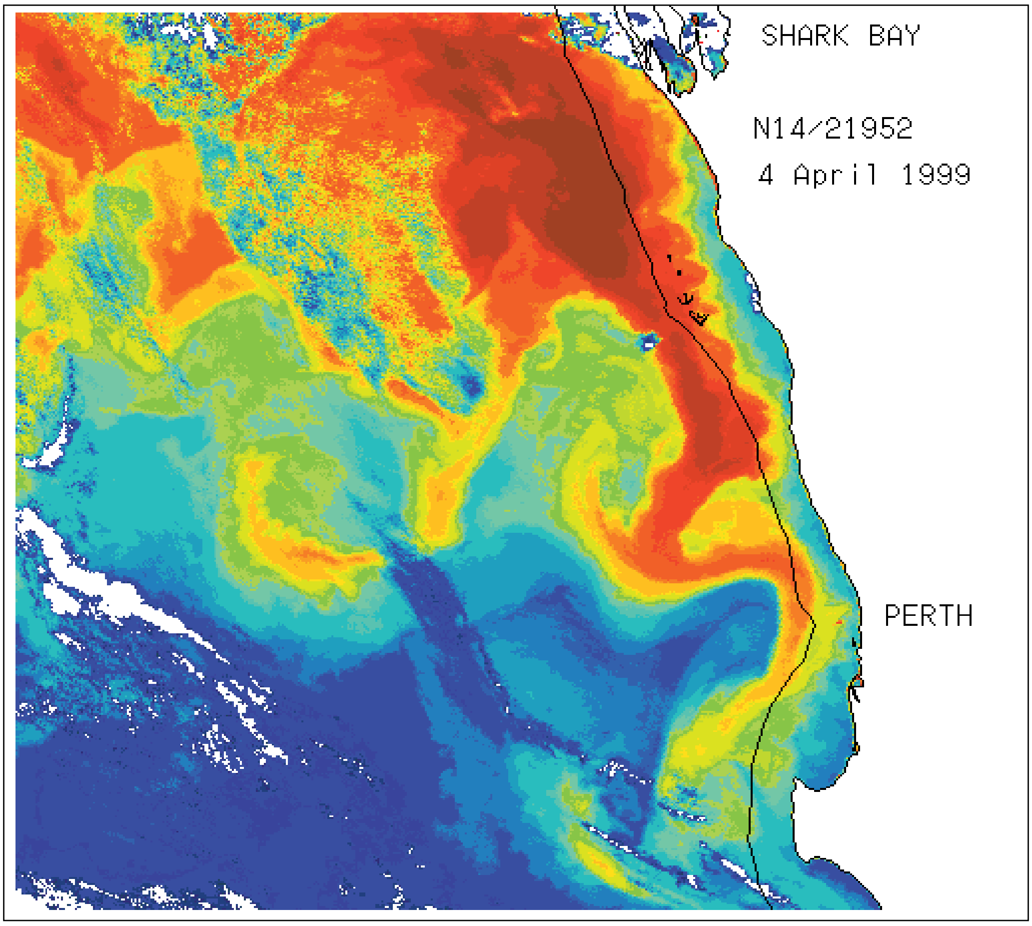


Plate 3.3–1 Satellite image of the Leeuwin Current (shown in red) in April 1999, from the thermal radiometer on a NOAA satellite. The black line marks the 200 m contour, and the white/blue speckled areas are clouds. Image from Alan Pearce, courtesy of WASTAC.

The Capes Current runs inshore of the Leeuwin Current, reaching its peak in summer. Pushed by the strong south-westerly winds characteristic of the West Australian summer weather pattern, it causes cool, high-salinity water to flow northwards along the coast.

These contrasting oceanic conditions create a large range in temperatures experienced by *P. cygnus* throughout its range from around 27ºC at North West Cape in February to 16ºC at August near Cape Leeuwin.

Oceanographic conditions also play a vital role in the recruitment of juvenile *P. cygnus* to the fishery after the larval stage (Section 3.7)

Currently there are two oceanographic modelling projects examining how the environment off the Western Australian coast influence *P. cygnus* phyllosoma and puerulus distribution and survival. See section 7.1.2 for more details.

3.3.2 Physical habitat

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 (Figure 3.1–1).

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 seasquirts, sponges and other sessile invertebrates.

The influence of the Leeuwin Current also 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.

Association of *P. cygnus* with different habitats, as well as habitat mapping throughout the western rock lobster fishery is outline in Department of Fisheries (2011).

3.4 Life History

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 (Plate 3.4–1c). 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 (Plate 3.6–1). Females with eggs attached under their abdomen (ovigerous) are also known as "berried" females (Plate 3.4–1d).

The eggs hatch in 5 to 8 weeks, depending upon water temperature

$$(Incubation\_time = 4412.4\exp^{0.217*Wtemp} \text{ Chittleborough 1976a}),$$

releasing tiny larvae called phyllosoma (Plate 3.4–2a) into the water column.

The phyllosoma larvae spend 9 – 11 months as plankton, carried offshore by ocean currents (Figure 3.4–3), where they feed on other plankton before the last phyllosoma stage moults into the free-swimming puerulus stage that settles onto the inshore reefs (Plate 3.4–2b). However, to move from outside the continental shelf to suitable inshore reef systems requires the larva to change into a puerulus at the right time to benefit from favourable currents before it swims the remaining distance to the inshore reefs. The subsurface currents there 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 which would enable them to make the 40 – 60 km swim from the shelf edge to inshore reefs in a few days.

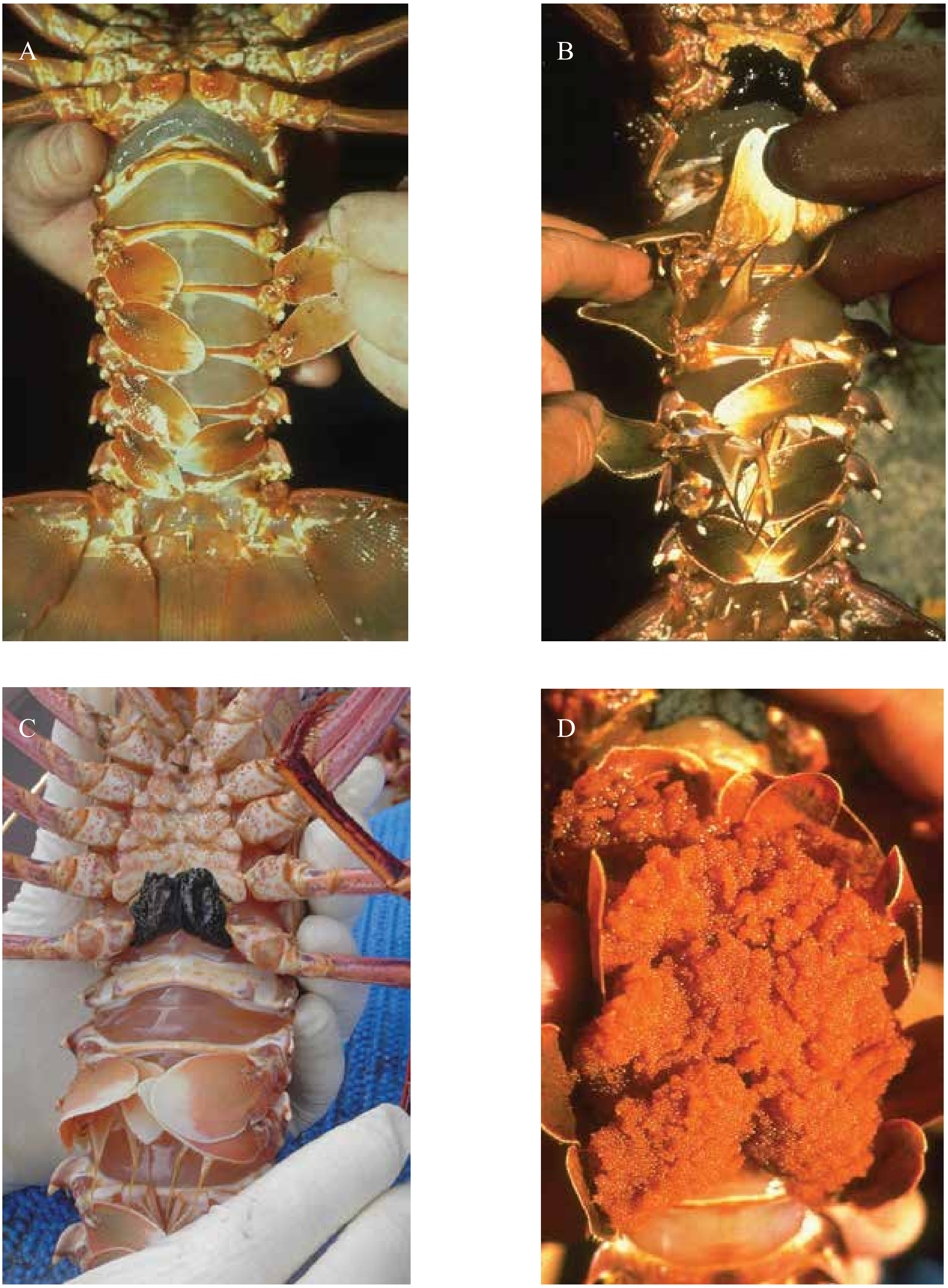


Plate 3.4–1 Ventral views of a) male, b) female, c) tar-spotted female and d) berried female western rock lobsters (Department of Fisheries, W.A.)

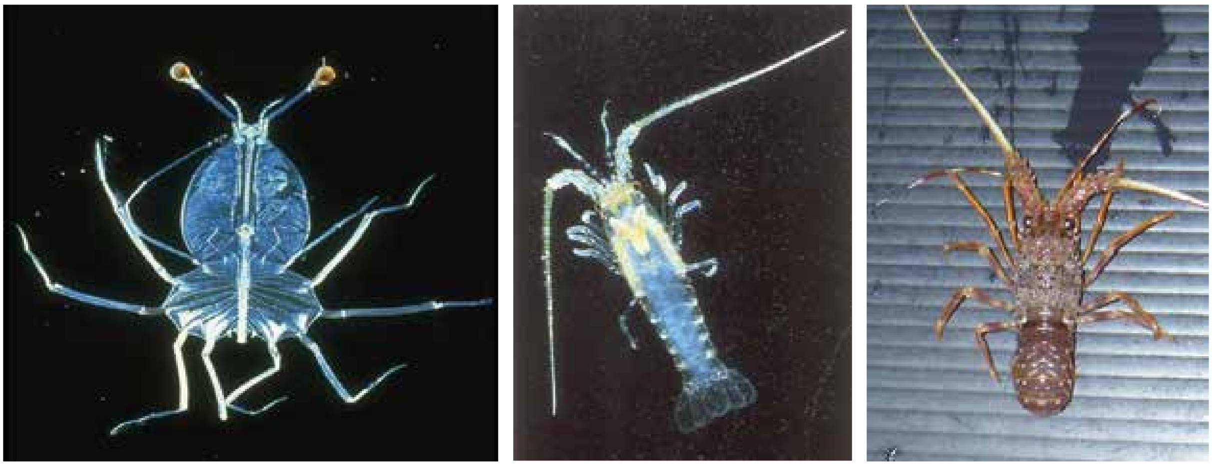


Plate 3.4–2 Life phases of the Panulirus cygnus a) phyllosoma (TL 20 mm); b) puerulus (CL 7-9 mm); c) juvenile (CL 9+ mm)

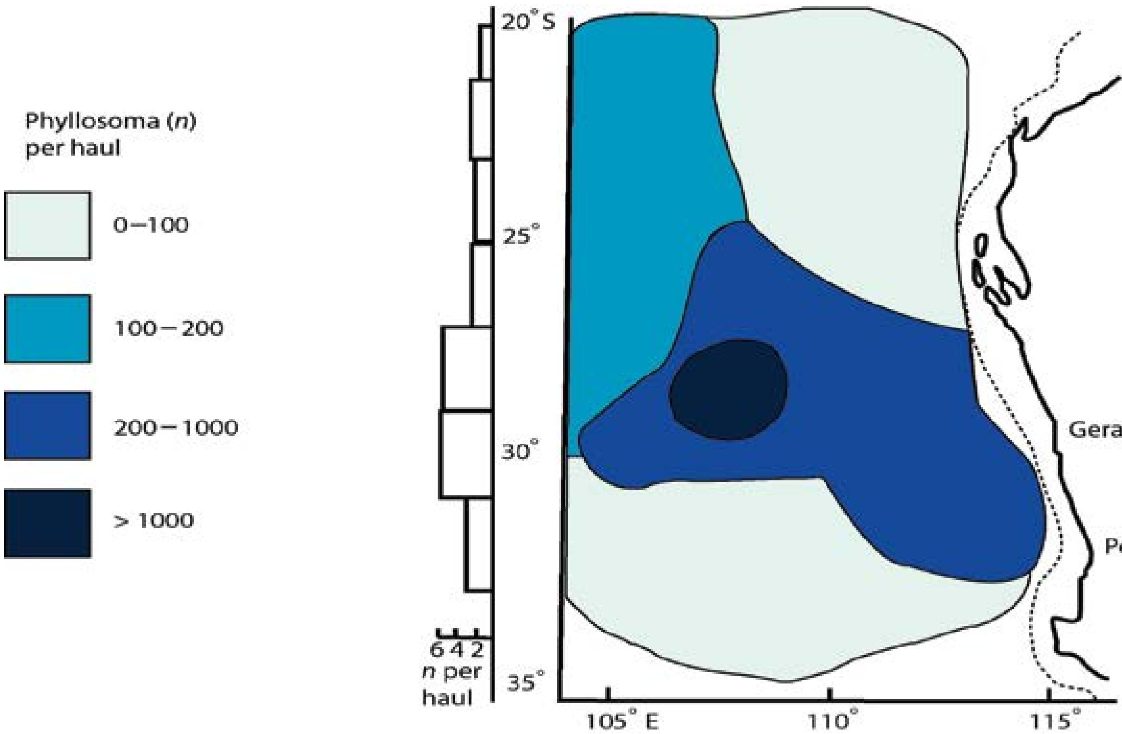


Figure 3.4–3 Distribution of western rock lobster phyllosoma larvae. The dotted line represents the Continental shelf (from Phillips 1981)

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 (Plate 3.4–2c). For details of juvenile recruitment to inshore areas, see Section 3.7.

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 return to their normal red colour at the next moult a few months later. The “white” phase of a rock lobster’s life is the migratory phase (Section 3.5.1). At this time (summer) they leave the coastal reefs and make a mass migration across pale white sands to their breeding grounds in deeper water, where they become sedentary again on the deeper reefs. A small percentage make far longer migrations off the edge of the continental shelf down to depths of over 200 m, before they change direction and follow the shelf in a northerly direction. When the “whites” reach the offshore breeding grounds, they undergo another synchronised moult to a red exoskeleton (February – March). This deeper offshore ground is where the spawning stock predominantly resides (Figure 3.4–4).

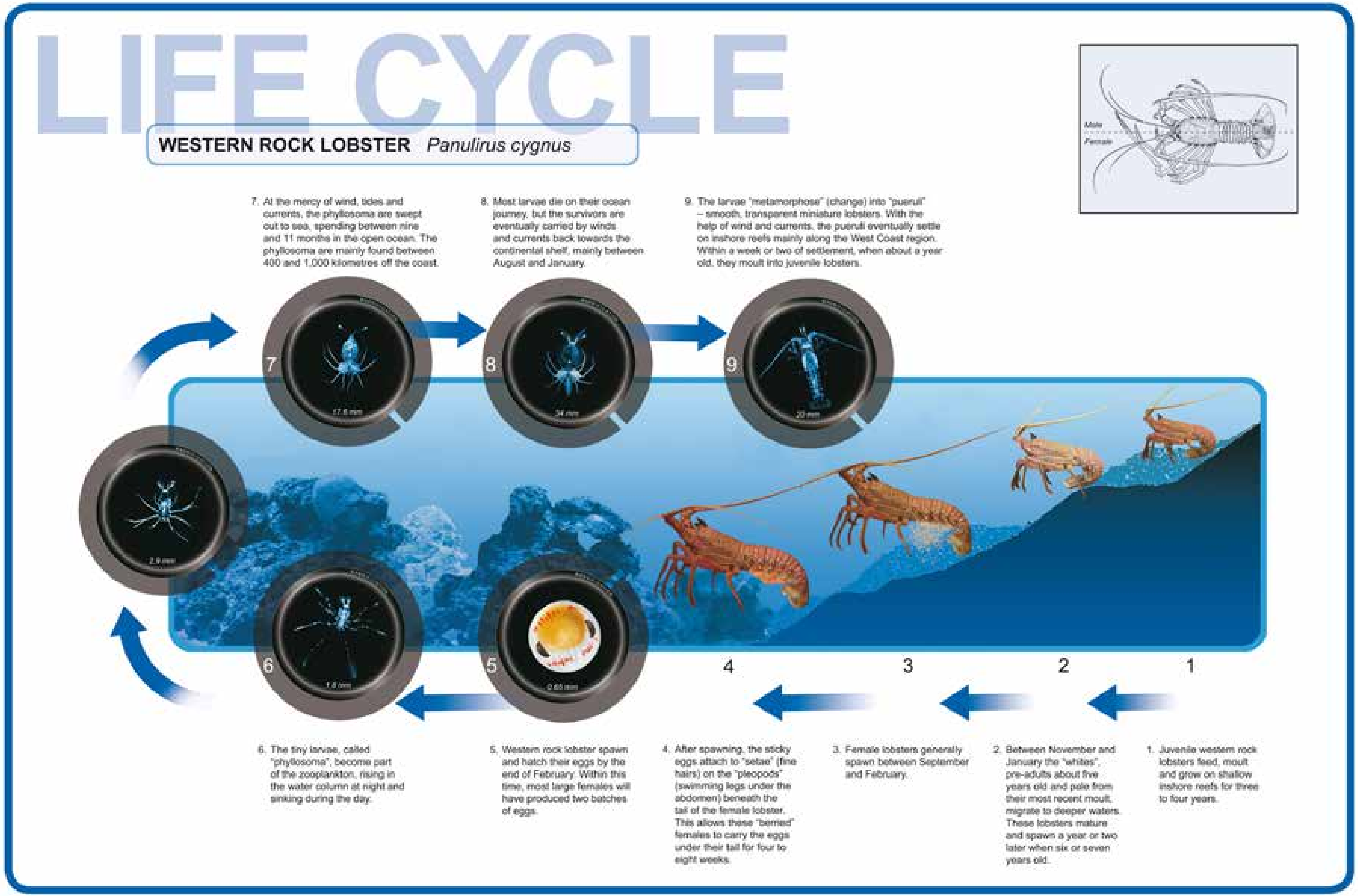


Figure 3.4–4 Life history of Panulirus cygnus (from Community Education Branch, Department of Fisheries, Western Australia)

3.5 Movement

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.

3.5.1 Migration

The large-scale "whites" migration is a feature of this lobster's life history (Section 3.4). Tagging studies (using mainly 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) as well as to provide growth information (Section 3.8).

Chubb et al. (1999) tagged and released over 66 500 lobster between 1988 and 1996 throughout the fishery. Some 75% of the recaptures were during the first season after release, with around 20% the following season, though there were recaptures up to 5 seasons after release.

The movement pattern of these tagged lobsters together with over 30 000 that have been tagged and released by the Department since 1996 have recently been re-analysed.

This recent work indicates that migrating lobsters generally move offshore in a westerly direction until they reach ~ 100 m depth where they change direction and move in a north-northwest direction (towards the north of the fishery). This migration can be considered an ontogenetic migration, which counter-balances the likely larval migration south.

Lobsters from as far south as Jurien Bay have been found to migrate over 600 km into the Big Bank region.

The northward extent of this migration each year appears to be associated with at least two main factors, the number of migrating lobsters (i.e. based on the puerulus settlement four years previously and the level of capture before they reach the 100 m depth) and the strength of the southward flowing current in the northern Abrolhos Big Bank region (meridional (north-south) current strength) during the time of the migration. Weaker south-flowing currents and a large number of migrating lobsters will result in this migration extending further north.

The strength of this current at this time of the year appears to be highly variable, and there has been a progressive increase in its average strength from 1994 to 2004. In 2004, the year of the strongest current, the northwards migration of lobsters only made it as far as the southern end of the Abrolhos Islands, as indicated by the deepwater distribution of undersize lobsters following the whites' migration each year. The current strength has been above average in six of the last eight years, which will have contributed to a lower level of migration north.

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 are 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 water temperature data at 1° intervals (at the moment we are using one temperature measure for each zone, but estimating "start of migration" times at 1° levels, from log book data) to better explain the migration of animals.

3.5.2 Foraging

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) and adults in deeper environments (Section 7.1.1). These data will provide preliminary information on foraging distances, home ranges and habitat use of adult and juvenile *P. cygnus*.

Detailed movement information can be found in Department of Fisheries (2011).

3.6 Reproduction

Adolescents nearing maturity undergo the "whites" migration, leaving the juveniles on the shallow inshore reefs. There are thus few mature lobsters in shallow waters (less than 40 m) except those at the Houtman Abrolhos Islands, cliffs north of Kalbarri, and inshore islands and reefs in the Jurien/Cervantes, Cape Naturaliste and Cape Leeuwin regions. Ninety per cent of mated ("tar-spotted") and berried females are caught in deep water (40 to 80 m) towards the edge of the continental shelf. Spawning in areas near the continental shelf may maximise larval dispersal due to the proximity of longshore ocean currents.

The attainment of sexual maturity begins around June when females moult prior to spawning. As a result of this moult, short fringing hairs (setae) appear on the endopodites of the swimmerets (< 5 mm), at which point they are considered "immature-setose". These setae elongate over a subsequent moult to become, 10 – 15 mm long (Plate 3.6–1), and it is at this time that a female lobster is considered fully matured (setose), being able to successfully produce and fertilise viable eggs.

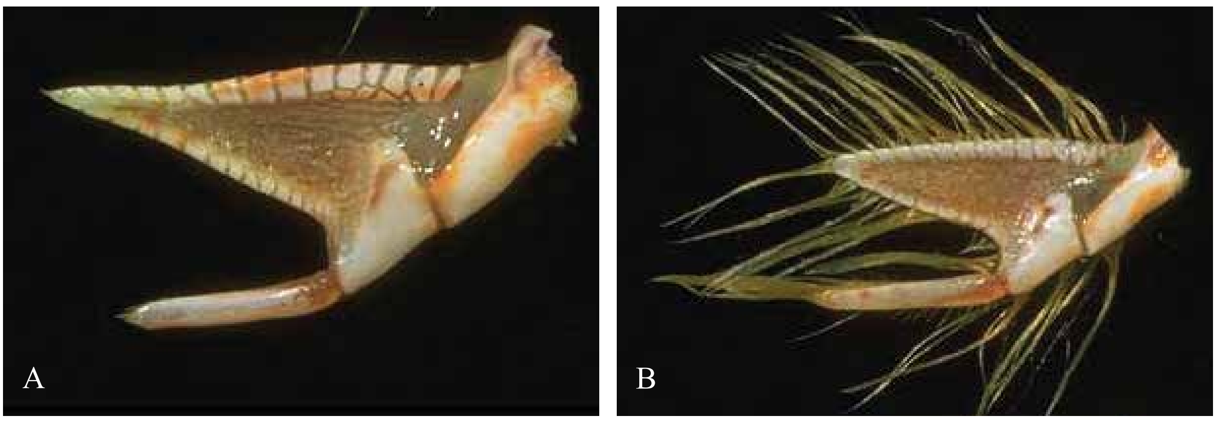


Plate 3.6–1 Pleopods with a) no setae and b) mature setae.

3.6.1 Size at maturity

There is considerable variation in the size of attainment of setose pleopods for females and the ability to reproduce (carapace length of 50% maturity - CL_{50}) of both female and male *P. cygnus* throughout the fishery (Figure 3.6–1, 3.6–2 & 3.6–3a). 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 (Figure 3.6–3a). 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).

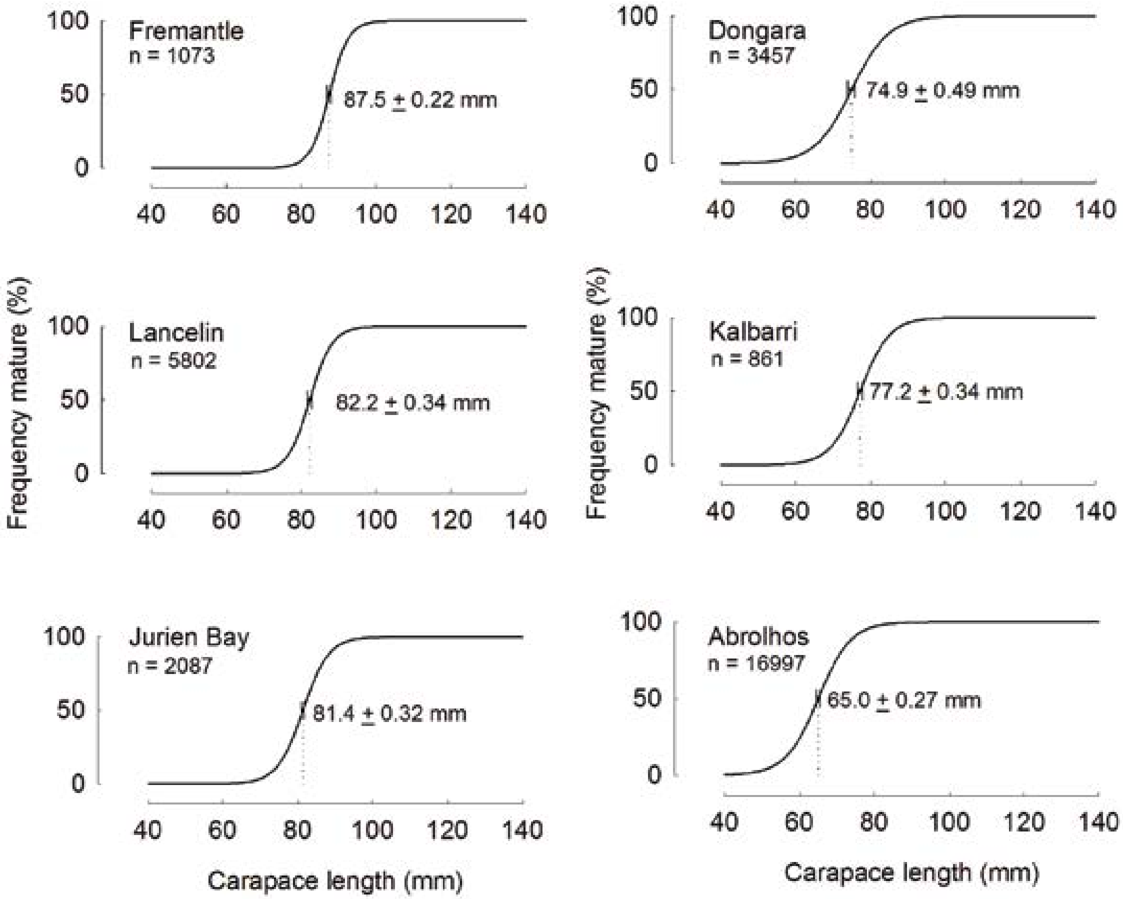


Figure 3.6–1 Logistic regressions fitted to the percentage of mature female *Panulirus cygnus* at different carapace lengths in six locations in Western Australia, based on data collected during the 2002 Independent Breeding Stock Survey. CL_{50} ±1 SE denotes the size at which 50% of the assemblage is mature and n the sample size (Melville-Smith & de Lestang 2006)

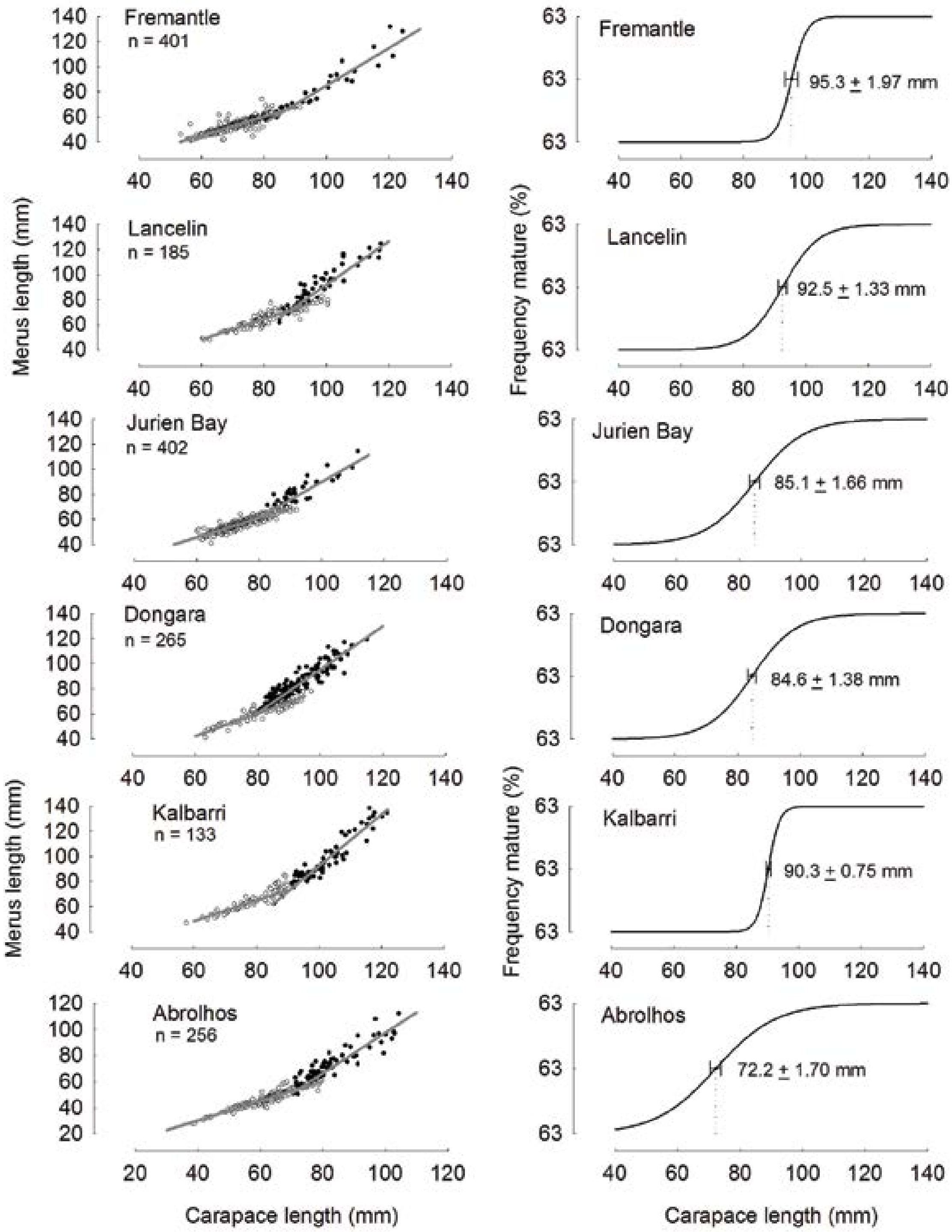


Figure 3.6–2 Relationship between the merus length of the second pereiopod and carapace length of immature (open circle) and mature (filled circle) male Panulirus cygnus (left) and logistic regressions fitted to the percentage of morphometrically mature males at different carapace lengths (right) in six locations in Western Australia, based on data collected during the 2002 Independent Breeding Stock Survey. CL50±1 SE denotes the size at which 50% of the assemblage is mature and n the sample size (Melville-Smith & de Lestang 2006).

Variation in size at maturity

Much of the spatial variation in size at maturity is explained by regional patterns in water temperature (Figure 3.6–3b), with lobster caught in warmer waters maturing at a smaller size than their colder water counterparts (Melville-Smith & de Lestang 2006).

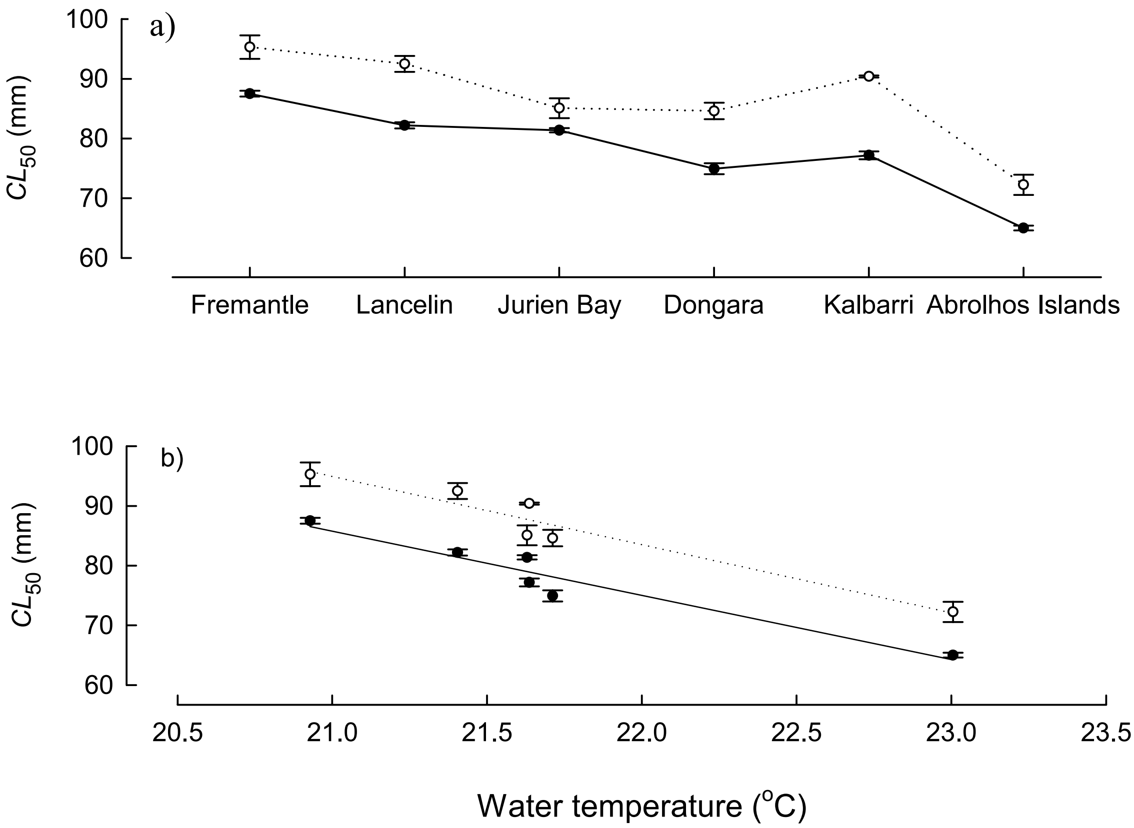


Figure 3.6–3 a) Size at maturity (CL_{50}) ±1 SE of female (filled circle) and male (open circle) Panulirus cygnus at six locations and b) linear regressions fitted to the relationships between female (filled circle) or male (open circle) CL_{50}s at each location and the corresponding mean annual water temperature at that location (Melville-Smith & de Lestang 2006).

There is also a temporal variation in the size at maturity (CL_{50}) at all sites from Fremantle to Kalbarri and offshore at the Abrolhos Islands from the early 1990s to 2009 (Figure 3.6–4). This reduction in the size at maturity is 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 deepwater breeding grounds and are therefore appropriate for use in developing measures of breeding biomass (i.e. for use in population dynamic models etc.).

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.

This decline over time has been further validated by analysis showing a consistent long-term decrease in mean CL of the 10% smallest mature females sampled during commercial (Section 4.2) and independent monitoring (IBSS) (Section 4.3) programs (Figure 3.6–5). Although using the smallest of mature females is a crude measure for comparing size at first maturity, it does have the advantage of not being derived from ratios of immature and mature animals and as such, not being influenced by the "setose rule". The mean CLs of the 10% smallest females sampled during commercial monitoring was, in the majority of cases, larger than corresponding values determined from IBSS data. This difference is due mainly to the IBSS being conducted over the peak of the breeding season (October to November) at the point when the majority of all mature females are mated or egg bearing. The commercial monitoring on the other hand does not begin until after the IBSS and covers the subsequent decline in breeding activity when small single breeding females are no longer reproductively active and can even have moulted into their non-reproductive phase, while large double-breeding females can still be brooding eggs (de Lestang and Melville-Smith, 2006). In fact, even though the IBSS is conducted over the same new moon period prior to the start of the fishing season (15th November), it does not always align with the peak of the breeding season. This variation between the timing of the IBSS and that of peak spawning is one factor contributing to the oscillating CL_{50} estimates for the various sites each year since 1994 (Figure 3.6–5).

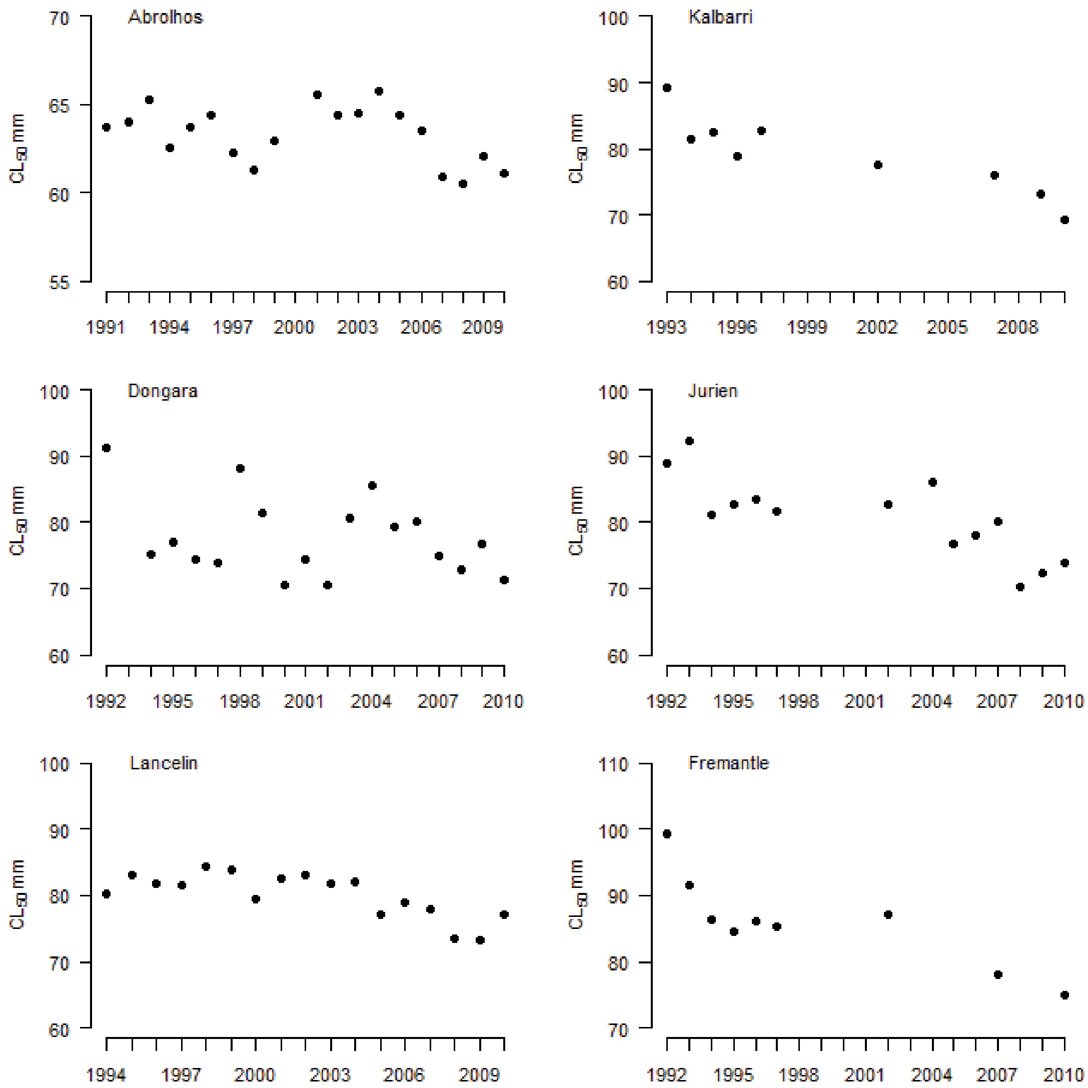


Figure 3.6–4 Temporal variation in size at maturity (CL_{50}) of female *Panulirus cygnus* at six locations from the early 1990s to 2010 from IBSS surveys (updated from Melville-Smith & de Lestang 2006).

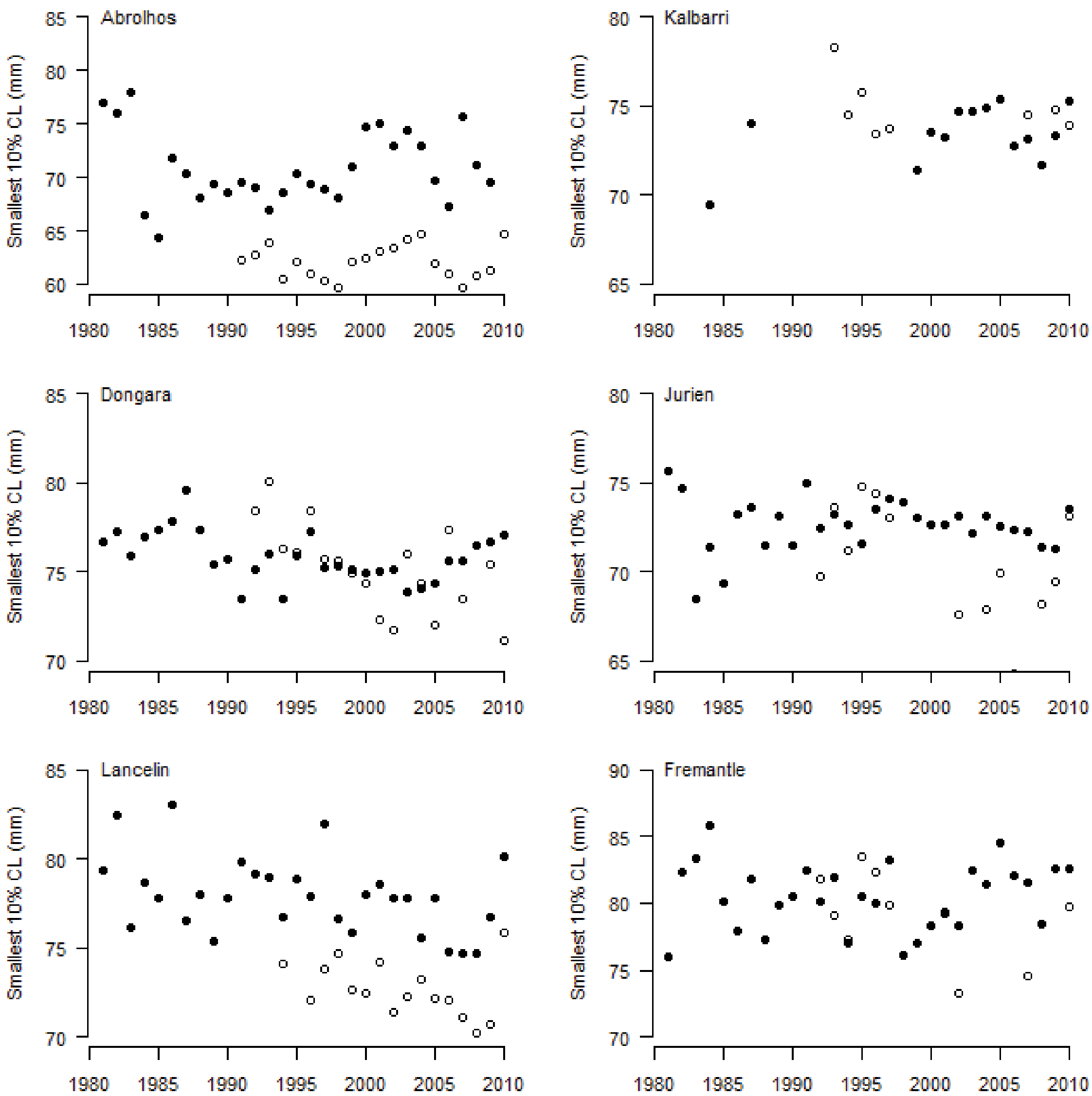


Figure 3.6–5 Mean carapace lengths of the smallest 10% of mature female *Panulirus cygnus* caught in each year at four locations from 1972 to 2010 based on data collected during Fishery Dependent Commercial Catch Monitoring (filled circle) and from 1992 to 2009 based on data collected during Fishery Independent Breeding Stock Surveys (open circle). (updated from Melville-Smith & de Lestang 2006).

The relationship between CL_{50} estimates and mean water temperatures at various locations throughout the fishery indicates that warmer water temperatures during the juvenile phase contribute to a smaller size at maturity. A negative relationship with water temperature has previously been shown for the mean size at which white lobsters migrate. Migrating lobsters are smaller when they have experienced above average water temperatures four years prior to their migration, i.e. during their first year after settlement (Caputi et al., 2009). This work estimated that an increase in water temperature by 1 C° reduced the mean size of migration by ~ 3 mm.

The population dynamic model (see Section 5.5) requires size at maturity estimates for fishing seasons from 1975 to the present and projections out to 2030. These estimates have been derived utilising all possible data sources included that from the DBSS (Section 4.2) and IBSS (Section 4.3) at all locations (Fremantle, Lancelin, Jurien, Dongara, Kalbarri and Abrolhos) and months from October and February. These data were restricted to deepwater samples (>40 m) for all locations except the Abrolhos Islands and Kalbarri, as only in these two locations does spawning occur in all water depths. This temporal range also covers the period prior to and after the introduction of the setose rule (1993) which has been shown to impact size at maturity estimates (see above).

The various sources of data are not all available over the entire time series (eg. IBSS surveys were not conducted prior to the 1990s). As such, when combined, the entire dataset is unbalanced and needs to be analysed using a Generalized Linear Model (GLM) capable of standardising mean estimates from unbiased datasets. A GLM of family binomial with a logit link to represent a logistic relationship was bootstrapped 1000 times to produce error estimates around its mean estimates. This model included a range of factors, namely; breeding season (*S*), setose rule (*R*) and month (*M*) with carapace length (*CL*) treated as a covariate. Due to incompleteness between the two survey types a separate model was applied to data from each of the two surveys (DBSS and IBSS), with estimates from the DBSS model being scaled to match those from the IBSS model (see below). Estimates of size at 50% maturity (CL_{50}) (Eq 3.6.1) and the slope (*S*) (Eq 3.6.2–4) of the model were determined using the equations;

$$CL_{50} = -\left(I + Y\right)/CL \text{ and} \qquad \text{Eq 3.6.1}$$

$$S = \frac{\left(S_1 - S_2\right)}{\left(2 * 0.001\right)}, \text{ where} \qquad \text{Eq 3.6.2}$$

$$S_1 = \frac{e^{I+Y+\left(CL_{50}+0.001\right)*CL}}{\left(1 + e^{I+Y+\left(CL_{50}+0.001\right)*CL}\right)} \text{ and} \qquad \text{Eq 3.6.3}$$

$$S_2 = \frac{e^{I+Y+\left(CL_{50}-0.001\right)*CL}}{\left(1 + e^{I+Y+\left(CL_{50}-0.001\right)*CL}\right)}. \qquad \text{Eq 3.6.4}$$

The base case of the month factor was November for IBSS data and December for DBSS data and the setose rule factor for both models was post 1992. As such the above equations for CL_{50} and *S* represent logistic models describing the attainment of maturity standardised to represent sampling conducted in November during an IBBS survey and December during a DBS survey after the implementation of the setose rule.

Estimates of CL_{50} from the DBSS model were scaled to match those from the IBSS model so that the mean CL_{50} determined from DBSS data for the period since the IBSS inception (early 1990s) to present was the same as the mean CL_{50} determined from the entire IBSS time series. The DBSS estimates were scaled down because they are known to be biased upwards due to the data being collected towards the end of the breeding season, a time when many single breeding females have finished spawning. The IBSS survey on the other hand is conducted at the peak of the spawning season when all mature females are spawning. Estimates of scaled DBSS CL_{50} were used as inputs for the Stock Assessment Model (Section 5.5) because this time series covered the temporal range of the model unlike the short time series of IBSS estimates.

The scaled estimates of CL_{50} were estimated for each season and location combination were smoothed using a Tukey's 3-point running mean smoother (Tukey, 1977) before missing years were determined based on a linear relationship between CL_{50} estimates and season for that location. Projected years from the present to 2030 were estimated as the mean of the most recent three seasons.

In general estimates of CL_{50} at all locations showed a progressive decline from the mid 1970s until present. The greatest decline was seen in the two most southern locations with the coolest water temperatures of Fremantle/Lancelin and Jurien, where the location with the warmest water temperatures (Abrolhos Islands) only declined slightly. A similar cyclical trend is also seen at each location with the early/mid 1990s period displaying peak values and the mid to late 2000s period showing dipping values. This trend correlates well with shallow water-temperatures 4 – 6 years previous.

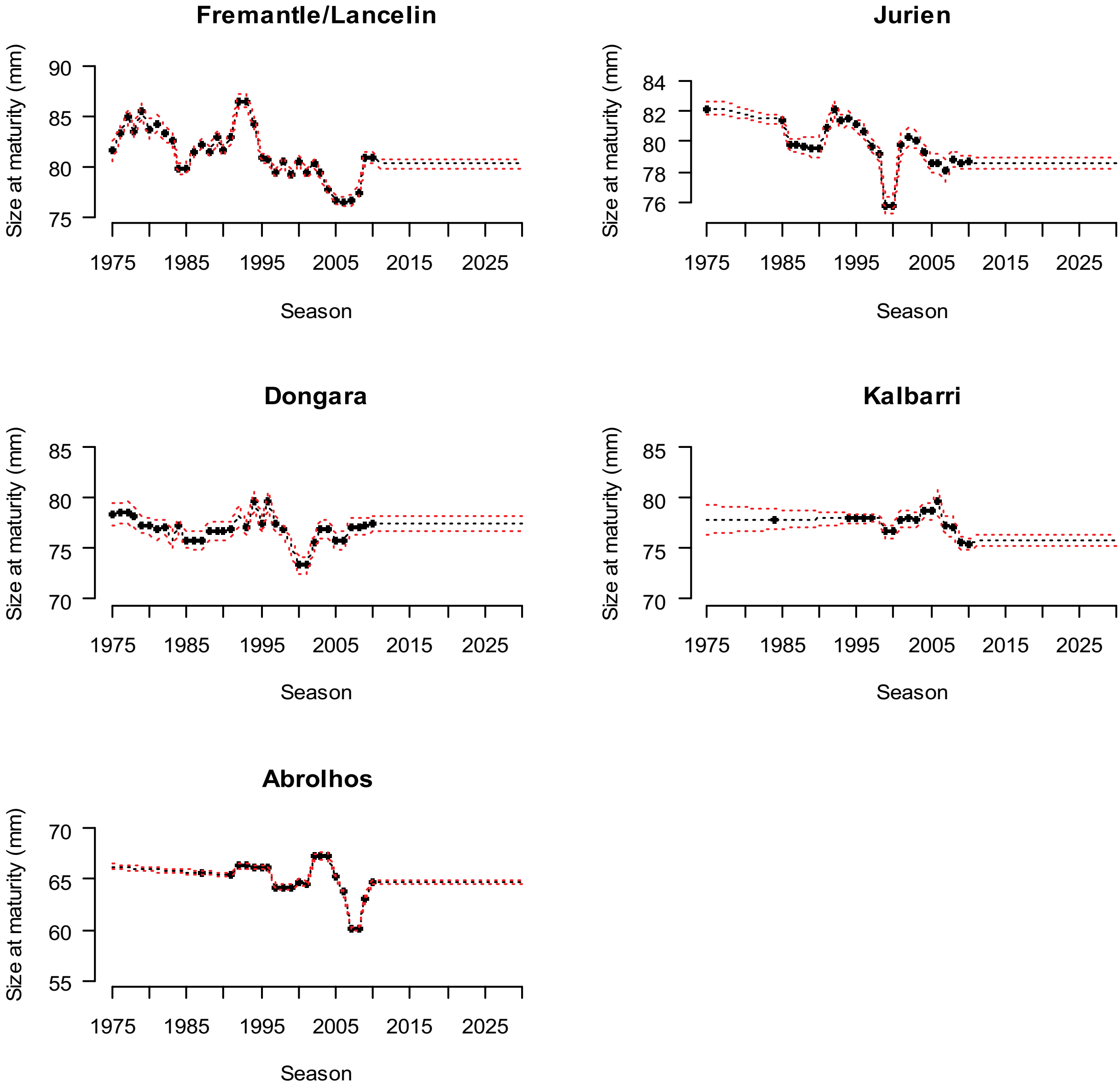


Figure 3.6–6 Model-derived size at maturity estimates for the five general regions used in the Western Rock Lobster Stock Assessment Model (see Section 5.5). Black dots represent seasonal CL_{50} estimates, with the black dotted line indicating the estimates derived for missing years from either a linear relationship between point estimates (years previous to present) or recycled point estimates from the most recent four seasons (years projected into the future). The red dotted lines represent the standard deviation of mean estimates.

For the Stock Assessment Model CL_{50} estimates were used to determine size at double breeding (DB_{50}) estimates since there is almost no temporal coverage in the data required to model this relationship directly. Temporal changes in DB_{50} were estimated by *pro rata* adjusting estimates of CL_{50} by a scaling factor determined from the relationship between CL_{50} and DB_{50} (Table 3.6–2). The error structure around trends in DB_{50} are considered to vary by the same relative magnitude as those estimated for the CL_{50}.

Table 3.6–1 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

3.6.2 Spawning season

Catches of berried females indicate that spawning peaks in late spring, with an increase from August/September peaking in November and tailing off in January/February, particularly on the coast. Catch rates of spawning females at the Abrolhos Islands remain high through December/January before declining in February (Chubb 1991) (Figure 3.6–7).

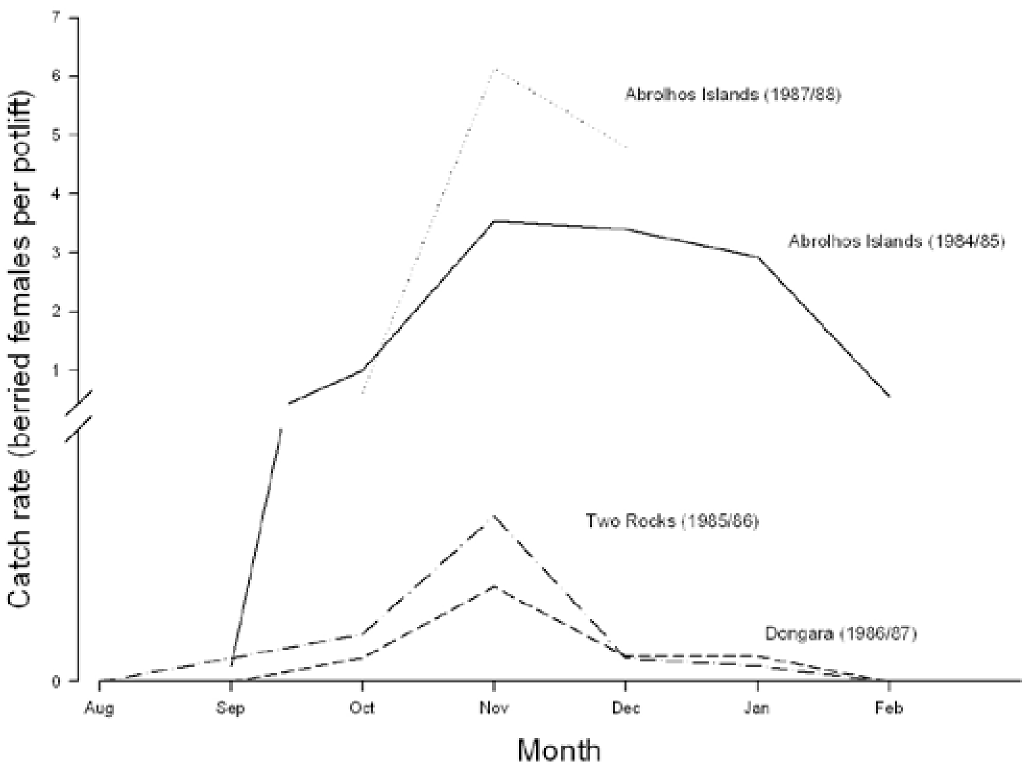


Figure 3.6–7 Monthly catch rates of berried females (number per pot lift) (adapted from Chubb 1991)

The monthly proportions of spawning females have also been shown to vary between years. This variation appears closely related to water temperatures during the start of the spawning season (September and October) (Figures 3.6–8 and 3.6–9). Warm water temperatures during these months' results in spawning occurring earlier and being completed by January, whereas in years following cool water September and October temperatures many females are still ovigerous in February (Figure 3.6–10).

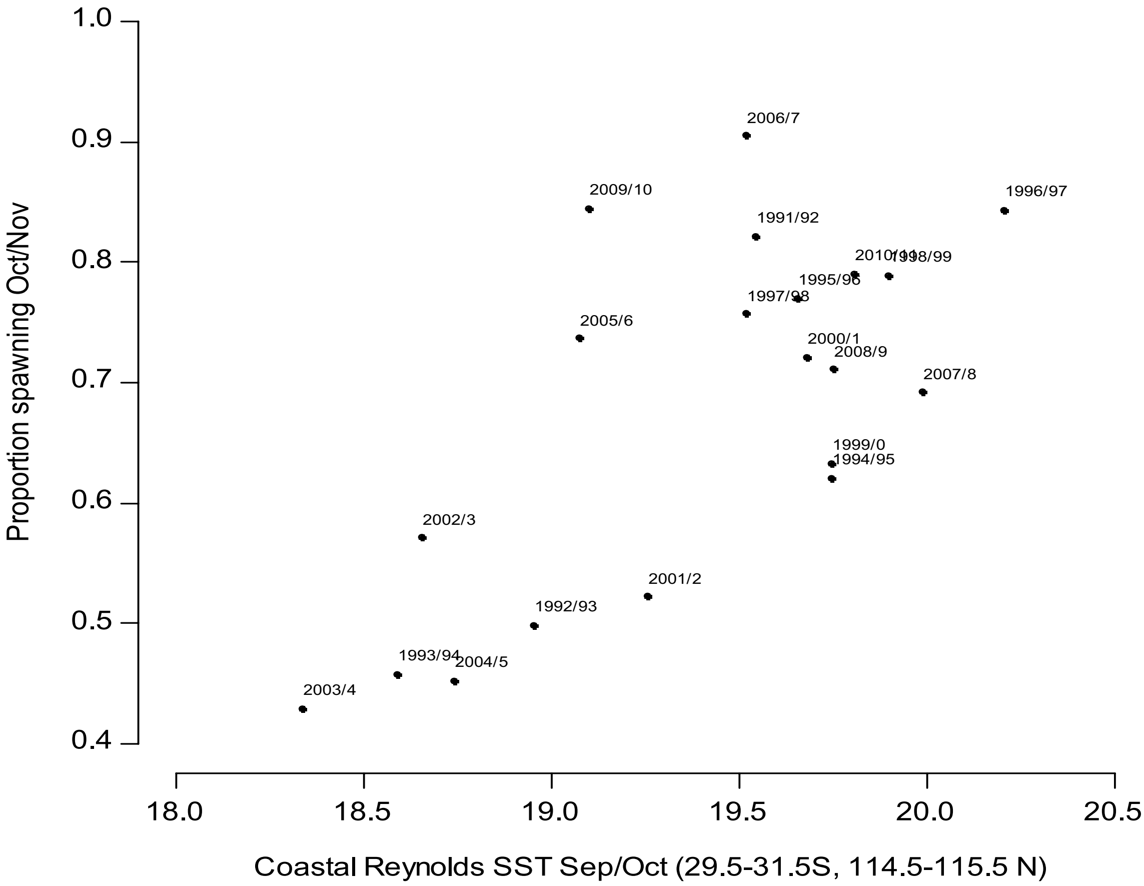


Figure 3.6–8 Relationship between the standardised proportion of mature sized females (>=85 mm CL) that were ovigerous from all locations south of 29º S on ~ 1 November and Reynolds SST water temperatures from blocks along the coast (29.5º – 31.5º S & 114.5º – 115.5º E).

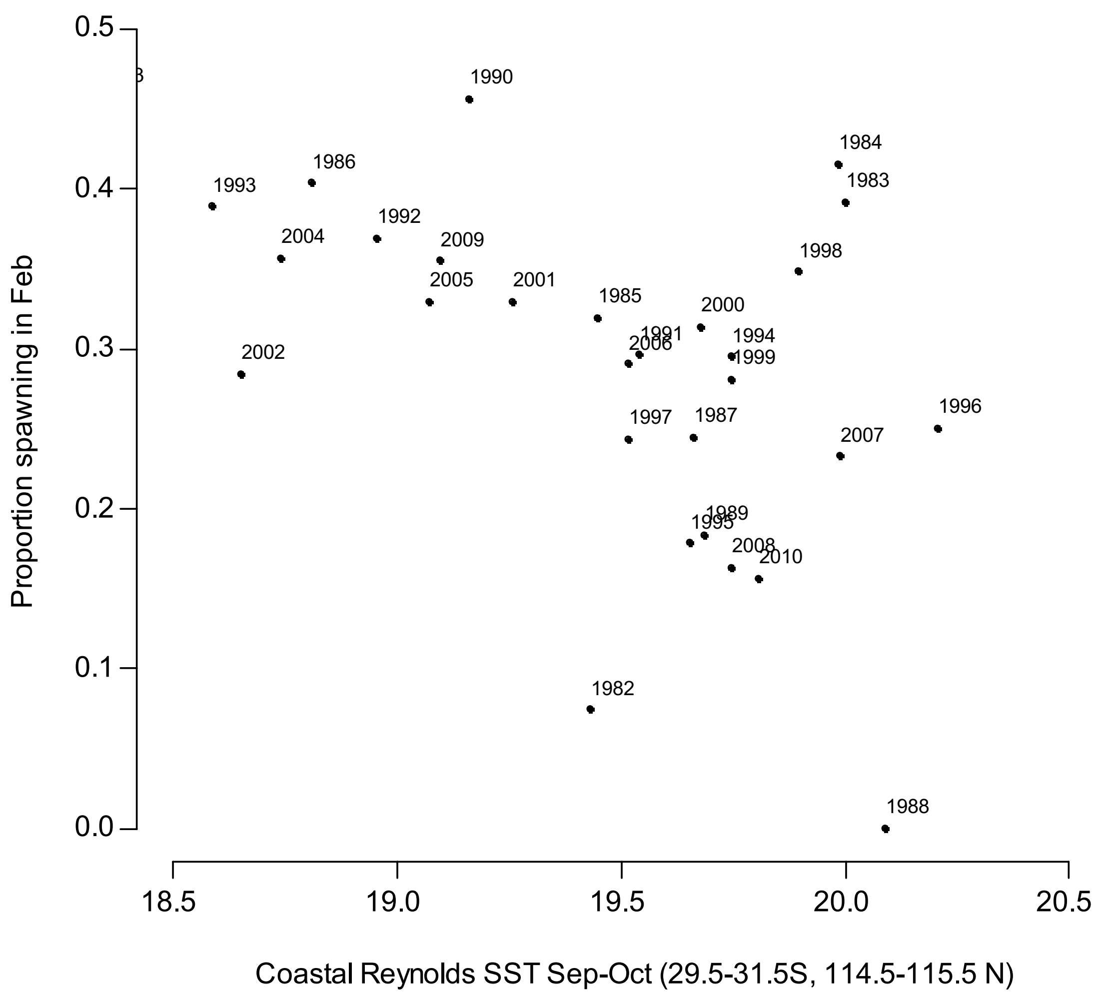


Figure 3.6–9 Relationship between the standardised proportion of mated females with eggs in February and Reynolds SST water temperatures from blocks along the coast (29.5° – 31.5° S & 114.5° – 115.5° E).

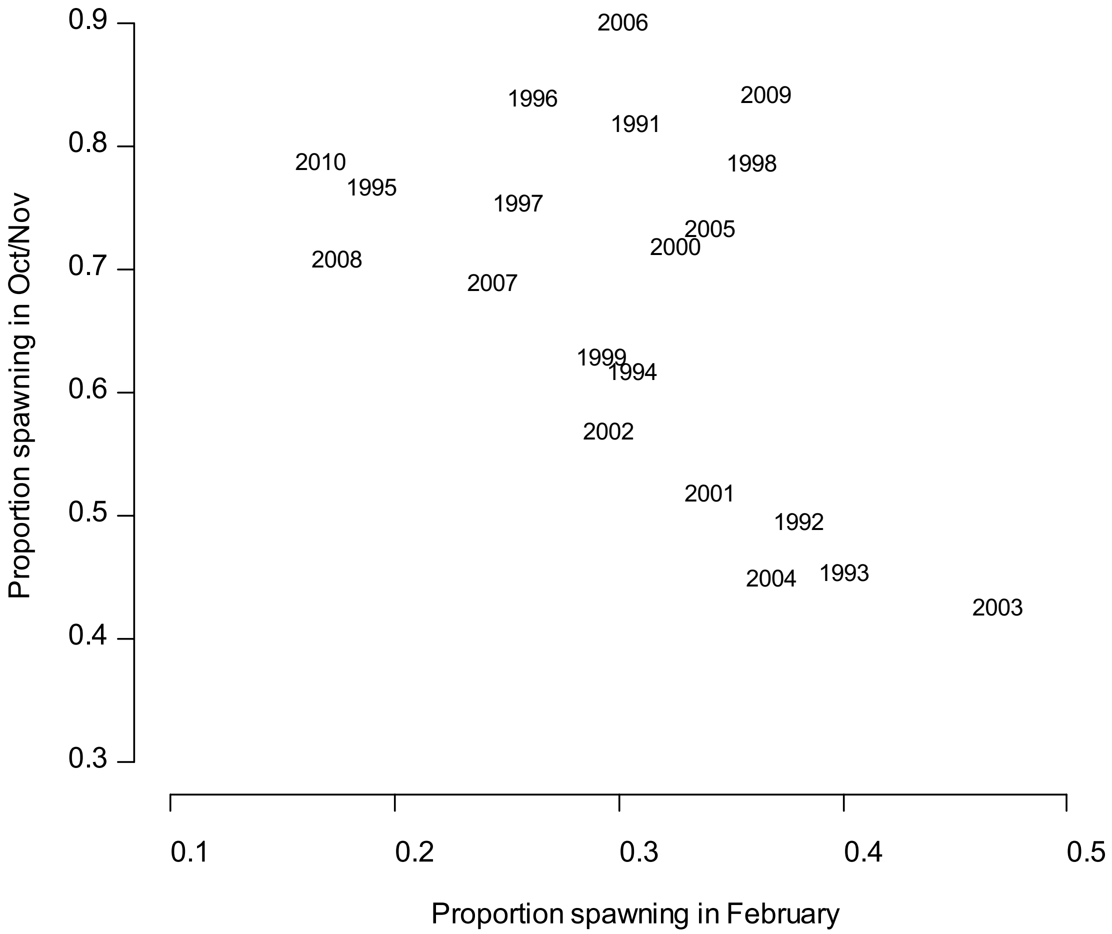


Figure 3.6–10 Relationship between the proportions of female lobsters spawning at the start and end of the spawning season.

3.6.3 Fecundity

The number of eggs produced by a particular female during a spawning period depends on the size of the individual ($Fecundity = 1.92 \times CL^{2.69}$) (Chubb 1991). Hence larger females produce more eggs per unit of size than smaller females, with large females capable of producing a million eggs (Figure 3.6–11), almost all of which are successfully fertilised (Morgan 1972).

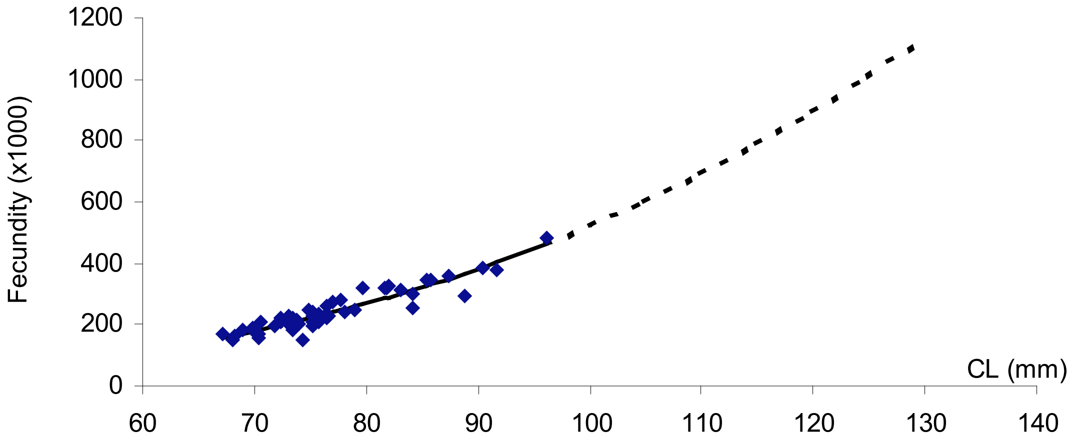


Figure 3.6–11 Fecundity of *Panulirus cygnus* in relation to carapace length (CL) Dotted line represents extrapolation of relationship

The greater number of eggs produced by large females was a main reason a maximum size for females was implemented to protect the breading stock.

While larger females have a greater egg production per brood spawned than smaller females, they also have a greater likelihood of spawning twice during the season (de Lestang & Melville-Smith 2006).

The size at which 50% of the lobsters are classified as "double breeders" displays a similar spatial pattern to the various sizes at maturity, changing with latitude along the coast and distance off shore (Figure 3.6–12). Double-breeding lobsters were larger at Fremantle than at Lancelin, while at Jurien Bay, Dongara and Kalbarri in the north of the fishery they were all similar in size and all were smaller in comparison to the southern fishery sites. The Abrolhos Island lobsters were smaller again than at all the coastal sites. The size at double breeding was consistently ~10 mm CL larger than the size at first maturity for females at these sites (de Lestang & Melville-Smith 2006). This factor further increases the potential for the larger females to produce more eggs during a season and supports the importance of protecting them.

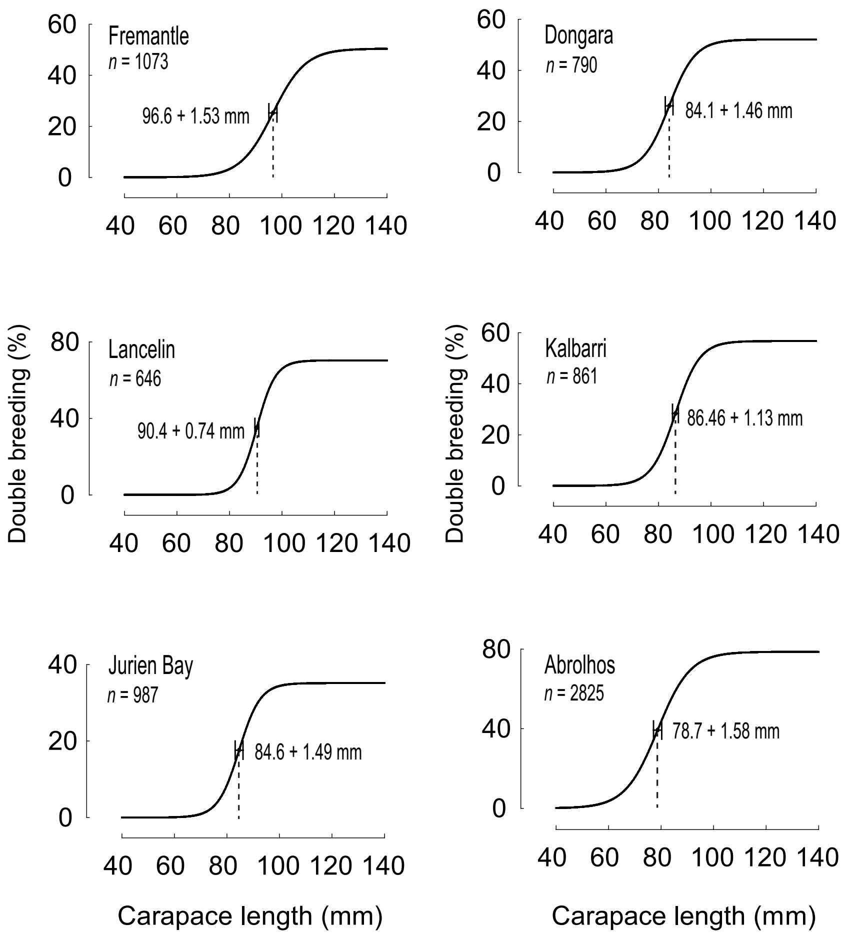


Figure 3.6–12 Probability of double breeding at five coastal locations and the Abrolhos Islands (de Lestang & Melville-Smith 2006).

3.7 Juvenile Recruitment

Most lobster larvae do not survive their long oceanic journey. Many are eaten by predators or are not carried close enough to the shallow reefs by the ocean currents to enable them to settle. Therefore, the number 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 high (Caputi et. al. 1995b) and a higher proportion of the 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 Niños events.

The settlement of pueruli occurs throughout the year, with peaks from late winter to mid-summer (Figure 4.1–2), and generally at night, around each new moon.

The Department of Fisheries monitors the highly variable recruitment of puerulus to the Abrolhos Islands and the coastal reefs on a monthly basis. These data are used as an index of future stock levels, providing a prediction of future catches three to four years in advance (Sections 4.1, 5.2 and 5.5).

3.8 Age and Growth

An essential requirement of a stock assessment model is its ability to "grow" animals in a realistic and practical manner throughout their life history. This requires the determination (either internally or externally of the model) of accurate growth parameters on the same scales used by the model (eg. unique for sexes, locations or time periods) (Punt and Kennedy, 1997; Starr et al., 2009). For example, in the Western Rock Lobster stock assessment model, growth parameters are used to construct size-transition matrices that facilitate the replication of population size compositions and their changes in response to moulting events (de Lestang et al., 2012).

For *P. 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). More recently the novel use of lipofuscin accumulation in the central nervous system has been trialled (Sheehy et al., 1998). The use of such a large range of techniques to examine the growth of *P. cygnus* (and also 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; Johnson et al., 2008).

Length-cohort analysis provides a direct measure of natural growth. This analysis is however only applicable for life stages where growth rates are fast and age cohorts are therefore 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 & 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; Hadden, 2001; 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'Mally 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 uses 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; Ehrhardt, 2008; Hadden et al., 2008, Starr et al., 2009; Helidoniotis et al., 2011).

This chapter examines the growth of *P. cygnus* over a large size range by combining two commonly used growth investigative techniques; tag-recapture for larger lobsters whose growth is not adversely impacted by the tagging process (Chittleborough, 1976; Dubula et al., 2005); and length-cohort analysis for smaller lobsters whose relatively fast growth rates allow individuals from subsequent age cohorts to be separated (Castro et al., 1998; Ulmestrand and Eggert, 2001). The growth equation used to describe the relationship between body size and growth was relatively plastic, allowing it to vary between a linear (the von Bertalanffy situation) and a logistic form, thus enabling the data to inform the model of the most appropriate relationship between these factors. This technique was applied to data from five biologically separate regions of the Western Rock Lobster fishery; the southern, central south, central north and northern region of the coastal fishery and the shallow waters at the offshore Abrolhos Islands.

Methods

Data sources

Data used for the length-cohort component of the growth model have been derived from a modified commercial pot sampling program (meshed-pot) that was initiated in the Western Rock Lobster fishery (WRL) in November 2007. The program allows interested fishers to use one extra lobster pot in addition to their maximum pot allowance, under the proviso that they modify the pot so that it retains small lobsters and that they measure and record their catch on a weekly basis. The main purpose of the survey was to determine the magnitude of offshore deepwater settlement; however a by-product of this project was substantial information on the size composition of lobsters below the legal minimum size of 76 mm carapace length. The number of fishers involved in this sampling, the intensity of catch reporting and the coverage across the fishery has increased since its inception (Table 3.8–1.)

Table 3.8–1 Number of lobsters measured by fishers caught in modified pots in 1° latitude transects during each fishing season.

Location	2007/08	2008/09	2009/10	2010/11
Abrolhos Islands		1738	5072	1683
Northern Coast		859	1319	600
North Central Coast	137	4352	6342	2532
South Central Coast	339	2289	3324	1068
Southern Coast	256	2605	3141	3348
Total	732	11843	19198	9231

Data used for the tag-recapture component of the growth model was derived from the Department of Fisheries (DOF) tagging program, initiated in December 1988. At the start of 2012 data on over 17 000 tag-recaptured lobsters had been returned, including the condition of the recaptured lobster (eg. carapace length, sex and breeding condition) and the location and date of capture (Table 3.8–2). In many of these cases the recaptured animal was provided to a DOF staff member so that the measurements could be verified. All lobsters were marked with individually numbered standard T-bar anchor tags produced by Hallprint™.

Table 3.8–2 Number of tagged lobsters recaptured by fishers and their details returned in full to the Department of Fisheries Western Australia after the data thinning process.

Location	Females	Males
Abrolhos Islands	2731	1223
Northern Coast	1451	481
North Central Coast	896	221
South Central Coast	2608	1190
Southern Coast	785	392
Total	8471	3507

The primary focus of the tagging program was to monitor the movement and growth of lobsters. Additional, ad hoc, tagging has also occurred and has concentrated on determining the impact of handling practices on the survival and growth of lobsters (Brown and Caputi, 1983, 1985, 1986). Growth may be underestimated from tag-recaptures as moult increments may reduce if tagging causes injuries (Hunt and Lyons 1986; Dubula, 2005), or leg loss (Brown and Caputi, 1986), or if lobsters that moult less frequently preferentially retain tags (Muller et al., 1997). Consequently, a methodical approach has been taken to "clean-up" the tagging data prior to analysis by removing known sources of bias. All data with very short times-at-liberty (< 3 months) show little change in size and so have been removed from the dataset. All lobsters that dropped any appendages when released or were retrieved with missing or regenerated limbs (Melville-Smith & de Lestang, 2007) or those tagged close to a synchronous moulting event (Dubula et al., 2005) were also removed from the analysis. Data was also discarded when the tag release and recapture locations were in different areas of the fishery, since the area where growth had occurred could not be determined. Finally tag-recapture data exhibiting unlikely events such as lobsters changing sex, shrinking by over 10 mm or growing over 50 mm in one year were also removed from the data set.

Growth model

The growth model describes the relationship between carapace length (CL) and change in CL (ΔCL) over a short period of time (one month). In the von Bertalanffy equation this relationship is linear with small lobsters having the largest ΔCL and largest lobsters having an asymptotic maximum length and therefore a ΔCL of zero. The relationship used in this study was a multiplicative double-logistic equation capable of replicating a linear relationship or something far more similar to a Gompertz population growth model (Hernandez-Llamas and Ratkowsky, 2004), (eg. with initial slow growth at small sizes increasing in mid sized individuals before again declining to slow growth in larger individuals). The form of the equation is;

$$\Delta L_{s,a} = \frac{1}{1+e^{\left(\frac{L_{s,a}}{\alpha_{s,a}}\right)}} \frac{(\beta_{s,a}-\delta_{s,a})}{1+e^{\left(\frac{L_{s,a}-\varphi_{s,a}}{\gamma_{s,a}}\right)}} + \delta_{s,a},$$

where $\Delta L_{s,a}$ is the change in carapace length (CL) over one month in each sex s and area a combination $\alpha_{s,a}$, adjusts the relative rate of early juvenile growth, $\beta_{s,a}$ and $\delta_{s,a}$ represent the maximum and minimum monthly growth rates of the population, respectively, $\varphi_{s,a}$ and $\gamma_{s,a}$ are the midpoint CL and rate of change between $\beta_{s,a}$ and $\delta_{s,a}$, respectively.

Model fitting

The double-logistic equation was used to replicate both the tag-recapture and length-cohort data sources, with each component of the model producing a Log-Likelihood measure of the goodness of fit to observational data. The two Log-Likelihoods were added and optimised to maximise the model's fit to both sets of observational data simultaneously.

Tag-recapture

The model was fitted to the tag-recapture data by estimating a recapture length from iteratively compounding through the growth equation from the initial release CL, the number of months an individual was at liberty prior to its recapture. The observed and estimated recapture lengths were then used to produce a Log-Likelihood (λ_t) for the tagging data based on the following equation;

$$\lambda_t = \sum\left(\frac{(L_{s,a}-\hat{L}_{s,a})}{2\sigma^2} - 0.5 * log(2\pi\sigma^2)\right) * w_{s,a,g},$$

Where $L_{s,a}$ and $\hat{L}_{s,a}$ are the observed and estimated recapture lengths of a lobsters of sex s and area a, σ is the standard deviation and $w_{s,a,g}$ is the weighting for that length-bin group g to reduce the influence of the large number of observations of lobsters in certain length bins (e.g. 76 – 90 mm CL). The weighting component is described by the equation;

$$w_{s,a,g} = \frac{1}{ln(n_{s,a,g})+1},$$

where $n_{s,a,g}$ is the count of recaptured lobsters of the same sex and area within 2 mm CL of the observed recapture length of the lobster $L_{s,a}$.

Length-cohort

The model was fitted to observed length-composition data by growing a simulated population of lobsters from settlement size (puerulus mean carapace length 8.7 mm) until they encompassed the size range of lobsters in the observed sample, i.e. replicating the natural process of recruitment and juvenile growth. A size transition matrix, derived from the double-logistic equation, was used to prescribe the proportions of lobsters moving from any 1 mm length bin to another after one month of growth (length bins used were consecutive 1 mm bins ranging from 6 – 85 mm).

The 10-year average (1998 – 2007) proportion of puerulus settling in each month of the settlement season (May – April) was determined for each of the five locations from observed puerulus settlement data (de Lestang et al., 2012). The proportion of puerulus settling in first month of the settlement season (May) were grown from a carapace length of 8.7 mm (first length bin) using the size transition matrix and recorded in length bins before being reduced in magnitude by natural mortality (*M*). This process was conducted for the 12-month settlement season using the equation:

$$N_{s,a,b,t} = \left(N_{s,a,b,t} + \left(N_{s,a,b',t-1} + R_{s,a,b',t-1}\right)G_{s,a,b,b'}\right)e^{-M},$$

where $N_{s,a,b,t}$ is the number of lobsters in length bin *b* of sex *s* and area *a* in month *t*, $G_{s,a,b,b'}$ is the proportion of lobsters growing from length-bin *b'* to length-bin *b* (derived from the size transition matrix), *M* is the monthly instantaneous rate of natural mortality and $R_{s,a,b',t}$ is the proportion of the annual recruitment occurring in month *t*. As the mean CL of a recruiting lobster (puerulus) was 8.7 mm CL, lobsters were only recruited into the only recruited into the first length-bin, eg. $\begin{matrix} b = 1 \\ b > 1 \end{matrix} R_{s,a,b,t} \begin{Bmatrix} P_1, P_2, P_3 \ldots P_{12} \\ 0 \end{Bmatrix}$.

After 12 months of recruitment, growth and natural mortality the population from the above process replicated the size composition of 0+ juvenile lobsters present at the end of April (age classes discussed refer to the age since settlement; they do not include the larval phase). The above process was then continued for a further 12 months (with settlement) until the size composition replicated 0+ and 1+ lobsters at the end of April. This population was then subjected to a further 13 to 24 months of growth and *M* (no recruitment) so that it then represented the size composition of lobsters with ages ranging from early 1+ to early 3+ in May (13 additional months) to late 2+ and late 3+ in April (24 additional months). The actual number of additional months of growth applied (13 to 24) depended on the month the observed data was collected. This replicated the period of growth from settlement to sampling experienced by the observed data.

This range of age classes were chosen based on previous work (eg. correlations between puerulus settlement and commercial catch levels) that indicates lobsters achieve carapace lengths of ~76 mm in three ½ to four years post settlement (Chittleborough, 1976; Phillips et al., 1992, Caputi et al., 1995; de Lestang et al., 2009). Therefore the ages of all lobsters <70 mm CL recorded in the meshed-pot sampling would consist ages mainly < 4 years. Furthermore, 0+ and 1+ lobsters have been shown not to readily enter the pots; they have therefore not been included in the simulated population.

A pot selectivity relationship was used to estimate the catch composition that would be derived from fishing the simulated population with meshed lobster pots. The pot selectivity parameters were estimated in the growth model, where the selectivity of a lobster to a meshed pot (*S)* was determined by the equation:

$$S = \frac{1}{\left(1+e^{\left(\frac{(L-75)}{\vartheta}\right)}\right)},$$

where ϑ is the rate of change in selectivity between zero and one, with 50% selectivity occurring at 75 mm CL, just above the maximum size class of 70 mm. The selectivity aims to replicate a progressive reduction in the catchability of a lobster with decreasing body size.

The observed and predicted size compositions were then used to produce a Log-Likelihood (λ_m) for the length-cohort data from the meshed pots based on the following multinominal equation;

$$\lambda_m = \sum\left(log\left(\hat{P}_{s,a,b}\right)P_{s,a,b}\right),$$

where P and $\hat{P}$ are the observed and estimated number of lobsters in length bin b, respectively.

Analysis of all tag-recapture and length-cohort data was conducted separately for each sex in five main areas of the fishery. The areas represent the southern (≥31° S), south central (31-30° S), north central (30-28° S) and northern (≤28° S) regions of the coastal fishery with a fifth offshore-shallow region at the Abrolhos Islands. Previous work has shown that the biology (eg. growth and size at sexual maturity) of lobsters varies significantly and in a progressive fashion between these areas (de Lestang and Melville-Smith 2006; Melville-Smith and de Lestang, 2006; Caputi et al., 2010). The splitting of the data into the different sex/areas provided two main benefits for the model. Firstly it allowed for a better fit to the observed data as there was less within area variation in the data compared to examining the growth over greater spatial ranges. Secondly it allowed for some priors to be added into the model based on previously determined differences/similarities known to occur between sexes/areas. The priors used were; growth rates of young female and male juveniles should be similar in the same area (Chittleborough, 1976); and growth rates in the middle of the four coastal areas (south and north central areas) should be transitional between growth rates measured in the areas directly to their north and south (Chittleborough, 1976; de Lestang et al., 2009). These priors were built into the model with deviations from these priors combined to penalise the overall Log-Likelihood. The penalties (θ) from the priors were determined based on the following two equations:

1. The initial rate of juvenile female and male growth in a common region should be similar: parameters β and α were penalised based on the following equation:

   $$\theta = \sum\frac{\left(\tau_{1,a}-\tau_{2,a}\right)^2}{2\sigma^2},$$

   where $\tau_{s,a}$ is the penalised parameter in sex s and area a.

2. The rate of change of a growth rate in a central coastal areas of the fishery should be intermediate of those found directly to the north and south of that area: parameter R was penalised based on the following equation:

   $$\theta = \sum\frac{\left(0.5\left(\tau_{s,a-1}-\tau_{s,a+1}\right)-\tau_{s,a}\right)^2}{2\sigma^2},$$

All parameters for the growth equation in the two sex and five area groupings together with parameters representing pot selectivity (length-cohort) and natural mortality (length-cohort) were all estimated by minimising the combined penalised negative Log-Likelihood $\{-(\lambda_t + \lambda_m) + \theta\}$ in AD model builder (Fournier et al., 2011).

Results

Tag-recapture data

The tag-recapture data covered a large size range of female and male lobsters across the fishery. After data thinning, the smallest release CL for a recaptured lobster at each location ranged from 42.2 mm at the Abrolhos Islands to 56.6 mm at Dongara. The largest release CL for a recaptured lobster ranged from 105.0 mm at the Abrolhos Islands to 149 mm at Jurien. Time at liberty for recaptured lobsters ranged from the thinned minimum of four months to maximum liberties for females in each area of 65 months (5.4 years) at Kalbarri to 223 months (18.6 years) at the Abrolhos and for males, 40 months (3.3 years) at Lancelin to 54 months (4.5 years) at

Dongara. The biggest increase in size was similar for both sexes in each location and ranged from ~45 mm in the Abrolhos Islands to about 55 mm for the coastal regions. Of particular note in the tagging data was the exceptionally small growth increments recorded for the majority of large recaptured females. For example, the mean increase in CL for three females at liberty for over 17 years in the Abrolhos Islands was about 10 mm.

The changes in CLs between tag release and recapture over all liberties for each sex in each area were well replicated by the double logistic growth model, without any obvious trends being present in the modelled residuals (Fig. 3.8–1). The residual plots show an even spread of over and under estimation throughout the range of release CLs, with an increased variability (both positive and negative) for lobsters ranging between 60 and 80 mm release CL (Fig. 3.8–1). It is noticeable that a far greater range of release CLs exists in the southern locations especially for female lobsters.

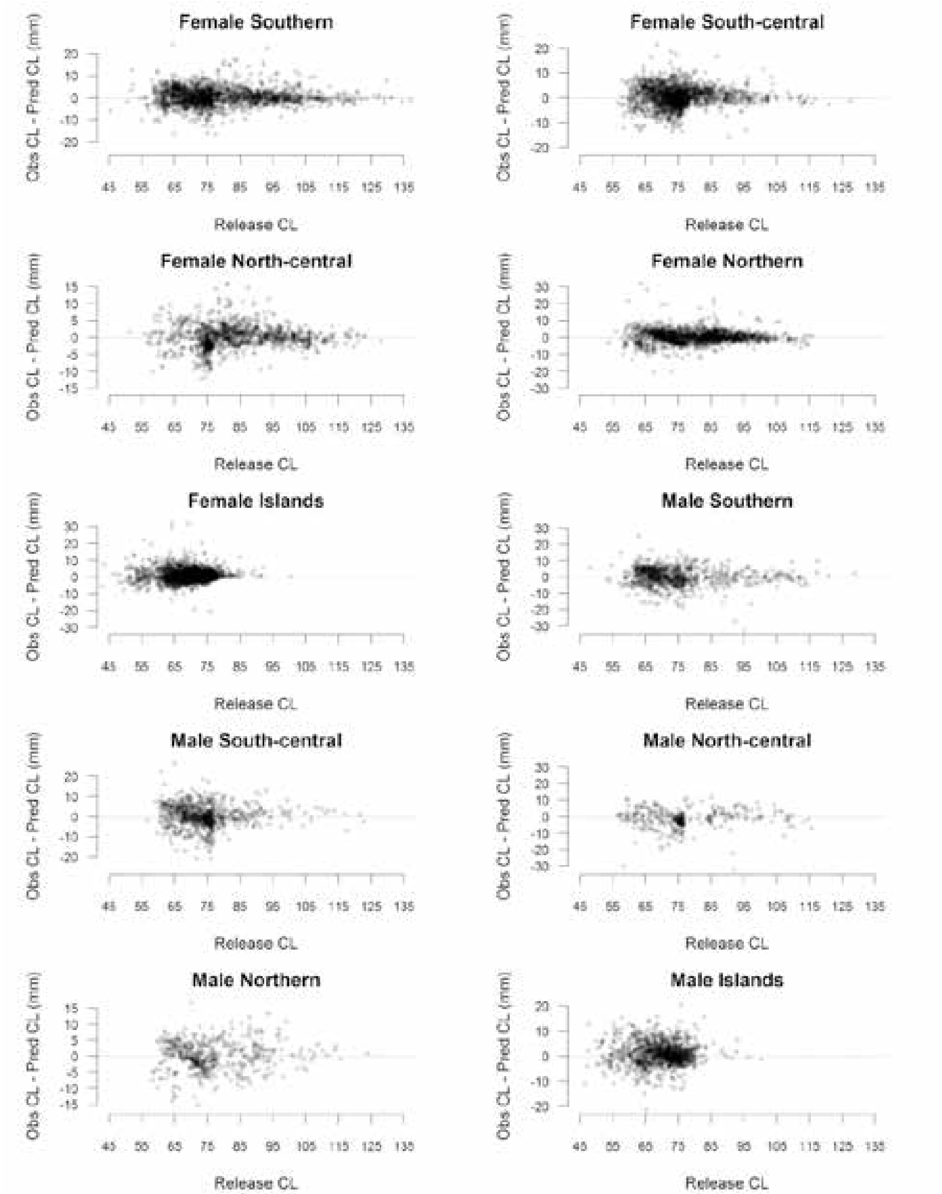


Figure 3.8–1 Residual plots showing the fit of the growth model to the recapture carapace lengths of lobsters in each area and sex combination. Transparent points have been plotted so darker regions indicate a greater level of over-plotting.

Length-cohort data

Size-composition data has been collected for western rock lobsters throughout the fishery, covering almost every month of the year. The smallest rock lobsters recorded during the meshed-pot sampling program in each area ranged from 17 mm CL in the north central area to 23 mm CL in the northern area. With the exception of two lobsters in the northern area and one in the north central area all lobsters with CL ≤ 30 mm (i.e. 79 lobsters) were captured in waters shallower than 30 m (most of these were caught in waters ≤ 10 m).

The double logistic model was able to reproduce similar size compositions to those produced by the meshed-pot sampling program for each sex in each area (Fig. 3.8–2). Pearson’s residual plots show an even spread of over and under estimation throughout the size range of juvenile lobsters modelled CLs, with relatively constant variability for all lobster CL except for those the upper two length bins (Fig. 3.8–3). Within these last two length bins the Pearson’s residuals indicate that the model is slightly under representing the contribution of lobsters.

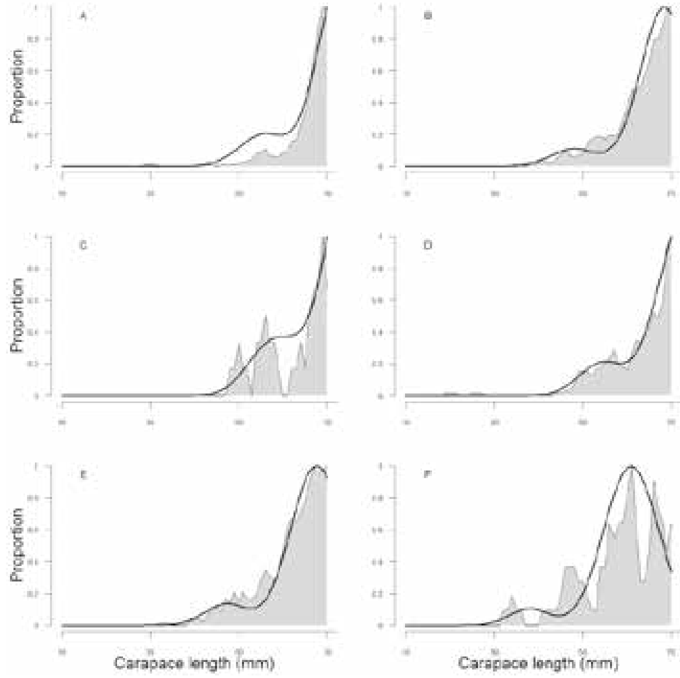


Figure 3.8–2 Six examples of observed (grey area) and model estimated (black line) size compositions of lobsters < 70 mm from the meshed pot sampling. A – F represent females in region 3 in January and September, males in region 2 in April, males in region three in January and September and females in region four in June, respectively.

Modelled growth rates were more similar between locations than between the two sexes, especially for larger lobsters. In general growth rates of both sexes increased from about 1 mm month^{-1} for early juvenile lobsters (8.7 mm CL) to a maximum of around 2 mm month^{-1} for late juveniles (60 mm CL) at which point growth rates between the two sexes diverged markedly (Fig. 3.8–4). From 60 mm CL female growth rates declined rapidly to minimum levels of less than 0.2 mm month^{-1} (Table 3.8–3) whereas those of males declined at a far slowly rate, so that at a CL of 100 mm, males were still growing about 0.8 mm month^{-1} faster than females in the same area (Fig. 3.8–4). Between the areas the fastest initial modelled growth rate for either sex was at the Abrolhos Islands (1.4 mm month^{-1}) while the slowest was in the northern area (1.2 mm month^{-1}). The fastest monthly growth rate of either sex increased progressively from 1.76 mm month^{-1} in the most southern coastal area to 1.81 in the most northern coastal area and then to 2.0 mm month^{-1} at the Abrolhos Islands (Fig. 3.8–4). The monthly growth rate of larger lobsters (>120 mm) was least at the Abrolhos Islands (0.1 and 0.2 mm month^{-1} for females and males, respectively) and greatest in the southern coastal sites (0.3 and 0.6 mm month^{-1} for females south central and males southern, respectively).

Table 3.8–3 Mean ± 1 sd parameter estimates for the double logistic relationship between CL and ∆CL for each sex and area.

	Area				
Parameters	**Southern**	**South central**	**North central**	**Northern**	**Abrolhos Islands**
Females					
α	-27.9 ± 9.08	-27.8 ± 10.2	-28.5 ± 8.43	-28.4 ± 9.93	-28.1 ± 10.9
β	2.25 ± 0.18	2.34 ± 0.23	2.34 ± 0.16	2.12 ± 0.20	2.48 ± 0.28
δ	0.04 ± 0.05	0.24 ± 0.09	0.11 ± 0.04	0.22 ± 0.08	0.07 ± 0.08
φ	78.1 ± 1.35	71.7 ± 2.19	71.5 ± 1.31	77.7 ± 1.55	61.5 ± 1.83
γ	12.4 ± 1.44	11.4 ± 1.92	10.2 ± 1.11	9.09 ± 1.74	5.89 ± 1.37
Males					
α	-23.0 ± 9.03	-22.3 ± 11.6	-23.3 ± 8.84	-23.7 ± 9.44	-23.4 ± 11.6
β	2.32 ± 0.36	2.24 ± 0.39	2.43 ± 0.28	2.08 ± 0.27	2.11 ± 0.34
δ	0.27 ± 0.51	0.21 ± 0.45	0.61 ± 0.24	0.28 ± 0.45	0.16 ± 0.49
φ	96.3 ± 18.1	94.0 ± 16.1	60.6 ± 7.04	99.0 ± 10.4	73.6 ± 5.00
γ	34.1± 13.1	27.5 ± 9.24	20.8 ± 6.91	14.7 ± 5.60	11.0 ± 7.65
	All areas				
Length-cohort					
ϑ	-5.69 ± 0.39				
M	1.22 ± 0.23				

Estimates of pot selectivity and average annual instantaneous natural mortality (*M*) of juvenile lobsters were also produced by the length-cohort component of the growth model (Table 3.8–3). The relative selectivity of a pot was estimated to decline quite rapidly for lobsters <75 mm CL. For example, 59 and 69 mm CL lobsters were predicted to be one tenth and half as likely to be selected by a pot as was a 75 mm CL lobster, respectively. The estimate of natural mortality (*M*) corresponded to an average reduction in the number of lobsters between age 0 (settlement) and age 3 – 4 years post settlement of ~70% per year.

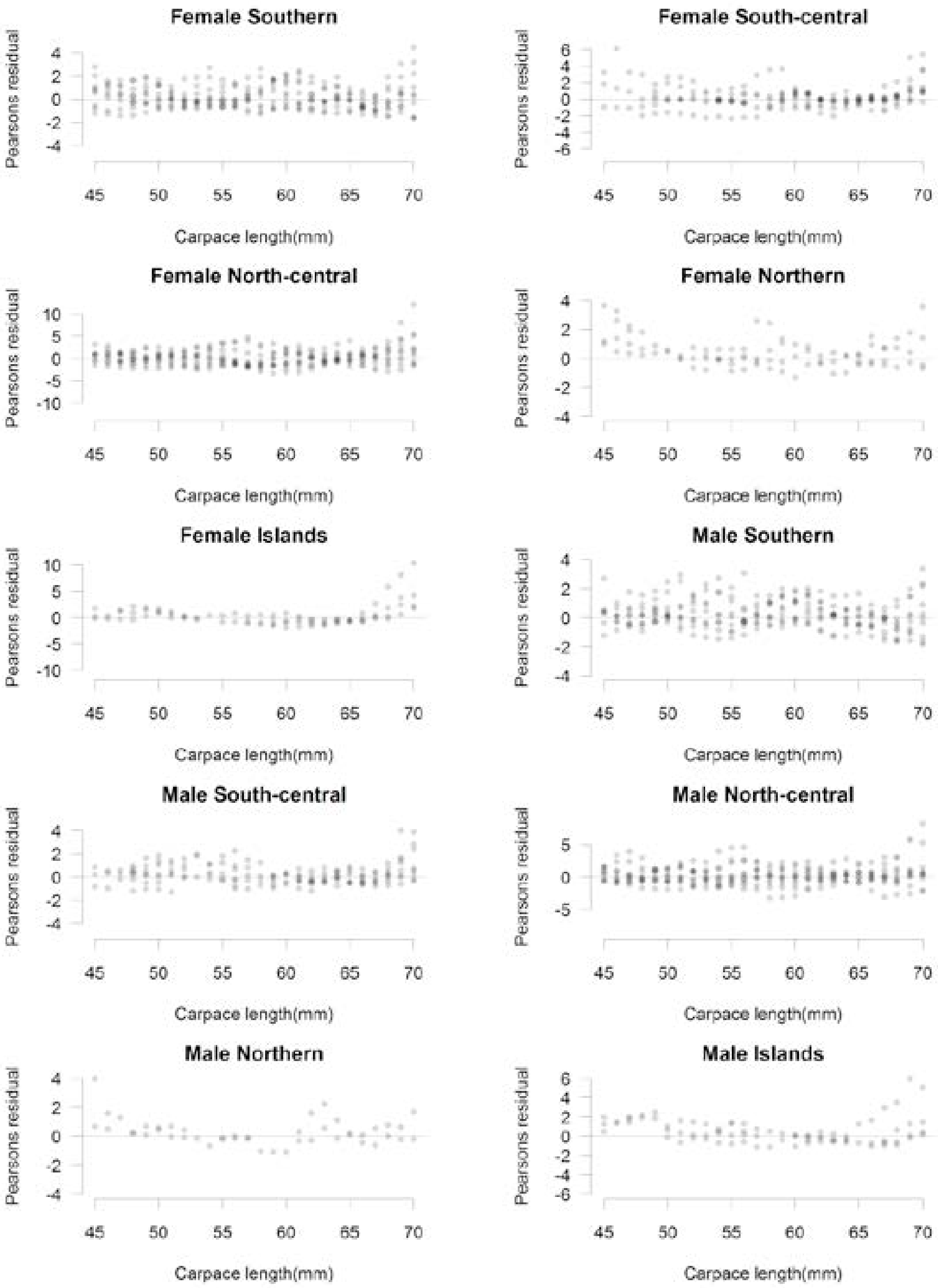


Figure 3.8–3 Pearson's residual plots showing the fit of the growth model to the length-cohort data collected by the meshed-pot sampling program in each month. Residuals determined for each month of data have been added onto the same sex/area plot.

Compounding the monthly growth rates estimated by the model allowed the production of the more traditional relationship: age vs length (Fig. 3.8–5). These growth curves for each location essentially followed similar patterns; however males grew far larger in adult life than did the females. All growth curves exhibited a slight increase in growth through the first two years after settlement before they declined in females around 60 – 80 mm CL and slightly later for males at around 80 – 100 mm CL (Fig. 3.8–5). The size of large females was consistently estimated to be lower than that for males in the corresponding area. The mean CL of males 20 years post settlement was between 140 and 200 mm CL whereas for females this ranged between 90 and

140 mm CL (Fig. 3.8–5). There was far greater uncertainty associated with the growth curves of male lobsters after ten years of age, with the confidence region of the size of lobsters at 20 years post settlement spanning 75 mm CL in some areas (Fig. 3.8–5).

All growth rates estimated, except that for females at the Abrolhos Islands, project that the minimum legal size of 76 mm is obtained between 3 and 4 years post settlement. Male lobsters in the northern coastal region were projected to reach this size first not long after their third birthday whereas females at the Abrolhos Islands were projected to reach this size four years after settlement (Fig. 3.8–5).

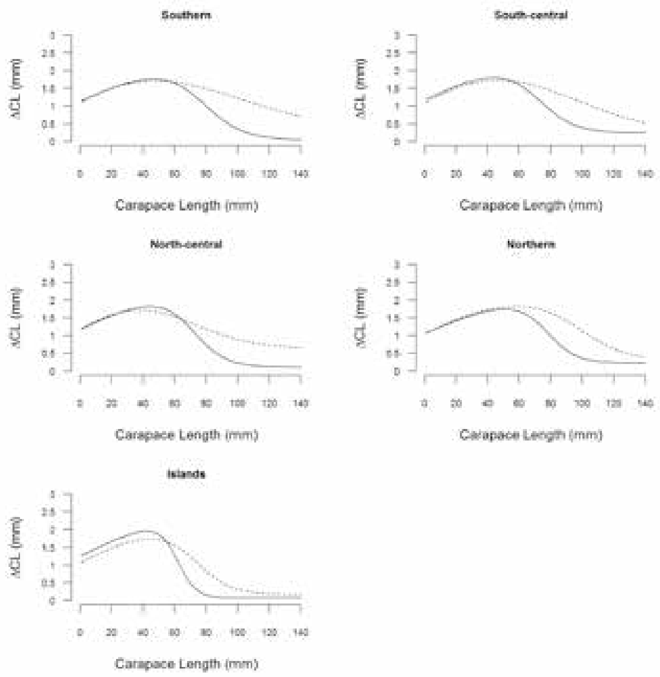


Figure 3.8–4 Relationship between the average change in CL (ΔCL) and CL of female (solid line) and male (dotted line) over one month in the five areas of the fishery.

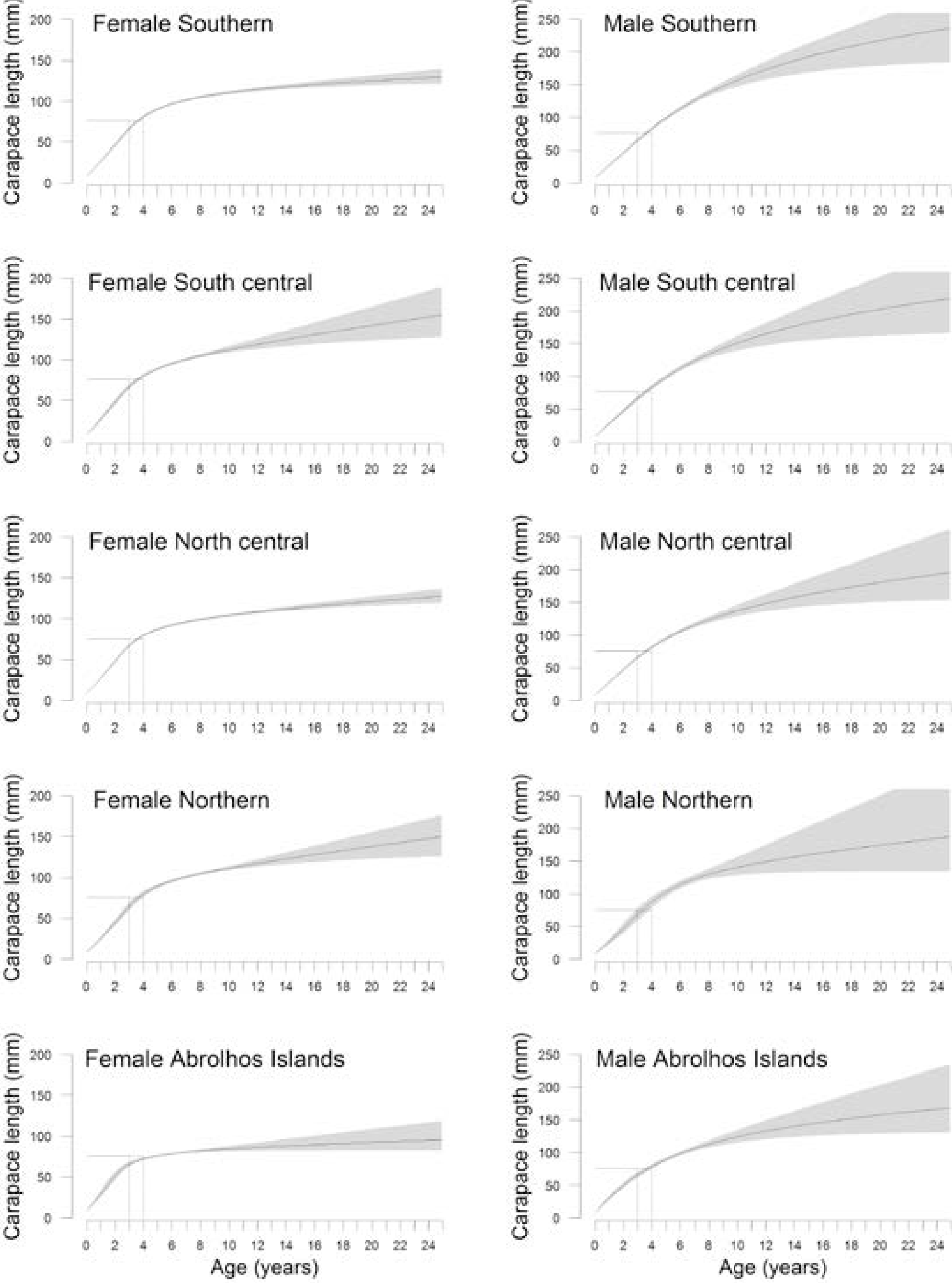


Figure 3.8–5 Growth curves constructed by compounding estimated monthly growth from an initial carapace length 8.7 mm (mean puerulus CL) for female and male lobsters in five areas of the fishery.

Discussion

Replication of tag-recapture and the size composition data sets

For each location and sex combination the growth model gave results consistent with patterns displayed by both the tag-recapture and the size composition data sets. The residual plots of the predicted and observed CL at recapture showed a good fit of the model to the tagging data, although there was noticeably more spread of residuals for lobsters in the smaller size classes, eg. below 80 mm CL. This greater spread is likely the result of the far greater numbers of lobsters of this size range present in the data set. A major focus of western rock lobster tagging has been the examination of the variability in a moulting event that occurs each year prior to a juvenile migration from shallow to deepwater habitats; when tagged the lobsters that undertake this migration are all below 80 mm CL, which has resulted in the dominance of tagged lobsters in this size range. There is also the possibility that this increased spread is due to the growth of *P. cygnus* of this size being more variable than that for larger size classes. It is well documented that growth in lobsters noticeably declines with the attainment of maturity, presumably as a result of moving resources previously used for somatic growth into reproductive development (Hartnoll, 1985; de Lestang, 2003). For *P. cygnus* the attainment of maturity occurs between 65 and 90 mm, a similar size range to that corresponding to the increased variability in growth shown in the model residual plots (Melville-Smith and de Lestang, 2006). The increased variability may therefore represent individual variability in the attainment of maturity within each of the locations used in this study.

The Pearson's residual plots highlighted the good fit between the modelled and observed size composition data over most the majority of the size range modelled (i.e. 45 – 68 mm). However above 68 mm CL in the upper 2 length bins (i.e. 68.0 – 70 mm), the plots show a small but consistent under-representation of the observed data. This consistent bias occurred only during the months of May and June when the overall simulated population of lobsters were at their youngest, i.e. representing early 2 and 3+ cohorts. The observed size composition data in each sex / location combination in these two months show two distinct modal groups and what is most likely the lower edge of a third model group, i.e. the 4+ cohort, in the upper few length bins. It is this lower edge of early 4+ lobsters, an age cohort not simulated by the model, which causes the asymmetry in the upper two length bins shown in the Pearson's residual plots. The inclusion of a third age cohort (4+) into the model, especially when very little or none of this cohort is represented in the observed data would provide little extra information for the overall model. This is especially the case since the model has a large amount of growth information available for these size classes in the tag recapture data set. Future developments of this model will examine the improved model fit *vs* parsimony of including this third cohort.

Analysing the size composition and tag-recapture data simultaneously allowed the model to estimate growth over the full life span of this species and to determine the appropriate relationship between CL and ΔCL. The size composition data informed the model of the early stages of juvenile growth whereas tag-recapture data covered that from pre-puberty to late adults. The two sets of data, covering all sizes allowed the model to use a more complicated / plastic equation to describe growth, that otherwise would have been indeterminable without a complete coverage of data. Describing growth from initial settlement to the start of biological changes such as migration and reproductive size/age and then on to the attainment of the minimum legal size is advantageous as it removes the need to extrapolate growth rates determined from one life phase into another phase that may exhibit different growth. Without information on lobsters less than 40 mm CL a likely extrapolation of growth into smaller length classes based solely on the tagging data would have been a levelling off the growth rate at the maximum level or a continued increase, rather than a decline as shown in this paper.

The growth model described in this paper was able to accurately reproduce the same ages to legal recruitment as those determined previously using correlations between levels of puerulus settlement and the magnitude of commercial catches, i.e. 3½ – 4 years post settlement (Caputi et al., 1995; de Lestang et al., 2009). The age to legal recruitment was similar for both sexes in each area except in the Abrolhos Islands where females attained this size almost one year after that of males. This difference in growth to legal between the two sexes may explain why the prediction of commercial catches using puerulus settlement levels, which contain both males and females, has never been as accurate at the Abrolhos Islands as at the coastal sites (de Lestang et al., 2009)

Relationship between CL and ΔCL

The growth model determined that the most appropriate relationship between CL and ΔCL for *P. cygnus* was of a form similar to that of a "Ricker" stock recruitment relationship (Ricker, 1954) or Gompertz growth model. These relationships display an initial increase in the growth in very small individuals, peaking around puberty and then declining to minimum levels in older mature animals, a quite a different relationship to that of the linear von Bertallanfy. The inappropriateness of a linear relationship in describing the change in CL and ΔCL across the entire life span of this lobster, and possibly other invertebrates, is highlighted by the process by which these animals undertake growth.

Invertebrates moult to increase their body size, absorbing water into their tissues to help break apart the old shell so their bodies may swell and the new shell can harden at a larger size (Waddy et al., 1995). This process results in a single moult growth increment being a fraction of the initial pre-moult body size (Hiatt 1948; Mauchline, 1977). This relationship is reported to be non-linear throughout life, i.e. best described by two or more separate lines, at least one for juveniles and one for adults (Somerton, 1980). Moult frequency also influences crustacean growth and is reported to be related to a number of factors including energy store levels and metabolic rate (Wahle and Fogarty, 2006). Moult frequency has been shown in lobsters and other crustaceans to change in a non-linear fashion with body size, decreasing with increasing size and then reducing step-wise with the attainment of maturity, especially for females (Wahle and Fogarty, 2006; Ehrhardt 2008; Linnane 2011). The combination of these two processes, moult increment and frequency, of which both which are reported to be non-linear, dictates the resultant rate of change of ΔCL with increasing CL should also be a non-linear relationship.

The faster reduction in growth rates displayed by female than male lobsters in this paper is related to the greater reallocation of resources from somatic growth into reproduction with the attainment of maturity (McGarvey et al., 1999; Lester et al 2004; Wahle and Fogarty, 2006). Female *P. cygnus* are highly fecund, even at relatively small carapace lengths (Chubb, 1991) and have been shown to also undertake a number of post-spawning moults each season to replenish reproductive structures (setae) damaged during the spawning process (de Lestang and Melville-Smith, 2006). Since these processes (egg production and moulting) have such high energy demands it is not surprising that large mature female lobsters allocate little of their energy stores into somatic growth during these moulting events. The strong relationship between size at maturity and the decline in growth can be seen in the model parameter estimates for female CL_{50} that range from 71 – 78 mm CL along the coast and to 61 mm CL at the Abrolhos Islands. These values are very similar to the female sizes at maturity previously reported for this species, i.e. 75 – 85 mm CL along the coast and 65 mm CL at the Abrolhos Islands (de Lestang and Melville Smith, 2006). Male CL_{50} estimates also correlate well with reported sizes at maturity with both measures generally being 15 – 20 mm higher than for females in their corresponding area (Melville-Smith and de Lestang, 2006).

For both sexes, initial growth rates were fastest at the offshore Abrolhos Islands and slowest in the southern coastal locations, a spatial pattern similar to that of the mean water temperatures.

Growth was also found to slow earlier in the warmer Abrolhos Islands and northern coastal areas, with the persistence of high growth rates in the southern areas resulting in lobsters growing to larger sizes. Increased juvenile growth rates (Hazell, 2001; Johnston et al., 2008) and reduced maximum sizes (Melville-Smith et al., 2010) in association with elevated water temperatures have been reported previously for this species and other crustaceans. Johnston et al., 2008 grew a range of *P. cygnus* from early post-settlement through until three years post settlement at a range of stocking densities, feeding rates and water temperature regimes. They found water temperature to be a significant factor on growth. A strongly positive relationship existed between water temperature and growth in the first few age cohorts, until the lobsters entered their third year post settlement. At this age many of the lobsters in the elevated water temperature treatments matured precociously and their growth rates declined dramatically. Lobsters in the cooler water treatments continued to grow at their higher "juvenile growth rates" throughout their third year post settlement (Melville-Smith et al., 2010).

This paper has demonstrated how two very different sets of data, each covering a separate part of the size range of *P. cygnus*, can be combined in a single modelling process to inform a model on the pattern of growth throughout the lobsters entire size range. A complete, non-extrapolated measure of growth rate has allowed the appropriate relationship between CL and ΔCL to be determined, highlighting the inappropriateness of the often used linear relationship between these factors. The growth of *P. cygnus* is well described using a non-linear function that vary throughout life to accommodate changes in growth occurring due to factors such as the attainment of maturity. Growth rates for *P. cygnus* vary markedly between sexes and between the various regions of the western rock lobster fishery. Male lobsters maintain higher growth rates for longer and attain greater body sizes than females, a fact that has been well documented in other lobster species (eg. Lozano-Alvarez et al., 1991; Bavacqua et al., 2010). In warm water temperature locations both sexes exhibit initial faster growth and earlier declines to slower, presumably adult growth, than in cooler water temperature locations. These differences in the patterns growth explain the greater presence of small mature lobsters at the Abrolhos Islands (Melville-Smith and de Lestang, 2006) and larger lobsters in the more southern regions of the Western Rock Lobster fishery (Chubb et al 1999).

3.9 Diet

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), whose populations probably have high productivity, high turnover rates and short life cycles. Juvenile rock lobsters have a range of diets and feeding strategies, varying greatly between seasons and between different habitats in the same season (Edgar 1990). Edgar (1990) reported that the diet of *P. cygnus* reflected the abundance and size distribution of available benthic macrofauna on all sampling occasions.

The diet of adult western rock lobster populations in deep coastal ecosystems (36–75 m) is currently being investigated by Waddington et al. (in prep), using gut content and stable isotope analysis. Results to date suggest that lobsters are primarily carnivorous and act as secondary consumers, and also suggest the diet shifts from an omnivorous diet in shallow inshore areas to a primarily carnivorous diet when the lobsters migrate to deep coastal ecosystems. The main prey items of lobsters in deep coastal ecosystems include crabs, amphipods and isopods, with diet largely reflecting the food availability of those taxa found free-living or associated with algae on the benthos in areas lobsters are known to forage. Dietary analysis also indicated that bait (pilchards) is an important component of lobster diet at the locations investigated. Bait is available to the lobsters through discards from fishing boats and is also used in pots, from which then lobsters escape through the neck or in the case of undersize lobsters through escape gaps.

There is no evidence that lobster size or sex affects the lobster's diet or trophic position in deep coastal ecosystems (size range investigated 65 – 120 mm CL) (Waddington et al. 2008).

Detailed dietary information and trophic interactions can be found in Department of Fisheries (2011).

3.10 Effects of Climate Change

From Caputi et al. (2010)

"Environmental factors, such as the Leeuwin Current (which is influenced by the ENSO cycle) and westerly winds in late winter/spring significantly affect puerulus settlement of the western rock lobster fishery of Western Australia. Climate change is causing an increase in water temperature that is seasonally variable, a weakening of westerly winds in winter, and an increase in the frequency of El Niño events. Rising water temperatures over 35 years may have resulted in a decrease in size at maturity and the size of migrating lobsters from shallow to deep water; an increase in abundance of undersize and legal-size lobsters in deep water relative to shallow water; and a shift in catch to deep water. The size of the migrating lobsters is related to the water temperature about the time of puerulus settlement (about 4 years previously). The climate change effect on puerulus settlement, catchability, females moulting from setose to non-setose, timing of moults and peak catch rates, are assessed. As climate change models project that the warming trend will continue, these biological trends are likely to continue. The changes may have negative (increasing frequency of El Niño events) or positive (increasing water temperature) implications for the fishery. These changes need to be taken into account in stock assessments and management."

4.0 Fisheries Time–Series Data

4.1 Puerulus

The puerulus stage of *Panulirus cygnus* settles naturally in near shore 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.

4.1.1 Methods

Locations

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 (see Table 4.1–1 and Figure 4.1–1).

Table 4.1–1 Location of historical and current puerulus collector sites and the number of collectors at each site.

Site	Initiated	Collectors (n)	Status
Abrolhos Is. (Rat Is.)	**1971**	**10**	**1971–1978; 1984 to current**
Alkimos	**1982**	**5**	**Current**
Cape Mentelle	**1984**	**7**	**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**	**8**	**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**

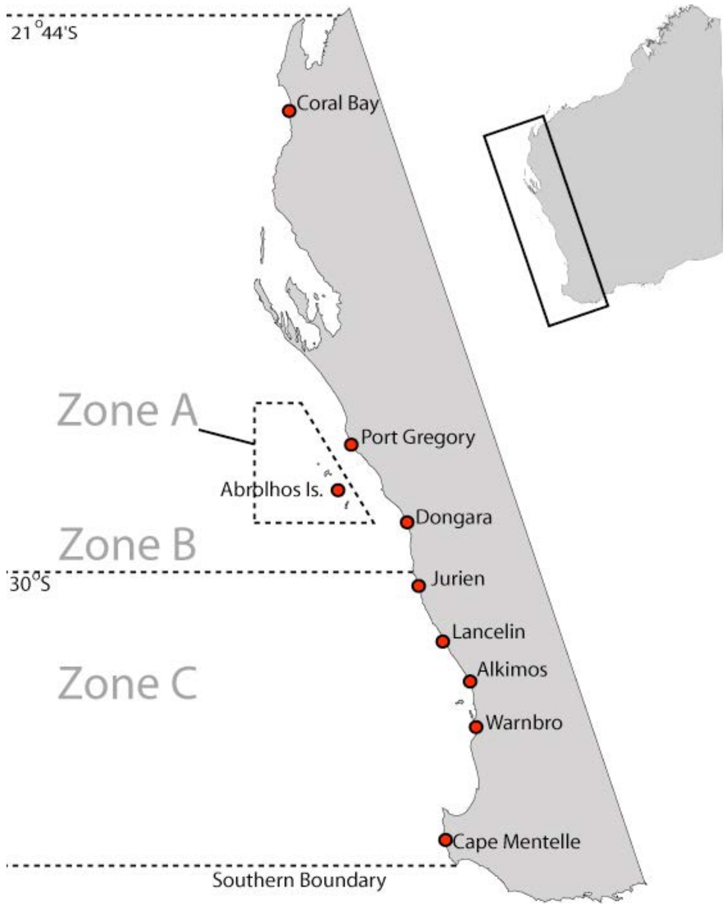


Figure 4.1–1 Location of current (2011) puerulus collector sites

Puerulus collectors

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 (Plate 4.1–1a).

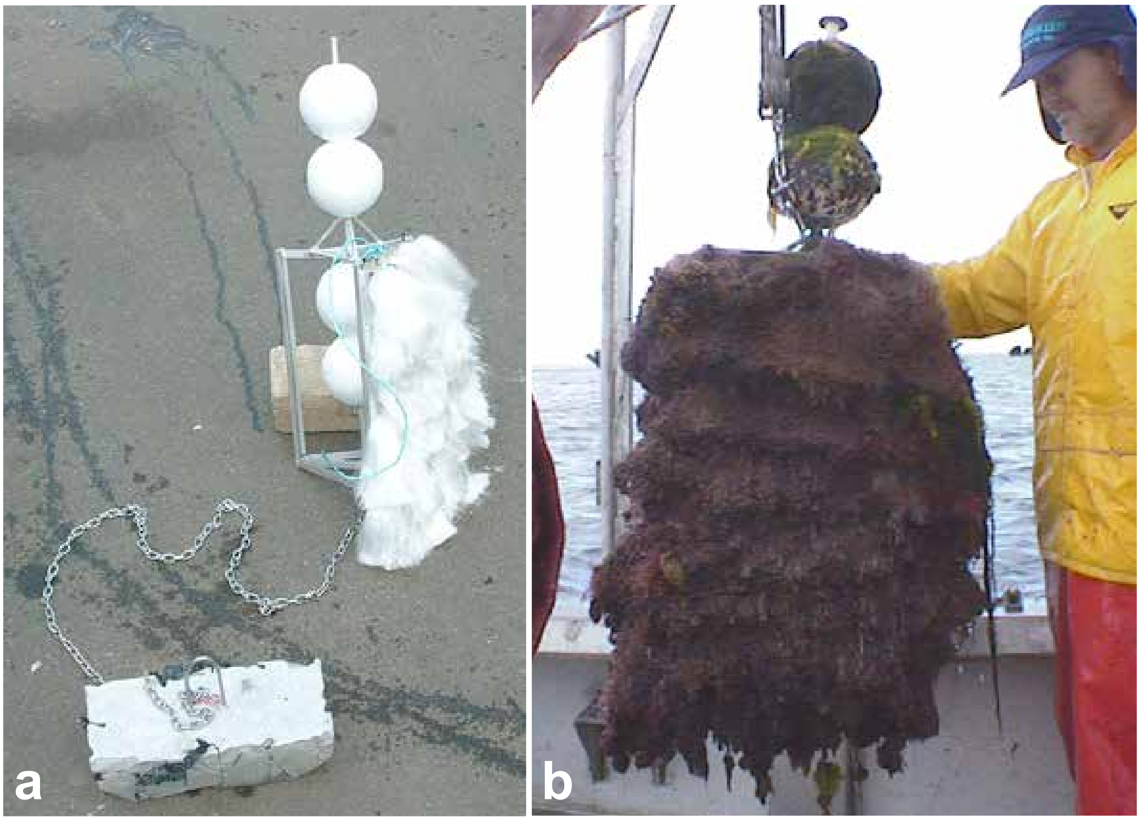


Plate 4.1–1 Puerulus collectors a) design with two panels removed to show internal construction and, b) retrieved from site before being "banged"

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. Preliminary 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.

Puerulus settlement monitoring

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 (Plate 4.1–2). 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.

Plate 4.1–2 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 – Plate 3.4–2c) are counted. Any specimens that are substantially larger than post-puerulus, and may not have been shaken out during the previous collection, 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 service the collectors from Warnbro Sound to Port Gregory, with the collectors at Point Quobba and Cape Mentelle are serviced by locally contracted people with staff from the Department of Environment and Conservation 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.

The environmental data and puerulus numbers are stored in an SQL-based database, which is used to construct monthly and annual trends of puerulus settlement (Figure 4.1–4 and 4.1–5).

Analysis

Puerulus settlement indices in each management zone (Figure 2.3–1) are based on one or more puerulus collection sites (Table 4.1–2). The settlement index for each collector site is the sum of each full moon period's average number of puerulus sampled per collector, over the settlement season (May to the following April). These indices are standardized to having been sampled by tanikalon collectors by dividing puerulus averages from Boral-Kinnear collectors by 0.85. When settlement index uses data from more than one puerulus location, a least-squares mean estimate (SAS 1987), 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. This proportion is identified 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 4.1–2).

Table 4.1–2 Sites and numbers of collectors used to calculate puerulus settlement indices for the three management zones.

Puerulus collector sites	Collectors used for indices
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)

4.1.2 Results

The puerulus settlement season runs from May to April the following year, with peak settlement in late winter to spring for coastal locations (Figure 4.1–2). Lancelin's peak is settlement occurs in December (Figure 4.1–3) though it seems to have a plateau of settlement from August through to December (Figure 4.1–2)

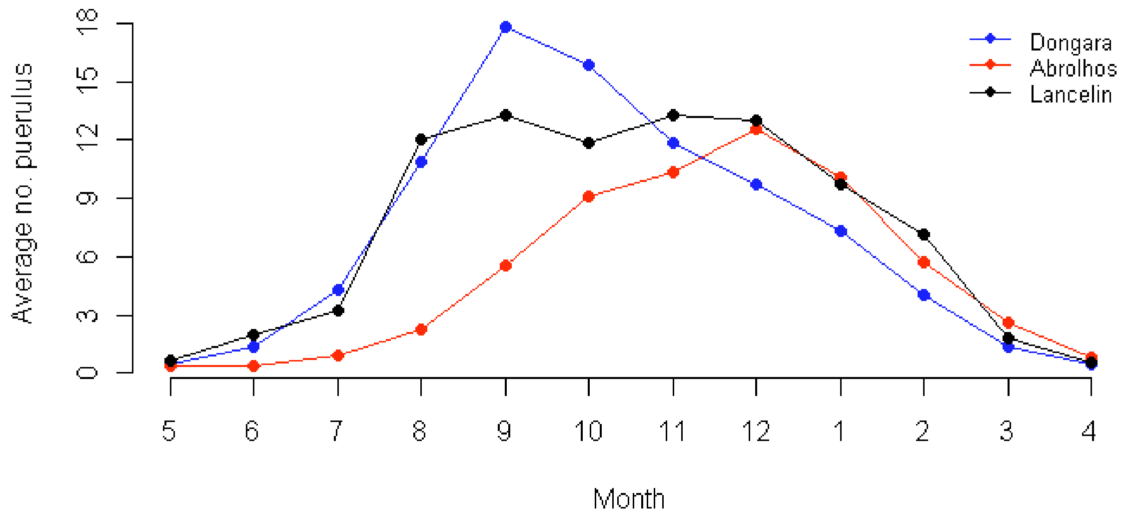


Figure 4.1–2 Average puerulus settlement by month for sites in the northern (Dongara), southern (Lancelin) and offshore (Abrolhos Islands) zones of the WRL fishery.

Although the month in which settlement peaks differs slightly between years, there is a difference between the coastal sites where settlement generally occurs in September / October compared to the though the southern most site of Cape Mentelle and the offshore site at the Abrolhos Islands, which peak in ~December (Figure 4.1–3).

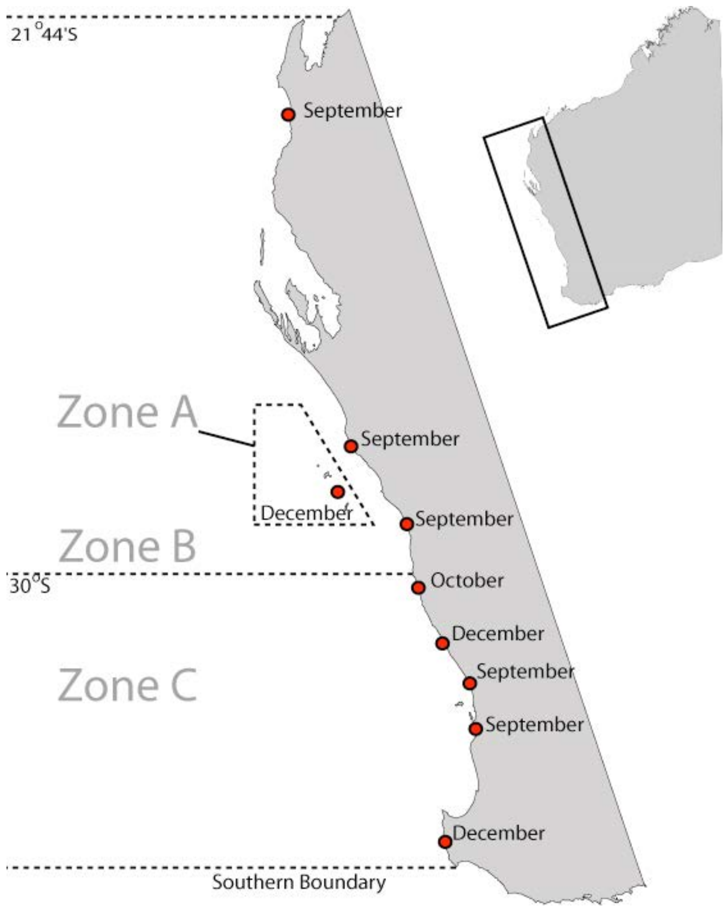


Figure 4.1–3 Most common month of peak puerulus settlement for puerulus collectors throughout the WRL fishery

Although catches of pueruli at the various sites throughout the fishery all exhibit similar inter-annual trends in puerulus settlement, the magnitude of settlement differs markedly between sites. Puerulus collectors on the mid-west coast (e.g. Seven Mile Beach and Jurien Bay) generally record the highest numbers of pueruli. The two Perth metropolitan collector sites (Alkimos and Warnbro Sound) are lower than those of the mid west, though considerably higher than the most southerly collector site (Cape Mentelle). In contrast, the second most northerly collector site in Figure 4.1–4 (Port Gregory, light green) has a settlement rate that is intermediate between the high mid-west (Seven Mile Beach and Jurien Bay) and lower metropolitan sites (Alkimos and Warnbro Sound).

There is a strong correlation between years of high puerulus settlement between sites, due mainly to oceanic conditions affecting survival and settlement rates on a coast-wide scale.

Puerulus settlement is significantly affected by the water temperature in the area where the larvae occur in February–April (which is influenced by the strength of the Leeuwin Current) and rainfall at the southern sites (in October and November) (rainfall is used as a proxy for the frequency of westerly winds in these months) (Caputi et al. 1995b).

The Leeuwin Current in June to December 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 (Caputi et al. 2001 and Caputi 2008).

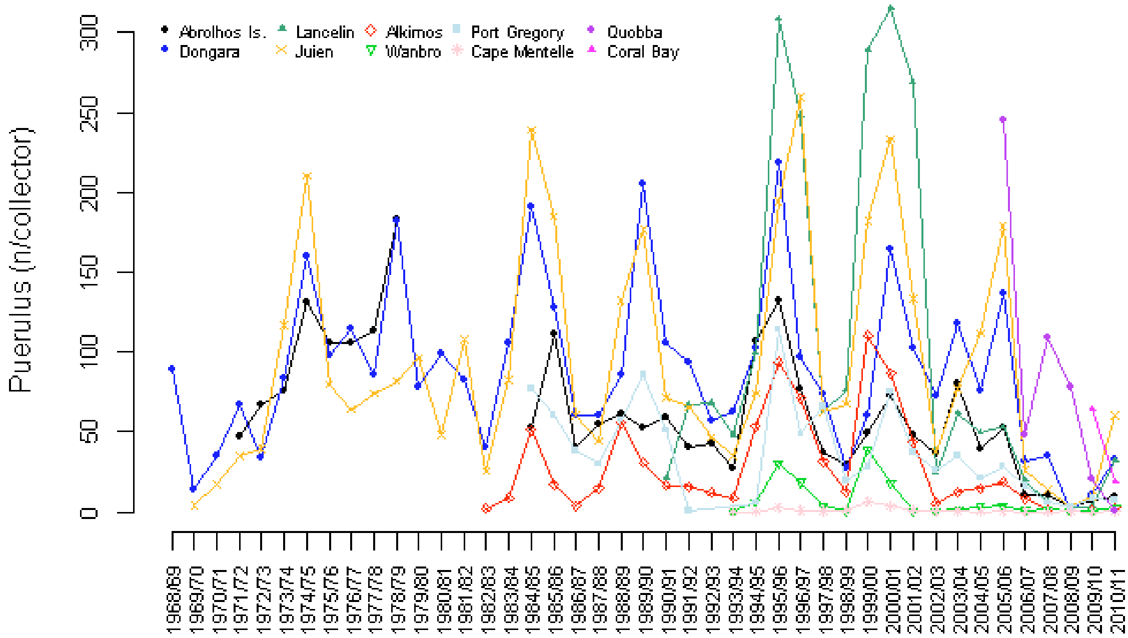


Figure 4.1–4 Puerulus numbers per collector for each season from 1968/69 at collector sites throughout the fishery.

Recent trends in puerulus settlement

The most recent above average settlement to occur in the fishery was recorded in the 2005/06. Since this season the fishery has received four consecutive years of below average settlement. Low levels in 2006/07 were likely linked to poor water temperatures during early larval life as they fitted into the historical relationship (see Figure 4.1–5). The three settlements seasons of 2007/08, 2008/09 (lowest level of record) and 2009/10 do not appear solely related to cool water temperatures during early larval life since they parted dramatically from the historical relationship (Figure 4.1–5). The unexplained nature of the most recent three settlements prompted the department to hold a Puerulus Risk Assessment workshop in April 2009 (http://www.fish.wa.gov.au/docs/op/op071/fop71.pdf). The workshop developed a range of research projects designed to investigate the cause of these low settlement levels. Details of these projects with their preliminary results, which are helping to form the basis of our current understanding behind the low puerulus settlement, are outlined in section 7.1.

Water temperatures leading up to the 2010/11 puerulus settlement season (February/April 2010) were again been below average. The 2010/11 settlement was therefore not expected to be above average, but did see an increase in puerulus settlement rates at a number of sites along the coast, mainly at sites in the centre of the fishery, Jurien Bay and Dongara (Figure 4.1–4). The settlement, whilst below average, has now returned within the historical relationship between settlement and offshore water temperatures in February (Figure 4.1–5). These levels are still below the long-term average since water temperatures in were cooler than average.

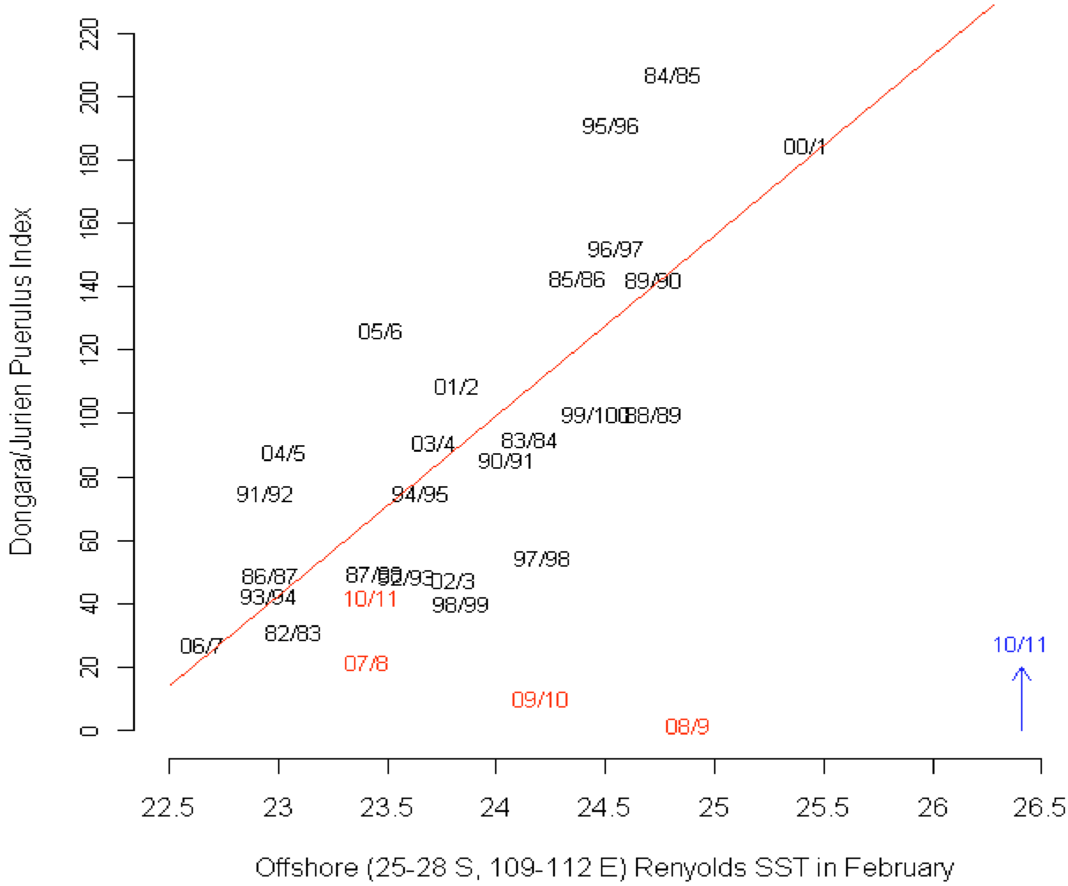


Figure 4.1–5 Relationship with offshore seas surface water temperatures and puerulus settlement index for Dongara and Jurien for each season. The last four settlement seasons are in red text, with offshore water temperature for the 2011/12 puerulus season indicated by a blue arrow.

Water temperatures for January and February 2011 are well above average, and 1°C higher than previously recorded. This was a result of a strong Leeuwin Current associated with the La Nina conditions. The effect of these conditions on the next year's (2011/12) puerulus settlement will be observed later in the year, starting in about August.

4.2 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 (Figure 3.6–1).

4.2.1 Methods

Locations

Monitoring has occurred every month throughout the fishing season (November–June) 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 4.2–1). At each locality, monitoring is conducted only onboard vessels fishing within 15 nautical miles north or south of the target port.

Sampling

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 Appendix B for specifics). The data are entered and stored on an SQL-based database for analysis.

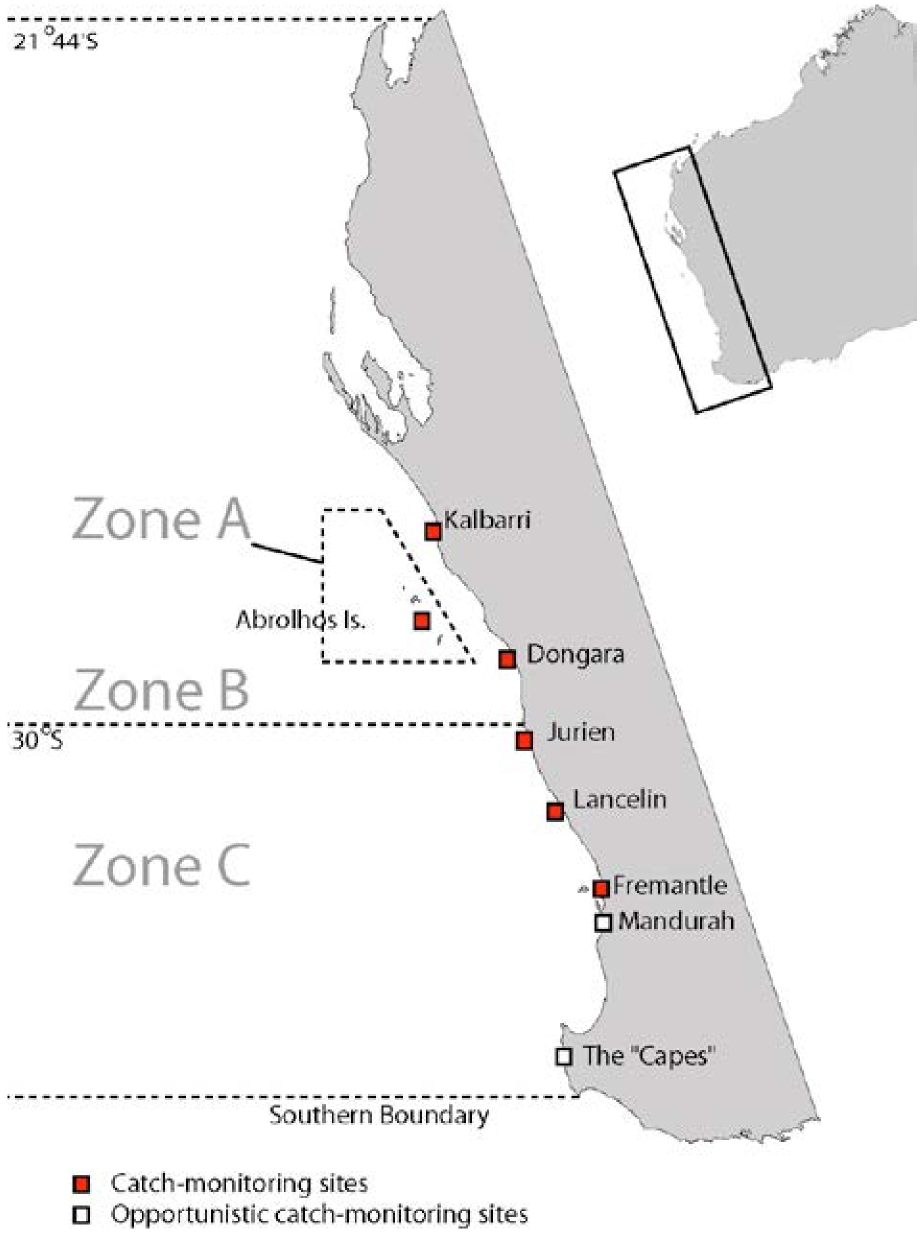


Figure 4.2–1 Locations of commercial catch-monitoring sites

Analysis

Data from commercial monitoring is used to construct the following annual indices, for the management of this fishery: breeding stock indices; juvenile (undersize) abundance; coast wide-water temperature trends; annual mean size of the smallest 10% of mature females; proportions moulting out of a setose phase each autumn; octopus catch rates; and by-catch. Of these indices, the most important for use in the management of this fishery are the breeding stock indices.

Fishery–Dependent Breeding Stock Indices.

Breeding stock indices are produced for each of the two coastal regions: the north coast index from monitoring at Dongara and Jurien, and the south coast index from monitoring at Lancelin and Fremantle. Each index is a least-squares mean (SAS, 1987) of eggs per pot lift in the deepwater breeding grounds of the region during the spawning season (September–February). The carapace length (CL) of each female measured during commercial monitoring in deep water

(>36 m in Zone B and >18 m in Zone C) is converted to an estimated seasonal fecundity based on a size-fecundity relationship and the number of expected batches of eggs to be produced by each animal in a season (equations 4.2.1–3).

To account for a moult in February, the carapace lengths of all females measured after this month (March–June) are reduced by 4 mm, which reduces them to the approximate length they would have been during the previous spawning season (i.e. September–February).

The annual estimate of egg production is a back-transformed value produced from a general linear model of the logarithm of the number of eggs per pot lift, with fishing season, monitoring location, sub-location nested within location, month and pot type included as factors. Water depth and water depth squared are included as covariates and the number of pots sampled for that observation weights the model.

Fishing efficiency adjustments as used in Biological Model (Section 5.5) are applied to the index to take into account increases in efficiency associated with the use of radar, colour echo sounders, GPS, etc. Annual variations in catchability due to environmental conditions are also taken into account by applying a 3-year moving average to the time series.

The seasonal fecundity (E) of a female at location i of carapace length CL (measured in mm) in season t:

$$E_{i,t}\left(CL\right) = f\left(CL\right) B_{i,t} \qquad \text{Eq 4.2.1}$$

where

$$f\left(CL\right) = 1.92CL^{2.69} \qquad \text{Eq. 4.2.2}$$

is the fecundity of the animal and

$$B_{i,t} = \frac{1}{1+exp\left(\frac{-log(19)\left(CL-SB50_{i,t}\right)}{SB95_{i,t}-SB50_{i,t}}\right)} + \frac{1}{1+exp\left(\frac{-log(19)\left(CL-DB50_{i,t}\right)}{DB95_{i,t}-DB50_{i,t}}\right)} \qquad \text{Eq. 4.2.3}$$

is the expected number of batches of eggs for the animal.

The sizes at maturity (SB) and at double breeding (DB) used in the equations above incorporate a progressive change in the size at maturity (SAM trend) outlined in Section 3.6.1.

Indices of Juvenile Abundance

Indices of juvenile abundance provide a qualitative assessment of recruitment to the fishery. Two indices are produced for each of the coastal regions, based on lobsters with carapace lengths < 68 mm and 68 – 76 mm. These indices provide information on estimated recruitment into the fishery two and one years in advance, respectively. These indices are LSMs of juveniles per pot lift in shallow waters (< 36 m) collected at Dongara and Jurien Bay (north coastal region) and Lancelin and Fremantle (south coastal region). The indices are adjusted to account for fishing efficiency increases (annual increase of 1.5%), as well as to account for the impact of increasing the number of escape gaps (from one to three or four) in 1986/87. To account for the escape gaps, all data points before 1985/86 are divided by two for the < 68 mm index.

4.2.2 Results

Fishery-dependent Breeding Stock Indices.

Monitoring of the commercial catches recorded a decline in egg production indices from the early 1970s until 1992/93 (Figure 4.2–2). In the late 1980s and early 1990s, egg production indices fell below their respective threshold levels. These declines prompted the introduction of management changes designed to increase the breeding stock (Box 2.2–1 – 1993/94). This and subsequent management measures have led to a recovery of the egg production in both the north and south of the fishery. It should be noted that with the substantial changes in fishing practices resulting from the recent move to Quota based management (Box 2.4–1), these results should be treated with caution since the relativeness of commercial catch rates pre and post quota are unknown. These indices will therefore not be updated until a time series of catch rates under Quota management are developed.

Indices of Juvenile Abundance

For each coastal region the two indices of juvenile abundance (CL < 68 and 68 – 76 mm) show very similar trends, as they reflect the variable puerulus settlement two and three years earlier (Figures 4.2–3 a, b). However there is greater fluctuation in the Zone C indices reflective of its more volatile recruitment.

There has been a decline in the <68 mm indices, a very low catch rate in Zone C this season, while it has remained steady in Zone B. Effects of recent low puerulus settlement would be expected to be seen in these indices first. However, the reduced puerulus settlement is also evident in the 67 – 76 mm indices with both Zones B & C falling in the 2009/10 season. This is likely to reflect the settlement in 2006/7 which was a poor settlement season (4.1–6).

It should be noted that with the substantial changes in fishing practices resulting from the recent move to Quota based management (Box 2.4–1), these results should be treated with caution since the relativeness of commercial catch rates pre and post quota are unknown. These indices will therefore not be updated until a time series of catch rates under Quota management are developed.

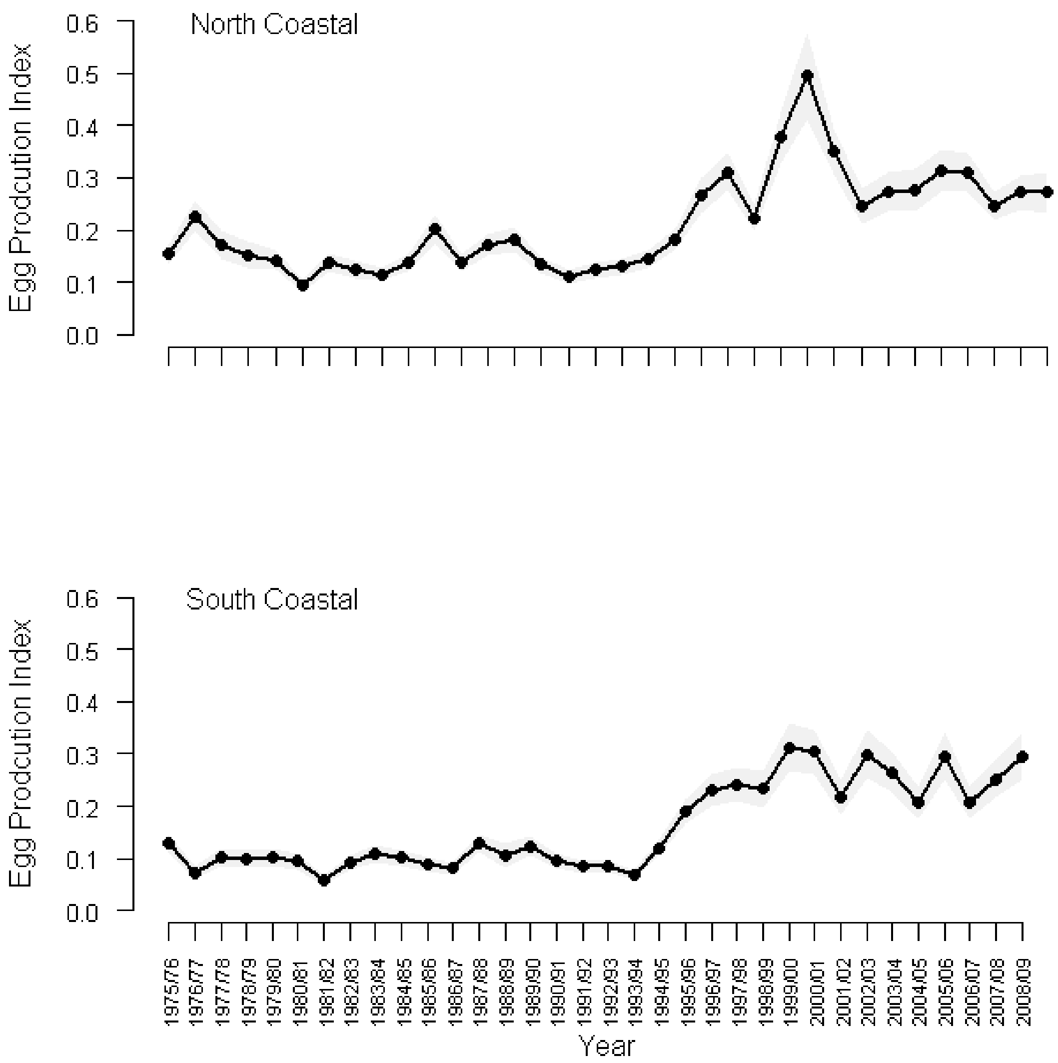


Figure 4.2–2 Fishery-dependent spawning stock indices (± 95% CI in grey) for a) the northern (Dongara and Jurien) and b) southern part of the fishery (Lancelin and Fremantle). Note, with the recent move to Quota based management, the relativeness of commercial catch rates pre and post quota are unknown. These indices will therefore not be updated until a time series of catch rates under Quota management are developed.

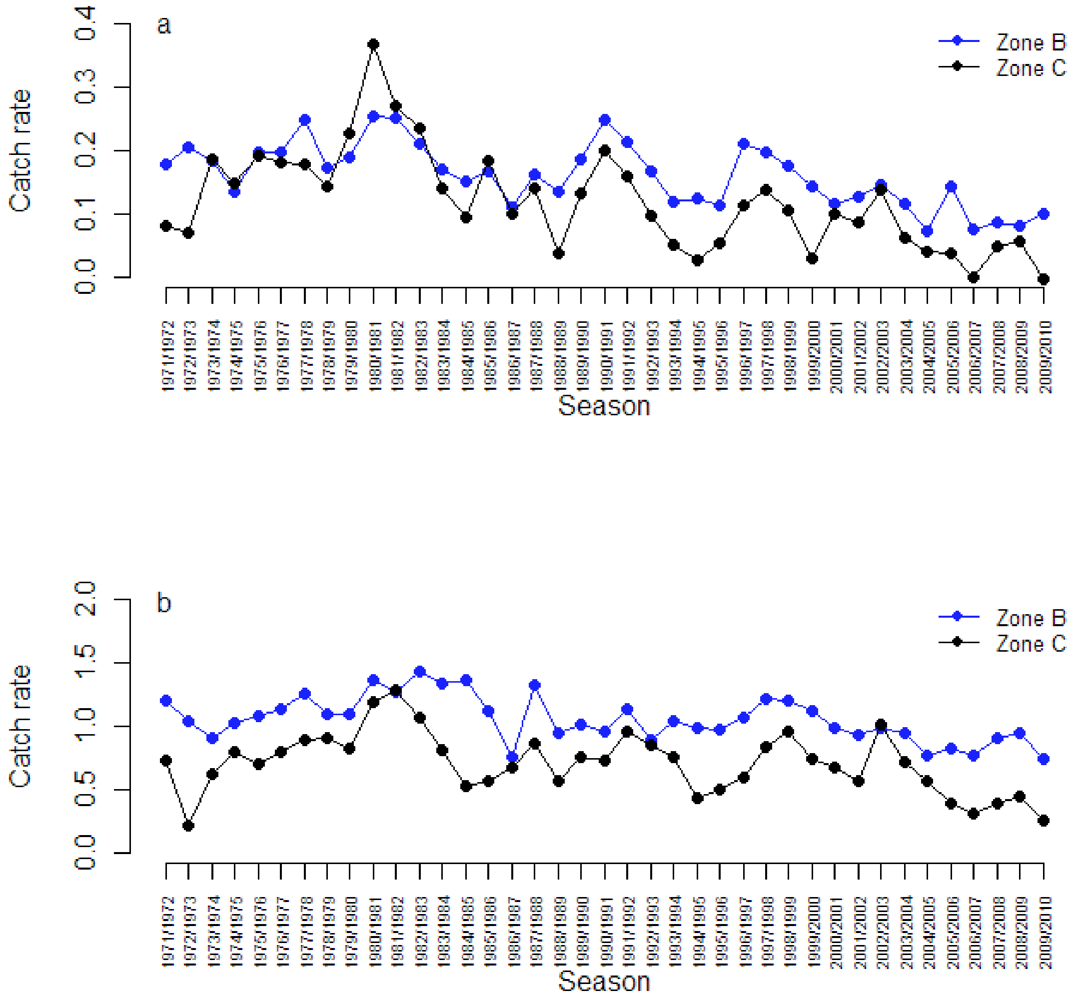


Figure 4.2–3 Juvenile indices for the zones B and C, adjusted for escape gap changes in 1986/87 and fishing efficiency. a) < 68 mm CL and b) 68 – 76 mm CL. Note, with the recent move to Quota based management, the relativeness of commercial catch rates pre and post quota are unknown. These indices will therefore not be updated until a time series of catch rates under Quota management are developed.

4.3 Independent Breeding Stock Survey (IBSS)

Since 1991, the Department of Fisheries has undertaken an annual survey of the breeding stock. This survey provides fisheries managers with a measure of the breeding stock, independent of the effects of increasing fishing efficiency, producing a cross-check of the trends apparent in the fishery-dependent breeding stock index, which is a longer time series.

4.3.1 Methods

Sampling locations

The 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 3.6.2). The IBSS involves the setting of standard fishing pots in up to five 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 4.3–1). As of 2009 a survey is now conducted annually in the Big-Bank region north of the Abrolhos Islands to monitor the effect of the area closure. Commercial WRL boats are chartered for all coastal locations, with the Department of Fisheries research vessel undertaking the survey at the Abrolhos Islands. For the coastal sites, the surveys are made at 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).

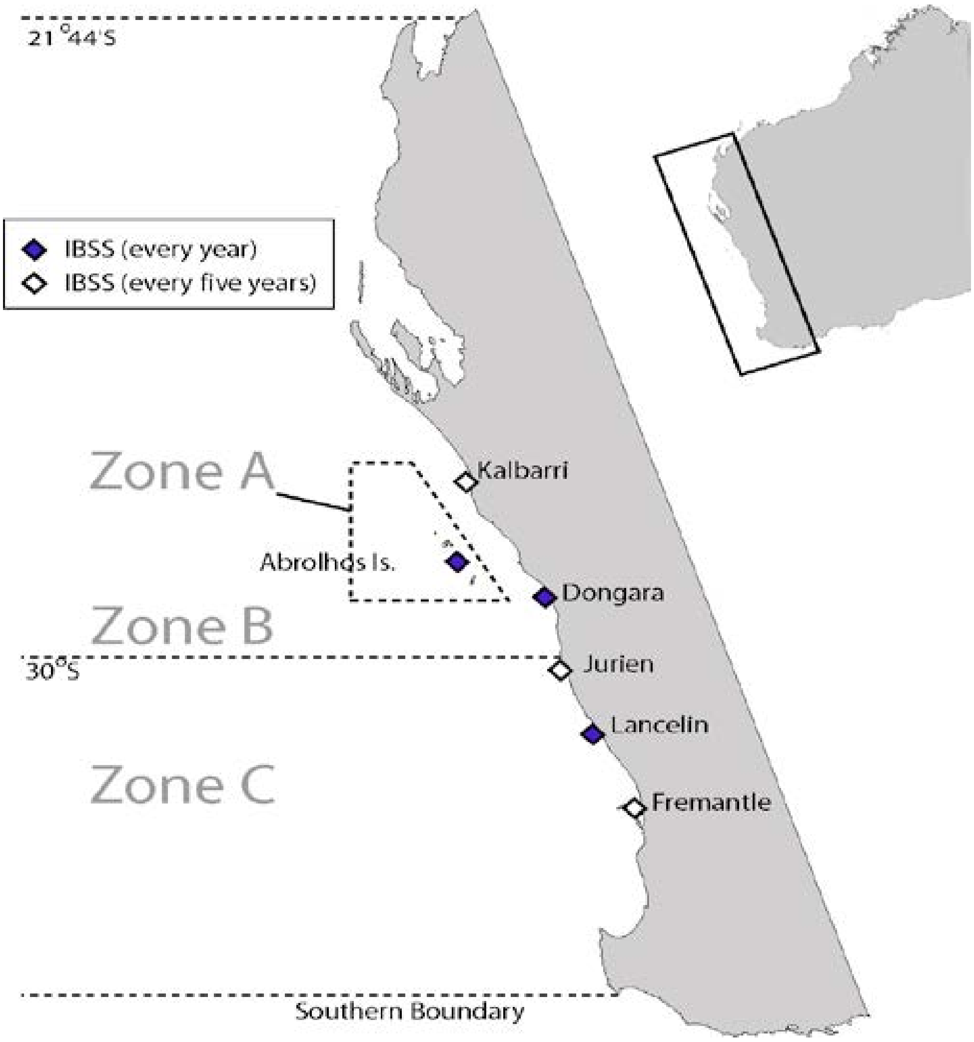


Figure 4.3–1 Location of independent breeding stock survey (IBSS) sites sampled annually (blue diamond) and at least every five years (white diamond).

Breeding stock sampling regime

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 of North Sea herring and salmon heads are used in standard amounts. Due to recent changes in Australian Quarantine regulations, the North Sea Herring has been substituted with local scaly mackerel. Anecdotal information from fishers indicates there is unlikely to be an effect on catch-rates due to this bait change. The data recorded are shown below in Appendix C.

Tagging

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 3.5 and 3.8. Lobsters without missing appendages, are tagged with a Hallprint ™ "standard T-bar anchor tag" dorsally and ventrally between the first and second abdominal segments (Plate 4.3–1).

Plate 4.3–1 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) . 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.

Both the IBSS data and tagging data are stored in a specific SQL-based database.

Analysis

Data from the IBSS are used to construct annual indices for the management of this fishery: Fishery-Independent Breeding Stock Indices (IBSI) and estimates of female size at maturity. Both indices together with the size-composition from these surveys are used as input data into the Stock Assessment model (Section 5.5).

Fishery-Independent Breeding Stock Indices (IBSI)

Yearly breeding stock indices are produced for the northern and southern coastal and Abrolhos regions, with coastal surveys conducted at Kalbarri, Dongara and Jurien used to produce the northern index, and Lancelin and Fremantle used for the southern index. To derive these indices, the logarithm of the number of eggs per pot lift, for each line of pots, is modelled by a general linear model with explanatory factors year, location, sub-location nested within location, pot type, depth category, day pull and swell range included. Back-transforming the resulting least-squares means (SAS, 1987) for the factor year, provides a standardized annual breeding stock indices.

Traditionally, the estimated seasonal fecundity of a female has been based on identifying whether the female is mature during the survey and if so, then using a size–fecundity and a size–double breeding relationship (Chubb 1991: equations 4.3.1–4) to determine the expected number of eggs in a spawning season that that female is likely to produce.

The number of eggs in a single batch of eggs:

$$Fecundity = 1.92CL^{2.69} \qquad \text{Eq. 4.3.1}$$

Probability that a female will spawn twice in that spawning season:

$$Pr\left(dbspawn_{ZoneB}\right) = \frac{1}{1+exp(4.075-0.0495CL+0.484)} \qquad \text{Eq. 4.3.2}$$

$$Pr\left(dbspawn_{ZoneC}\right) = \frac{1}{1+exp(4.075-0.0495CL-0.484)} \qquad \text{Eq. 4.3.3}$$

$$Pr\left(dbspawn_{ZoneA}\right) = \frac{1}{1+exp(6.675-0.1063CL)} \qquad \text{Eq. 4.3.4}$$

where *CL* is the carapace length.

In the construction of the Fishery-dependent Breeding Stock Indices (Section 4.2) and the Biological Model Breeding Stock Indices (Section 5.5) females are assigned a probability of being mature (as opposed to knowing this deterministically) based on location-specific size at maturity (SAM) trends (Section 3.6.1), which can also vary annually due to environmental factors. IBSS egg production indices are produced using both measures of maturity (observed and SAM trend), to ensure that the use of the SAM trend in the other two indices is appropriate.

4.3.2 Results

Comparison between observed maturity and SAM trend on the IBSS

The use of either the observed or SAM trend assignment of maturity had little impact on the overall trend in IBSS egg production (Figure 4.3–2). At the Abrolhos Islands the magnitude of the index was consistently smaller using the trend over observed maturity assignment, indicating that the SAM trend estimates (carapace length) may be slightly high in this area. As this difference if fairly consistent the use of the SAM trend would not alter relative comparisons of egg production between different time periods at the Abrolhos.

The overall note for consistency, the 'SAM trend' have been used to produce subsequent IBSS indices (Figure 4.3–3).

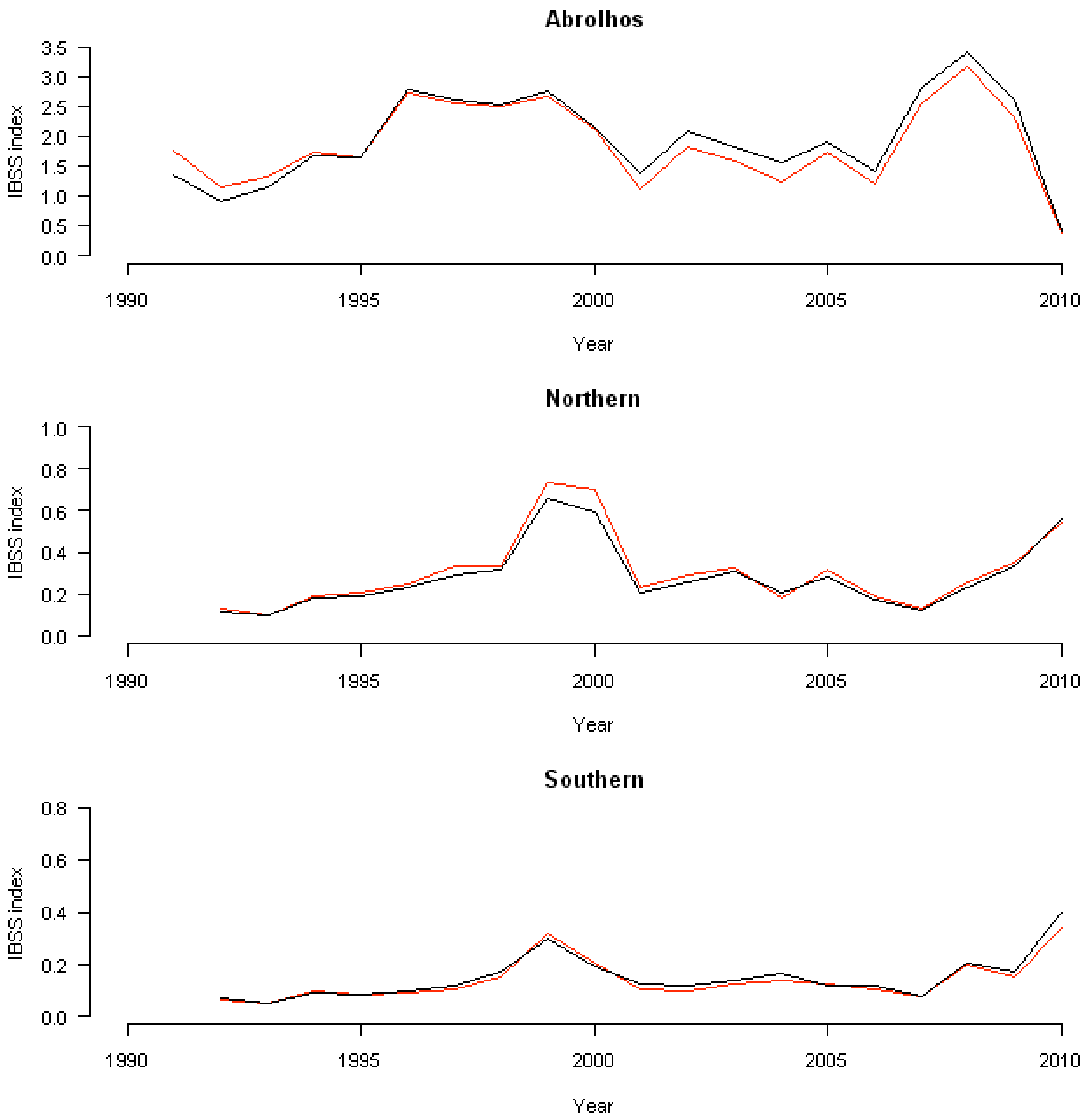


Figure 4.3–2 Estimated IBSS indices for assigning sexual maturity to females by methods of 'observed' (deterministic, red) and 'SAM trend' (probabilistic, black – see section 3.6.1) for (a) Abrolhos, (b) northern and (c) southern parts of the fishery.

Impact of water temperatures on the IBSS

The Department of Fisheries is currently conducting research into the impact a range of environmental variables, especially water temperature, have on the catchability of lobsters during the IBSS. Changes in catchability have the potential to alter estimated levels of egg production in individual years, but are unlikely to result in significant changes in the overall trend to the indices.

Standardised Fishery-Independent Breeding Stock Index (IBSI)

In the three main parts of the fishery the IBSI has shown an increase since its inception in 1991, through the 1990s, reaching a peak in 1999 or 2000 (Figure 4.3–3 a – c). In each part of the fishery the index then declined throughout the following decade but at levels above those estimated for the early 1990s, until the upturn in 2008 and 2009. Results from the 2010 survey indicate that breeding stock levels at coastal locations have again increased to maximum levels.

At the Abrolhos Islands however, the 2010 survey produced the lowest breeding stock level on record. Closer examination of this data indicated that this downward trend is caused by the incorrect datum being used by the vessel conducting the 2010 survey. As such all pot sets were incorrectly positioned ~250 m to the south-east of their desired location, thus generally away from the reef edge areas into sand habitats.

The fishery-independent index provides a cross-check to the long-term, fishery-dependent breeding stock index and the model-derived breeding stock index.

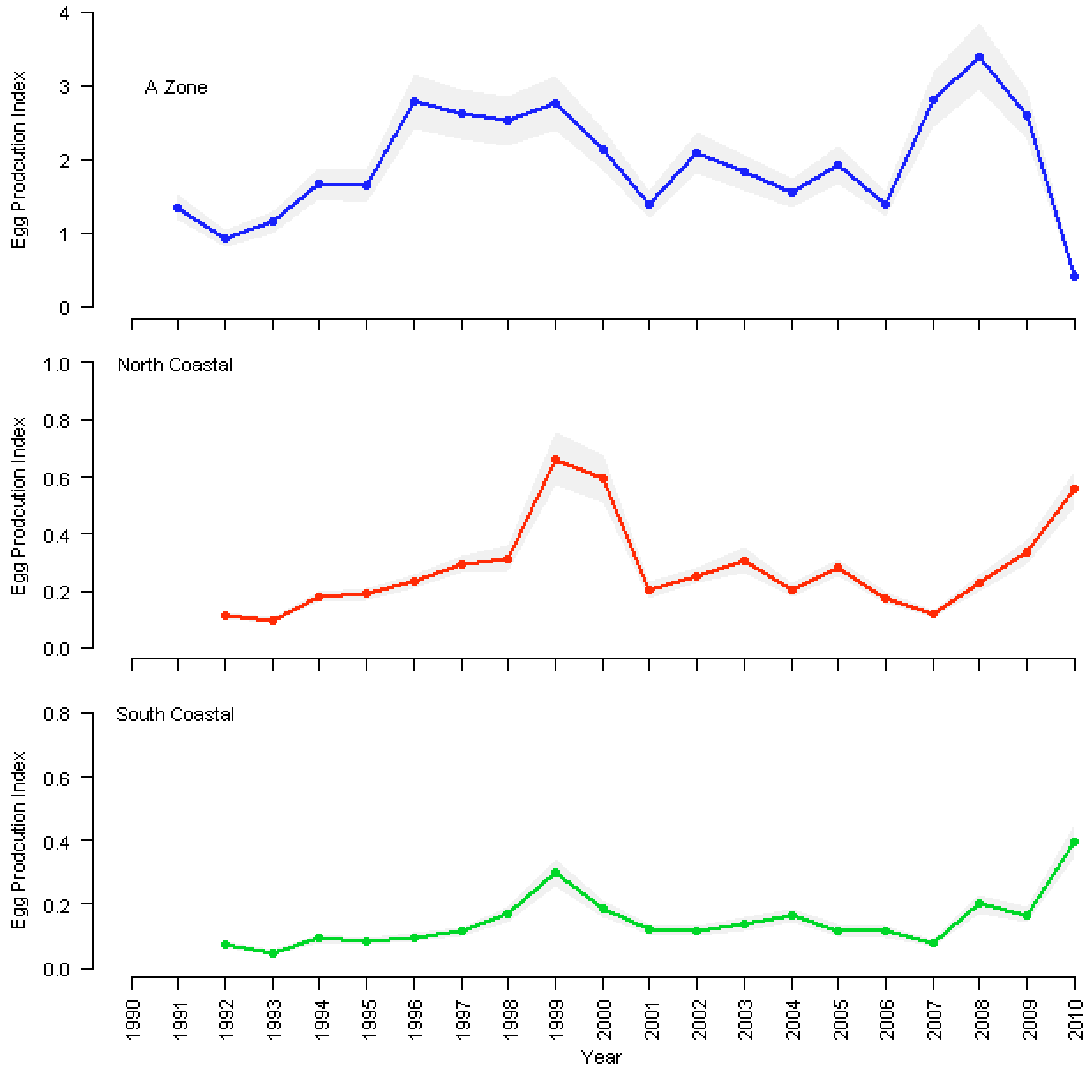


Figure 4.3–3 The IBSS indices (± 1 SE) for A, B and C zones. Trend SAM has been used to construct these indices.

4.4 Volunteer Research Log books

Fisheries Research Log books have been issued to fishers since 1963. They are given to about 60% of commercial fishers each year; 30 – 40% of fishers complete the log book. Returns from fishers varies between years, from a peak in 2002/03 of 41% of the whole fleet to current levels (2006/07) of around 28%. Over the last 8 years, on average, 36% of the fleet have returned Research Log books, with almost all (~90%) of those returning the log book completing the voluntary section, which provides additional information on catches and environmental conditions (Appendix D). The research log books provide the Department of Fisheries with detailed information on commercial fishers' practices, daily catch and effort by depth at a higher spatial resolution than the Catch and Effort data (Section 4.5). A summary of their catch rate is returned to individual fishers at the end of the year, together with a comparison to the zone average.

The indices produced from these log book data are:

- Log book catch and effort by 1° S transect in waters < 20 and > 20 fathoms (36 m).
- Catch rate of spawners, setose and maximum size females that are returned to the sea. An estimate of the total number of setose returned is obtained by weighing up the log book data to the total fishery (Catch and Effort data) where necessary.
- Catch rate of undersize lobsters.
- Daily index of swell height.
- Octopus catches and, recently, lobster mortalities.
- As of the 2010 season, the percentage of high-grading legal lobsters.

4.4.1 Methods

The log books are divided into two sections: a core section and a voluntary section (Appendix D). The data are stored in an SQL-based database that can be queried to produce catch and effort statistics on fine spatial and temporal scales.

4.4.2 Results

Over the last 20 years, volunteer log books have provided data over much of the fishery (Figure 4.4–1). Areas of high log book returns correspond to areas of high fishing effort, namely Big Bank (north of the Abrolhos Islands), Geraldton to Dongara, and the area around Lancelin (north of Perth). This distribution is very similar each year, as shown by returns from the 2005/06 season (Figure 4.4–2).

The large proportion of fishers who fill out log books and the spatial coverage of these data means that general trends apparent in the log books are representative of the general fishing patterns across the fishery. For example, the daily catch rates recorded in the log books, show as series of peaks and troughs associated with changes in the fishery (whites to reds) and also lunar effects, are representative of those that occur across the entire fleet (Figure 4.4–3).

This fact allows log book data, which are recorded on a fine temporal and spatial scale, to be used to divide catch and effort data into finer scales than their reported monthly time steps and 1° blocks (Section 4.5).

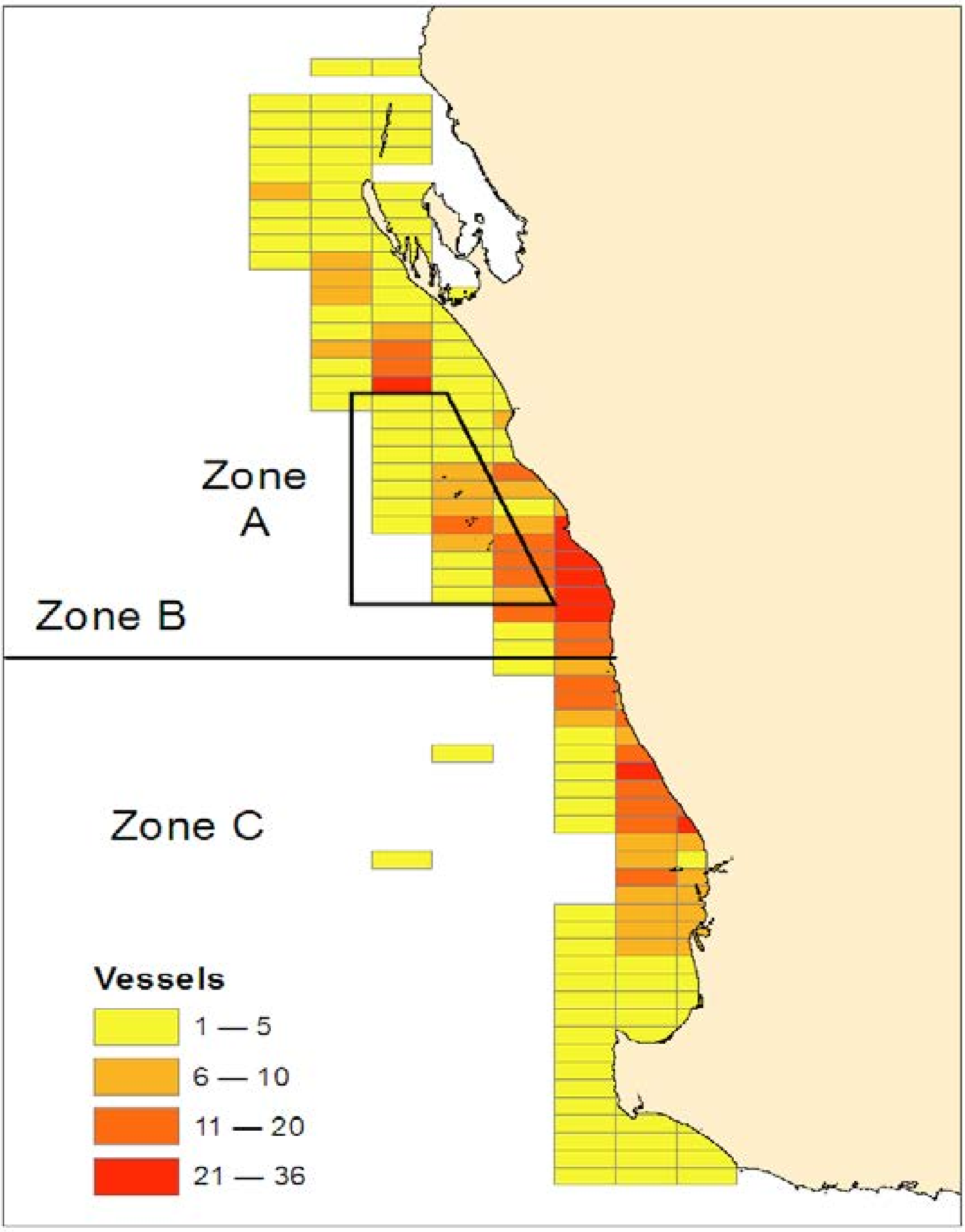


Figure 4.4–1 Mean number of vessels that returned log books for each block in seasons 1986/87 – 2005/06. The colour of each block represents the number of vessels that returned log books for that block.

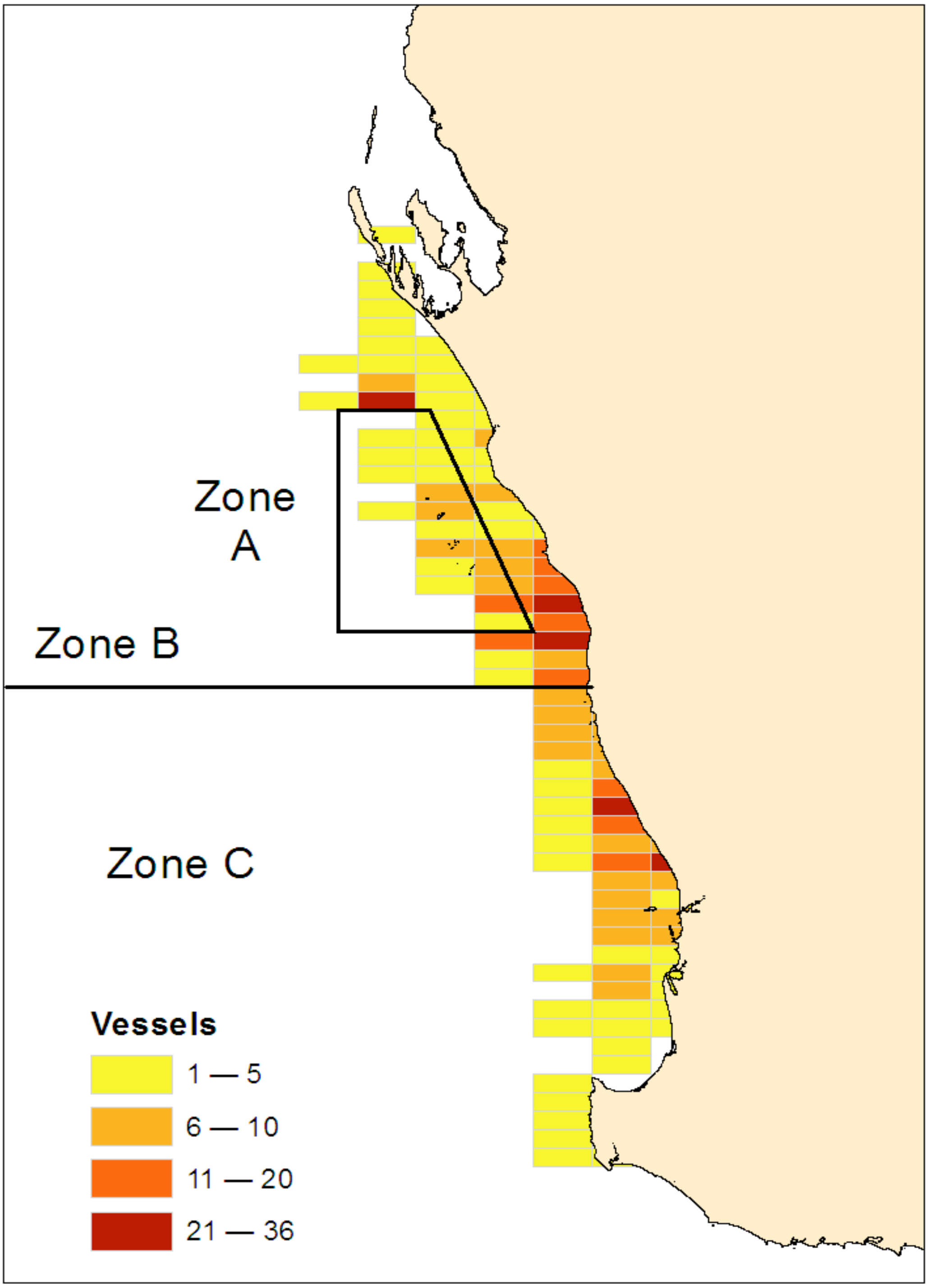


Figure 4.1–2 Number of vessels that returned log books for each block in the 2005/06 season. The colour of each block represents the number of vessels that returned log books for that block.

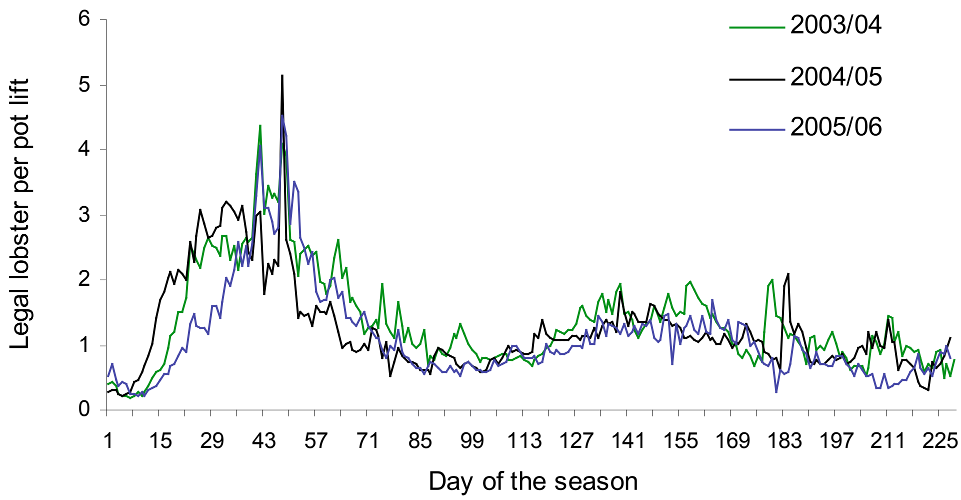


Figure 4.4–3 Daily catch rate of coastal sites for three seasons (2003/04 – 2005/06)

4.5 Catch and Effort Statistics (CAES)

The compulsory catch and effort monthly returns (Appendix E(1)) from commercial fishers are used to assess the total commercial catch and effort within the fishery. These data provide crucial information on the performance of the fishery, enabling inter-annual trends in catch and effort to be examined. Additional to this is a voluntary fishing gear survey, sent out at the start of every season, to record technology changes in the fleet. Of these indices, the most important for management of the fishery, are produced by CAES returns, namely:

- Monthly catch and nominal effort for lobsters recorded in 60 nautical mile blocks in each management zone.
- Monthly catch and effort of by-catch species, (e.g. octopus, deep-sea crabs) recorded in 60 nautical mile blocks in each management zone
- Interactions with threatened, endangered and protected species.

CAES data were collected by regional officers sporadically before 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. The records were given to the regional officer, who summarised them by block and sent them to head office for analysis.

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 1963. From 1964 a standardised Commonwealth statistic collection system was by the Commonwealth Bureau of Census and Statistics (ABS), with the data entered into a computer from 1967.

Problems with the method of data collection and potential inaccuracies saw a major alteration to statistics collection in 1975, leading to a change in which data were collected. Returns were stored electronically from 1975 with the system taken over by the Department of Fisheries in 1989; however, ABS continued to help with reporting. Since 1992, all aspects of the CAES database and reporting have been the responsibility of the Department of Fisheries.

4.5.1 Methods

For seasons up to and including 2009/10, returns from fishers were received monthly, with a deadline of 15 days after the end of the month. Fishers who are in arrears with their returns are contacted every few months by the CAES returns officer, requesting their return. Once a year a written reminder is sent to fishers that it is a licensing requirements to provide a return. By the end of the financial year, the annual return rate of around 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) (Appendix E(2)) every time they land a commercial catch.

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) and incorrect block numbers (fishing in a block outside the zone they are licensed for). When catches do not match that provided by lobster processors, both datasets are interrogated 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.

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, is been used to assess changes in fishing efficiency (Section 5.1).

4.6 Processor Returns

Each month, processors of western rock lobster must complete forms for the Department of Fisheries from as part of their licensing requirements. The collated information provides the most accurate measure of the total catch of the fishery.

4.6.1 Methods

Processing factories deal with almost 100% of the commercial catch landed, with only occasional small domestic sales. Usually 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. Five companies deal with the export (unrestricted) processing of western rock lobster, while a small portion of the catch goes to processors solely for the domestic market (restricted).

There are different reporting requirements for the processor licence holders. Unrestricted processors are required to fill out a monthly return log (Appendix Fa) and monthly breakdown of product lines (green tails, whole cooked, whole green and live) by grade (A – H) (Table 4.6–1) and market (export or local) (Appendix Fb). Restricted processors are required to submit only a monthly return log (Appendix Fa)

Table 4.6–1 Processor grades for *P. cygnus* showing the weight and carapace length (CL) ranges.

Lobster Grade	Grade 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 +

Processor returns (grades, product lines etc. Appendix Fb) are entered into a SQL database and used to calculate the total catch by zone, product lines and grades.

Each month a breakdown by grade product line is sent to processors. Another monthly summary sheet is sent to district offices of the Department of Fisheries and to processors outlining the catch in that month for three areas: Fremantle (Capes to Wedge Is.), Jurien (Green Is. to Green Head) and Geraldton (Leeman to Shark Bay). This is compared to the catch at the same time last year and also the 10-year cumulative average to give an indication of how the season is progressing.

Predictions of catches of A and B grade lobsters using a standardised coastwide puerulus settlement index (least squared mean of Dongara, Jurien, Lancelin and Alkimos) lagged 3 and 4 years, adjusted for water temperature and management factors.

4.6.2 Results

The composition of the commercial catch can also be examined through processor grade data. The proportion of the catch has traditionally been dominated by “As”, though this has declined over the last 20 years, with the most recent season showing “Bs” as the dominant grade (Figure 4.6–1). These two smaller grades account for on average 71% of the catch by weight, and show a significant relationship with puerulus settlement (Figure 4.6–2). The recent years of low puerulus settlement predict a very small catch of these two grade categories (Figure 4.6–2).

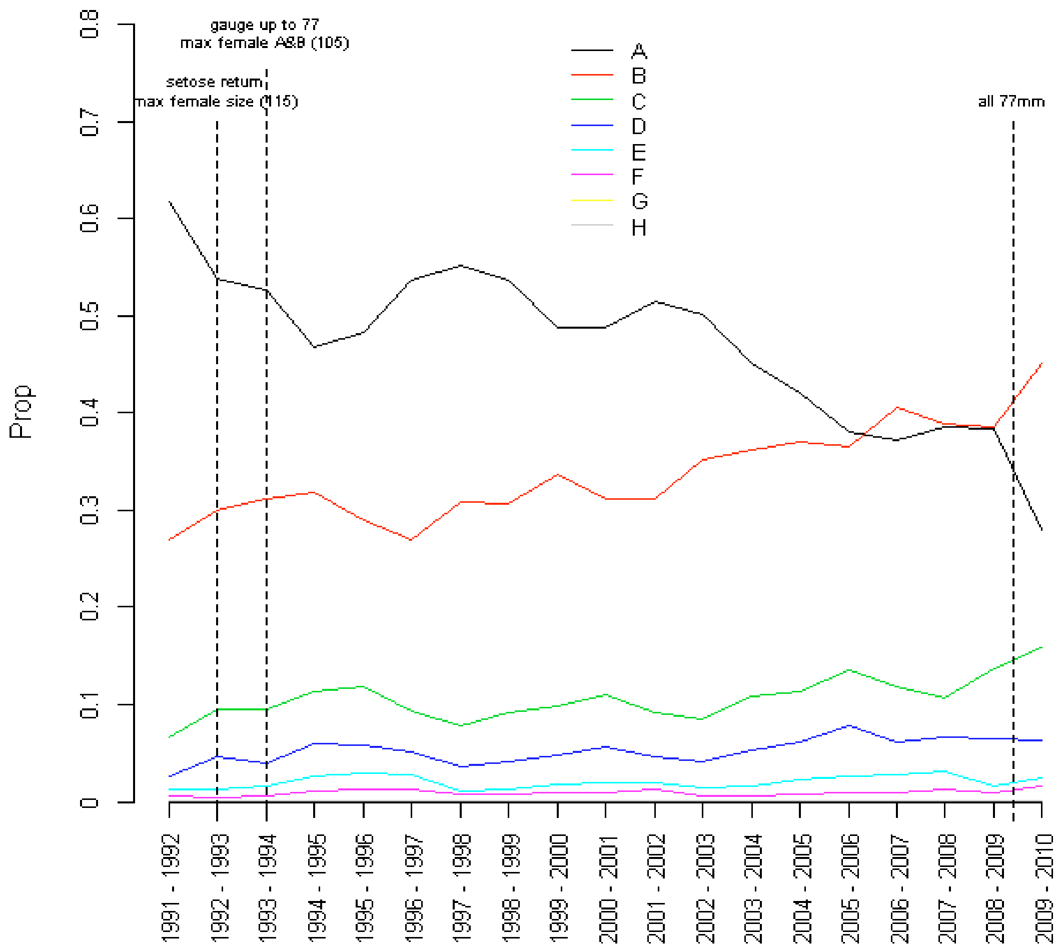


Figure 4.6–1 Proportion of commercial catch from processors by grade and year. Dashed lines indicate the seasons where there were management changes that are likely to influence catch rates of different grades

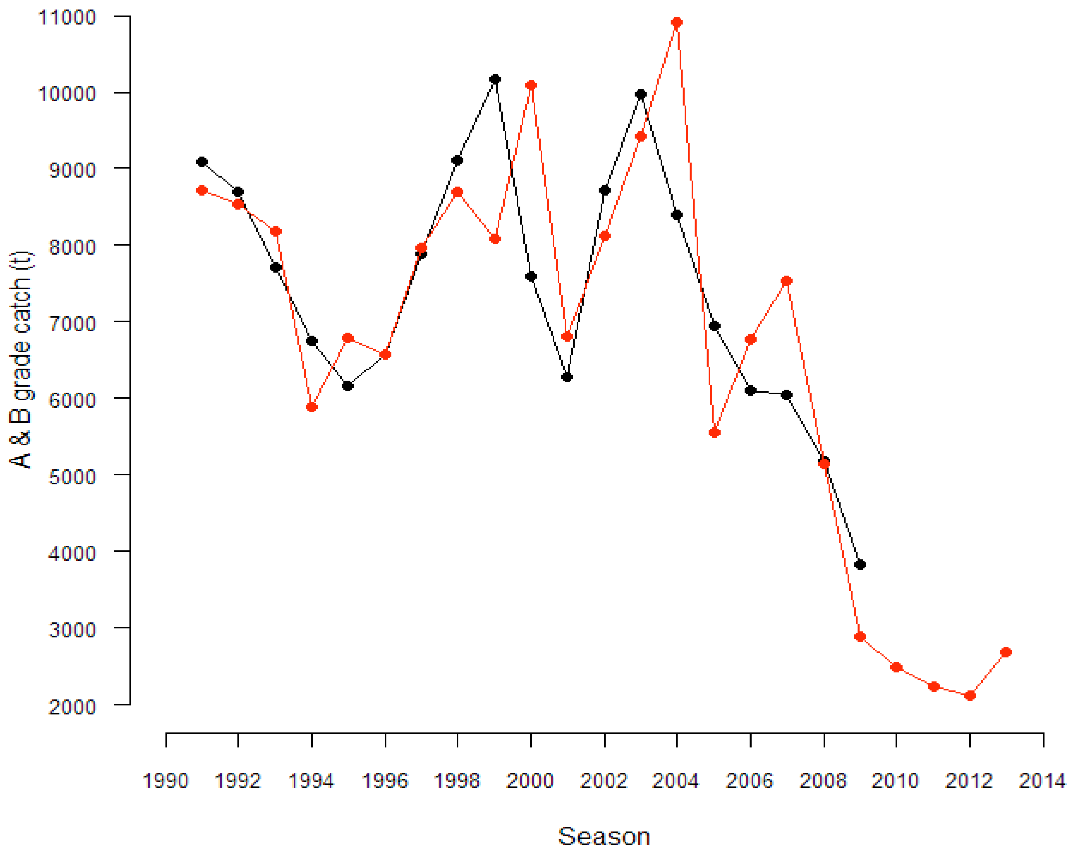


Figure 4.6–2 Catch of A and B grade lobsters (tonnes) for each season (black), and the model prediction (red) using puerulus settlement lagged three and four years.

4.7 Environmental Data

Environmental conditions such as water temperatures and oceanic currents greatly influence their 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) and CSIRO. These data complement environmental data collected by the Department of Fisheries during monitoring programs (Sections 4.1, 4.2, 4.3, 4.4).

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 (http://www.bom.gov.au/oceanography/projects/abslmp/abslmp.shtml), 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, 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 (BOM website). It is sourced from BOM at (http://www.bom.gov.au/climate/current/soi2.shtml) 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 3.7 and Figure 4.7–1).

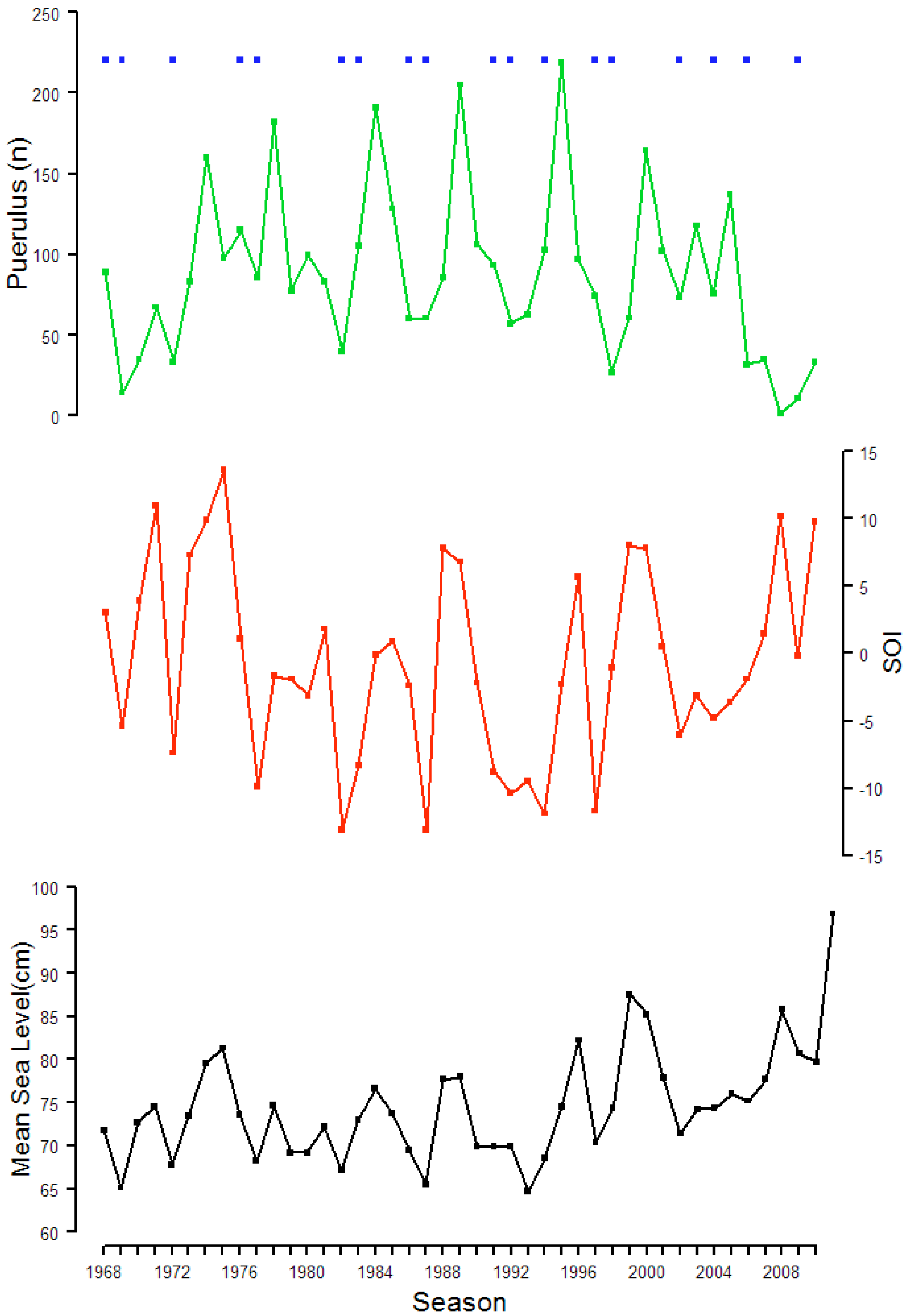


Figure 4.7–1 Mean sea level for Fremantle (black), the Southern Oscillation Index (red), and puerulus settlement at Seven Mile (green) showing the effects of El Niño events (blue squares) (Updated from Pearce & Phillips 1988); ENSO events as per NOAA CPC (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml)

4.8 Recreational Fishery Surveys

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 Perth and Geraldton coasts.

4.8.1 Methods

Mail surveys

Since 1986/87 season, information on the catch, effort and fishing characteristics of recreational rock lobster fishers has been collected in Western Australia, by an annual mail survey of randomly selected rock lobster licence holders. Initially this survey was sent out to one in four fishers enclosed with their licence expiry reminder letters, which usually went out at the start of a new season. In the 1988/89 season, all licence holders were sent a survey form.

From the 1995/96 season, a set number of licence holders have been randomly selected at the end of the fishing season from the recreational lobster licence database. The survey form is mailed to them with a post-free return envelope, a service provided since the initial survey in 1986/87. The questions in the survey have changed little: additional questions were added in the 1998/99 season (Appendix G and H).

The questions are in the following groupings:

- Participant details, such as name, address and phone number. Additional data was then sought on the age, gender, main language spoken at home, highest education, email address, and the number of years they have been lobster fishing recreationally, and which licence type (rock lobster or umbrella) they use.
- Fishing details. In the early surveys fishers were asked whether the licence holder fished that season, in which months they fished, when they usually fished (weekend, weekdays, school holidays or annual leave) and how many days they fished, broken down by fishing method. The fishers were also asked how many lobsters they caught (also broken down by method) and how many pots they pulled each day. Later surveys asked how many days the fisher fished in each month and the catch of that month, broken down by fishing method. The additional questions have enabled a more thorough examination to be made of the method, fishing effort and the associated catch.
- Location details of fishing effort (broken down by the methods used) were also refined in later mail surveys. Initially the location data were quite coarse: the location (town name) and postcodes were used as identifiers for location, with an indication of the methods used at that site. This was later broken down into 23 coastal regions (Figure 4.8–1) with the numbers of days fished by each method in each location. The smaller blocks in the more recent surveys have allowed for a better resolution of lobster fishing along the West Australian coast.

While western rock lobster is the main targeted species, with the total number of tropical and southern lobsters caught (broken down by method) are recorded in the survey.

A lot of the more recent information gathered from the mail survey centres on the attributes of the fishers. This includes weather they are a boat owner and the length of boat, or whether they have regular access (excluding charter boats) to a boat. Also the equipment on the boat (black and white or colour echo sounder, view bucket, radar, pot winch, GPS) is recorded, along with the pot types and the depth at which they are set. Divers are asked to record their depth ranges and the diving equipment used (e.g. SCUBA, snorkel, hookah, torch, loop, hook or dive computer) and whether they dived off charter boats (number of days and catch). These data are useful for tracking the influence of changes in gear technology on the ability of recreational fishers to catch lobster.

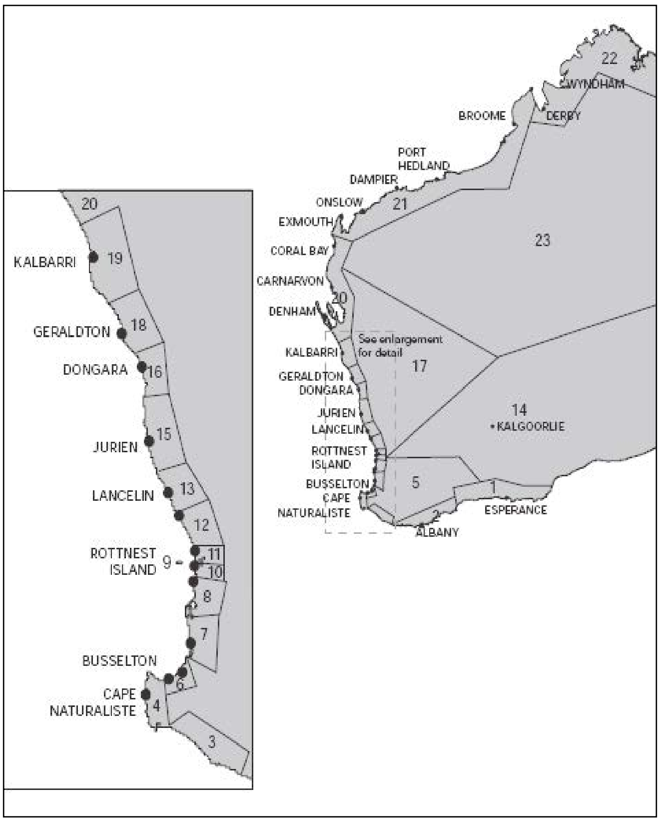


Figure 4.8–1 Map codes for regions of licence holder's place of residence and fishing locations (Melville-Smith & Anderton 2000).

One survey (1998/99), examined fisher attributes and attitudes to such issues as management effectiveness, enforcement, fishery regulations (bag limit, pot limit), degree of illegal recreational fishing activities, and fishers' knowledge of current regulations (size limits etc.). The results and analysis are reported in Melville-Smith & Anderton (2000)

Telephone diary surveys

Telephone diary surveys of recreational rock lobster fishers were undertaken in 2000/01 and 2001/02 and have run annually from 2004/05. This initially involved 400 to 450 people being called randomly from the licence holder database; however, in the 2006/07 season it increased to 800 participants. Participants are selected randomly from two licence types: half holding a rock lobster licence and half hold an umbrella licence (covering all recreational licensed fisheries).

Trained interviewers initially call the randomly selected licence holders four or more times before they are deemed to be non-respondents. Respondents are sent a diary and asked to fill it out for each day they go fishing for rock lobsters. Each month (or fortnightly if they are a regular fisher), they are phoned and asked to read out from their diary the days they went fishing and their catch (Table 4.8–1). Over the length of the season 90 – 95% of fishing events are diarised.

Table 4.8–1 Data recorded as part of the phone diary survey

Where and When	Fishing Method	Times	Catch
Location	No. of Pots	Start time	Species
Date	Diving	Finish time	No. Kept / Released

Interviewers also ask additional information such as the depth of fishing, method of diving, whether it was boat- or shore-based, and any other comments. Location information is pooled into regions (see Appendix I).

In 2005/06 a phone diary survey of registered boat owners living on the west coast also estimated the western rock lobster catch and the fishing effort.

Boat ramp survey

A boat ramp survey was held in the 2006/07 season saw for the first time. This survey monitored the lobster catch taken by fishers from two popular boat ramps in the northern metropolitan region (Hillarys and Ocean Reef) for 30 random days during December and January. The ramps are in one of the subregions of the telephone diary survey. An enforcement officer was used, as he had the power to ask to see the catch of fishers. The boat ramp survey will be used to validate catch rate estimates from the telephone diary survey in the Hillarys and Ocean Reef Area.

4.8.2 Results

Mail survey response rate

Between the 1986/87 and the 1994/95 seasons, when the Department of Fisheries licensing section was responsible for including survey forms in the licence reminders sent out, there is some uncertainty as to exactly how many surveys were dispatched. As a result, there is therefore no way to determine response rates. However, the 1988/89 survey, which was sent to all licence holders, had a response rate of 36%. This figure is assumed to be typical of all surveys before 1995/96 (Figure 4.8–2). Various inducements or reminders have been used successfully to increase survey returns (Figure 4.8–2).

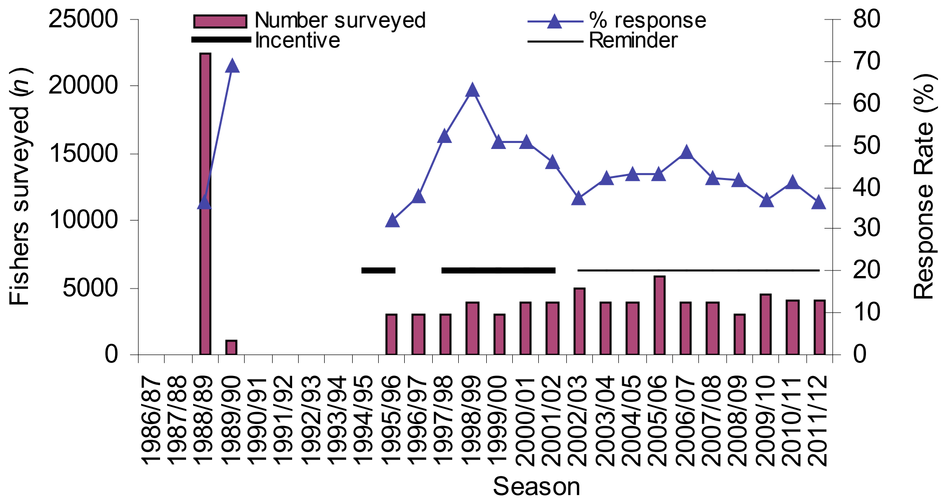


Figure 4.8–2 Return rates of recreational lobster fisher mail surveys. Thick line indicates the period when inducements (with or without reminders) were offered, with the thin line for when only reminders were sent.

However, they did not change the estimates of key variables such as total recreational catch.

The non-response bias is standard throughout the duration of the Thomson & Melville-Smith (2005) study and not influenced by inducements.

Comparison of survey techniques

The dedicated phone diary survey and the mail survey are the two main survey techniques that have been used to examine recreational catch and effort. The catch and effort results of the methods have shown major discrepancies. For the four seasons in which the phone diary was used, a direct comparison with the mail survey was possible (Table 4.8–2) (IFAAC 2007).

Table 4.8–2 Comparison of variables estimated from phone diary and mail surveys, for the seasons in which both methods were used. Adapted from IFAAC (2007)

Variable	2000/01		2001/02		2004/05		2005/06	
	Diary	Mail	Diary	Mail	Diary	Mail	Diary	Mail
Response Rate	83%	51%	78%	51%	82%	43%	84%	43%
Effort (days)	15.5	26	14.4	27	10.3	29	10.3	25
Total Recreational Catch (t)	332	560	235	545	201	721	131	408
CPUE (lobsters/day)	1.81	1.5	1.63	1.5	1.95	1.6	1.64	1.3

The mail survey has two inherent biases that may result in the different catch estimates of the recreational sector:

1. It requires respondents to recall their catch and effort over a 7.5 month period. In contrast, the phone diary survey requires fishers to record fishing activity in a diary after each fishing event, combined with monthly telephone contact.
2. The mail survey is affected by non-response bias, where the fishing activity of those who return the questionnaire is different from those who do not respond. The mail survey had response rates of around 40 – 50%, whereas the phone diary survey had response rates of around 80% (Table 4.8–2).

The phone diary survey minimises both non-response and recall bias and is therefore likely to produce a more accurate estimate of recreational catch and effort than the mail survey.

As mail and phone diary surveys produced very different catch estimates, a conversion factor was developed to adjust the results of the mail survey to those of the more accurate phone diary survey, using only the four seasons in which phone diary surveys were made. The conversion ratios are shown in Table 4.6 (IFAAC 2007).

Table 4.8–3 Ratios for converting estimated total catch from diary survey to mail survey. Ratios have been determined with a linear model with no intercept, using data for different seasons (indicated with a tick) (IFAAC 2007).

Model	2000/01	2001/02	2004/05	2005/06	Ratio (s.e)
I	✓	✓			1.90 (0.30)
II	✓		✓		2.20 (0.84)
III		✓	✓		2.85 (0.62)
IV	✓	✓	✓		2.23 (0.50)
V	✓	✓	✓	✓	2.29 (0.42)

The conversion factors range vary between 1.9 and 2.9 (Table 4.8–3). However, to maintain some consistency over the next few years, it was decided to use the 1.9 conversion ratio for the 2000/01 and 2001/02 seasons (Table 4.8–3). When the conversion factor is applied to catch rates since the inception of the mail survey (1986), it demonstrates a much reduced recreational catch (Figure 4.8–3).

The Department of Fisheries' current position on recreational catch is:

"... the best estimates of the recreational catch of western rock lobster over the last 17 years are obtained by using the mail survey data which has been suitably adjusted using the calculated level of bias."

However further comparison of mail survey and phone-diary survey is required to refine this adjustment and this is currently underway.

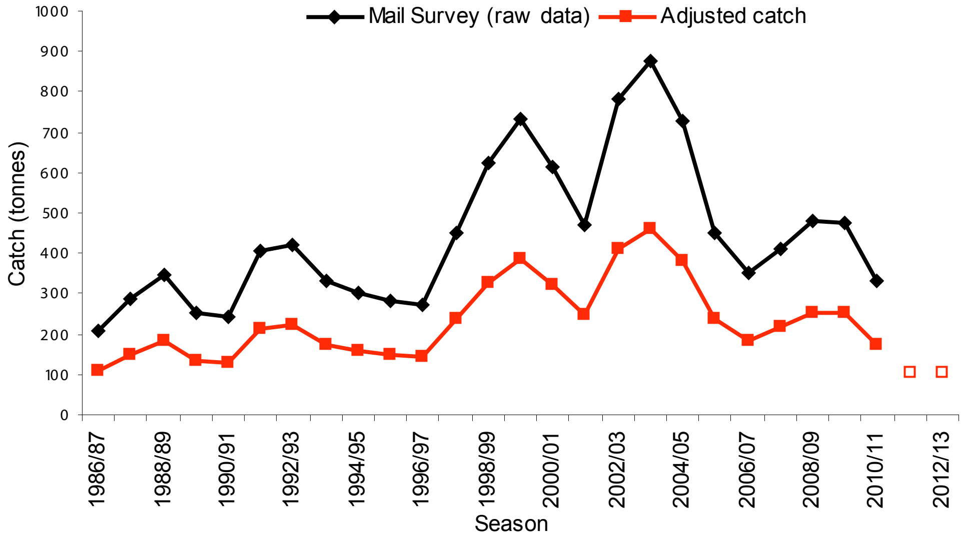


Figure 4.8–3 Recreational catch estimates based on "raw estimates" from the mail surveys (black) and the adjusted estimates calculated from the "phone diary-based" correction factor (red), with forecasted recreational catches (open red squares) based on puerulus settlement (updated from IFAAC 2007).

Effort

Most of the effort in the recreational sector is focused on just a few months near the start of the season, declining as the season progresses (Figure 4.8–4). The low number of days fished in November is a reflection of the season opening only in the middle of the month rather than a lower overall fishing effort (Melville-Smith & Anderton 2000). Similar results were also shown by phone diary surveys (Figure 4.8–5)

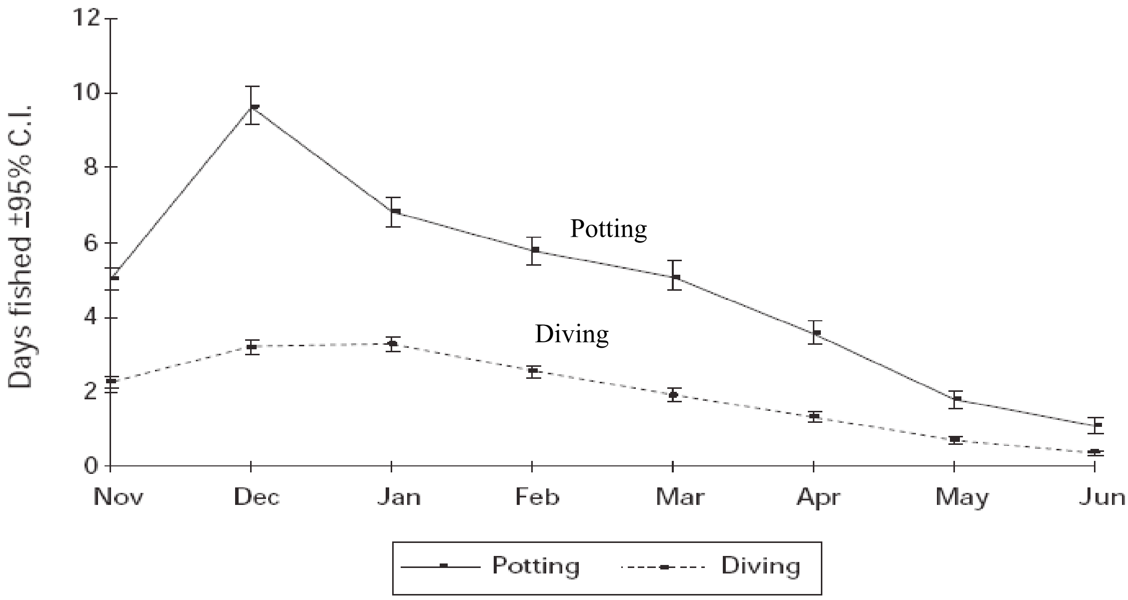


Figure 4.8–4 Average number of days fished per month by recreational lobster pot and dive fishers who reported fishing in the 1998/99 survey (Melville-Smith & Anderton 2000).

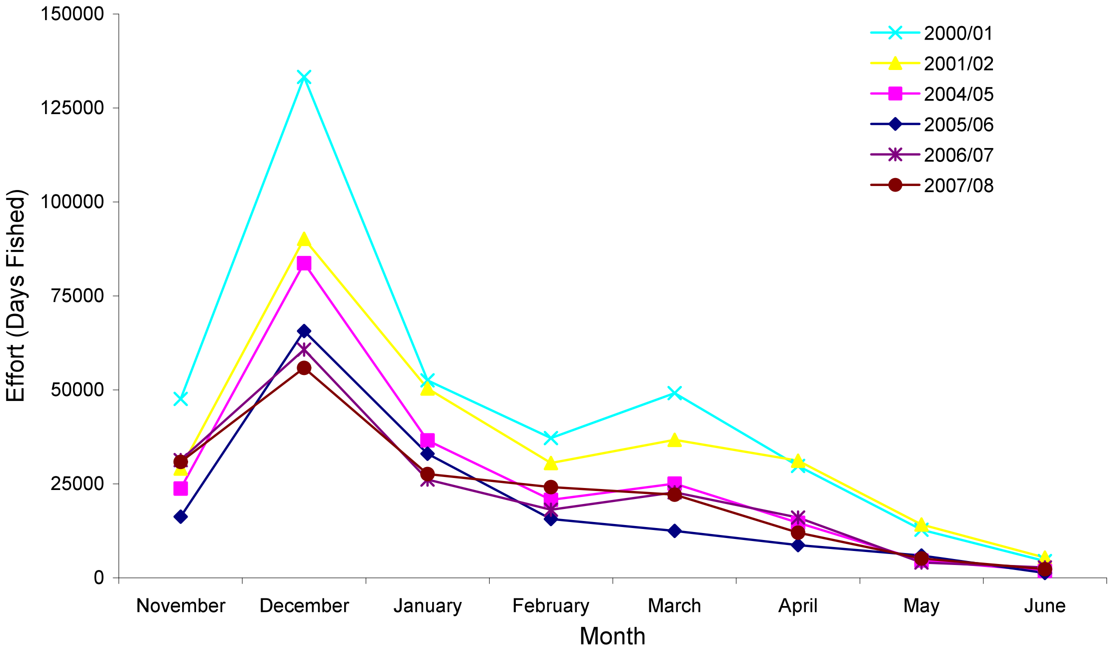


Figure 4.8–5 Number of days fished by month from the phone diary survey for the six seasons surveyed (Updated from IFAAC 2007).

Most of the fishing effort is focused in Geraldton (Zone B), Jurien Bay (Zone C) or the Perth and surrounding areas (Mandurah–Lancelin; Zone C), with most licence holders residing in the Metropolitan Region (Figure 4.8–6) (Melville-Smith & Anderton 2000).

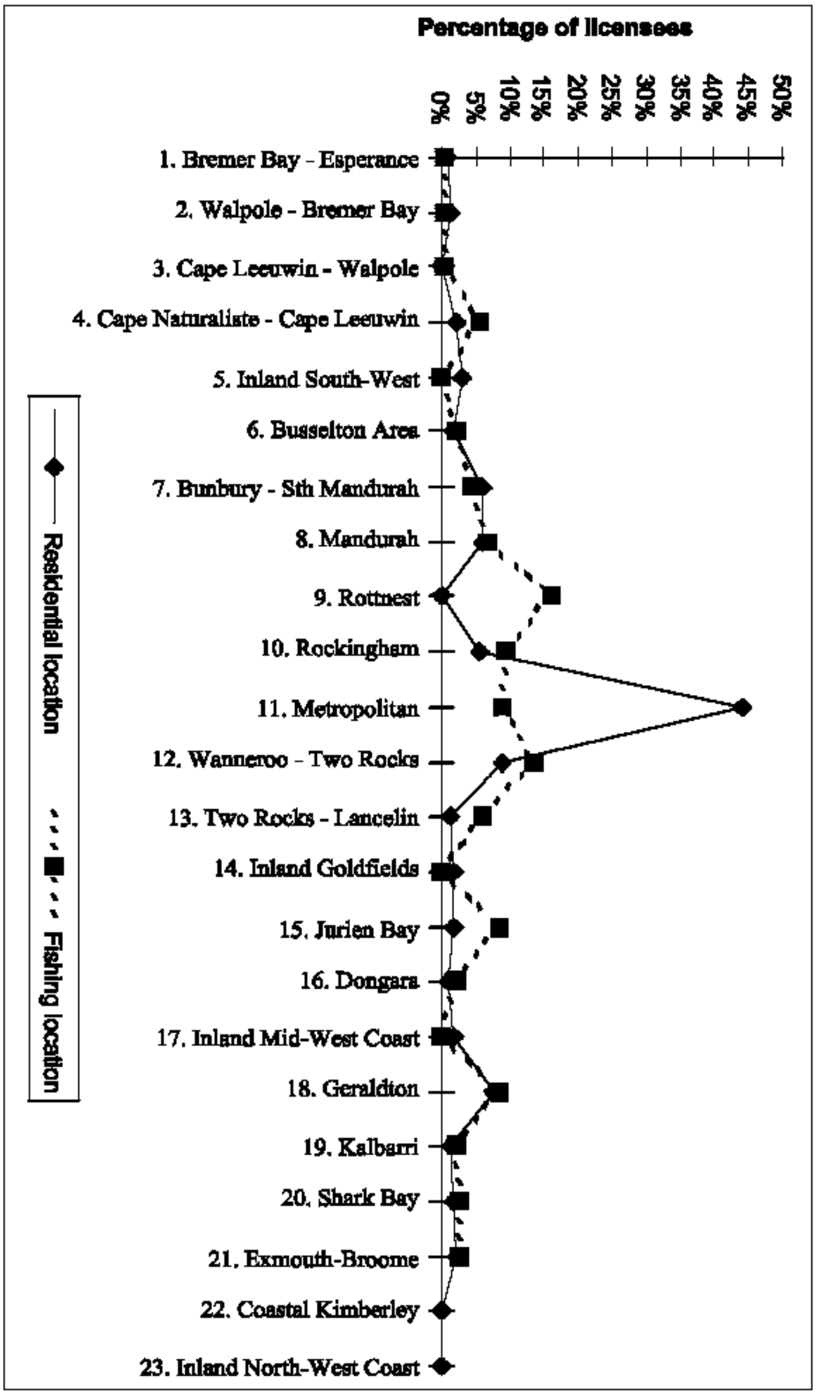


Figure 4.8–6 Location of residence and fishing for lobster licence holders (Melville-Smith & Anderton 2000)

Catch rates

The recreational component of the total catch, based on adjusted recreational catch estimates (see 4.8.2 Comparisons of survey techniques), differs between the northern (Zone A and B) and southern (Zone C) zones of the fishery. Zone A and B have remained relatively stable at around

1 – 2% while there are fluctuations in Zone C, with an overall increasing trend (Figure 4.8–7) (IFAAC 2007). Recently, due to a nominal TAC for the commercial sector, the recreational proportion of the catch in both northern and southern zones has increased, with further increases predicted due to capping of commercial catch in up future seasons. This however, is predicted to fall as the two poor recruitment seasons (Figure 4.1–4) begin to enter the fishery.

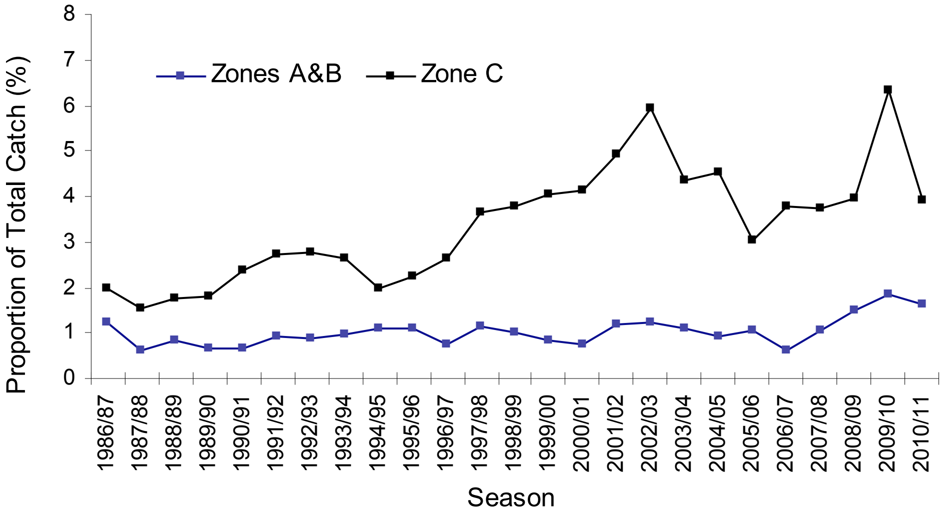


Figure 4.8–7 The proportion (%) of recreational catch in a zone compared with the total lobster catch in that zone (zones A and B and Zone C; using adjusted recreational catch estimates). Note the recreational catch in Zone A is minimal (IFAAC 2007).

4.9 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 deepwater (>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 3.8).

4.9.1 Methods

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. Data is similar to that collected as part of the commercial monitoring program (Section 4.2), 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 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.

During the 2007/08 and 2008/09 season, fishers used a modified "meshed" pot of their own design; however all used an original commercial batten pot as the basis. Variation included additional battens, trawl, wire or plastic mesh to enclose the pot. For the 2010/11 season, analysis was undertaken on the previous years data on catch rates and size distribution, with a standardised wire mesh pot supplied to all fishers in the study.

4.9.2 Results

Coverage of Fishery

The number of participants in the trial by year and latitude is outlined in Table 3.1. The trial currently (2010/11) has 35 fishers participating with good spatial coverage across the fishery. The location of pots from the 2009/10 season shows the extent of the fishery for which there is catch information (Figure 4.9–1).

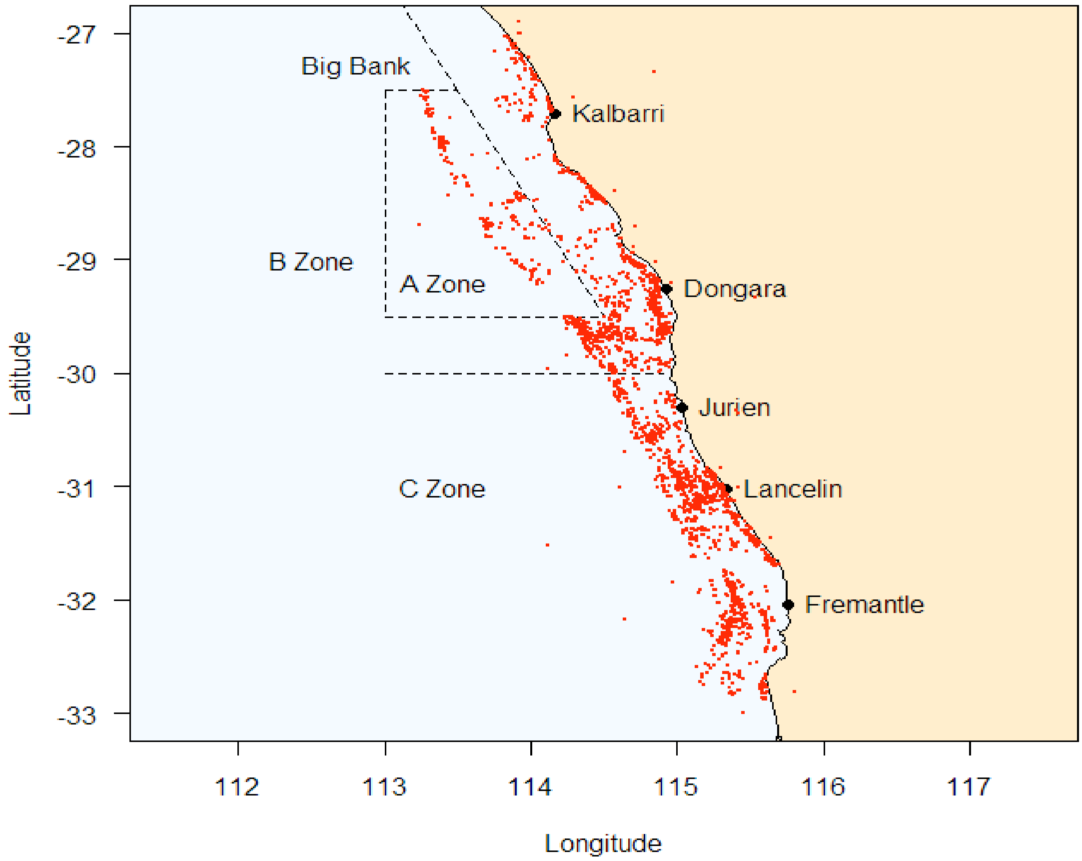
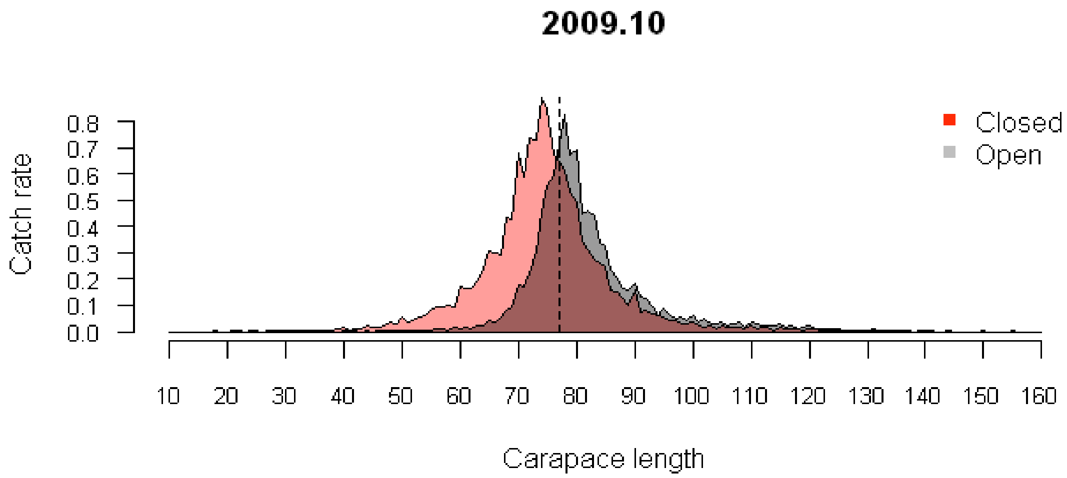


Figure 4.9–1 Location of catch data from meshed and open pots for the 2010/11 season.

Performance of meshed vs. open pot

The meshed pot has consistently produced better catch rates for the undersize component of the population than the open pot, with similar representation of the legal component (Figure 4.9–2).



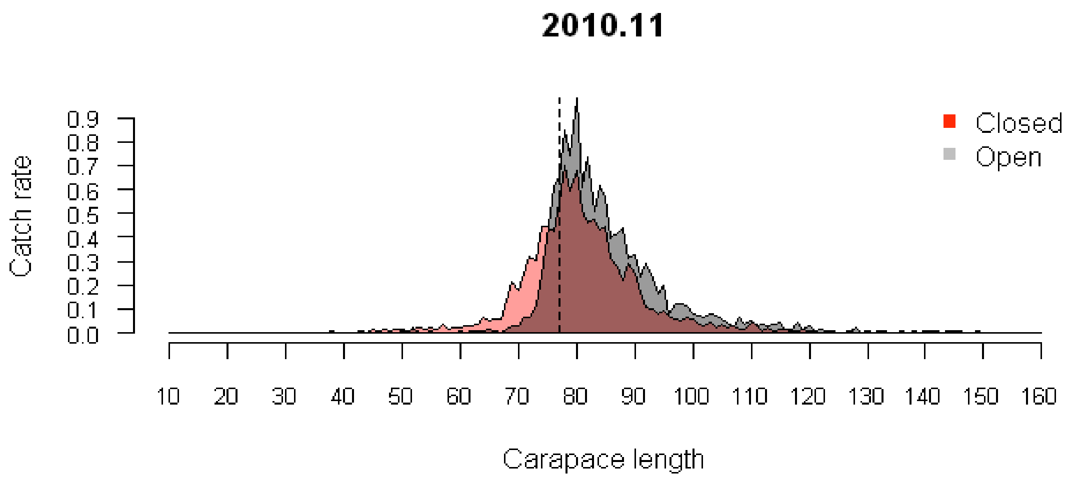


Figure 4.9–2 Size catch rate distribution for meshed (red) and open (grey) pots from the 2009/10 and 2010/11 fishing seasons.

It has enabled an examination of the size composition of lobsters from different depth categories to examine the likelihood of deepwater settlement. This doesn't appear to be the case with very low catch rates of small lobsters in water depths greater than 20 fathoms (Figure 4.9–3).

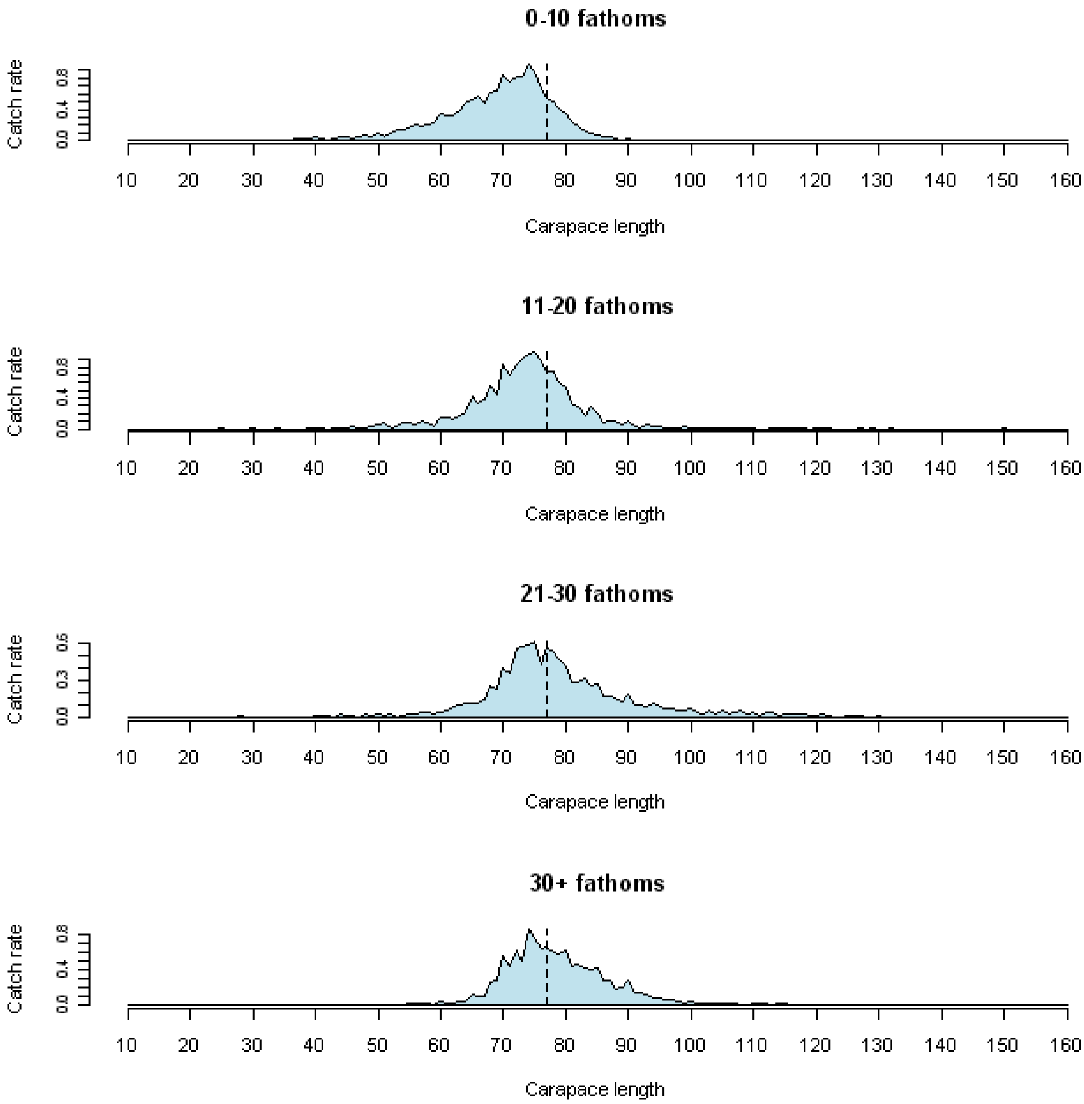


Figure 4.9–3 Catch rates of lobsters from the mesh potting program by 10 fathom water depth categories

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 afore mentioned monitoring programs (e.g. Commercial catch monitoring; Section 4.2)

5.0 Stock Assessment

5.1 Fishing Efficiency

Increases in fishing efficiency (fishing power) on measures of nominal fishing effort can lead to stock assessments being seriously flawed if these increases are not properly accounted for. The first assessment of fishing power increases in the Western Rock Lobster fishery were conducted by Brown et al. (1995), who examined the impact of advances in fishing technology, such as echo sounders and Global Positioning Systems (GPS). Subsequent estimations of fishing efficiency have been made to account for more recent and subtle increases in fishing efficiency and their effects on nominal effort. These factors include technology advances such as ocean plotting and ocean mapping software, mobile phones, weather predictions and pot reductions resulting in less competition between pots (i.e. pot saturation effect) and the movement of pots from below-average fishers leaving the industry to above-average fishers. See papers by Brown et al. (1995), Fernandez et al. (1997), Wright et al. (2006) and de Lestang et al. (2009) for more details.

Both Brown *et al.* (1995) and Fernandez *et al.* (1997) used regression methods to identify the effect of the factors they considered in modelling commercially attained catch rates. Wright et al. (2006) used Delury depletion analysis and that of de Lestang and Melville-Smith (2009) examined the relationship between recruitment, effort and subsequent catch. More recently a direct approach for estimating fishing efficiency has been examined, applicable for years after 1990. This approach compares commercially attained catch rates, which are subject to changes in fishing efficiency, with catch rates attained from a standardized sampling regime in the same location, which are not subjected to changes in fishing efficiency.

Outcomes from these studies have been examined and a regime of average annual fishing efficiency changes in shallow (≤20 f) and deep water (> 20 f) in the three zones of the fishery has been developed.

5.1.1 Methods

Pre-1990 estimates.

Brown et al. (1995) utilised several data sources to examine changes in gear and the use of improved technologies on fishing efficiency from 1971 – 1992. These included;

- Compulsory monthly commercial fisher returns (Section 4.5)
- Voluntary research logbooks (Section 4.4)
- Boat gear and technology interviews (Section 4.5); plus a one-off interview of 50 fishers, to account for information from 1971 – 1989
- Compulsory monthly processor returns (Section 4.6)

The effects of gear alterations were examined for a number of seasons in each management zone, in both shallow and deep water and during the “whites” and “reds” parts of the fishing season.

A GLM analysis was used to compare catch rates of vessels with and without the technology (e.g. GPS) after taking other factors that are likely to affect the catch rate into account (e.g. month, location of fishing).

Soak Time

A 48–hour soak time (a pot that is left for 48 hours from the time that it is set, to the time that it is pulled), produced an average 20% increase in the catch rate in deep water (>37 m) compared to pots with a 24-hour soak time. However, from 1971 – 1992 there was no significant trend in the proportion of days fished with 48-hour soaking time. Therefore this was not included in fishing efficiency calculations.

Pot Type

Pot type (Figure 1.1–1) usage did change during the period of this study, especially in the southern zone (Zone C). Logbook data showed that beehive pots produced better catch rates in deep water, while batten pots were more effective in shallow water. This was not borne out in the interview data of the 50 fishers. This efficiency change from pot type was applied to adjustments of fishing power in Zone C only, as this was the zone that showed major change in pot type usage.

Post-1990 estimates.

Three separate studies have investigated changes in fishing efficiency in the Western Rock Lobster fishery since 1990, namely Wright et al. (2006), de Lestang & Melville-Smith (2009) and de Lestang & Thomson (in prep).

Delury depletion analysis

Delury depletion analysis (Wright et al., 2006) has been employed to determine, amongst other factors, changes in lobster catchability on a zone wide basis (all depths) during the "reds" non-migratory part of the fishery (March to June). The changes in catchability between subsequent years are considered representative of the change in fishing efficiency between those years (see Section 5.4 for more details).

Catch prediction analysis

The relationship between levels of puerulus settlement and subsequent catch 3 – 4 years later has been used to investigate changes in fishing efficiency in various regions throughout the fishery (de Lestang & Melville-Smith 2009). This method examines the impact of water temperature, changes in management legislation (minimum sizes, setose rule) and fishing effort with an average cumulative fishing efficiency has on the above relationship. This model uses data from the puerulus settlement monitoring (Section 4.1), commercial catch (Section 4.2) and volunteer logbooks (Section 4.4). Estimates of annual fishing efficiency from this model have been produced for the same years (1990 – 2008) in specific 1^{o} latitudinal locations for the entire season and the whites (November – January) and reds (February – June) periods of the fishery.

Standardised catch rate analysis

A comparison of volunteer logbook (Section 4.4) and Independent Breeding Stock Survey catch rate data (Section 4.3) have been used to estimate changes in fishing efficiency in areas surrounding the IBSS grounds since the early 1990s. Both data sets have therefore been restricted to areas and depth levels for which there is substantial overlap in data.

- Only logbook data from blocks that overlayed the IBSS breeding stock area were used in the analyses.
- Depth ranges used were 10 – 30 f for Abrolhos and 20 – 30 f for all other sites).

- Volunteer logbook data was limited to catch data derived from 1 and 2-day soak times in April – June.
- Only data relating to batten pots in IBSS was used.
- Standardised volunteer logbook catch rates recorded for the end of the fishing season (April – June) were compared to the following IBSS catch rates recorded four months later in that year (October/November).

The yearly catch rate from volunteer logbook data was determined as the total legal catch (kg) divided by total number of potlifts. This was standardized by ANOVA for depth (depth was measured in 10 f increment levels i.e. 10 – 20 f, 20 – 30 f for the Abrolhos), soak time and month. The yearly catch rate from IBSS data was determined as the total legal weight (kg) divided by the total number of potlifts in each line of pots. Each line was treated as a replicate and these catch rates were standardized by ANOVA for sub-location (each major area was divided into smaller sub-locations for IBSS) and depth (10 fm increments).

The difference in catch rates between volunteer logbooks and IBSS at the start of the time series was considered to be representative of the greater efficiency of the commercial fishers in that area and difference in catchability between the two periods. Any increases or decreases in this difference over the subsequent years were considered to represent additional changes in the efficiency of the commercial fleet in that area.

The initial difference in fishing efficiency at the start of the time series (Δ) was determined (Eq 5.1.1).

$$\Delta = \frac{1}{2}\sum_{i=0}^{1}\left(C_{logb,t_i} - C_{IBSS,t_i}\right), \qquad \text{Eq 5.1.1}$$

where C_{logb,t_i} and C_{IBSS,t_i} are the standardised catch rates in year t_i for logbook and IBSS, respectively. An estimated volunteer logbook catch rate, adjusted for fishing annual efficiency increases was also determined (Eq 5.1.2).

$$\overline{C_{logb,t_i}} = C_{logb,t_i}/(1+r)^{t_i - t_0}, \qquad \text{Eq 5.1.2}$$

where $t_i - t_0$ represents the number of years since the start of the time series and *r* represent the estimated level of efficiency change. The objective function (Eq 5.1.3)

$$\sum_{i=0}^{n}\left(\Delta - \overline{C_{logb,t_i}}\right)^2 \qquad \text{Eq 5.1.3}$$

was minimised using the "optim" function in R that employed the quasi-Newton function "BFGS". Standard errors were derived from the square root of the inverse of the resultant Hessian matrix.

5.1.2 Results

Pre-1990 estimates

Pot type, along with increasing boat size, increasing bait use, use of plastic necks and steel bottomed traps were not included in the overall calculations of fishing power, rather they were applied separately to effort adjustments. These were combined into a "background" efficiency increase, which was subjectively assigned as an annual 1% increase.

Colour Sounders and GPS

Each of these technologies significantly ($p < 0.05$) increased efficiency by 29% in shallow water and 53% in deep water, over the study period 1971 – 1992. This equates to an annual increase of 0.5 – 2% increase in shallow and 1 – 4% increase in deep water.

These increases in efficiency for boats with the technology was applied to the percent of boats each year that had the technology to determine the annual increase in fishing efficiency for the whole fleet.

Post-1990 estimates.

Delury depletion analysis

The Delury depletion analysis estimated that the average annual increase in efficiency from 1990 to 2008 ranged from 2.3 – 8.1% (Table 5.1–1). The very high errors associated with the average estimate over the 19-year period highlights the large inter-annual variability of these estimates. This is due in part to the sensitivity of the depletion model to factors such as catchability and the moulting cycle of lobsters, which have been shown to vary dramatically between years.

Table 5.1–1 Efficiency estimates and standard errors (se), for each management zone in the reds period of the fishery for 1990-2008.

Reds annual fishing efficiency estimates (%)			
Location	Mean	Standard Error	d.f.
A Zone	2.31	4.15	18
B Zone	6.16	20.2	18
C Zone	8.11	13.2	18

Catch prediction analysis

Estimates of annual changes in fishing efficiency from catch prediction modelling ranged from 0 – 1.6% (Table 5.1–2). Although these estimates have been produced with relatively tight variances, it is likely that they are confounded with factors other than just efficiency change. The catch prediction model assumes that the contributions of recruits to the overall catch and migration patterns between locations both remain relatively constant over time. In reality this is probably not the case. Recent changes in the levels of residual biomass, especially in deeper waters regions, indicates that these assumptions may be inappropriate, and that the estimates of efficiency change might be biased downwards by a progressive increase in the contribution of residual stock to the commercial catches.

Table 5.1–2 Fishing efficiency estimates derived from recruitment-catch relationships with associated standard errors (se), for each location for the entire season, the whites and the reds period of the fishery.

	Annual fishing efficiency estimates (%)		
Location	**Whole season**	**Whites**	**Reds**
Abrolhos	NA	NA	0.65 ± 0.49
Kalbarri	0	0	0
Geraldton	1.11 ± 0.40	1.40 ± 0.66	0.70 ± 0.61
Dongara	1.20 ± 0.48	1.60 ± 0.92	0.59 ± 0.70
Jurien	0.59 ± 0.62	0.95 ± 1.04	0.66 ± 0.85
Lancelin	1.17 ± 0.59	1.15 ± 1.16	1.10 ± 0.70
Fremantle	1.17 ± 0.59	1.15 ± 1.16	1.10 ± 0.70

Standardised catch rate analysis

Initial estimates of average annual efficiency changes from the early 1990s to 2009 were relatively similar at all locations (ca. 2 – 3%) except in Fremantle, where the estimated annual fishing efficiency was more than double that at any other location (7.4%) and at Kalbarri where an estimate could not be determined (Table 5.1–3; Figure 5.1–1.a-f). These two latter locations did not appear to have enough observations (years) for the model to conduct robust comparisons between the two datasets.

Table 5.1–3 Fishing efficiency estimates, with associated standard errors (se), for each location in April – June.

	Reds annual fishing efficiency estimates (%)		
Location	**Mean**	**Standard Error**	**d.f.**
Abrolhos	2.41	1.59	20
Kalbarri	1.69	1.79	8
Dongara	2.78	2.45	19
Jurien	1.50	1.70	14
Lancelin	5.61	7.38	18
Fremantle	1.99	1.18	10

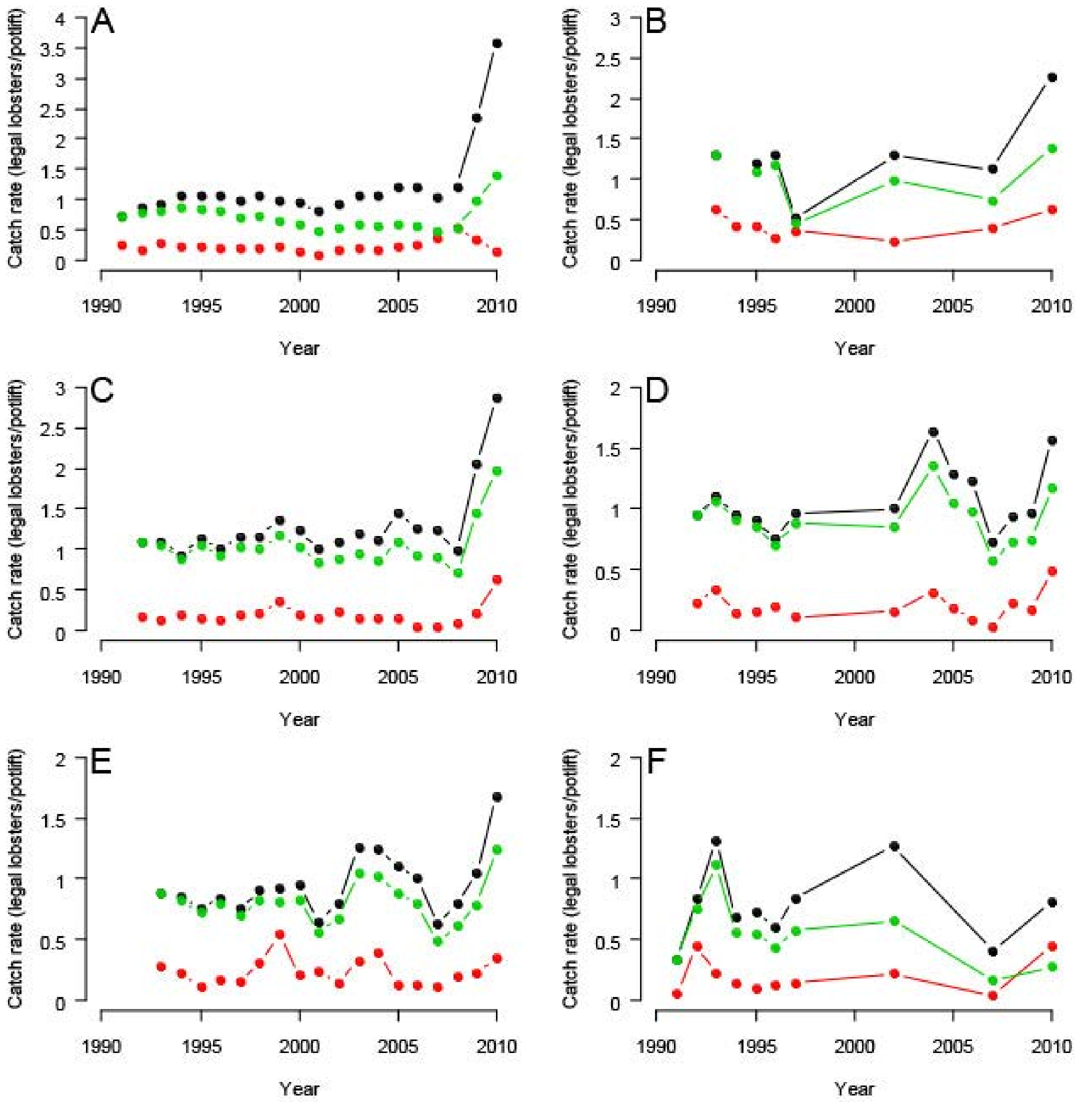


Figure 5.1–1 Raw catch rates from volunteer commercial logbooks in April – June (black) and Independent Breeding surveys in October/November (red) in the same areas. Volunteer commercial logbooks adjusted for increases in fishing efficiency are shown in green. A: Abrolhos Islands, B: Kalbarri, C: Dongara, D: Jurien, E: Lancelin, F: Fremantle.

Standardised Effort and Nominal Effort

Brown et al.'s (1995) estimates of annual efficiency changes have been used for the period prior to 1990 (Table 5.1–4). For the post-1990 period estimates have been based on the standardised catch rate analysis since this model was considered relatively unbiased by lobster catchability and/or model assumptions. As the standardised catch rate model only produced estimates for deep-water locations (> 20 f), those for shallow water areas for the post 1990s period were based on pre-1990s comparisons between the two water depths. Thus in the pre-1990s shallow water fishing efficiency was between 0.25 and 0.5 less than in deep water. Therefore a mid-point value of 0.37 less than deepwater has been used to derive average annual efficiency increases for shallow waters for years after 1990 based on deepwater estimates for the same period from the standardised catch rate analysis.

Table 5.1–4 shows these estimates of annual fishing change by zone and water depth. These estimates represent the cumulative effect of all factors leading to efficiency changes (e.g. pot reduction, technology improvement etc.). These are the values used to standardise empirical catch rates between seasons and are the basis for efficiency increases in the stock assessment model (Section 5.5). These estimates, which are averaged over a number of years, are broken up into annual step-wise changes by the stock assessment model to account for the instantaneous changes in efficiency due to factors such as pot reductions (see Section 5.5 for more details).

Table 5.1–4 Annual estimated percentage increase in fishing efficiency across all zones, for both deep and shallow water, for fishing season from 1971/72

	Annual increase in fishing efficiency (%)	
Fishing Seasons	**A, B & C Zones**	
	< 20fm	> 20fm
1971/72 – 1984/85	1.0, 1.0, 1.0	2.0, 2.0, 2.0
1985/86 – 1986/87	1.5, 1.5, 1.5	2.0, 2.0, 2.0
1987/88	1.5, 1.5, 1.5	2.5, 2.5, 2.5
1988/89 – 1989/90	1.5, 1.5, 1.5	2.0, 2.0, 2.0
1990/91 – 2009/10	2.0, 2.0, 2.0	3.0, 3.0, 3.0

5.2 Catch Prediction

Catch prediction based on the level of puerulus settlement is an important tool to manage this fishery sustainably. Several datasets are used to predict the catch three to four years in advance. This allows sufficient lead-time to implement any changes in management strategies to provide a sustainable and profitable catch.

Chittleborough and Phillips (1975) were the first to describe a relationship between the levels of puerulus settlement at the coast and variation in commercial catches. This work soon led to the first catch predictions being produced by Morgan et al. (1982), which were based on puerulus settlement at four locations (Seven Mile Beach, Jurien Bay, Rat Island and Garden Island). They predicted the seasonal commercial catch of "whites" on a fishery-wide basis. Predicting the whole seasons catch ("whites" and "reds") was then determined by Phillips (1986) and Caputi and Brown (1986), using puerulus and juvenile abundances, respectively. The method used for predicting catch on a regional (management zone) basis for both the whites and reds fisheries was developed by Caputi et al. (1995a). It is described in more detail in the following section. The Department of Fisheries has recently modified the technique of Caputi et al. (1995a) to incorporate finer-scale variation in puerulus settlement, juvenile growth rates, fishing efficiency and water temperature (de Lestang et al., 2009).

Recent management arrangements aimed at significantly reducing the harvest rate throughout the fishery were implemented during the 2008/09 fishing season (Box 2.4–1). These changes have significantly altered the relationships used historically for production catch predictions, rendering these techniques obsolete. These changes have resulted in a significant reduction in effort (ca. 60-70%) and changed distribution of effort between months, which have resulted in a marked increase in carryover of lobsters between months and years. The Integrated Stock Assessment Model (Section 5.5) is now used to produce all catch predictions for the commercial fishery. As the recreational catches have not been significantly altered by these management changes their catches are still estimated directly from levels of puerulus settlement and effort.

5.2.1 Methods

Commercial catch prediction

See section 5.5 – Integrated Stock Assessment Model

Recreational catch and effort prediction

The recreational catch has increased substantially since rock lobster-specific licences were first introduced in the 1986/87 fishing season. This increase, and the corresponding increases in the recreational portion of the total catch (Figure 4.8–7), is of particular interest in relation to the new management initiative of Integrated Fisheries Management (Section 2.6).

Recreational-catch prediction uses several fishery datasets: recreational fishery licence numbers, estimate of participation rates and catch and effort (Section 4.8), estimate of commercial catch (Section 4.5), and index of recruitment (Section 4.1).

Melville-Smith et al. (2001) found that a multiple regression of puerulus settlement at the Alkimos collector (Figure 4.1–1) for three and four years previously and seasonal licence usage best explained the recreational catch for that season, as most of the recreational catch is taken in the off the Metropolitan coast.

When examined by zone, the combined parameters of puerulus settlement at Alkimos three and four years previously and seasonal licence usage in Zone C best explained the catch within that zone. However, for Zone B, licence usage was significant in explaining the catch, while settlement at the collector for Zone B (Dongara) was not.

The predictions from this model were based on the assumption that effort levels in the future were the same as to those in the recently completed season.

However, Melville-Smith et al. (2004) modelled future recreational effort, to improve the prediction of recreational catch. Settlement rates at the Alkimos collector were found to be strongly correlated with licence usage three to four years later, enabling catches to be predicted three to four years into the future.

5.2.2 Results

Commercial catch prediction

See section 5.5 – Integrated Stock Assessment Model

Recreational catch prediction

Estimated recreational catch, using the model of Melville-Smith et al. (2004), which incorporates forecasts of recreational licence usage, has provided good estimates of actual catch by recreational fishers (Figure 5.2–1), with the actual catch falling within the 95% confidence intervals of the model. As for the commercial fishery, these predictions have been used for management purposes, such as estimates of future catch shares under IFM (IFAAC 2007)

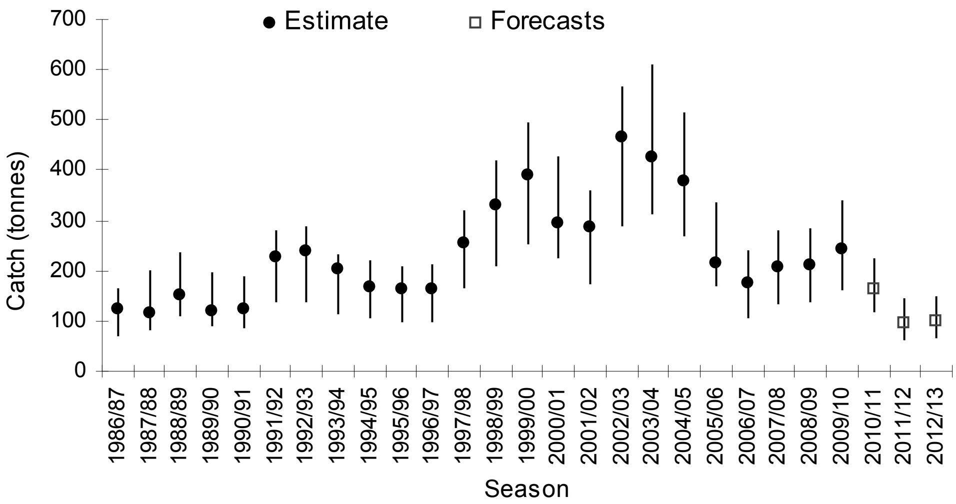


Figure 5.2–1 Model predictions of recreational catch (open square), with 95% CI (bars), with actual catches (solid circles) (updated from Melville-Smith et al. 2004).

5.3 Stock-Recruitment–Environment Relationship

For complete details see Caputi et al. (1995b).

Understanding the relationship between breeding stock and recruitment (SRR) is necessary for good management of the fishery. In some lobster species these relationships have been difficult to determine, due mainly to lobsters having a long larval stage, with the result that environmental conditions strongly affect recruit survival and distribution. In fact in most cases, in order to detect a SRR, a stock must first be fished to a level that negatively affects recruitment significantly. The construction of an SRR also requires mid- to long-term data sets on recruitment (e.g. puerulus settlement), abundance (Section 4.1), breeding stock (Section 4.2) and environmental factors (Section 4.7).

Recruitment–spawning stock relationships (RSR) describe the impact mortality (both natural and fishing) has on the ability of recruits to replenish the spawning stock. When combined with an SRR, the resultant model can predict equilibrium levels of stock and recruitment for different levels of effort, which is invaluable in the management of many fisheries.

5.3.1 Methods

An *SRR* and an *RSR* were determined for each of the three management zones. Puerulus settlement indices were used for each zone, with Rat Island settlement used for Zone A, Seven Mile Beach used for Zone B and Alkimos for Zone C (Section 4.1). The northern and southern coastal fishery dependent breeding stock indices (Section 4.2) were used as measures of the breeding stock in those two areas. Since no direct breeding stock index was available for the Abrolhos Islands, and the majority of the catch in this location is of a mature size, the annual commercial catch was used as a measure of the breeding stock for Zone A.

Two environmental measures were used for calculating the SRRs: Leeuwin Current strength, as measured by the mean sea level at Fremantle; and as a proxy of westerly winds, mean monthly rainfall at five locations in the southern part of the fishery over two periods (July – September and October – November). A unique index of westerly winds was for the Abrolhos Islands, was based on rainfall at three locations between Jurien and Geraldton from July to November.

SRRs were developed based on the power curve (Eq 5.3.1).

$$Puerulus = aStock^{b} \qquad \text{Eq 5.3.1}$$

where *Puerulus* is an index of puerulus settlement, *Stock* is a measure of the breeding stock, and *a* and *b* are parameter estimates.

For the recruitment–spawning stock relationship (RSR), nominal fishing effort (pot lifts) was obtained from CAES (Section 4.5) and standardised for increases in efficiency (Section 5.1). The recruitment to RSR is shown in Eq 5.3.2.

$$Sn_t = 0.819\exp\left(-0.426En_{t-2}\right),\ Ss_t = 0.430\exp\left(-0.208Es_{t-2}\right) \qquad \text{Eq 5.3.2}$$

where *Sn* and *Ss* are the spawning indices for the north and the south, respectively, and *En* and *Es* are the standardised effort (million pot lifts).

5.3.2 Results

Stock-recruitment–environment relationship

The strong relationship between environmental factors and puerulus settlement necessitates the incorporation of environmental variables into any examination of a stock–recruitment relationship. This relationship is examined regionally because of the regional difference in the environmental impacts (Section 4.7).

When the environmental factors were incorporated into the SRR for Zone B, the combined spawning index did not explain variations in puerulus settlement at Dongara. Rather settlement was dominated by the environmental factors– Leeuwin Current and westerly winds–, with the decline in spawning stock not affecting puerulus settlement. The spawning stock index was also not significant in the southern zone, where recruitment of puerulus at Alkimos was affected by rainfall (westerly winds).

However, at the Abrolhos Islands, when the spawning stock index was combined with the rainfall in northern locations, the result was significant in explaining recruitment at the Abrolhos Islands. The Abrolhos Islands may therefore be more susceptible to reductions in spawning stock, as environmental factors do not dominate the index as they do in the coastal locations (for more detail see Caputi et al. 1995b).

Recruitment–spawning relationship

Estimates of the numbers of recruits into the spawning stock showed that fishing effort two years before spawning, when lobsters recruit into the fishery, significantly affected the spawning index. The abundance of pueruli was not significant. This indicates that the fishing effort on recruits reaching legal size is the main factor affecting the abundance of the spawning stock. In all regions of this fishery, fishing pressure is currently at such levels that strong recruitment years do not necessarily translate into good spawning stock (for more detail see Caputi et al. 1995b).

5.3.3 Discussion

As the spawning stock has generally increased since this analysis was undertaken, the spawning stock is unlikely to have become a significant factor affecting the numbers of puerulus settling. Therefore the focus in more recent years has been to update the environment–puerulus relationship (Section 4.7) to understand the factors affecting puerulus settlement.

However, it would be useful to update both of these relationships, particularly the RSR, to understand the effect on these relationships of changes in fishing effort and other management measures (e.g. setose rule).

As a result of the low puerulus settlement in the three years (2006/07 to 2008/09) including the record low settlement in the 2008/09 two FRDC projects are underway examining the potential causes (viz. environmental conditions and breeding stock) of the low settlement (see Section 7.1.2).

5.4 Depletion Analysis

For full details see Wright et al. 2006. (Abstract below)

A depletion technique was applied to the western rock lobster fishery in Western Australia for the non-migrating part of the season, March to June. The catch for the migrating part of the fishery was used to estimate the annual exploitation for the whole season. To take into account environmental effects (water temperature and swell) on catchability that affect the assumptions of the depletion technique, estimates of the changes in catchability between March and June of each year were obtained. The trends in catchability, residual biomass and exploitation for three zones of the fishery since the 1983/84 season were examined. These show that the exploitation in the north coastal zone decreased from c. 75% in the early 1990s to c. 60% in the mid 1990s as a result of a major change in management in 1993/94 (including 18% nominal effort reduction and increased protection of mature females). However, in the last 10 years exploitation has increased again to c. 75%, mainly owing to increases in catchability (e.g., efficiency increases) as there has been little change in the nominal effort. The results from this study provide some insight into changes in catchability that can be used in other stock assessment techniques such as length-based assessments.

Harvest rate is now estimated through the biological model (Section 5.5).

5.5 Biological Modelling

The western rock lobster fishery targets *Panulirus cygnus* over more than 1000 km of coastline along the central and lower west coast of Australia. The fishery is fully exploited and has been managed via a suite of input controls (eg. pot, time and size limits) (Section 2) until the 2009/10 season. Historically, levels of effort in this fishery have been periodically adjusted in response to increases in fishing efficiency and the performance of a number of key population indices, especially measures of the breeding stock (Sections 4.2 & 4.3) and levels of post-larval recruitment (puerulus).

Site-specific breeding stock indices have been produced for this fishery from two sets of data:

1. Monthly depth-specific monitoring of commercial catches throughout the fishery (Section 4.2)
2. Standardised independent annual surveys at certain locations just prior to the start of the season (Section 4.3).

Levels of post-larval recruitment are measured monthly and used to predict commercial and recreational catches three and four years later (Caputi et al. 1995; de Lestang et al. 2009, Section 4.1).

In 2008, climatic conditions were generally favourable for good puerulus settlement (e.g. strong Leeuwin Current and warm offshore waters) and empirical measures indicating that breeding stock levels in the main parts of the fishery were within historic ranges (Section 4.2 & 4.3).

Despite this, the puerulus measures indicated that recruitment had been the lowest in a forty-year time series. This unexpectedly poor puerulus settlement was the most significant point in a five year period of below average puerulus settlement since 2006/07.

The low puerulus settlement required fisheries managers to examine possible causes (i.e. environmental and breeding stock levels) and the likely impact that this recruitment may have on future breeding stock levels and catches in 2011/12 and later seasons. Furthermore, it was necessary for managers to assess how to modify current effort levels to ensure biological sustainability of the fishery into future.

An assessment model which synthesised all the available data was 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, 1995) was developed that was length-structured and had greater temporal and spatial detail and incorporated more of the known biological processes of *Panulirus cygnus*.

5.5.1 Methods

The framework for the new model and a draft version was developed and then reviewed by a panel of four national and international fisheries modellers in 2007 (http://www.fish.wa.gov.au/docs/op/op050/fop050.pdf). The panel's comments and suggestions for improvement were integrated into the draft model. Two separate models were then developed in tandem on two separate Platforms (AD-Model Builder (Otter Research, 2003) and R (R Development Core Team, 2008)). The models used half monthly time-steps starting from the assumed birth date of November 1. The relatively fine temporal scale enables known timing of moulting and movement to be realistically incorporated. As lobster biology and catchability varies throughout the fishery, the model used 14 areas, 7 shallow (<= 20 fm, i.e. 36 m) and 7 deep (> 20 fm).

A second assessment review was conducted in 2010 by three internationally recognised experts. Their review suggested a number of changes to the current model (www.fish.wa.gov.au/docs/op/op081/fop81.pdf):

1. The code be made more efficient to reduce the processing time.
2. The number of time-steps, areas, and length-bins should be reduced to make the model less complex and reduce processing time.
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. This data consists of length frequency data from DBSS and IBSS and the CPUE from the IBSS.
4. The growth should be determined by estimating the parameters in the model from the tagging data.
5. The movement parameters, including northward movement should be estimated from tagging data incorporated in the model.
6. Initial conditions be modified.

All changes suggested by the second assessment team were incorporated into the model with only point 4 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 as priors into the stock assessment model (see Section 3.8). The revised model contains 11 areas;

5 shallow (<= 20 fm, i.e. 36 m) and 6 deep (> 20 fm) and 11 time-steps each representing either a different period in the biology of the lobster or behaviour of the commercial fishers (Figure 5.5.1).

Data sources

Catch and effort

The population model uses catch and effort data in 11 time intervals (Table 5.1–1) from November 1974 to June 2014 in each of the 11 model areas. This detailed data was obtained from monthly catch and effort statistics recorded in 1° by 1° blocks which was further partitioned into shallow (≤20 fm) and deep (>20 fm) depth ranges and the model time-steps using skippers voluntary daily logbook data which is completed by 30 – 40% of the fleet.

Table 5.5–1 Time intervals used in the assessment model

Model time-step	1	2	3	4	5	6	7	8	9	10	11
Time interval	Nov15-Nov30	Dec1-Dec14	Dec15-Dec31	Jan1-Jan14	Jan15-Mar14	Mar15-Mar31	Apr1-Apr30	May1-Jun30	July1-Aug31	Sep1-Oct31	Nov1-Nov14

The small contribution of the recreational catch (ca. 3 – 4%), combined with difficulties determining its spatial distribution and the need to convert its effort into units comparable to the commercial sector, have meant that currently the recreational catch and effort is ignored in this version of the model.

Future projections of effort for the years 2010/11 to 2013/14 in each time-step/location were based on the number of pot-lifts in time-steps 1 – 8 in the 2009/10 season with an additional number of pot-lifts in time-step 9 arbitrarily chosen as 0.8 times that in time-step 8. As fishing patterns become known throughout the season, effort input to the model will be adjusted so as the resultant catch is 5500 t.

The stock assessment is undertaken on the assumption that puerulus and the subsequent recruits would be at the low level of 2010/11 in the 2011/12 and subsequent seasons. This can now be considered an appropriate approach given the preliminary puerulus settlement data observed in 2011/12.

Efficiency increases

The increase in the efficiency of a pot (Section 5.1) is specific to location and generally results from improvements in technology (i.e. depth sounders and GPS), duration of soak time, reduction in pot saturation (due to pot reductions) (Section 5.4; Wright et al. 2006) and the movement of pots from low to high catch rate fishers (Section 5.1).

Efficiency increase was estimated in the model (five parameters per area) and consisted of area-specific base levels of annual increase compounding since 1975 together with step-wise increases due to significant advances in technology and pot reductions.

Empirical measures of efficiency increase indicate that there have been approximately three periods of relatively constant change due to technology advancements; prior to, during and after the 1990s. These periods represented pre and post GPS uptake by the fishery and then the advent of newer technology such as mobile phones and internet-based weather predictions, respectively. Base level efficiencies represent the first period (i.e. pre 1990) with the efficiency in the following two periods being the base level scaled by estimated parameters. This produces three levels of underlying efficiency increases for the three periods of relatively constant change due to technology advancements.

Pot reductions occurred in fishing seasons 1993/94, 2005/06, 2008/09 and 2009/10. The magnitude of the efficiency increase resulting from these pot reductions was assumed to be proportional to the pot reduction and unique between the shallow and deepwater locations. Pot reduction multipliers were estimated for the two water depths and used to scale the underlying level efficiency increases as step-wise increases during the season of the pot reduction. This produced region/season specific estimates of fishing efficiency which were then used to produce matrices of cumulative efficiency increase by compounding the efficiency increase for a season with those increases that had occurred in previous seasons.

The change in management to individual catch limits will make a significant change to fishing efficiency as a result of changes in pattern of fishing including bait usage, fishing to markets, some not fishing peak catch periods.

Puerulus data

Puerulus settlement data was first collected for this fishery in 1968 at Seven Mile Beach. Since this time a number of additional sites have been added and these data have been shown to be very representative of the magnitude of juvenile recruitment in the surrounding locations (Sections 4.1, 5.2). de Lestang et al. (2009) examined which locations best represented recruitment in each of the model areas. These relationships have therefore been adopted for use in this model. Regions 1 and 2 use settlement data from Alkimos, regions 3 and 4 use a least squares mean (LSM) (SAS Institute Inc., 1987) of settlement at Jurien, Lancelin and Alkimos, regions 5, 6, 9 and 10 use a LSM of settlement at Dongara and Rat Island, regions 7, 8 and 11 use a LSM measure of settlement at Port Gregory and Dongara.

Growth

Preliminary analysis of the tag-recapture data indicated that growth was relatively similar in four broad areas of the fishery, the south (regions 1, 2), the mid (regions 3, 4), the north (regions 5 – 8, 10, 11) and the shallow Abrolhos Islands (region 9). Data was therefore pooled into the areas and analysed as described in Section 3.8 to produce parameter estimates for a logistic model relating carapace length and change in carapace length over a one-month period (Table 5.3.2).

In the model all lobsters are grown bi-annually, at the beginning of time-step 3 and 6 (December 1 and March 15). Lobsters are grown in this fashion in the model to represent the synchronous whites and reds moults that occur each season on approximately the above dates. The monthly increment parameters are used to develop a location/sex-specific size transition matrix representative of bi-annual (six-month) growth by moulting lobsters six times.

The size transition matrix is constant across years with the length after moulting, L, being a normally distributed length $\mathrm{N}(L, \mathrm{cv} \cdot L)$ with the cv being the coefficient of variation, taken to be 0.05. The numbers of lobsters are then distributed across the length bins according to proportion at length.

Table 5.3–2 The values of the logistic function calculated outside the model where $M^{I}_{s,r}$, $I^{50}_{s,r}$ and $S^{I}_{s,r}$ are the parameters of the growth model equation (Eq 5.5.2).

Area	1,2		3,4		5-8, 10,11		9	
Sex	Female	Male	Female	Male	Female	Male	Female	Male
$M^{I}_{s,r}$	1.492	1.492	1.444	1.444	1.426	1.426	3.381	3.381
$I^{50}_{s,r}$	90.72	125.6	86.639	142.66	89.084	118.5	61.945	49.813
$S^{I}_{s,r}$	10.208	18.886	10.595	22.55	7.524	16.6	4.818	25.83

Migration

Movement of lobsters is generally from inshore to offshore and occurs at the beginning of time-step 3 (December 15) each year. Movement also occurs in a northward direction in most deep-water regions, and occurs in time-step 4 (January 1).

The numbers of lobsters migrating depends on; the number of lobsters in the source area, the proportion of lobsters designated as "whites" in that area (based on size class) and the proportion of those that will migrate. An empirical model has been fitted to the proportion of white lobsters in the catch each season. This model assumes the size composition of white lobsters is normally distributed and that the mean varies annually in a linear fashion. This assumption allows for progressive changes in the size composition of whites migrating that may result from factors such as changing water temperatures (Caputi et al. 2010), and removes some of the effects of sampling error.

Any lobster designated as "red" in the source area will not migrate. Of the "whites" in the source area, a proportion, which is constant over time, move to the destination area. This proportion of the "whites" which move is estimated in the model from tagging data. Migration in the model begins in the southern most location and progressively moves north. This gives a lobster the ability to migrate as far west and north in the fishery as necessary to replicate observed movement from tag recaptures, e.g. from the centre of the fishery to the most northern region (area 8).

Of the lobsters that migrate west some are capable of moving into more than one location (since more than one location exist directly offshore). In these cases a matrix of proportion distribution are used to designate the proportions of lobsters migrating into each location. Currently the model does not estimate these proportions (Tables 5.5–3).

Table 5.5–3 Matrix describing the source-destination areas and proportional distribution of westerly migrating lobsters amongst destination areas.

		To						
		2	4	6	8	9	10	11
From	1	1.00						
	3		1.00					
	5			0.70			0.30	
	7				0.80			0.20

Model structure

The model runs on 11 time steps per year from November 1 1975 to October 31 2016 in 11 regions, which include inshore and offshore components using the 20-fathom depth contour

(Fig. 5.5–3). The regions 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.

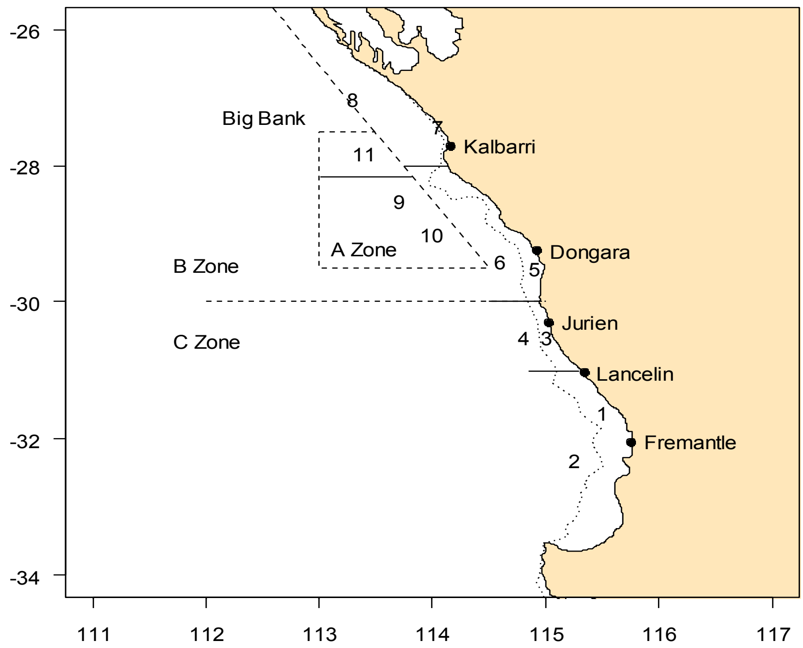


Figure 5.5–1 The model areas of the western rock lobster fishery.

Basic dynamics

Changes in the number of animals of sex *s* in length-class *L* in region *r*, at the start of time-step *t* of year y, $N^s_{r,y,t,L}$, are due to recruitment, growth, movement and mortality. The order of events during each time-step are recruitment, growth, movement then mortality (although recruitment, growth and movement do not occur in each time-step). The number of animals after recruitment and growth during time-step *t* of year *y* is given by equation 5.5.1:

$$\tilde{N}^s_{r,y,t,L} = \begin{cases} \sum_{L'} G^s_{r,L',L} N^s_{r,y,t,L'} + R_r \phi_L e^{\varepsilon_{r,y}} & \text{if } t = 1 \\ \sum_{L'} G^s_{r,L',L} N^s_{r,y,t,L'} & \text{otherwise} \end{cases} \quad \text{Eq 5.5.1}$$

where $G^s_{r,L',L}$ is the probability of an animal of sex *s* in region *r* growing from length-class L' to length-class *L*, R_r is the average recruitment to region *r*, ϕ_L is the proportion of the annual recruitment which recruits to length-class *L*, [illegible] is the recruitment residual for region *r* and year *y*. See Figure 5.5–1 for the map of the regions.

The incremental lobster growth is bi-annual but and is taken to be represented by a logistic function (Eq 5.5.2).

$$I_{s,r} = \left(\frac{\hat{M}^I_{s,r}}{1 + e^{((\ell_L - \hat{I}^{50}_{s,r})/\hat{S}^I_{s,r})}} \right) \quad \text{Eq 5.5.2}$$

where $\hat{M}^I_{s,r}$, $\hat{I}^{50}_{s,r}$ and $\hat{S}^I_{s,r}$ are the maximum growth increment, the inflection point, and the slope of the logistic function. The values of the growth parameters are estimated with imposed priors of values estimated outside the model.

Recruits enter the fishery as age 3 lobsters (2 year post settlement). The length of these lobsters is determined by growing them for four bi-annual moults from an initial length of 8.5 mm (puerulus mean length) then distributing them across the length bins assuming the lengths are normally distributed with cv = 0.05.

For subsequent moults, they are distributed along the length bins using the growth transition matrix, $G^{s}_{r,L',L}$. The growth transition matrix is determined by taking each initial length class L', growing it by the increment $I_{s,r}$, and determining the proportion which go to length class L assuming the length is normally distributed with cv = 0.05.

The number of animals after movement during time-step *t* of year *y* is then given by equation (5.5.3).

$$\tilde{N}^{s}_{r,y,t+1,L} = \tilde{N}^{s}_{r,y,t,L}\left(1-\lambda_r \Lambda^{s}_{r,y,t,L}\right) + \sum_{r'\neq r} v_{r',r}\tilde{N}^{s}_{r',y,t,L}\lambda_{r'}\Lambda^{s}_{r',y,t,L} \qquad \text{Eq 5.5.3}$$

where λ_r is the movement rate from area region r' to region *r*, $\Lambda^{s}_{r,y,r,L}$ is the fraction of the animals of sex *s* in length-class *L* in region *r* during time-step *t* of year *y* which are "whites" (Eq 5.5.4).

$$\Lambda^{s}_{r,y,t,L} = \frac{K_{r,y,L}}{\sqrt{2\pi}\sigma^{\Lambda}_{r,y}} e^{-\frac{(L_m - P^{\Lambda}_{r,y})^2}{2(\sigma^{\Lambda}_{r,y})^2}} \qquad \text{Eq 5.5.4}$$

$K_{r,y,L}$ is a scaling factor, $P^{\Lambda}_{r,y}, \sigma^{\Lambda}_{r,y}$ are the mean and standard deviation of the length which defines the probability of an animal being a "white", L_m is the midpoint of length-class *L*, and $v_{r',r}$ is the fraction of animals which move from region r' to region *r*.

The number of animals after mortality during time-step *t* of year *y* accounts for landings and discards (due to protected lobsters being caught and high-grading), and that fishing and natural mortality differ between "whites" and "reds", and is given by equation 5.5.5.

$$N^{s}_{r,y,t,L} = \tilde{N}^{s}_{r,y,t,L}[\Lambda^{s}_{r,y,t,L}e^{-Z^{s}_{1,r,y,t,L}} + (1-\Lambda^{s}_{r,y,t,L})e^{-Z^{s}_{2,r,y,t,L}}] \qquad \text{Eq 5.5.5}$$

where $Z^{s}_{\tau,r,y,t,L}$ is the total mortality on animals of type τ (1 = "whites", 2 = "reds") in length-class *L* and region *r*, during time-step *t* of year *y* (Eq 5.5.6).

$$Z^{s}_{\tau,r,y,t,L} = F^{s}_{\tau,r,y,t,L} + M_{\tau,y,t} + D^{s}_{\tau,r,y,r,L} \qquad \text{Eq 5.5.6}$$

where $F^{s}_{\tau,r,y,t,L}$ is the fishing mortality associated with the landed catch of animals of type τ in length-class *L* and region *r* during time-step *t* of year *y*, $F^{s}_{\tau,r,y,t,L}$ is the fishing mortality associated with the discarded catch of animals (including high-grading under quota) of type τ in length-class *L* and region *r* during time-step *t* of year *y*, and $M_{\tau,y,t}$ is the instantaneous rate of natural mortality on animals of type τ during time-step *t* of year *y*.

Catches and fishing mortality

The landed catch (in weight) from region *r* during time-step *t* of year *y*, $\hat{C}_{r,t,y}$, (Eq 5.5.7).

$$\hat{C}_{r,y,t} = \sum_s \sum_L W_L^s \tilde{N}_{r,y,t,L}^s \left\{ \frac{\Lambda_{r,y,t,L}^s F_{1,r,y,t,L}^s}{Z_{1,r,y,t,L}^s}(1-e^{-Z_{1,r,y,t,L}^s}) + \frac{(1-\Lambda_{r,y,t,L}^s) F_{2,r,y,t,L}^s}{Z_{2,r,y,t,L}^s}(1-e^{-Z_{2,r,y,t,L}^s}) \right\} \quad \text{Eq 5.5.7}$$

where W_L^s is the weight of an animal of sex *s* in length-class *L*.

The discarded catch (in weight) from region *r* during time-step *t* of year *y*, $\hat{D}_{r,t,y}$, (Eq 5.5.8).

$$\hat{D}_{r,y,t} = \sum_s \sum_L W_L^s \tilde{N}_{r,y,t,L}^s \left\{ \frac{\Lambda_{r,y,t,L}^s D_{1,r,y,t,L}^s}{Z_{1,r,y,t,L}^s}(1-e^{-Z_{1,r,y,t,L}^s}) + \frac{(1-\Lambda_{r,y,t,L}^s) D_{2,r,y,t,L}^s}{Z_{2,r,y,t,L}^s}(1-e^{-Z_{2,r,y,tL}^s}) \right\} \quad \text{Eq 5.5.8}$$

The fishing mortality, up to 2009, by type and landed / discarded is given by equation (Eq 5.5.9).

$$F_{r,y,t,L}^{\tau,s} = V_{r,y,t,L}^{\tau,s}\, q_{r,t}\, q_{r,y,t}^W\, q_L^A\, \theta_{r,y,t}^\tau\, E_{r,y,t}\, \eta_{y,L}\, q^\tau \quad \text{Eq 5.5.9}$$

$$D_{r,y,t,L}^{\tau,s} = \delta(1-V_{r,y,t,L}^{\tau,s})\, q_{r,t}\, q_{r,y,t}^W\, q_L^A\, \theta_{r,y,t}^\tau E_{r,y,t}\, \eta_{y,L}\, q^\tau + \varpi\, \delta(V_{r,y,t,L}^{\tau,s})\, q_{r,t}\, q_{r,y,t}^W\, q_L^A\, \theta_{r,y,t}^\tau E_{r,y,t}\, \eta_{y,L}\, q^\tau$$

where $V_{r,y,t,L}^{\tau,s}$ is the availability of animals of type τ, sex *s* and length-class *L* for capture during time-step *t* of year *y*, q_L^A is the length-specific selectivity for animals in length-class *L* (Eq 5.5.10).

$$q_L^A = 1.151 - 0.0072 l_L \quad \text{Eq 5.5.10}$$

$q_{r,t}$ is the catchability coefficient in region *r* during time-step *t*,

q^τ is the catchability coefficient multiplier for "whites" (assumed to be the same for all regions and time-steps) where $q^{\tau=1}$ is estimated and $q^{\tau=2} = 1$

$\theta_{r,y,t}^\tau$ is the relative efficiency for fishing for animals of type τ in region *r* during time-step *t* of year *y*,

$q_{r,y,t}^W$ is the impact of temperature on the catchability of "reds" in region *r* during time-step *t* of year *y* (Eq 5.5.11).

$$q_{r,y,t}^w = 1 + \gamma_1 T_{r,y,t}^2 + \gamma_2 T_{r,y,t} + \gamma_3 \quad \text{Eq 5.5.11}$$

$T_{r,y,t}$ is the temperature in region *r* during time-step *t* of year *y*, $\gamma_1, \gamma_2, \gamma_3$ are the parameters of the temperature-catchability relationship,

$E_{r,y,t}$ is the nominal effort (in potlifts) in region *r* during time-step *t* of year *y*,

δ is the mortality rate for discards,

ϖ is the proportion of the catch high graded, taken as 0 up to 2009 and 0.1 after 2009,

$\eta_{y,L}$ is the selectivity of the escape gaps during year *y* on animals in length-class *L* given by in Table 5.5–4.

Table 5.5–4 Values of $\eta_{y,L}$, the selectivity of the escape gaps of width 54 mm and width 55 mm for length classes, *L*

	L	<13	13	14	15	16	17	>17
	CL (mm)	<69	69-71	71-73	73-75	75-77	77-79	>79
Gap 54 mm	y ≤ 2009	0	0.05	0.15	0.6	0.9	1	1
Gap 55 mm	y > 2009	0	0	0.05	0.5	0.7	1	1

Initial conditions

The size-structure by sex in each region at the start of the first year (1975) is calculated by projecting an arbitrary size-structure for 1965 forward using an estimated fishing mortality, F_r^I , and treating the recruitments for 1965 – 74 as estimable parameters. As the effort (pot-lifts) is known for the period 1965 to 1974, the constant fishing mortality F_r^I is tuned to the average of the fishing mortalities over time-step and year, which are calculated as the product of catchability and effort for the 10 years prior to 1975.

Outputs

The key output statistic is the egg production by region (Fig. 5.5–2). Egg production is defined as equation 5.5.12.

$$Egg_{r,y} = \sum_L N^{\text{fem}}_{r,y,t,L}\, \omega_{r,y,L} \qquad \text{Eq 5.5.12}$$

where $\omega_{r,y,L}$ is the expected number of eggs produced by a female in length-class L and region r during year y (Eq 5.5.13).

$$\omega_{r,y,L} = \left(\frac{1}{1+e^{-\ell n 19(\ell_L - L_{50,y})/(L_{95,y}-L_{50,y})}} + \frac{1}{1+e^{-\ell n 19(\ell_L - D_{50,y})/(D_{95,y}-D_{50,y})}} \right) \qquad \text{Eq 5.5.13}$$

where $L_{50,y}, L_{95,y}$ are the parameters of egg-length relationship for a single batch of eggs, and $D_{50,y}, D_{95,y}$ are the parameters of batch-length relationship for the number of batches of eggs produced in a spawning season.

A more comprehensive range of outputs including estimated catch, breeding stock and harvest rate levels by area are provided in Appendix O.

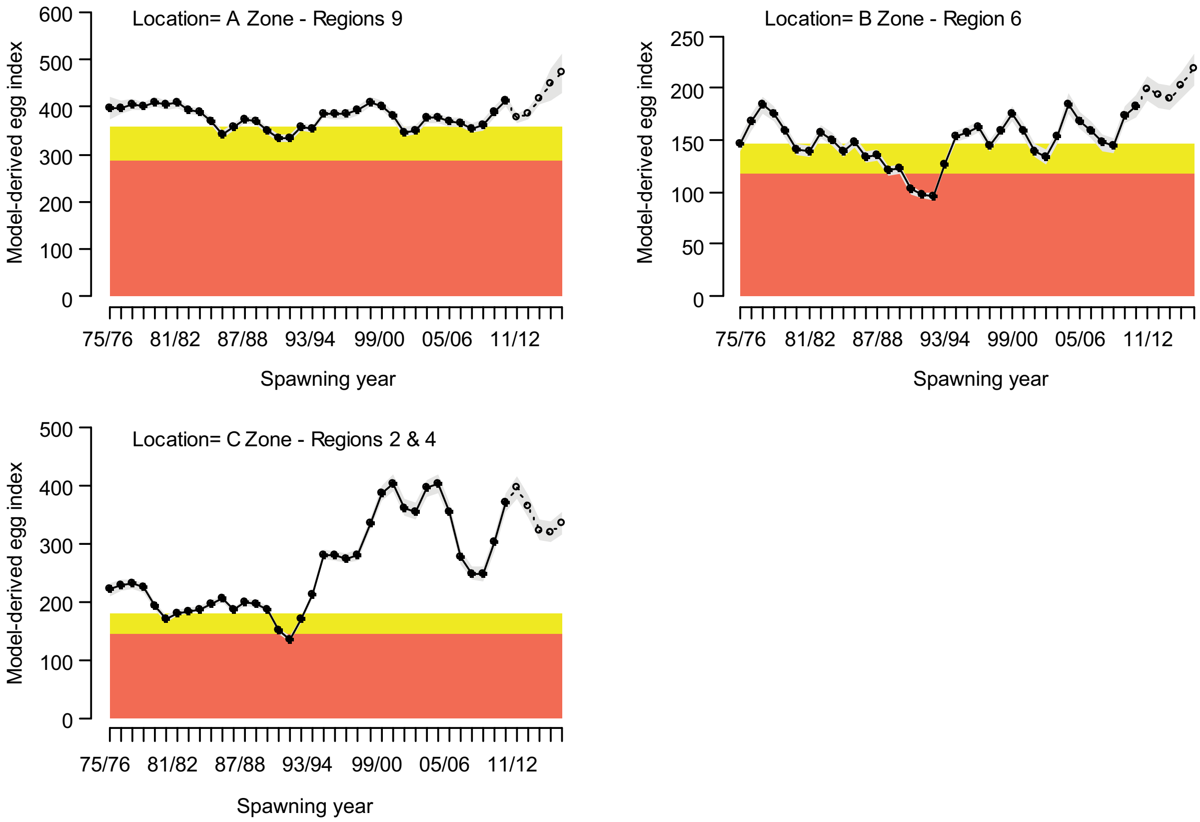


Figure 5.5–2. Modelled-derived zonal estimates of the egg production under a constant catch scenario of 5500 t (current proposed TACC levels). Mean estimates are shown in black, with projections indicated by open circles. The grey area represents the 50% confidence region, with its lower boundary the 25 percentile. The yellow and red regions represent the threshold and limit reference areas. The breeding stock in zones A and B represent the central areas of these zones that have historically been used in the decision-rule framework.

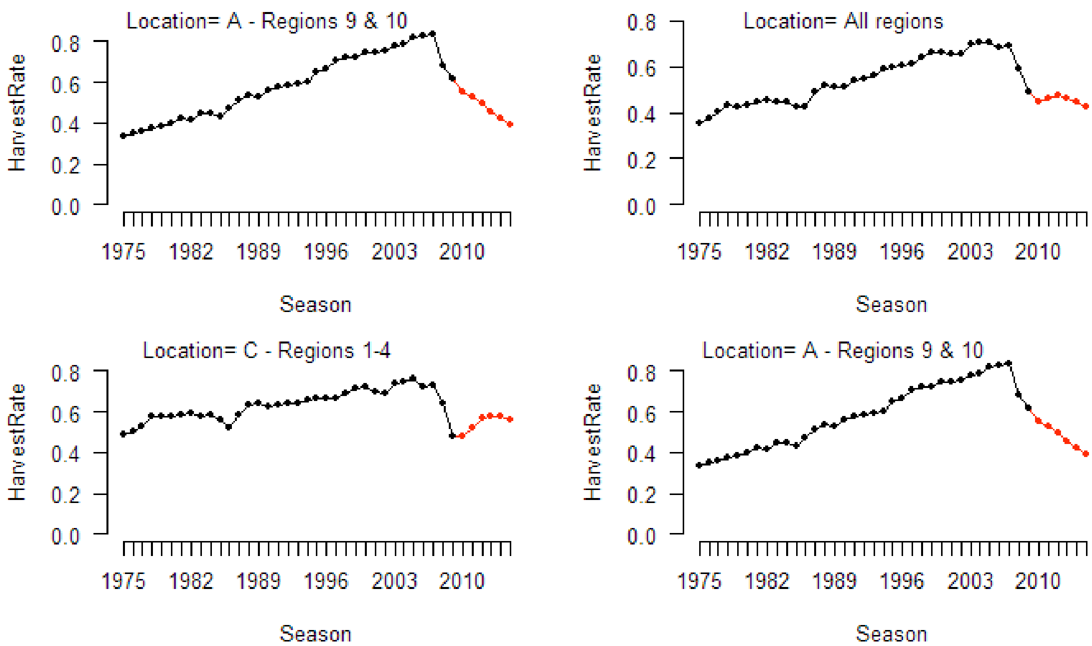


Figure 5.5–3 Modelled-derived zonal estimates of the harvest rate (commercial catch/(commercial catch + legal biomass in July) under a constant catch scenario of 5500 t (current proposed TACC levels). Mean estimates are shown in black, with projections indicated by red.

Parameterization and objective function

Most of the parameters of the population dynamics model are estimated by fitting the model to the available data although many are pre-specified (Table 5.5–5). Table 5.5–6 lists all of the data on which parameter estimation is based.

The model considers 45 length-classes of width 2 mm from 45 mm to 133 mm and 135+ mm. Recruitment occurs during time-step 1, growth occurs during time-steps 3 and 6 and movement occurs during time-step 3 and 4. Whites are only assumed to occur during time-steps 1 – 4.

The catchability coefficients vary by region and time-step and are parameterized as shown in equation 5.5.14.

$$q_{r,t} = q_r^R . q_t^T \qquad \text{Eq 5.5.14}$$

where q_r^R and q_t^T are regional and time-step estimated parameters, respectively. There are nine distinct values of q_r^R estimated since $q_{r=10,11}^R = q_6^R$. There are five distinct values of q_t^T estimated since $q_{t=1,9,10,11}^T = 1$ and $q_2^T = q_3^T$ and $q_7^T = q_5^T$.

Natural mortality is assumed to be time-invariant over the period of the historical assessment and equal to M^τ for "whites" ($\tau = 1$) and "reds" ($\tau = 2$).

The vulnerability to capture has two components, the pot selectivity related to the escape gaps which may be 54 mm and 55 mm and also to the management arrangements (minimum size, maximum size, ovigerous, and setose rules). Thus the vulnerability changes over time to reflect changes in management rules. As length bins are width 2 mm with bin boundaries being odd numbers, the vulnerability when the minimum size is at the mid point of the interval, the vulnerability is halved (Eq. 5.5.15a, b).

$$\underset{y<1993}{V_{r,y,t,L}^s} = \begin{cases} 1 & \text{if } s = \text{male; } L_\ell \ge L_\tau^{\min} \text{ and } L_u \le L_{r,\tau}^{\max} \\ 0.5 & \text{if } s = \text{male; } L_m = L_\tau^{\min} \\ 1 - O_{r,y,t,L} & \text{if } s = \text{female; } L_m \ge L_\tau^{\min} \text{ and } L_u \le L_{r,\tau}^{\max} \\ 1 - 0.5 \cdot O_{r,y,t,L} & \text{if } s = \text{female; } L_m = L_\tau^{\min} \text{ and } L \le L_{r,\tau}^{\max} \\ 0 & \text{otherwise} \end{cases} \qquad \text{Eq 5.5.15a}$$

$$\underset{y\ge1993}{V_{r,y,t,L}^s} = \begin{cases} 1 & \text{if } s = \text{male; } L_\ell \ge L_\tau^{\min} \text{ and } L_u \le L_{r,\tau}^{\max} \\ 0.5 & \text{if } s = \text{male; } L_m = L_\tau^{\min} \\ 1 - S_{r,y,t,L} & \text{if } s = \text{female; } L_\ell \ge L_\tau^{\min} \text{ and } L_u \le L_{r,\tau}^{\max} \\ 1 - 0.5 \cdot S_{r,y,t,L} & \text{if } s = \text{female; } L_m = L_\tau^{\min} \\ 0 & \text{otherwise} \end{cases} \qquad \text{Eq 5.5.15b}$$

where $O_{r,t,L}$ is the proportion of ovigerous females in region *r* during time-step *t*, $S_{r,t,L}$ is the proportion of setose females in region *r* during time-step *t*, $L_\tau^{\min}$ is the minimum legal size in the season τ , $L_{r,t}^{\max}$ is the maximum legal length in region *r* and season τ , L_ℓ, L_m ,and L_u are the lower, mid-point, and upper limits of the size class *L*.

The objective function contains seven terms. Six of these relate to fitting the catch, commercial monitoring length-frequency, IBSS length-frequency, IBSS egg index data, growth data, movement data, and the seventh is a penalty on the recruitment deviations by transect.

The contribution of the catch data to the objective function is based on the assumption the square root of the observed catch is normally distributed about the model prediction (Eq 5.5.16).

$$L_1 = \kappa_1 \sum_r \sum_y \sum_t \left\{ \ell\text{n}\sigma_r^C + \tfrac{1}{2(\sigma_r^C)^2}(\sqrt{\hat{C}_{r,y,t}} - \sqrt{C_{r,y,t}^{\text{obs}}})^2 \right\} \qquad \text{Eq 5.5.16}$$

where $C_{r,y,t}^{\text{obs}}$ is the observed catch (in weight) in region *r* during time-step *t* of year *y*, σ_r^C is the (estimated) extent of measurement error for region *r*, and κ_i is the weight assigned to the i^{th} data source.

The contribution of commercial length-frequency data to the objective function is based on the assumption that the length-frequency data are a multinomial sample of the catches-by-length and is based only on length classes ≥ 77 mm (Eq 5.5.17):

$$L_2 = -\kappa_2 \sum_s \sum_r \sum_y \sum_t C_{s,r,y,t,L}^L \ell\text{n}\rho_{s,r,y,t,L}^L \qquad \text{Eq 5.5.17}$$

where $C_{s,r,y,t,L}^L$ is the observed number of animals of sex *s* in region *r* in length-class *L* caught during time-step *t* of year *y*, and $\rho_{s,r,y,t,L}^L$ is the model-estimate corresponding to $C_{s,r,y,t,L}^L$ (Eq 5.5.18):

$$\rho_{s,r,y,t,L}^L = \frac{\eta_{y,L} q_L^A N_{r,y,t,L}^s}{\sum_{L'} \eta_{y,L'} q_{L'}^A N_{r,y,t,L'}^s} \qquad \text{Eq 5.5.18}$$

The contribution of the fishery-independent survey length-frequency data (from IBSS) to the objective function is based on the assumption that the length-frequency data are a multinomial sample of the survey-selected abundance and is based only on length classes ≥ 77 mm (Eq 5.5.19).

$$L_3 = -\kappa_3 \sum_s \sum_r \sum_y \sum_t C_{s,r,y,t,L}^{IBSS} \ell\text{n}\rho_{s,r,y,t,L}^{IBSS} \qquad \text{Eq 5.5.19}$$

where $C_{s,r,y,t,L}^{IBSS}$ is the observed number of animals of sex s in region r in length-class L caught during the IBSS survey in time-step t of year y, and $\rho_{s,r,y,t,L}^{IBSS}$ is the model-estimate corresponding to $C_{s,r,y,t,L}^{IBSS}$ (Eq 5.5.20).

$$\rho_{s,r,y,t,L}^{IBSS} = \frac{\tilde{S}_L q_L^A N_{r,y,t,L}^s}{\sum_{L'} \tilde{S}_{L'} q_{L'}^A N_{r,y,t,L'}^s} \qquad \text{Eq 5.5.20}$$

where $\tilde{S}_L$ restricts the comparison to lobsters of legal size as the selectivity of pots used during the IBSS for smaller individuals is unknown (Eq 5.5.21).

$$\tilde{S}_L = \begin{cases} 0 & \ell_L < 77mm \\ 1 & \ell_L \geq 77mm \end{cases}$$ Eq 5.5.21

The contribution of the IBSS catch rates to the objective function is based on the assumption that survey catch-rates in numbers are log-normally distributed about the model prediction (Eq 5.5.22).

$$L_4 = \kappa_4 \sum_r \sum_t \sum_y \left\{ \ell n \sigma^{IBSS}_{r,t} + \tfrac{1}{2(\sigma^{IBSS}_{r,t})^2} (\ell n IBSS_{r,y,t} - \ell n(q^{IBSS}_{r,t} \tilde{N}^{IBSS}_{r,y,t}))^2 \right\}$$ Eq 5.5.22

where $IBSS_{r,y,t}$ is the catch-rate index from the IBSS survey for region *r* during time-step *t* of year *y*, $\tilde{N}^{IBSS}_{r,y,t}$ is the model-estimate of the IBSS survey index (Eq 5.5.23).:

$$\tilde{N}^{IBSS}_{r,y,t} = \sum_s \sum_L \tilde{S}_L \, q^A_L \, N^s_{r,y,t,L}$$ Eq 5.5.23

$q^{IBSS}_{r,t}$ is the catchability coefficient for the IBSS survey, and $\sigma^{IBSS}_{r,t}$ is the extent of sampling error for the IBSS survey.

The contribution of the movement data to the objective function is based on the assumption that the movement data are a multinomial sample of the probability of being in a region after a certain time at liberty and taking fishing and natural mortality into account (Eq 5.5.24).

$$L_6 = -\kappa_6 \sum_s \sum_r \sum_t N^M_{s,r,t} \ell \text{n} \rho^M_{s,r,t}$$ Eq 5.5.24

where $N^M_{s,r,t}$ is the number tagged and $\rho^M_{s,r,t}$ is the proportion expected to arrive in area *r* after movement in time-step 3 and 4 according to the dynamics of the model.

The penalty imposed on the recruitment deviations is based on the assumption that the puerulus counts provide indices of recruitment after log-transformation (Eq 5.5.25).

$$L_5 = \kappa_5 \sum_r \sum_y \left\{ \ell \text{n} \sigma_{r,y} + \tfrac{1}{2(\sigma_{r,y})^2} \left(\ln(P_{r,y}) - \frac{\alpha_r + \bar{R}_r + \varepsilon_{r,y}}{\beta_r} \right)^2 \right\}$$ Eq 5.5.25

where $P_{r,y}$ is the puerulus count for area r during year y, R_r is the mean recruitment, $\varepsilon_{r,y}$ are the recruitment deviations, α_r and β_r are the constant and power for the relationship between puerulus counts and recruitment, $\sigma_{r,y}$ is the error between the puerulus counts and the recruitment given by equation 5.5.26.

$$\sigma_{r,y} = \sqrt{(CV^P_{r,y})^2 + \varphi^2}$$ Eq 5.5.26

where $CV^P_{r,y}$ is the sampling coefficient of variation for the puerulus count for area r and year y, φ is the uncertainty of the relationship between puerulus counts and recruitment.

Penalties

A prior is imposed on the estimated values of the initial fishing mortality F_r^I given by equation 5.5.27.

$$P_1 = \left(F_r^I - \frac{\sum_{y=1965}^{1974} \sum_{1}^{11} E_{r,y,t} q_{r,y,t}}{(1974-1965+1) g 11} \right)^2$$

Eq 5.5.27

A prior was imposed on the values of the logistic function for determining growth increments given by equation 5.5.28

$$P_2 = \frac{(M_{s,r}^I - M_{s,r}^I)^2}{2\sigma_{M^I}^2}, \quad P_3 = \frac{(\hat{I}_{s,r}^{50} - I_{s,r}^{50})^2}{2\sigma_{M^I}^2}, \quad P_4 = \frac{(\hat{S}_{s,r} - S_{s,r})^2}{2\sigma_s^2}$$

Eq 5.5.28

where the values of the priors $M_{s,r}^I$, $I_{s,r}^{50}$ and $S_{s,r}^I$ are shown in Table 5.5–2.

A prior was imposed on the values of the parameters for proportion moving (Eq 5.5.29)

$$P_3 = 300(\lambda_3 - 0.3)^2 + 140(\lambda_5 - 0.5)^2 + 140(\lambda_{10} - 0.5)^2 + 300(\lambda_{11} - 0.7)^2$$

Eq 5.5.29

Priors were imposed on the recruitment deviation terms (Eq 5.5.30)

$$P_4 = 0.5\left(\frac{\varepsilon_{r,y}}{\sigma^R}\right)^2$$

Eq 5.5.30

Priors were imposed on the logarithm of the mean recruitment (Eq 5.5.31)

$$P_5 = 50.0\left(\ln(R_{10}) - \ln(R_9) + \ln(0.05)\right)^2 + 50.0\left(\ln(R_{11}) - \ln(R_9) + \ln(0.05)\right)^2$$

Eq 5.5.31

Priors were imposed on the efficiency parameters (Eq 5.5.32)

$$P_6 = \begin{cases} 100\left(\theta_{r,y,t}^{\tau} - 0.5\right)^2 & \text{if} \quad \theta_{r,y,t}^{\tau} < 0.5 \\ 100\left(\theta_{r,y,t}^{\tau} - 3.0\right)^2 & \text{if} \quad \theta_{r,y,t}^{\tau} > 3.0 \\ 50\left(\theta_{r,1990,t}^{\tau} - 1.0\right)^2 & \text{if} \quad \theta_{r,1990,t}^{\tau} < 1.0 \end{cases}$$

Eq 5.5.32

Priors imposed on these error terms were (Eq 5.5.33)

$$P_7 = 0.5\left(\frac{\zeta_y^1}{\sigma^M}\right)^2 + 0.5\left(\frac{\zeta_y^6}{\sigma^R}\right)^2$$

Eq 5.5.33

Projections

The aim of the projections is to calculate egg production and harvest rates in future years under specified levels of effort (and hence catch) as well as the expected values for natural mortality, and egg production as a function of length. The projections allow for uncertainty in natural mortality, egg production as a function of length, and recruitment. This is achieved by parameterizing these three quantities for year y > 2009 (Eq 5.5.34).

$$
\begin{aligned}
&M_{\tau,y,t} = M_{\tau} e^{\zeta_y^1 - (\sigma^M)/2} && \zeta_y^1 \sim N(0;(\sigma^M)^2)\\
&L_{50,y} = L_{50,y} + \zeta_y^2 && \zeta_y^2 \sim N(0;(\sigma_{L_{50,y}})^2)\\
&L_{95,y} = L_{95,y} + \zeta_y^3 && \zeta_y^3 \sim N(0;(\sigma_{D_{95,y}})^2)\\
&D_{50,y} = D_{50,y} + \zeta_y^4 && \zeta_y^4 \sim N(0;(\sigma_{D_{50,y}})^2)\\
&D_{95,y} = D_{95,y} + \zeta_y^5 && \zeta_y^5 \sim N(0;(\sigma_{D_{95,y}})^2)\\
&\varepsilon_{\tilde{r},y} = \alpha_{\tilde{r}} \varepsilon_{\tilde{r},t}^P + \zeta_y^6 && \zeta_y^6 \sim N(0;(\sigma^R)^2)
\end{aligned}
$$

Eq 5.5.34

where σ^M is the extent of uncertainty in natural mortality, $\sigma_{L_{50}}, \sigma_{L_{95}}$, $\sigma_{D_{50}}$ and $\sigma_{D_{95}}$ reflect the uncertainty in the projected egg production-length relationship, and σ^R is the extent of variation in recruitment (about the assumed puerulus count for each future year y). Terms are added the objective function to implement the random components of Equation 5.5.25.

Diagnostics

A range of diagnostic plots are produced to aid in the evaluation of the models fit to the various data sets used in the objective function (Appendix O). This includes the estimation of catches, size compositions, recruitment level and movement patterns for the various areas, sexes and time-steps.

Table 5.5–5 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, $K_{r,y,L}$, $P_{r,y}^{\wedge}$, $\sigma_{r,y}^{\wedge}$	Pre-specified	Appendix J
Egg production – length parameters, $L_{50,y}, L_{95,y}$, $D_{50,y}, D_{95,y}$,	Pre-specified	Appendix K
Annual natural mortality, M^{τ}	Pre-specified	0.30 0.22
Proportion of ovigerous females, $O_{r,t}$	Pre-specified	Appendix L
Average recruitment, R_r	Estimated (one per region)	
Proportion of setose females, $S_{r,t}$	Pre-specified	Appendix M
Availability to capture, $V_{r,y,t,L}^{\tau,s}$	Pre-specified	Appendix N
Weight-at-length $W_L^s = a_s L^{b_s}$	Pre-specified	af=1.6086E-06 am=2.5053E-06 bf=2.8682 bm=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
Proportion recruiting by length, ϕ_L	Pre-specified	CV=0.05
Efficiency increase, $\theta^{\tau}_{r,y,t}$	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, $q^{IBSS}_{r,t}$	Estimated	
Puerulus count uncertainty, φ	Pre-specified	0.2
Catch measurement variation, σ^{C}_{r}	Estimated	
Extent of sampling error for the IBSS survey, $\sigma^{IBSS}_{r,t}$	Estimated	

Table 5.5–6 The data used when projecting the population dynamics model.

Data type
Fishing effort, $E_{r,y,t}$
Temperature, $T_{r,y,t}$
Catch-in-weight, $C^{\text{obs}}_{r,y,t}$
Commercial length-frequency data, $C^{L}_{s,r,y,t,L}$
IBSS length-frequency data, $C^{IBSS}_{s,r,y,t,L}$
IBSS catch-rare, $IBSS_{r,y,t}$
Normalized puerulus count, $e^{P}_{\tilde{r},y}$
CV of the puerulus count, $CV^{P}_{\tilde{r},y}$

5.6 Economic Model

The first economic modelling was instigated by effective effort reductions (effort equivalent to pot numbers) of 15 and 5% recommended for Zones B and C, respectively, for the 2005/06 season to ensure breeding-stock levels (Figures 4.2–2 and 4.3–2) remained above their biological reference points (Section 2.0). To achieve these reductions, management proposed a number of temporal closures, legal-size changes and pot reductions, a combination of which were considered by industry (Box 2.2–1 2005/06). To assist with the decisions, an economic model was developed by the Department of Fisheries (Thomson & Caputi 2006) to assess the short-term (1 – 2 years) economic impacts of various effort-reducing measures on the expected gross margin of fishers in each zone.

Subsequently, a preliminary model has been developed to examine the issue of maximum economic yield (MEY) through input controls in the western rock lobster fishery (Reid 2009). This deals with fishery-wide MEY, which it concluded, was at effort levels significantly lower than the 2007/08 effort levels. Resultant additional profits in the fishery from 2008/09 – 2013/14 were in the order of $40 – 45million in Zone A, $70-80 million in Zone B and $135 – 145 million in Zone C based on a series of assumptions (for details see Reid 2009).

5.6.1 Future Direction

With the significant changes in the management regime in 2008/09 and 2009/10 a more thorough assessment of economic performance of the fishery is being planned over the next three years (see Section 8.1.1), which will also influence the harvest rate target in the decision-rule framework.

6.0 Biological Reference Points and Stock Status

6.1 Management Decision Framework

The management decision rule framework presented in this document reflects the framework at the time of the assessment in mid 2011. A discussion paper on proposed changes to the decision rule framework will be circulated in early 2012 to reflect the new framework under the individual catch quota system. This new framework will include a range of new proposals aimed at ensuring both the sustainability and economic efficiency of the fishery are optimised under the catch quota system. More specifically, the new proposals include the spatial expansion of breeding stock grounds used to determine breeding stock levels and the introduction of target exploitation measures to aid in maintaining economic efficiency.

The decision rules framework used for all 2011 assessments was expanded in 2009 to include modelled-derived breeding stock estimates and uncertainty into the decision-making framework, as recommended by the workshop and the Marine Stewardship Council's stock assessment reviewers (see 2006 reassessment and the 2007, 2008 and 2009 annual surveillance reports at http://www.msc.org/track-a-fishery/certified/south-atlantic-indian-ocean/western-australia-rock-lobster/reassessment-downloads-1) and was supported by the Department of Fisheries.

Under the Department of Fisheries' Integrated Fisheries Management (IFM) policy, the decision rules framework and the stock assessment model will be updated to include the catch share of the fishery's other stakeholders (e.g. recreational and indigenous sectors), as well as the commercial sector. Under IFM the percentage of the recreational rock lobster catch could be an additional indicator, with a reference value of five per cent of the total catch.

6.1.1 Taking Account of Uncertainty

The harvest strategy and decision rules developed below incorporate uncertainty by expressing the rules in terms of the probability of the indicators (estimated egg production values) being above or below their reference values. For example, if the estimated egg production were equal to its threshold value this would be equivalent to stating that there is only a 50% probability that the actual egg production is above the threshold value.

Stock assessment reviewers have recommended that the decision rules associated with sustainability should be more precautionary by accounting for uncertainty and that there should be a greater than 50% probability that the indicator value is above the egg production threshold value. This has been incorporated into the framework by providing the 75% probability level associated with the egg production indicator values over time (Figure 5.5–2).

6.1.2 Indicators, Reference Values and Performance

Accepted fisheries management practice is to describe harvest strategies in terms of "indicators", "reference values" and "performance" (Anon 2007). The types of indictors and reference points used reflect the level of knowledge of the species, the fishery and the sophistication of the assessment tools being used (empirical data, models, etc). An explanation of each of these terms and their application to the fishery is provided below.

Indicators

Indicators measure some aspect of the status of the fished stock such as level of breeding stock or biomass (weight of animals), etc. An indicator may be a direct observation (such as catch per unit effort or catch rate of breeding lobsters) or it may be estimated using a stock assessment model. The value of an indicator may be either an absolute measure, e.g. 10,000 tonnes of catch, or a relative measure such as an index, e.g. an egg production index, which is based on catch rates of breeding lobsters per pot lift.

In Figure 6.1–1 the hypothetical target, threshold and limit for a single sustainability indicator – egg production – are illustrated. The solid black line represents the historic egg production values, the horizontal lines the threshold and limit reference values, and the green the target or 'healthy' region and the red the 'high risk' unsustainable region.

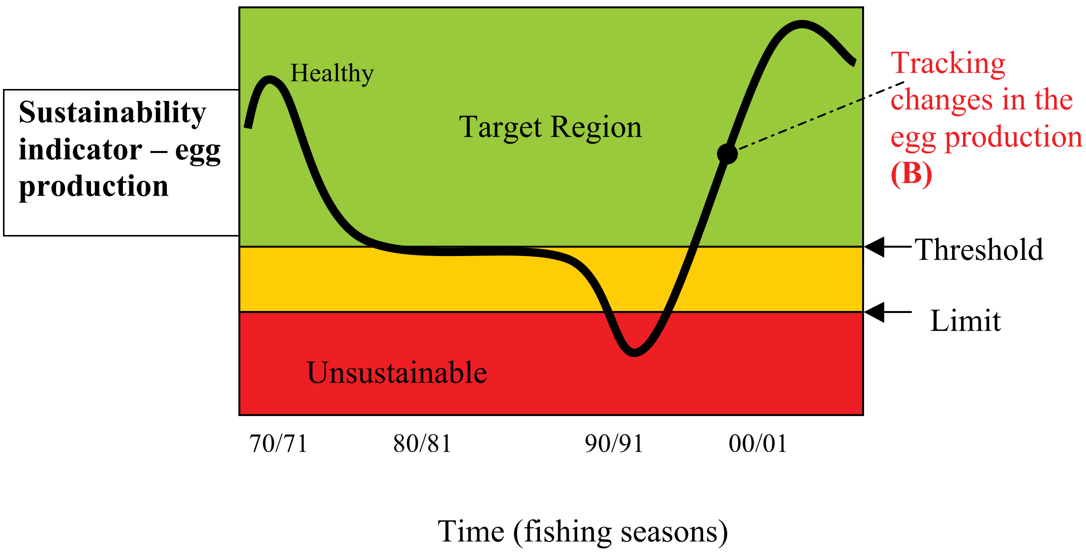


Figure 6.1–1 A hypothetical example of variation in rock lobster egg production over time with reference to biological sustainability reference regions (adapted from Bray 2004).

Reference Values

For harvest strategies to be effective, indicators need to be expressed in terms of quantifiable reference values that are related to the management objectives. These reference values can be a target (where you want to be), threshold (where you review your position), or limit (where you don't want to be). Reference values for indicators are used to determine the performance of the fishery against its objectives, thereby triggering and guiding management action.

In some circumstances if a reference value is breached (e.g. the egg production falls below a safe level, i.e. below its threshold or limit) the actual management response required will be prescribed in general terms by a decision rule. For example, it could be specified that if the egg production falls below the 1980s level, the management response, which could involve an effort reduction (e.g. a reduction in days fished, or pot numbers, etc), closure of an area, a limit on catch, change in minimum and maximum size, or a combination of them, would be required to bring it back to a safe level (in this example the 1980s level) within three years.

So long as the egg production was brought back to a safe level within this period, it is left to managers and stakeholders to work out the details. In other circumstances the management action may be to conduct a review to assess the cause and then determine an appropriate management response.

Reference values for indicators are defined as:

Target The optimum value (range of values) for the fishery from a sustainability/biological and/or economic/social perspective.

Threshold An upper or lower boundary outside of which a management response may be required to avoid hitting the limit value.

Limit An upper or lower boundary outside of which immediate, significant and more prescribed management action is required, i.e. management options become narrower and their implementation is much more urgent if the limit value is reached.

Performance

Performance is evaluated in terms of where an indicator value (e.g. level of egg production or harvest rate) is in relation to a reference value, such as a target. For example, if the egg production was within the target range, the fishery would be considered 'healthy' and achieving its sustainability objective (Figure 6.1–1).

6.1.3 Management Objectives

An essential component of the framework is the specification of the management objectives for the fishery, as this enables the selection of the appropriate indicators, performance limits and targets.

Section 3(1) of the *Fish Resources Management Act 1994* (FRMA) specifies the objects of the FRMA which are:

to conserve, develop and share the fish resources of the State for the benefit of present and future generations.

Section 3(2) of the FRMA also has a number of specific objects; of particular relevance are objects (b) and (e) which state:

(b) to ensure that the exploitation of fish resources is carried out in a sustainable manner; and

(e) to achieve the optimum economic, social and other benefits from the use of fish resources.

In line with the objects of the FRMA above, the Department of Fisheries proposes two key objectives for use in developing advice on future management arrangements.

Sustainability Objective

The purpose of this sustainability objective is to ensure that the egg production (breeding stock) is at a safe level, i.e. above its threshold value, and is likely to remain above this level in the short to medium term with a reasonable level of certainty. This has been expressed more specifically as:

Ensure that the egg production in each Zone of the fishery remains above its threshold level *(currently the mid 1980s level for the coastal zones)*, and the probability of still being above this level in five years time is at least 75 per cent.

The use of the 75% probability at the five-year timescale to determine acceptable performance is consistent with the outcomes of the Western Rock Lobster Stock Assessment and Harvest Strategy Workshop (Department of Fisheries 2008).

It should be noted however, that the predictions of egg production (breeding stock) in the fifth year are not based on actual puerulus settlement figures; therefore there is a higher level of uncertainty associated with them. Consequently, in the current assessment a precautionary approach was taken by assuming the puerulus settlement in 2011/12 was similar to the puerulus settlement in 2010/11.

6.1.4 Indicators

Egg Production Measures

This section discusses the strengths and weaknesses of three ways of measuring the breeding stock and hence calculating egg production. It is important to choose the most accurate and robust measure, as it will be used as the basis for deriving the egg production index, which has been chosen as the sustainability indicator representing the breeding capacity of the rock lobster stocks.

Fishery-Dependent Breeding Stock Index Estimates

Historically the Fishery-Dependent Breeding Stock Index (FDBSI) (Section 4.2) has been used as the measure of the breeding stock, as it has the longest time series, dating back to the early 1970s. It is an empirical measure estimated from information obtained from an at-sea commercial catch monitoring program conducted by the Department of Fisheries, which requires research staff to go on board commercial vessels and measure a proportion (usually 100%) of the day's catch.

The commercial monitoring program currently operates from six locations (it started with four locations) for each month that the fishery is open. The breeding stock data are combined into a northern coastal index (Dongara and Jurien) and a southern coastal index (Lancelin and Fremantle). These indices are smoothed using a weighted three-year moving average to enable the underlying trends to be more clearly identified. A great strength of this index is the large number of pots (and hence number of rock lobsters) that are sampled across the entire fishery. For full details see Section 4.2.

Some of the main points regarding the use of the FDBSI as an estimate of the breeding stock abundance are:

- A FDBSI has been calculated for the northern region (Dongara/Jurien), southern region (Lancelin/Fremantle) since the early 1970s but is not available for the Abrolhos Islands.
- The FDBSI is:
  - standardised by month, depth, location, pot type, swell and moon phase;
  - adjusted for fishing efficiency increases;
  - based on deep water catch rates; and
  - assumes a standard size at maturity.

Future improvements to the calculation of the FDBSI are planned to take account of the changes in the size of sexual maturity over time (Section 3.6.1), and better estimates of increases in fishing efficiency (Section 5.1).

Fishery-Independent Breeding Stock Index Estimates

An alternative relative empirical measure for breeding stock is the Fishery-Independent Breeding Stock Index (FIBSI) (Section 4.3), so named because information is collected independently from the commercial fishery. The FIBSI is derived from an annual research survey that the Department of Fisheries has been conducting since the early 1990s. The annual index of the breeding stock and the egg production index that is derived using this method is independent of commercial fishing operations and some of the biases associated with it, such as increases in fishing efficiency.

These surveys have been undertaken annually in October/November using standardized fishing gear at specific GPS points in three to six locations between Fremantle and Kalbarri, including the Abrolhos Islands.

The FIBSIs have tended to vary more than the FDBSIs, when viewed on a year-to-year basis. This is because the samples are smaller and it is impossible to take into account all the annual environmental and catchability factors that affect the FIBSI over the period of fishing (e.g. water temperatures, swell, etc.). For full details see Section 4.3.

Model Estimates

With the recent development of a new spatial population dynamic stock assessment model (the model) (Section 5.5) for the fishery it is possible to produce a model-derived measure of breeding stock. The model uses all the available information from the fishery, including a comparison with the FDBSI and FIBSI, to estimate a measure of the breeding stock and the uncertainty associated with it. This measure of breeding stock is based on the whole fishery compared to the specific locations used in the FDBSI and FIBSI and is therefore the preferred measure. Hence the model estimate of breeding stock has been chosen to produce the egg production index for the fishery. The model also provides an improved method of estimating egg production for Zone A.

An important additional advantage of using a stock assessment model is that the impact of proposed management changes on the egg production can be evaluated and projected into the future. For full details see Section 5.5.

Egg production values used in the decision rules framework are those estimates derived from the stock assessment model.

6.1.5 Reference Values

Egg Production

Target, threshold and limit reference values for egg production have been derived from the Sustainability Objective . It is proposed that the threshold value for egg production be based on the mid 1980s level for Zones B and C, as it was considered to be a period of lower exploitation in the fishery, particularly in the deeper water breeding stock areas, that preceded the general take up of major innovations in technology, such as GPS, high definition colour echo sounders and computers.

The threshold value for Zone A has been based on the historic range of egg production as, unlike the coastal Zones (B and C), breeding in Zone A commences below legal size and hence the breeding stock may not be depleted by fishing to the same extent as in the coastal fishery.

The abundance of lobsters in Zone A does not vary to the same extent as in the coastal Zones (as shown by more stable catches), which means the abundance of the breeding stock may also be more stable. It is therefore suggested that maintaining the breeding stock within historic range (i.e. above the low levels of the mid 1980s – 1983/84 to 1986/87, Figure 5.5–2) with a high level of certainty may provide adequate protection for the egg production in Zone A. However, it should be noted that there is currently concern regarding the levels of breeding stock in the northern and southern areas of Zone A and in the Big Bank region (Brown 2009) and this is being considered in the new decision-rule framework discussion paper in early 2012.

A limit reference value of 20% below the threshold value is proposed for Zones B and C, because it is between the threshold value and lowest value recorded for them. The same limit reference value of 20% below the threshold value is also suggested for Zone A.

Egg production reference values for Zones A, B and C (coastal areas north and south of 30°S respectively, Figure 5.5–2) are:	
Target Range	Egg production above the mid 1980s level.
Threshold value	Egg production at the mid 1980s level.
Limit value	Egg production 20 per cent below the threshold level.

6.1.7 Decision Rules Framework

Management Guidelines

The management tools that can be used to achieve a desired outcome will depend on a number of factors including the management system in use (e.g. input controls, catch quota, or some other system), timeframes for implementation, compliance issues and economic, social and equity considerations, and they will be subject to consultation with stakeholders. Consequently, the precise management actions required if an indicator (i.e. egg production or harvest rate) reference value (threshold or limit) is breached are not detailed in this paper. However, some guidelines are proposed.

Proposed Guidelines for Decision Rules

Egg production

A critical element of this proposed harvest strategy is that fishery managers and stakeholders will generally be in a position to take management action prior to an indicator (egg production or harvest rate) breaching its reference value (threshold or limit). For example, if puerulus settlement and model outputs predict that the egg production is likely to breach (go below) its threshold value in four or five years time, corrective management action may commence immediately to ensure it does not.

If the egg production indicator value is currently in breach of its threshold or limit value, or will be in the short term (one or two years), it would trigger a more immediate and urgent management response to correct it than if the breach were predicted to occur in four or five years time.

Indicator Value	Management Response
Greater than 75 per cent probability that it is still greater than the threshold value in five years.	No management action is required.
Less than 75 per cent probability that it is still greater than the threshold value in five years.	Initiate a review process that will generate recommendations regarding the most effective forms of management response, to be completed within three months. Implement management measures to ensure the egg production indicator values in the fifth year are greater than the threshold value, with a 75 per cent probability. In general any stock rebuilding strategy should include the following (adapted from Department of Agriculture, Fisheries and Forestry 2007 p44): clear specifications of objectives, including targets and time frames; performance criteria to evaluate the effectiveness of the strategy against its objectives; actions required to achieve the objectives of the strategy; key threats to recovery of the stock or to the economic performance of the fishery and strategies to counter them; the estimated duration and cost of the strategy / process, including apportionment of cost across government and other stakeholders; parties affected by the implementation of the strategy; and any significant related environmental impacts (positive or negative) arising from the implementation of the strategy.

6.2 Stock Status

The status of the lobster stocks in each of the three management zones (A – C) is assessed annually based on trends exhibited by a number of empirical and model-derived indices. These include fishery-dependent (Section 4.2), fishery-independent (Section 4.3) and modelled (Section 5.5) indices of breeding stock (BSI) and model-derived indices of Harvest Rate (HR). The primary performance indicator of stock status is currently the model-derived Egg Production Index relative to its estimate during the mid 1980s fishing seasons for the north and south coastal zones (B and C zone) and the Abrolhos Islands (A zone). The use of multiple indices allows for the cross checking of general trends, with agreement increasing assessment confidence or disagreement highlighting areas that need further examination.

6.2.1 Stock Status by Zone (2010/11 fishing season)

Model analysis was last conducted in July 2011 using the updated "output" version of the model. The stock status report below is based on this model.

Current larval recruitment

*Leve*ls of recruitment in all zones have been well below average levels since 2006/07 (five consecutive seasons). Low levels in 2006/07 were likely linked to low water temperatures during early larval life. The following three low settlement years 2007/08, 2008/09 (lowest level on record) and 2009/10 do not appear solely related to cool water temperatures during early larval life. These low levels are yet to be explained. Further research is underway to examine the potential causes (Section 7.1).

The most recent completed settlement season (2010/11) has seen a marked improvement in the levels of settlement at most sites throughout the fishery, with settlement levels fitting with the historical relationship with water temperature. These levels are still below the long-term average since water temperatures in February/April 2010 were cooler than average and very few storm fronts crossed the West Australian coast during late winter/spring of 2010.

Water temperatures for February 2011 are well above average as a result of a strong Leeuwin Current associated with the La Nina conditions. The effect of these warmer conditions have historically been associated with improved settlement in the following year (2011/12) which will be monitored later, sta*rting in about August 2011.*

Recent Management Changes

The fishery has changed management systems from an input to a catch-limit controlled fishery, with a nominal Total Allowable Commercial Catch (TACC) of (5500 t) being imposed for the 2010/11 fishing season. Each fishing unit has been allocated a zone-specific portion of this TACC and input controls (e.g. pot usage and temporal closures) have remained.

Proactive management measures were introduced in 2008/09 and 2009/10 as a result of the low puerulus settlement, resulting in nominal fishing effort reductions of 44 and 72% to ensure a carryover of legal size from these reasonable catch years into the predicted low catch years to assist maintain the breeding stock above threshold levels over the coming five year period. This resulted in catches of 7600 and 5900 t in 2008/09 and 2009/10, respectively, compared to the catch predictions based on historic (2007/08) levels of fishing of 9200 and 8700 t, respectively. These large reductions in catch (up to 4400 t) resulted in significant increases in residual biomass over the last two seasons which have flowed into the available stock for the coming predicted low recruitment years commencing in 2010/11.

Breeding Stock and Harvest rate by zone

Zone A

- The model-derived harvest rate estimate has declined markedly in recent years due to management changes since 2008/09. It is predicted to remain relatively steady over the next five fishing seasons under current levels of catch (Section 5.5).
- The 2010 IBSS survey in this zone was compromised due to a GPS plotter malfunction. Attempts will be made using the 2011 survey to develop a scaling factor to adjust the 2010 catches relative to those that would have been expected if the pots had been set correctly. The previous survey indicated a high level of egg production.
- The model-derived egg production index is currently well above its historical minima. The model predicts this index will remain well above its threshold reference point with 75% certainty over the following five fishing seasons under current levels of catch (Section 5.5).

Egg production in **Zone A** (Abrolhos Islands) is above threshold and limit reference points and is predicted to remain above this level with > 75 certainty over the subsequent five fishing seasons under current levels of catch. Harvest rates have decreased in recent seasons and will continue to remain relatively low over coming years under current management arrangements.

Zone B

- The model-derived harvest rate estimate has declined markedly in recent years due to management changes. It is predicted to remain relatively steady over the next five fishing seasons under current levels of fishing effort (Section 5.5).
- The fishery-independent BSI for 2010 was amongst the highest on record (Section 4.3), and increased from the previous season's measure. The high 2010-point is not considered the result of extremely favourable environmental conditions during the survey.
- The model-derived egg production index is currently well above its historical minima. The model predicts this index will remain above its threshold reference point with 75% certainty and its limit reference point over the following five fishing seasons under current levels of catch (Section 5.5).

> Egg production in **Zone B** (Northern Coastal) is currently above threshold and limit reference points and is predicted to remain relatively steady with > 75% certainty over the following five seasons under current levels of catch. Harvest rates have decreased in recent seasons and will continue to remain low over coming years under current management arrangements.

Zone C

- The model-derived harvest rate estimate has declined markedly in recent years due to management changes. It is predicted to remain relatively steady over the next five fishing seasons under current levels of fishing effort (Section 5.5).
- The fishery-independent BSI for 2010 was the highest on record (Section 4.3), being well up from the previous (2008 and 2009) year's estimates. Unlike the 2008 estimate however, the 2010-point is not considered the result of extremely favourable environmental conditions during the survey.
- The model-derived egg production index is currently well above its historical minima. The model predicts this index will remain well above its threshold reference point with 75% certainty and its limit reference point over the following five fishing seasons under current levels of fishing effort (Section 5.5).

> Egg production in **Zone C** (Southern Coastal) is currently above threshold and limit reference points. This index is predicted with > 75 % certainty to remain relatively high over the subsequent five fishing seasons under current management. Harvest rates have decreased in recent seasons and will continue to remain low over coming years under current management.

7.0 Current Issues and Research

There are several projects that are currently at various stages of completion. They are investigating a variety of research topics relevant to the effective management of the West Coast Rock Lobster Fishery (Table 7.1). The project's objectives are outlined below. All pertinent results will be reported in future editions of this document.

Table 7.1 Details of current research projects including start and completion date, section for further information collaborators and funding sources. Collaborators in bold indicates lead agency for the project otherwise the projects are led by Department of Fisheries.

Project Title	Project Dates	Collaborators	Funding Source	Instigated By
Identifying factors affecting the low western rock lobster puerulus settlement in recent years.	Jul 2009 – Jul 2012	CSIRO	FRDC	Low Puerulus Risk Assessment Workshop (A)
Evaluating source-sink relationships of the Western Rock Lobster Fishery using oceanographic modelling.	2009 –10	CSIRO	FRDC	Low Puerulus Risk Assessment Workshop (A)
Evaluating the use of novel statistical techniques for determining harvest rates and efficiency increases in the Western Rock Lobster Fishery.	Jul 2010 – Dec 201l	Prof Norm Hall A Prof Stewart Frusher Prof John Hoenig	FRDC	Low Puerulus Risk Assessment Workshop (A)
Evaluation of population genetic structure in the western rock lobster	Jul 2009 – Jul 2011	UWA	FRDC	Low Puerulus Risk Assessment Workshop (A)
Assessing possible environmental causes behind the reduced colonization of puerulus collectors by a wide suite of species.	Dec 2008 – Apr 2010	UWA	FRDC	Low Puerulus Risk Assessment Workshop (A)
Biological Oceanography of the Western Rock Lobster	2010 – 12	**University of WA** Murdoch University CSIRO University of Auckland	FRDC	Low Puerulus Risk Assessment Workshop (A)
Management implications of climate change effect on fisheries in Western Australia. WRL will be one of the main focuses.(B)	2011 – 2014	CSIRO WAMSI	FRDC	DoF, CSIRO WAMSI. Flow on from Low puerulus workshop (A)

(A) For details of Low Puerulus Risk Assessment Workshop see; Brown (2009).

(B) This project is part of the National Climate Change Adaptation Plan: Marine Biodiversity and Resources, details of which can be found at: http://www.frdc.com.au/Default.aspx?PageID=2476227&A=SearchResult&SearchID=1194242&ObjectID=2476227&ObjectType=1

7.1 Identifying factors affecting low puerulus settlement in recent years

7.1.1 Background

Research projects have explored aspects of the rock lobster stock and recruitment relationship and the influences of environmental conditions. The results of the projects, amongst other things, will enable a review of the appropriateness of the 1980 level of egg production (breeding stock) as the threshold value for the coastal Zones (B and C) of the fishery and the historic level of catch that is currently used as the egg production (breeding stock) threshold value for Zone A.

The projects also provided information on the importance of particular breeding stock areas (e.g. Big Bank, northern and southern Zone A, deep water off Dongara), which could lead to specific breeding stock areas being given greater protection.

7.1.2 Project Objectives and Preliminary Findings

Identifying factors affecting the low western rock lobster puerulus settlement in recent years. (FRDC 2009/018)

Objectives

1. To use a larval advection model and the rock lobster population dynamics model to assess the effect of the spatial distribution of the breeding stock on the puerulus settlement.
2. To assess environmental factors (water temperature, current, wind, productivity, eddies) and breeding stock affecting puerulus settlement.
3. To examine climate change trends of key environmental parameters and their effect on the western rock lobster fishery.
4. Provide industry (WRLC) and Fisheries managers with an evaluation of relative impact of breeding stock and environmental effects on the puerulus settlement and its implications for management in the protection of the breeding stock.

Preliminary findings:

ENSO events, which are associated with weak Leeuwin Currents and cooler water temperatures during the larval phase, have long been known to be associated with low puerulus settlement. Similarly, weak westerly winds (associated with fewer storms and lower rainfall) in late winter/spring have also been known to be associated with lower puerulus settlement (Section 5.3).

The environmental conditions in the first year of low settlement (2006/07) had very cold water in February – April 2006 and hence a low settlement was expected. In 2008, for the first time, an above-average water temperature was associated with a very low settlement indicating that other factors are involved (Figure 4.1–5).

It is now clear that the Indian Ocean Dipole (IOD) also appears to have a significant influence on levels of puerulus settlement, with a positive index being related to poor settlement levels. The effect of the IOD appears to be associated with the strength of the westerly winds in winter/spring near the period that settlement is occurring.

The Indian Ocean Dipole remained positive for three consecutive years from 2006 – 2008, the first time three consecutive years have been recorded. Moreover, 2008 was the first time in 30 years that a positive IOD has occurred at the same time as a *La Niña* event.

Settlement remained relatively low in 2009/10 despite the IOD moving back to a neutral position in 2009 indicating again that other factors are involved.

Westerly wind patterns during the current settlement season (2010/11) have again been extremely unusual, with the westerly component being far weaker than average. The second lowest winter/spring rainfall in 2010 on record reflects this with the 2006 having the lowest rainfall on record.

Evaluating source-sink relationships of the Western Rock Lobster Fishery using oceanographic modeling. (FRDC 2008/087)

Objectives

1. To determine the relative contribution of larval production from different areas to the abundance and spatial distribution of puerulus settlement over 15 years using a larval advection model.
2. Provide industry (WRLC) and Fisheries managers with an evaluation of source-sink relationships and its implications for management in the protection of the breeding stock

Preliminary findings:

Eggs released towards the very northern part of the fishery (e.g. Northern Abrolhos Islands & Big Bank) appear to have a much higher chance, on average, of successfully recruiting as juveniles (Caputi et al. 2010, Feng et al. 2011). Possible annual variability in the relative success among regions will be examined in next phase of this project in 2010–2012.

Settlement success may also be greater for eggs released from deeper water areas (80–100 m) closer to the edge of the continental shelf.

The effect of temperature on the growth and survival of larvae was identified as an important component affecting settlement success. Higher success was associated with early larval release (November – December) compared with late releases (February) and the proportion of early release larvae was affected by the water temperature in May – October prior to spawning which includes the period when females are moulting back to setose and begin mating. When water temperatures are very cool (as occurred in May – June 2007) there is less early larval release. This could have affected the 2007/08 spawning period and in turn contributed to the low settlement in 2008/09.

This indicates that environmental conditions up to six months prior to actual spawning also need to be examined in addition to those present during the larval phase.

Overall, these preliminary results suggest that whilst the breeding stock in all regions needs to be maintained, the stock in the northern areas (despite being a relatively small percentage of the total), including the deep-water Big Bank stocks, may be particularly important. The relative importance of these northern stocks could be even more important during periods of unfavourable environmental conditions for the larval phase.

Evaluating the use of novel statistical techniques for determining harvest rates and efficiency increases in the Western Rock Lobster Fishery. (FRDC 2009/019)

Objectives

1. Assess current data sources and their potential for use in estimating harvest rates and efficiency increases in the western rock lobster fishery.

2. Evaluate whether additional sources of information are needed to produce more robust estimates of harvest rate and efficiency increase.
3. Assess whether the estimates of harvest rate and fishing efficiency are reliable and could be used to assist in the management of the western rock lobster fishery.
4. Provide industry (WRLC) and fisheries managers with an evaluation of change-in-ratio and index removal techniques for determining harvest rates and efficiency creep.

Evaluation of population genetic structure in the western rock lobster (FRDC 2009/020)

Objectives

1. Develop additional new microsatellite markers for western rock lobster.
2. Test whether the adult population of western rock lobster is genetically homogeneous throughout its range.
3. Test whether the spatial genetic structure in the next generation of recruits (pueruli) matches the spatial genetic structure found in adults. (If so, this suggests spatial structure is due to limited dispersal or local adaptation).
4. Estimate effective population size of the western rock lobster and test for severe bottlenecks in population size.

Assessing possible environmental causes behind the reduced colonization of puerulus collectors by a wide suite of species. (FRDC 2008/085)

Objectives

1. Begin monitoring the community composition of marine flora and fauna along the Western Australian coastline during this current poor settlement period.
2. Develop standard methodology for monitoring the spatial and temporal variability in the settlement of marine flora and fauna.
3. Determine what environmental parameters may be linked to the majority of variation in the floral and faunal communities colonizing puerulus collectors, focusing on those relating to puerulus settlement.
4. Identify indicator marine flora and fauna species for monitoring the influences of environmental change on Western Australian marine environment.
5. Detect any known or potential introduced marine pests within the Western Australian environment.

Biological Oceanography of the Western Rock Lobster

The Australian Marine National Facility RV Southern Surveyor was used in July 2010 to examine phyllosoma larval density at four locations from Shark Bay to Rottenest and the food web that supports phyllosoma growth at sea. The project was led by UWA in collaboration with other research groups including the Department of Fisheries. The data is still being analysed but they did find good quantities of lobster larvae associated with the eddy structures from the Leeuwin Current. A second cruise was undertaken September 2011 for some of these transects.

7.1.3 Finding from additional projects

Patterns of 'white' lobsters migrations:

Reductions in the migration of 'white' lobsters north into Big Bank over a number of years, due to strong meridinal currents, high fishing pressure on the 'whites' and low puerulus settlement, is consistent with the lack of small lobsters and a relatively low catch rate of larger lobsters observed in Big Bank during a recent lobster survey (November 2009).

Fishing in the Big Bank area increased substantially during the 1990s. The recent catch trends indicate that the relative abundance in this region has declined to a far greater extent than has occurred at other locations throughout the fishery, probably as a result of this extended period of lower migration. While egg production has not historically been directly monitored in this area, these levels are likely to be reflected by the drops in catch rates.

Breeding Stock

The overall level of egg production for the 2009/10 spawning season was considerably higher than during the previous two seasons. Especially in Zone B the levels were at record highs and in Zone C it was close to the highest.

Separate estimates for the northern and southern parts of Zone B will be generated using the new model. Separate estimates of breeding stock in deepwater (80 – 100 m) compared to shallower depths (40 – 80 m) are also being examined. These may show different patterns.

The next breeding stock survey, including Big Bank and extending into deep water areas, is planned for October-November 2011.

7.1.4 Conclusions

Based on the information outlined above, the most likely scenario to explain the recent poor levels of puerulus settlement still involves a combination of events.

The long standing levels of fishing when combined with a run of environmental conditions unfavourable for the northwards migration of the whites, led to a reduction in lobsters and therefore egg production at the northern end of the fishery (e.g. northern Abrolhos Islands and Big Bank) which oceanographic modelling suggests may often be the most important for successful larval production. Combined with the environmental conditions during this period also being highly unfavourable for larval return/survival due to weaker westerly winds (including the increased frequency of positive Indian Ocean Dipole events) and cooler water temperatures (ENSO events, weaker Leeuwin Currents) may have resulted in the very low settlement levels recorded in recent years.

The continuation of low levels of settlement recorded so far this year (2010) despite a substantial lift in egg production levels for the relevant spawning season combined with the finding that phyllosoma levels this year appeared reasonably abundant and the very low levels of westerly winds (storms) experienced this year increases the likelihood that the major driver for the low settlements is environmentally driven. This is suggests that the transport of puerulus across the shelf is being adversely affected.

Based on this scenario, the management actions available to influence future recruitment levels designed to increase the egg production in the northern areas and deeper waters, through a reduction in the harvest rate of animals moving into these areas (e.g. reduce exploitation on animals that are or will in the future migrate) and by increasing protection of animals that do move into this area or are already resident there (e.g. through closed areas, reducing the maximum size of females) may be valuable but not sufficient to ensure a return to ‘normal’ settlement levels.

A second expert based workshop on low puerulus settlement was undertaken in May 2011. This workshop formally examined the information that has been generated on this issue and re-examine the likelihoods for each of the proposed scenarios. The outcomes from this exercise included recommendations with respect to future research projects plus outlining any possible alternate direction or options for management.

7.2 Lobster Movement through Acoustic Tracking

Acoustic tracking is a relatively new technique that allows provides information on movement patterns, habitat usage and home ranges for aquatic species. As part of FRDC project 2008/013, “Assessing the ecological impact of the Western Rock lobster fishery in fished and unfished areas”, lobsters will be tracked in offshore deepwater environment (50m), to examine not only their movement, but their habitat utilization patterns.

7.3 Effects of Closed Areas

A new monitoring program has examining the impacts of fishing activities on WRL and their associated benthic habitats. This project will examine the abundance, size and sex compositions of lobsters inside and outside of sanctuary zones in shallow water sites off Jurien and the Perth metropolitan coast. These lobsters are captured in commercial and recreational batten lobster traps with blocked escape gaps (Section 4.3). Their sex, size and stage of maturity (i.e. external eggs) are recorded and they are then tagged with a spaghetti tag and returned to where they were caught. Divers will make underwater visual surveys in the same locations to provide an alternative measure of lobster abundance and size composition. These surveys will run concurrently with benthic habitat and invertebrate and fish surveys.

The possible outcomes of this work will include:

i. An improved understanding of what virgin shallow-water lobster stocks may have been like in abundance and size structure

ii. Information on whether no-take zones may be of any use in the sustainable management of this species

iii. Information about whether all lobsters move into deep water

iv. Growth-rate data, unbiased by either size-related catchability or inaccurate reporting.

Detailed movement information can be found in Department of Fisheries (2011)

8.0 Suggestions for Future Research

The main areas being considered for future research are described below.

8.1 Bio-economic Modelling

An application for funding has been made for a three year bio-economic project to developed better information on optimising the rock lobster harvest. The outputs of the project will be used in conjunction with the stock assessment model.

8.1.1 Background

Historically the main focus of the assessment of the western rock lobster fishery (WRLF) has been on the status of the stock to ensure biological sustainability of the stock. More recently the economic performance of the fishery has been examined (Cameron-Bird, Julian Morrison FRDC 2007/052) and a comparison of the economic effects of the different management strategies proposed for 2005/06 was undertaken (Thompson and Caputi 2006). In 2008, a preliminary assessment of the maximum economic yield (MEY) was undertaken by the Department of Fisheries Economist to demonstrate that there were alternative management options to optimize profits (Reid 2009). However there is a need for further assessment of the MEY analysis to take into account variability associated with the parameters assumed and alternative management approaches. This includes examination of inter-annual patterns of the fishery (because economic traits of peak catches are different to other periods) and in catch composition effects on price, as stock rebuilding will lead to a greater range of size grades being landed. This assessment would take into account the outputs from the WAFIC IDU 08/07 project that is updating the financial data collection for the WRLF as well as information from the processing sector on prices of rock lobsters under different management arrangements.

This project is part of the CRC Future Harvest Theme that has been supported by the Seafood CRC.

The western rock lobster fishery is facing significant economic pressure from the cost-price squeeze as well as reduced catches as a result of low puerulus settlement and resultant management changes. It is therefore important to undertake a bio-economic assessment of the management strategies to ensure economic optimization of the fishery. As a result of the low puerulus settlement there have been significant reductions in fishing effort (ca. 50% in 2008/09) that are taking into account the economic aspects of the fishery e.g. MEY assessment and reducing the peak catches in March-April. It is important that an economic assessment is undertaken of these strategies.

Objectives

- To estimate the annual catch and effort to achieve optimum economic yield
- To evaluate intra-annual market-based management strategies.
- To evaluate the economic effect of current and proposed management changes.

Planned Outcomes

- Determination of annual catch and effort to achieve optimum economic yield taking into account net present value.
- Determination of a Target Reference Point for the decision-rule framework to achieve optimum economic yield.

- Assessment of the impact of current (ca. 35% whites and 60% reds) effort reduction implemented in the 2008/09 season and that proposed for the 2009/10 season

Evaluation of intra-annual market-based management strategies to assess within year economic performance of different management strategies of fishing the whites (December) and reds (March–April) peak catches.

8.2 Integrated Fisheries Management

The decision rules framework will be updated to include the catch share of all the fishery's stakeholders (e.g. commercial, recreational, indigenous, etc) under the Department of Fisheries' Integrated Fisheries Management (IFM) policy. Under IFM the percentage of the recreational rock lobster catch could be another indicator, with a threshold reference value of 5% of the total catch.

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10.0 Appendices

Appendix A – Catch Disposal Record Form (2010/11 season)

Government of Western Australia
Department of Fisheries

WEST COAST ROCK LOBSTER FISHERY

007426

PART 1A PRE FISHING NOMINATION (CALL IVR NUMBER)

Master to complete before moving the boat to commence fishing, after calling the IVR number.

Pre Fishing Confirmation Number: ______ Date of call: / /

PART 1B DETAILS OF FISHING TRIP

This section need only be completed once per landing, prior to completing part 1C.

Zone fished (circle one): A B C

Main block number (refer to map):

Depth range of pots (fathoms): ______ to ______

Total number of pots pulled:

Pull period in days (eg 1 or 2):

Crew Numbers Onboard (inc master):

Did you interact with a protected species (circle one): Yes No

If Yes, list Details Below	No Alive	No Dead

Retained Species (other than Western Rock Lobster)	Number	Weight (kg)
Octopus (Headed Wt)		
Southern Rock Lobster		

You must supply number and approximate weight in kilograms of each species

PART 1C PRE LANDING NOMINATION (CALL IVR NUMBER)

Master must phone IVR and complete this section prior to entering a landing area

Pre landing Confirmation No: ______ Landing Area No: ______ Date: / /

No of Containers (must be tagged & secured): ______ **OR** No of Lobsters on board: ______

All lobsters must be in tagged, secured containers before any lobsters are removed from the boat

PART 1D POST LANDING NOMINATION (DECLARATION OF CATCH)
CALL IVR NUMBER AFTER WEIGHING LAST CONSIGNMENT*

The Master must complete this section, immediately upon weighing each consignment.

MFL Number: ______

Master's CFL Number: ______

Master's Full Name (Please Print): ______

Consignment ______ of ______ for this trip

Transporting own catch (circle one): Yes No

No of Containers	Gross Weight	Net Weight
	. kg	. kg

Tag numbers for this consignment (e.g. from AA0001 to AA0010):

Time weighted (24Hr): : Date weighed: / /

All CDR Numbers related to this landing – From: ______ to ______

Personal Consumption (circle one): Yes No

If **Yes**, full name of crew member receiving lobsters (please print):

Receiver No:

Receiver Name:

Residential address where lobsters will be delivered:

Upon weighing the last consignment of this landing, the Master must call the IVR number and obtain a Post Landing Confirmation number

*Post Landing Confirmation No:

PART 1E MASTER'S DECLARATION

I declare that the information I have given is true and correct.

Boat LFB: ______ Boat Name: ______ Master's Contact Phone Number: ______

Master's signature: ______ Date of Declaration: / /

NOTE: It is a major offence to make false or misleading statements, or to fail to fully complete this form.
When completed, the top **(WHITE)** form must immediately be sent to: **Catch Monitoring Section**, Department of Fisheries, Locked Bag 43, Cloisters Square WA 6850. The second **(YELLOW)** form is to be kept in the book. The third **(GREEN)** form must be provided by the **MASTER** to the **RECEIVER**. When completed the third **(GREEN)** form must immediately be sent by the **RECEIVER** to: **Catch Monitoring Section**, Department of Fisheries, Locked Bag 43, Cloisters Square WA 6850.

Appendix B – Header sheet used to record all ancillary data collected during the commercial monitoring program

W.A.M.R.L. ROCK LOBSTER LENGTH MONITORING

Batch Data Header Sheet Coded Information
Version 3

Header Reference Information:

Date:(/ /) Vessel Reg. No.: ( )

Vessel Name:________________________________

Depth Category: ( ) Depth Range: (to fms)

Sample Location: ( ) Sample Sub-Location: ( )

Latitude: (^{o} 'S) Longitude: (^{o} 'E)

Catch and Effort Data:

Total Catch Wt: (kg) (Nearest Kg)

No. Pots Pulled: ( ) No. Pots Sampled:( )

Pot Types: ( )________________________________

No. Pots Pulled x Pot Type: (________________________________

Bait Types: ( )________________________________

Days Between Pull: ( ) 0 - 9 (9 day maximum).

Sample Indicator: ( ) **0** = Boat, **1** = Factory, **2** = Fishermens.

Predation Data:

No. Pots with Octopus Caught in Pot: ( )

Total No. Octopus Caught: ( )

No. Pots with Escaped Octopus: ( )

No. Rock Lobsters Predated by: Octopus: ( ), Unknown:( )
(Predation evident and/or dead) Cuttlefish:( ), Fish: ( )

Total No. **Dead** Rock Lobsters: ( )

No. RLs with Black-Spot: ( ) No. RLs with Microsporidiosis : ( )

Environmental Data:

Bottom Type:(/) ie. **R**ock, **W**eed, **S**and, **C**oral + **L**umps.

Salinity Bottle No's: Surface = ____________, Bottom = ____________.

Surface Salinity:(ppt) Surface Temperature:(^{o}C)

Bottom Salinity:(ppt) Bottom Temperature:(^{o}C)

Nansen Sample Depth:(fms) Water Depth:(fms)

Bait Packaging Disposal: ( ) Used Bait Disposal: ( )

Sample Recorders Initials:( )

Other Research Information

Skippers
Name:____
Attitude to fishery management and research:______________________________

Pattern of fishing:
Use of
GPS;____

Use of Sounder
:____

Fishing lumps, setting lines
etc;____

Beach Prices:

Whole Catch	$	.	/kg,	Company Name________________
A+B's	$	.	/kg,	
C+D's	$	.	/kg,	
rest	$	.	/kg.	

Weather Conditions:

Swell: m, Seas: m, Moon Phase:(Circle) New/First Q/Full/Last Q

Wind: kts., Current: kts., Tide: kts., Approx. Air Temp: ^{o}C.

Additional Comments: **ie.** Factors affecting catch and effort/new technology/reaction to management.

Appendix C – Data recording sheet for the IBSS, showing information recorded.

Page ______ of ______

ROCK LOBSTER RESEARCH DATA RECORDING SHEET

Temperature: Surface ....°C
Bottom ....°C @ ....Fms

Date: ....

Boat Name & No: ....

Salinity: Bot No. ....Surface.............‰
Bot No. ....Bottom...............‰ @........Fms

G.P.S..–North: ....S/ ....E
South: ....S/ ....E

Swell Height & Direction: ..../ ....

Depth: ....Fathoms

Wind Speed & Direction: ....kts/ ....

Tag Series: ....

Current Speed & Direction: ....kts/ ....

Line No: ....

Cloud Cover: ....%

Pot Pull Direction: ....

I.B.S.S. DATA DAY No. .... GPS Mark Shape/Colour .... Location/ Sub Area .... Total Catch .... Mature ♀s ....

TAG No.	BIO TAG	REC	POT No.	POT TYPE	DAY PULL	CARAPACE LENGTH	SEX	COLOUR	SETOSE PLEOPS	TAR SPOT	EGG STAGE	DEV. GON.	DAMAGE OLD		DAMAGE NEW		REGEN.			REMARKS
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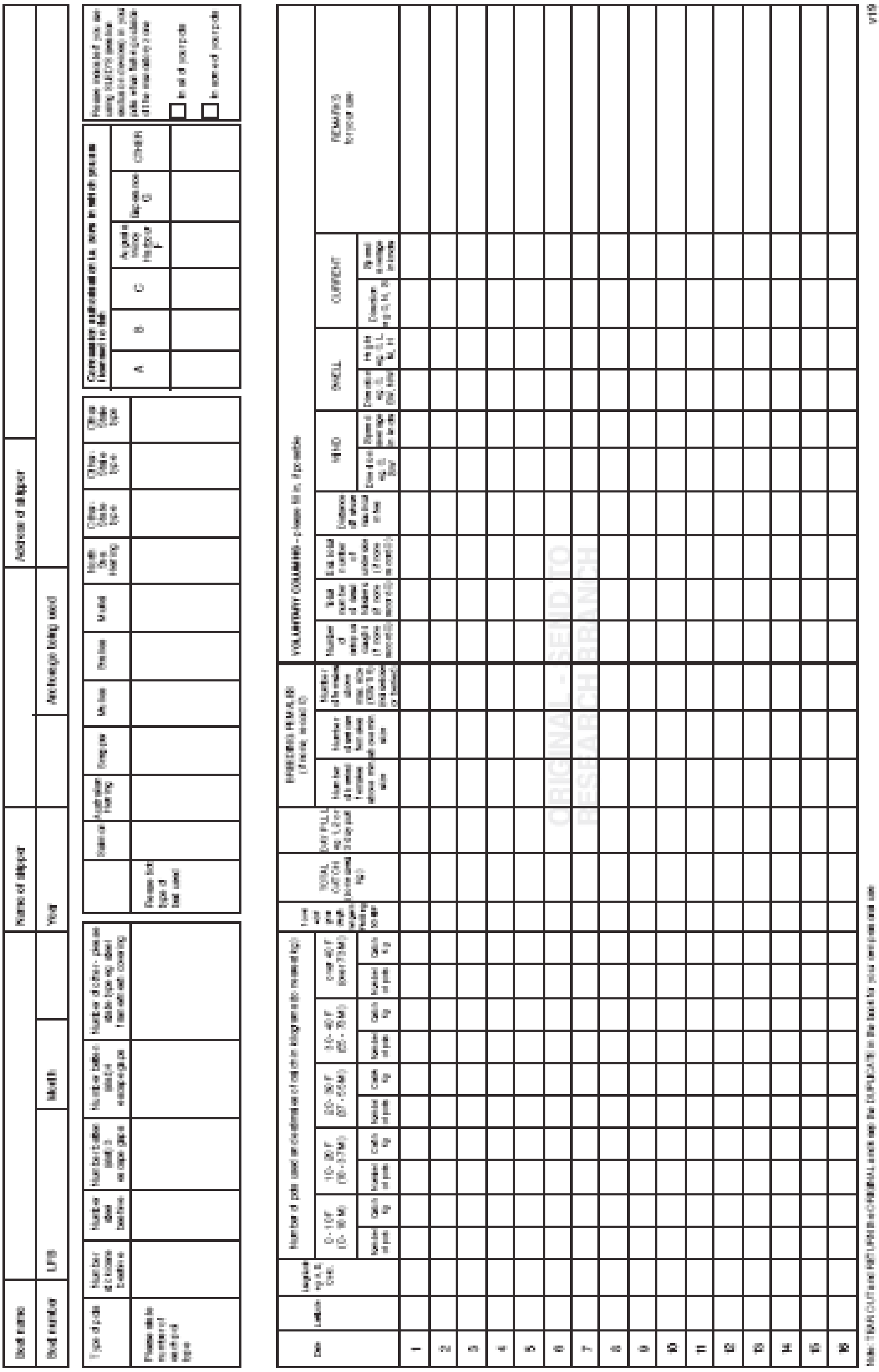
Appendix D – Voluntary log book filled in by commercial fishers.



Appendix E(1) – CAES log book showing the data recorded by fishers monthly

Original post to Department of Fisheries   Duplicate - retain for your records

Office Use

Rock lobster and Potting: catch and effort return

Fish Resources Management Regulations 1995 Regulation 64

Year	Month	Boat registration LFB	Boat name	
Fishing Boat Licence FBL		Managed fishery licence(s) MFL		
Anchorage		Master's CFL No.	Master's name (Authorisation holder or agent)	
Months you propose not to fish		Phone no.	Address	
No. days fished.	Crew number (inc master)	Fuel purchased (litres)	I certify that the information on this form is correct (Master, authorisation holder or agent)	Date signed

Fishery eg. WCRL, ESP, CSCR (one fishery per column)						Fishery eg. WL, SBS			
If applicable Zone fished (one zone per column)						*If applicable* Zone fished			
Potting method eg. PT, OP, CT (one method per column)						Other methods			
Block number (one block per column)						Block number			
Days fished						Days fished			
						Hours fished per day			
Pots pulled per day						Pots/traps pulled per day			
						Hooks per day			
						Shots/pulls per day			
						Net length (m) per shot			
						Mesh size range (mm)			
Species (include all retained catch)	Condition codes	kg	kg	kg	kg	Species (include all retained catch)	Condition codes	kg	kg
Western rock lobster									
Octopus									
Southern rock lobster									

Dealer/processor	Crew names
Have you had an interaction with a protected species? Yes ☐ No ☐ If yes, was animal released Alive ☐ Dead ☐	Species, location and other comments

Notification of months when no fishing occurred is required on this form. A signed facsimile of this form may be submitted

Fisherman's summary of landings and effort. *Please note: This sheet is to assist you in completing the returns in this book, but does not replace the research log book.*

Day	Method code	Block	Hours of fishing and searching	No. of shots or hooks	No.of pots or traps	Length of net (m)	Weight Landed (kg)								Landings or remarks			
							Species/ Condition	Species/ Condition	Species/ Condition	Species/ Condition	Species/ Condition	Species/ Condition	Species/ Condition	Species/ Condition	Species/ Condition	Species/ Condition	Species/ Condition	Species/ Condition
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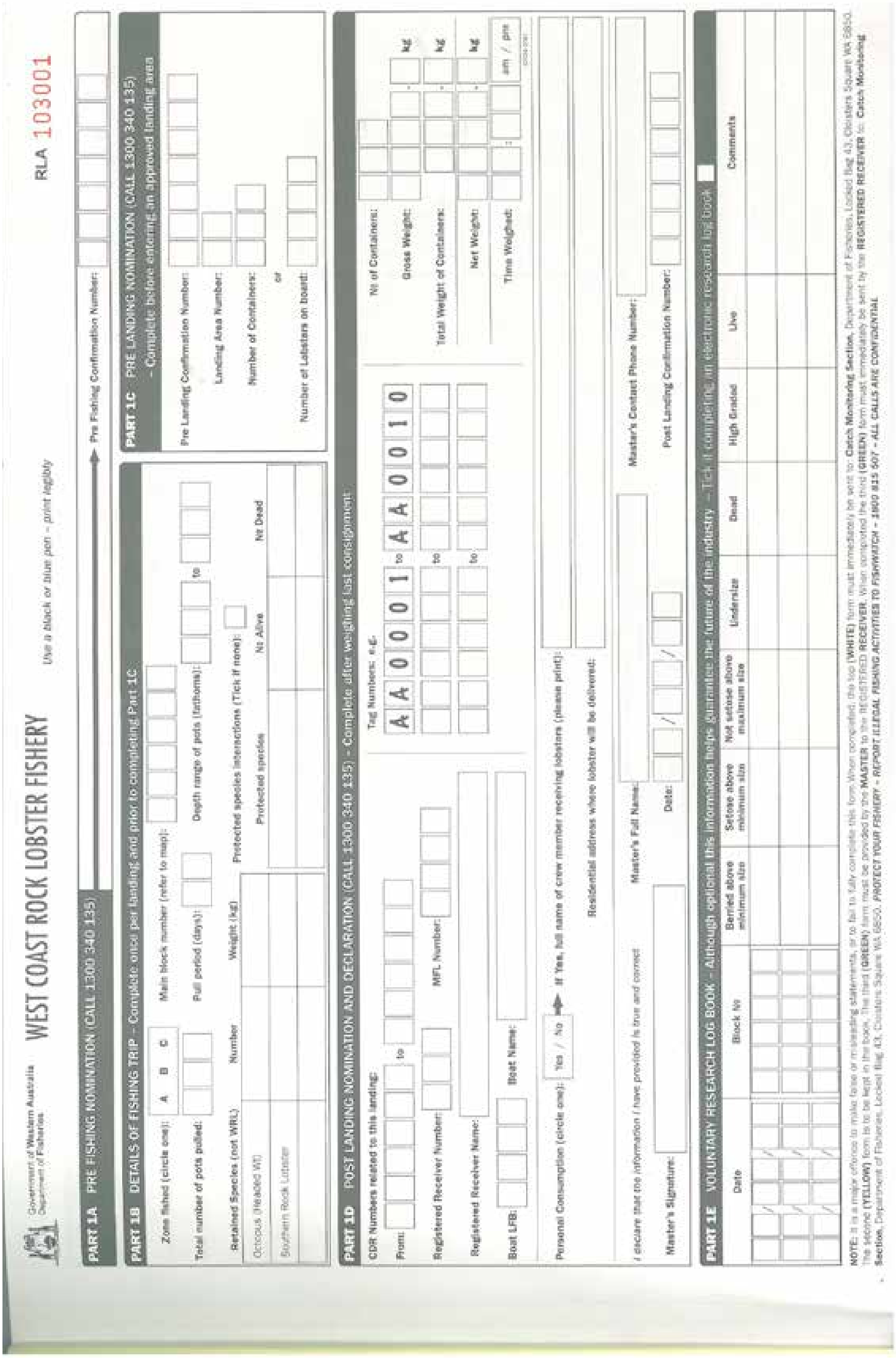
Total																		

Appendix E(2) – Catch Disposal Record (CDR) form showing the data recorded by fishers monthly



Government of Western Australia
Department of Fisheries

WEST COAST ROCK LOBSTER FISHERY

Use a black or blue pen – print legibly

RLA 103001

PART 1A PRE FISHING NOMINATION (CALL 1300 340 135) → Pre Fishing Confirmation Number:

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

Zone fished (circle one): A B C

Main block number (refer to map):

Total number of pots pulled:

Pull period (days):

Depth range of pots (fathoms): to

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

Protected species interactions (Tick if none):

Protected species	№ Alive	№ Dead

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

Pre Landing Confirmation Number:

Landing Area Number:

Number of Containers:

or

Number of Lobsters on board:

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

CDR Numbers related to this landing:

From: to

Tag Numbers: e.g. AA0001 to AA0010

to

to

Registered Receiver Number:

MFL Number:

Registered Receiver Name:

Boat LFB:

Boat Name:

№ of Containers:

Gross Weight: kg

Total Weight of Containers: kg

Net Weight: kg

Time Weighed: am / pm

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

Residential address where lobster will be delivered:

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

Master's Full Name:

Master's Contact Phone Number:

Master's Signature:

Date: / /

Post Landing Confirmation Number:

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

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

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

Appendix F – Forms filled out by rock lobster processors a) log of fisherman and catch for that month, and b) breakdown of product and grades of lobsters exported or sold domestically.

Rock Lobster Monthly Processor Return Log

Fish Resources Management Act 1994

Regulation 64

Government of Western Australia

Department of Fisheries

Return of Rock Lobsters Processed during the Month of: ____________________ **Year:** ________________

Name of Firm:

Address (of processing establishment):

Name of Fisherman:	Boat Number	Live Weight (Kg)
	TOTAL	

Date: ____/____/____ **Signature:** ____________________________

Fish for the future

FISHERIES
WESTERN AUSTRALIA

FISHERIES WESTERN AUSTRALIA
Fish Resources Management Act 1994,
Regulation 64

NAME OF FIRM: ____________________
ADDRESS OF PROCESSING ESTABLISHMENT: ____________________
FOR MONTH: ____________ YEAR: ________

PROCESSING * See note below	WEIGHT OF CARTON (Kg)	GRADES (if the grades A, B, C, etc. have been subdivided, please specify the subdivided grade in the column provided)																								
		A			B			C			D			E			F			G			H			BAIT TAILS
GREEN TAILS				TOTAL			TOTAL			TOTAL			TOTAL			TOTAL			TOTAL			TOTAL			TOTAL	
EXPORT	11.34																									
LOCAL	11.34																									
OTHER - please specify																										
WHOLE COOKED				TOTAL			TOTAL			TOTAL			TOTAL			TOTAL			TOTAL			TOTAL			TOTAL	
EXPORT	10.00																									
LOCAL	10.00																									
OTHER - please specify																										
WHOLE GREEN				TOTAL			TOTAL			TOTAL			TOTAL			TOTAL			TOTAL			TOTAL			TOTAL	
EXPORT	10.00																									
OTHER - please specify																										
LIVE				TOTAL			TOTAL			TOTAL			TOTAL			TOTAL			TOTAL			TOTAL			TOTAL	
EXPORT	8.00																									
OTHER - please specify																										
OTHER PROCESSING (please specify)				TOTAL			TOTAL			TOTAL			TOTAL			TOTAL			TOTAL			TOTAL			TOTAL	

* Please give export and local grades separately.

DATE: _____ / _____ / _____ SIGNATURE: ____________________

Appendix G – Mail survey (1997/98 season) representative of those sent until 1998

FISHERIES
WESTERN AUSTRALIA

Recreational rock lobster fishing survey

1997/98 season

Please complete and return to
W.A. Marine Research Laboratories
PO Box 20, North Beach, 6020
Enquiries (08) 9246 8482 / (08) 9246 8444

Assist us by filling in this survey form and put yourself in line for a prize

Name

Address

Post Code

1. Contact phone no. (to verify any entries below)

2. Did you fish for rock lobsters between 15 November 1997 and 30 June 1998 (please tick Yes or No below)

☐ Yes — If you answered yes, please complete this survey and return it to us.

☐ No — If you answered no, you can stop here, but <u>**please still return**</u> the survey form to us.

All these questions refer to you as a single licence holder - please fill out one form for one licence.

3. What **METHODS** did you use to fish for rock lobsters last season? (please tick) — Pots ☐ Diving ☐ Other ☐ If other, please describe.

4. How may lobster **POTS** did you pull each day you went fishing?

5. During which **MONTHS** did you fish for rock lobsters? (tick more than one if appropriate) — Nov ☐ Dec ☐ Jan ☐ Feb ☐ Mar ☐ Apr ☐ May ☐ Jun ☐

6. **WHEN** did you do most of your fishing for rock lobster? (tick more than one if appropriate) — Week-ends ☐ Week-days ☐ School Holidays ☐ Annual Holidays ☐

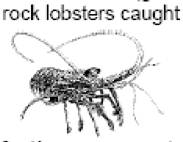
7. On how may **DAYS** during the season did you go fishing for rock lobsters? (your best estimate of the total number for each method) — By using pots? By diving? By other methods?

8. What was the total number of **LEGAL SIZE WESTERN** rock lobsters you caught during the season? (your best estimate) — By using pots? By diving? By other methods?

9. **WHERE** did you do most of your fishing? (list locality or town with [1] being the most often fished. Indicate which fishing methods you used in each area)

	Town/locality	postcode	Pots	Diving	Other
[1]					
[2]					
[3]					

10. Total number of **TROPICAL** (green or painted) or **SOUTHERN** rock lobsters caught this season? — By using pots? By diving? By other methods? Tropical? Southern?



Space for any further comments you'd like to make is provided overleaf

RLSurv98.p65

Comments (optional)

Fold 1

Postage is Paid.

Fold the form to show the return address - staple or tape the page and mail it.

Thank you for your input into the survey.

Fold 2

Rock Lobster Research
Western Australian Marine Research Laboratories
PO Box 20
NORTH BEACH WA 6020

BUSINESS REPLY POST
Permit No. 481 Issued at Perth
Postage and fee will be paid on delivery to:-

O.H.M.S.

No postage stamp required if posted in Australia

Appendix H – Mail survey sent out in 1999, illustrating the more recent, detailed mail surveys

FISHERIES
WESTERN AUSTRALIA

Recreational Rock Lobster Fishing Survey: 1998/99 Season

Participating in this survey will put you in the running to win one of three cash prizes:
1st prize $500, 2nd prize $200, 3rd prize $100

Please complete and return (**free postage**) to:
W.A. Marine Research Laboratories
PO Box 20, North Beach, 6020
Enquires: (08) 9246 8482 or (08) 9246 8444

Please note that all information supplied will be treated as strictly confidential

1. **Contact details** in case we need to verify any information you provide. We will also contact you if you win a prize.

Name: ____________________ *Ph:* __________
Home address: ______________________________
______________________________ *Postcode:* __________

2. How are you **licensed** to fish for rock lobster? (tick one)
☐ Rock lobster licence only
☐ Umbrella licence (all recreational fisheries)

3. What is your **age**? _ _ _ _ _

4. What is your **gender**? Male ☐ Female ☐

5. What is the **main language** spoken at home?
_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

6. What is your highest level of **education**? (circle one)
a) Below Year 12
b) Year 12
c) Apprenticeship or TAFE certificate
d) Tertiary

7. **Did you fish** for rock lobster between 15 November 1998 and 30 June 1999? (tick Yes or No).

YES ☐ If you answered Yes, please **go to question 8**, complete this survey, and return it to us.

NO ☐ If you answered No, please **skip ahead to Q21**, complete the survey, and return the form to us.

All the questions refer to you as a single licence holder - please fill out one form for one licence.

8. What **methods** did you use to fish for rock lobsters last season? (please tick)
Pots ☐
Diving ☐
Other ☐
If Other, please describe:
_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

9. Please indicate **the approximate number of days** you fished for rock lobster in each month using the following methods:

	Pots	Diving	Other
Nov '98	_ _ _	_ _ _	_ _ _
Dec '98	_ _ _	_ _ _	_ _ _
Jan '99	_ _ _	_ _ _	_ _ _
Feb '99	_ _ _	_ _ _	_ _ _
Mar '99	_ _ _	_ _ _	_ _ _
Apr '99	_ _ _	_ _ _	_ _ _
May '99	_ _ _	_ _ _	_ _ _
Jun '99	_ _ _	_ _ _	_ _ _

10. **Where** did you do most of your fishing? (list locality or town with [1] being the most often fished). Please note the number of days fished using each method.

[1] Town/Locality _ _ _ _ _ _ _ _ _ _ _ _ Postcode _ _ _ _ (if known)
Number of days fished at locality:
Pots _ _ _ _ *Diving* _ _ _ _ *Other* _ _ _ _

[2] Town/Locality _ _ _ _ _ _ _ _ _ _ _ _ Postcode _ _ _ _ (if known)
Number of days fished at locality:
Pots _ _ _ _ *Diving* _ _ _ _ *Other* _ _ _ _

[3] Town/Locality _ _ _ _ _ _ _ _ _ _ _ _ Postcode _ _ _ _ (if known)
Number of days fished at locality:
Pots _ _ _ _ *Diving* _ _ _ _ *Other* _ _ _ _

11. If you used pots, **how many lobster pots** did you typically pull each day you went fishing? _ _ _ _ _ _ _ _

12. **When** did you do most of your fishing for rock lobster? (tick more than one if appropriate)
Weekends ☐
Weekdays ☐
School Holidays ☐
Annual Holidays ☐

13. What was the **total number of legal size western rock lobster** you caught during the season? (your best estimate)
By using pots _ _ _ _ _
By diving _ _ _ _ _
By other methods _ _ _ _ _

14. Please indicate the **number** of legal size **tropical** (green/painted) or **southern** rock lobster caught during the season:

Lobster	Pots	Diving	Other
Tropical	_ _ _	_ _ _	_ _ _
Southern	_ _ _	_ _ _	_ _ _

15. Do you own (or have regular access to) a **boat**? (tick one)

Yes ☐ **Go to Q16** No ☐ **Skip to Q18**

16. What is the **length of the boat** in metres? ______ m

17. Please tick the equipment you used: (tick more than one if appropriate)

- B/W Echo Sounder ☐
- Colour Echo Sounder ☐
- View Bucket ☐
- Radar ☐
- Pot Winch ☐
- GPS ☐
- None of the above ☐

18. In what **depth range** did you **dive** for rock lobster last season?

Depth	Percentage of Time Diving
0-10 m	_____
11-20 m	_____
21-30 m	_____
Below 30 m	_____
Didn't dive	☐

19. In what **depth range** did you fish for rock lobster using **pots** last season?

Depth	Percentage of Time Potting
0-10 m	_____
11-20 m	_____
21-30 m	_____
Below 30 m	_____
Didn't pot fish	☐

20. Please tick the **type(s) of pots** you used when fishing for lobster last season: (tick more than one if appropriate)

- Stick/cane beehive ☐
- Batten pots ☐
- Plastic pots ☐
- Don't use pots ☐
- Other ____________ (please specify)

21. For **how many years** have you participated in the recreational rock lobster fishery? _____

22. Consider the following statement: "Fisheries management is effective in conserving rock lobster stocks". Do you: (circle one answer only)

a) Strongly agree
b) Agree
c) Not sure
d) Disagree
e) Strongly disagree

23. In your experience, how fair do you think fisheries officers are in dealing with infringements that they find. As far as you know, do they treat people: (circle one)

a) Always fairly
b) Sometimes fairly
c) Never fairly
d) Don't know, no contact with fisheries officers.

24. Consider the following statement: "**Recreational** rock lobster fishers generally abide by fisheries regulations". Do you: (circle one answer only)

a) Strongly agree
b) Agree
c) Not sure
d) Disagree
e) Strongly disagree

25. Please indicate the **number of contacts** you had with fisheries personnel while fishing for rock lobster in the last season: (circle one, but if greater than 1 contact please write number)

i) Fisheries officers:
  a) None
  b) Seen only
  c) 1 contact
  d) More than 1 contact _____
  e) Did not fish last season

ii) Volunteer fisheries liaison officers (VFLO's):
  a) None
  b) Seen only
  c) 1 contact
  d) More than 1 contact _____
  e) Did not fish last season

[Note: VFLO's are recreational fishers who donate their time to educate other fishers about conservation and fish management. They usually wear distinctive yellow shirts and hats].

26. How many times in total (over all your fishing years) have you come into contact with a fisheries officer (not a VFLO) while fishing for rock lobster? ________

27. Consider the following statement: "**Commercial** rock lobster fishers generally abide by fisheries regulations". Do you: (circle one answer only)

a) Strongly agree
b) Agree
c) Not sure
d) Disagree
e) Strongly disagree

28. The current **pot limit** is 2 for recreational fishers. Do you think this number is: (circle one)

a) Too low
b) About right
c) Too high
d) Don't know

29. The current **bag limit** is 8 lobsters per day for recreational fishers. Do you think this number is: (circle one)

a) Too low
b) About right
c) Too high
d) Don't know

30. In your experience, what percentage **of recreational fishers** do you think **regularly sell** some or all of their **catch**? (circle one)

a) 0%
b) 1-2%
c) 3-5%
d) 6-10%
e) More than 10%
f) Don't know

31. In your experience, what percentage of **recreational** fishers do you think **illegally pull other recreational** fishers' pots? (circle one)

a) 0%
b) 1-2%
c) 3-5%
d) 6-10%
e) More than 10%
f) Don't know

32. In your experience, what percentage of **recreational** fishers do you think **illegally pull commercial** fishers' pots? (circle one)

a) 0%
b) 1-2%
c) 3-5%
d) 6-10%
e) More than 10%
f) Don't know

33. In your experience, what percentage of **commercial** fishers do you think **illegally pull recreational** fishers' pots? (circle one)

a) 0%
b) 1-2%
c) 3-5%
d) 6-10%
e) More than 10%
f) Don't know

34. What **evidence** have you **seen of illegal pot pulling** in the rock lobster fishery?
a) None
b) Heard rumours it occurs
c) Occasionally witnessed it
d) Regularly witnessed it

35. If you see a recreational fisher breaking the rules, what would you do? (circle one answer only):
a) Do nothing, but feel bad about it.
b) Report the illegal activity
c) Talk to the person directly
d) Ignore it
e) Don't know

36. What percentage of recreational fishers do you think illegally keep undersized lobster? (circle one)
a) 0%
b) 1-2%
c) 3-5%
d) 6-10%
e) More than 10%
f) Don't know

37. In your usual fishing area, how many times do you think you could break the size regulations without getting caught by fisheries officers?
______

38. What is your understanding of the minimum size rules for taking western rock lobster?
(tick more than 1 box if appropriate)
☐ 76 mm, 15 Nov-30 Jun
☐ 76 mm, 1 Feb-30 Jun
☐ 77 mm, 15 Nov-30 Jun
☐ 77 mm, 15 Nov-31 Jan
☐ Don't know

39. What percentage of days fished do you usually catch your **daily bag limit** for Western rock lobster?
(circle one)
a) less than 20%
b) 20-40%
c) 41-60%
d) 61-80%
e) More than 80%
f) Don't know

40. In your experience, what percentage of recreational fishers do you think **fish out of season**? (circle one)
a) 0%
b) 1-2%
c) 3-5%
d) 6-10%
e) More than 10%
f) Don't know

41. What size fine do you think **would be imposed** on someone convicted of being in possession of 6 undersized lobster as a first offence?
(circle one)
a) $200 to $500
b) $500 to $1000
c) $1000 to $2000
d) $2000 to $3000
e) More than $3000
f) Don't know

42. How much do think someone **should be fined** if they are caught with 6 undersized lobster (and have no previous convictions)? $ _____

43. Among recreational rock lobster fishers you know, how would you describe their attitude towards fishers who keep undersized lobster? Would they think the practice is: (circle one)
a) Very wrong
b) Basically wrong, but OK every so often
c) Fine if you can get away with it
d) Don't know

44. How should recreational rock lobster fishers **be able to catch lobster**:
(tick those appropriate)
Free-diving ☐
SCUBA ☐
Pots ☐
Hookah ☐
Spear ☐
Loops ☐
Shepherd's crook ☐
Other _____________ (please specify)

45. Consider the statement: "It doesn't hurt to keep lobsters if they are just undersize". Do you: (circle one)
a) Strongly agree
b) Agree
c) Not sure
d) Disagree
e) Strongly disagree

46. Do you think **the current legal size** for western rock lobster is: (circle one)
a) Too small
b) About right
c) Too large
d) Shouldn't be a limit
e) Don't know

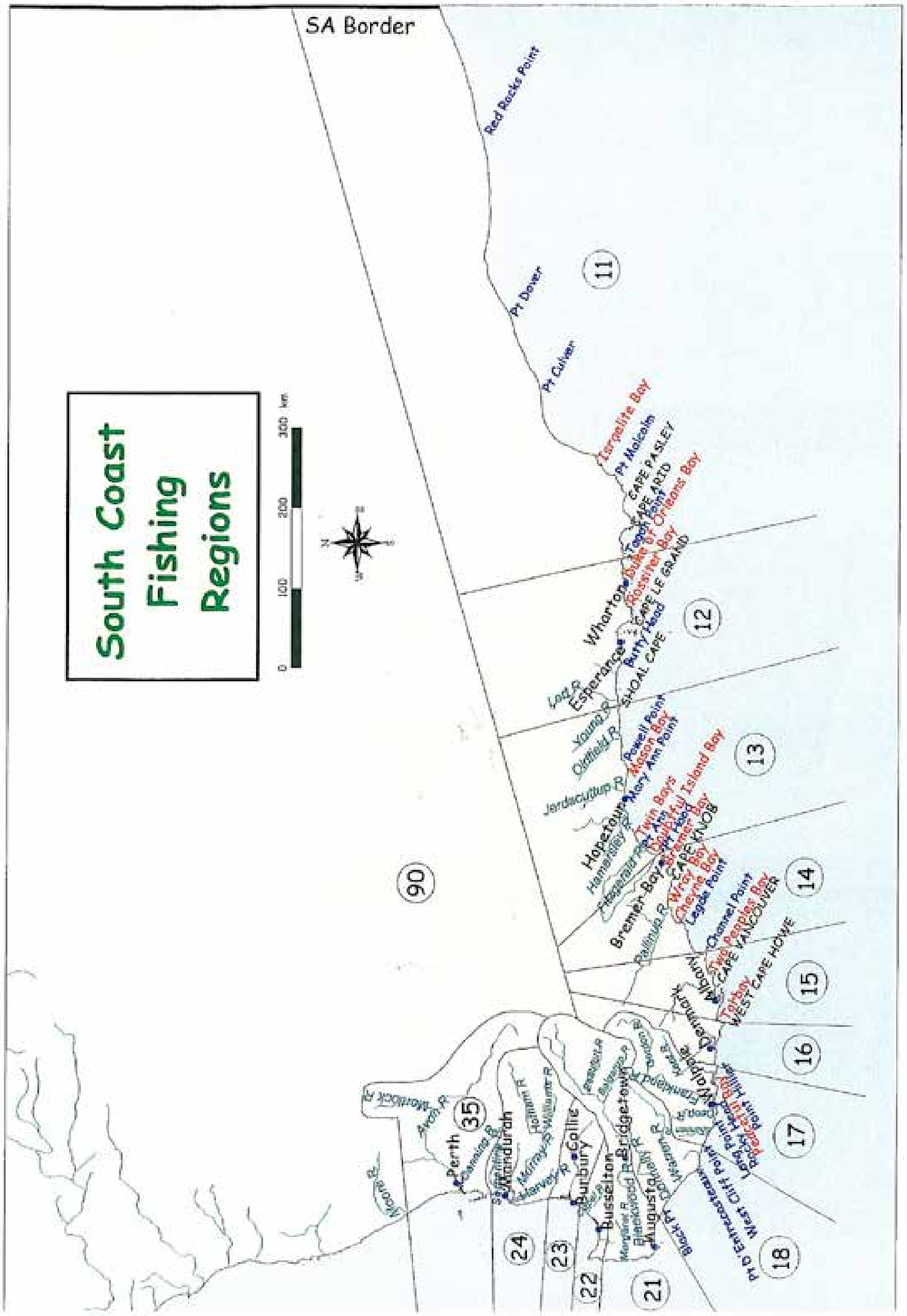
47. Fishers tell us that the following issues are considered important in the recreational rock lobster fishery. Please number these according to the priority Fisheries Officers should give each issue (1 for highest priority, 8 for lowest priority).

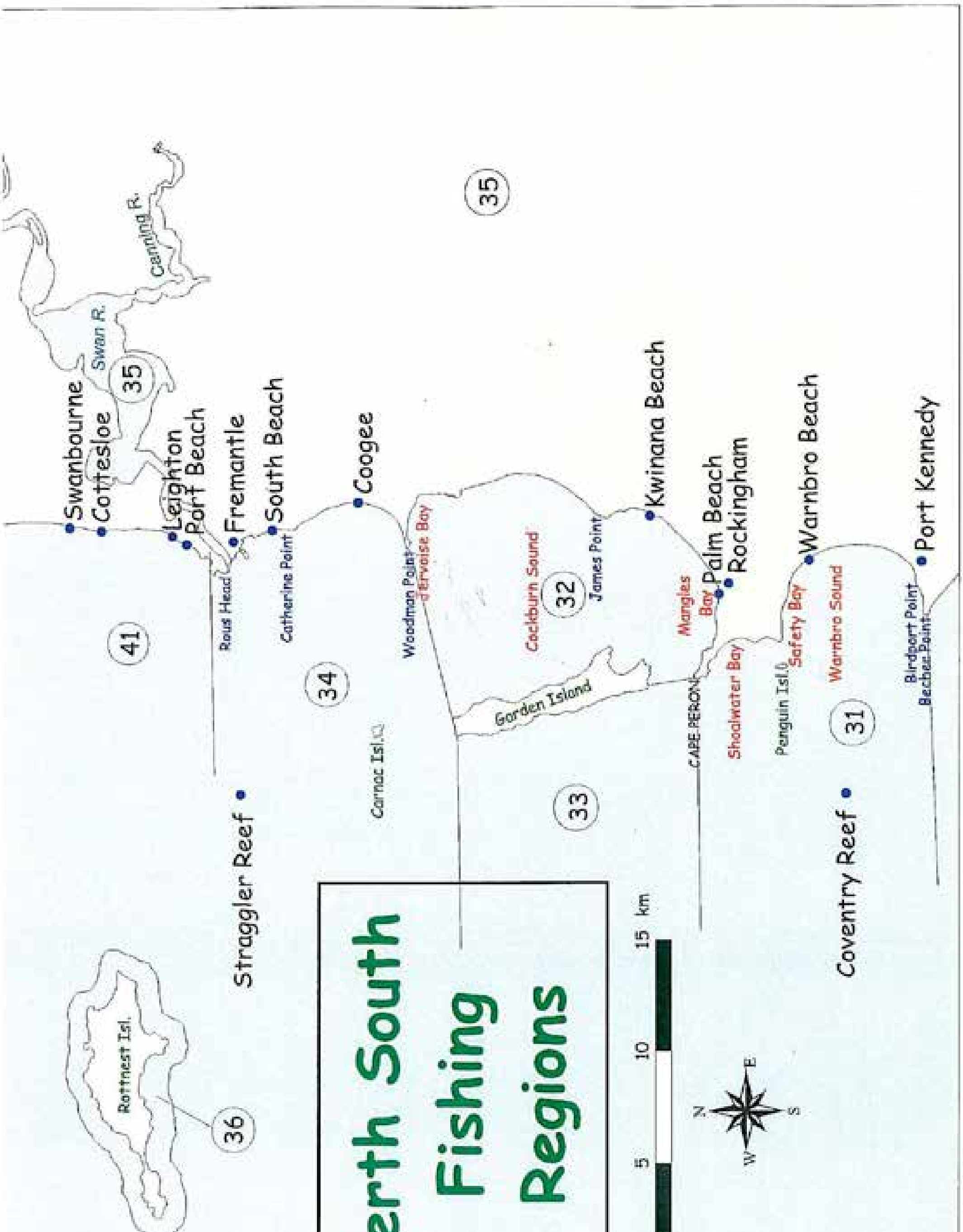
Issue	Priority
Divers poaching rock lobsters from pots	___
Education	___
Undersize lobsters	___
Illegal pot-pulling of recreation pots by recreational fishers	___
Oversize female lobster	___
Over-potting	___
Illegal pot-pulling of recreation pots by commercial fishers	___
Mature female lobster	___
Bag limits	___

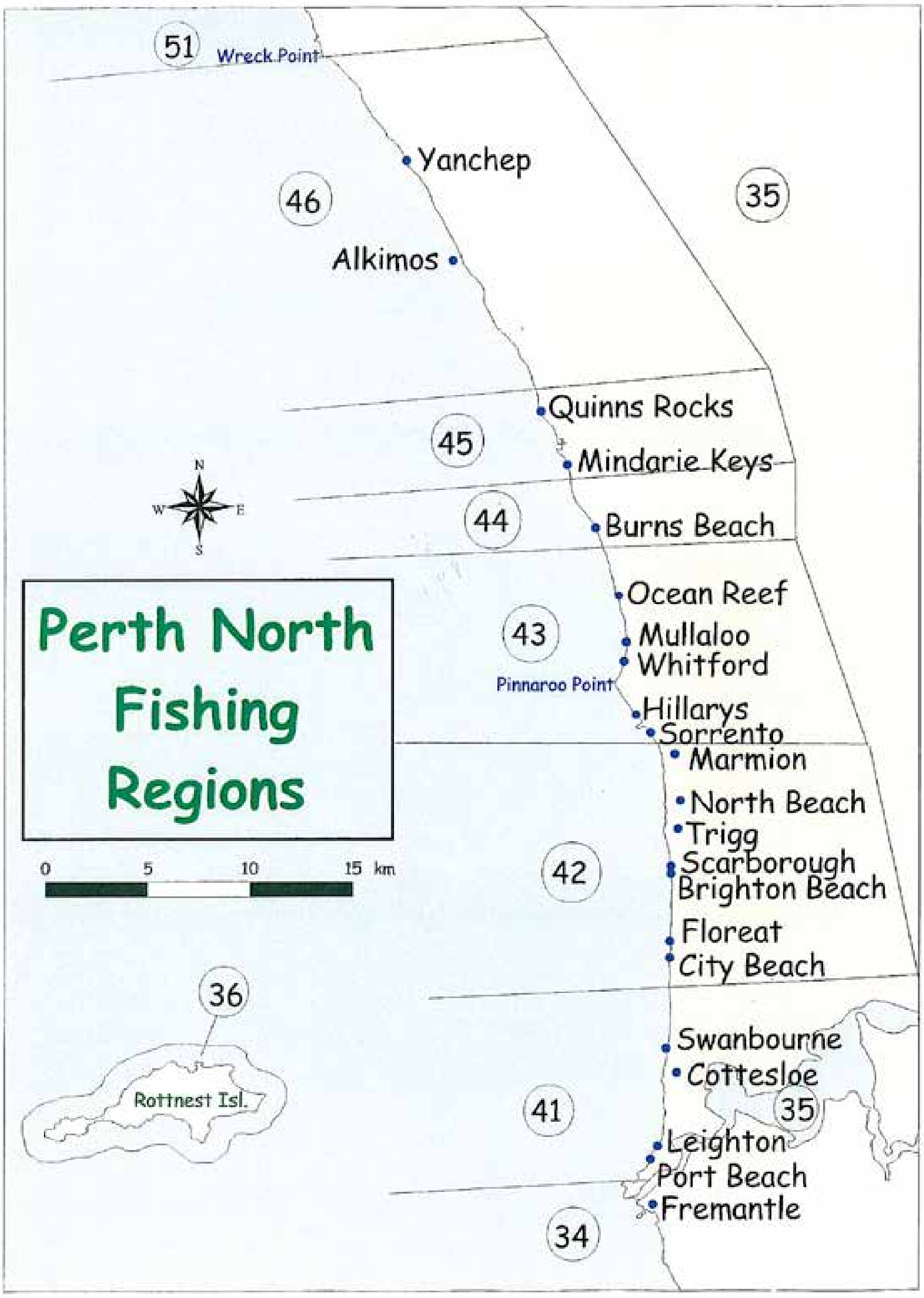
48. Are there any issues you feel are important which were not listed in Q47?
....
....
....
....
....
....
....
....

Thankyou for taking the time to complete this survey

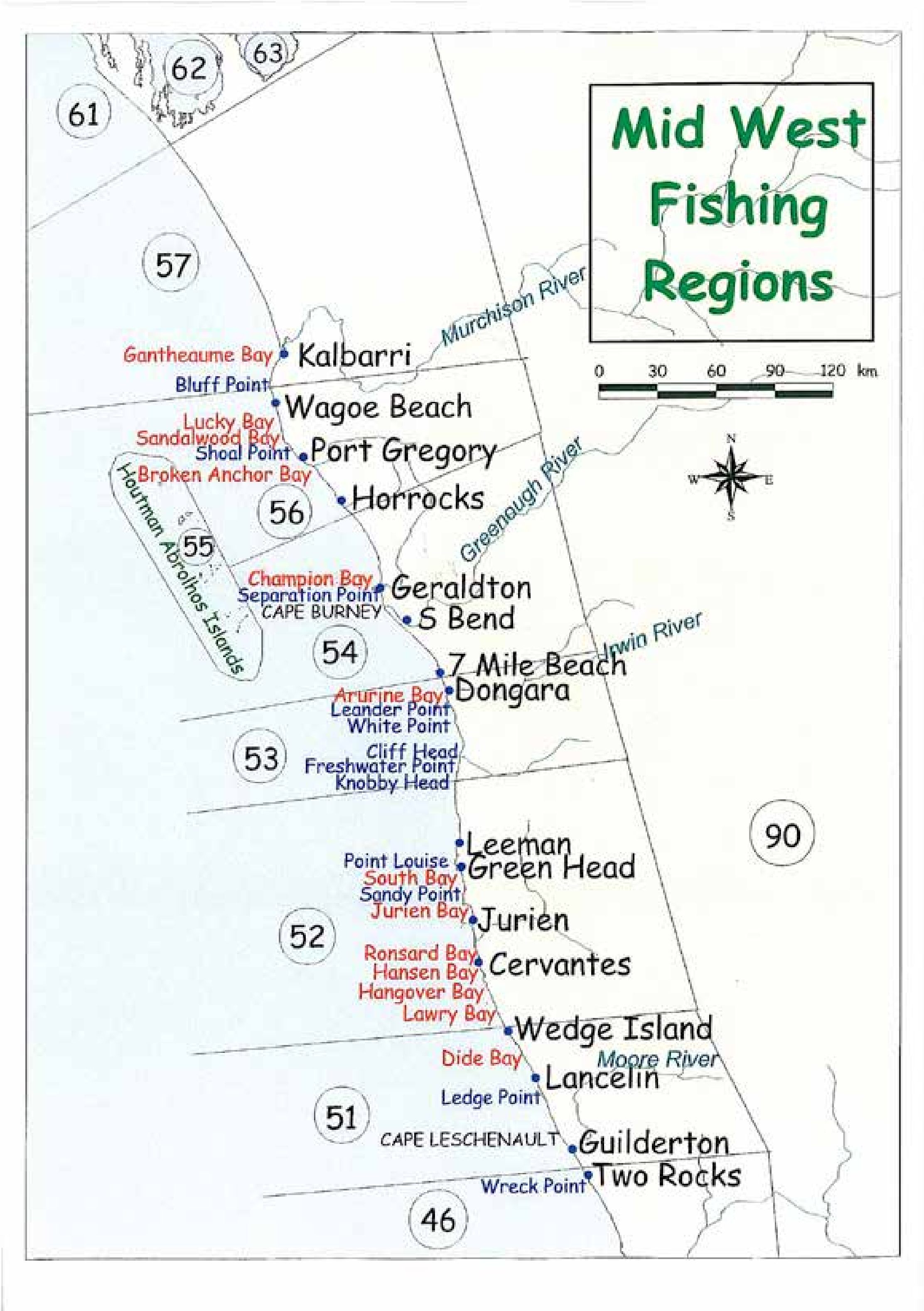
Appendix I – Location maps used in the phone diary survey




Perth South Fishing Regions
Swanbourne
Cottesloe
Leighton
Port Beach
Fremantle
South Beach
Coogee
Kwinana Beach
Palm Beach
Rockingham
Warnbro Beach
Port Kennedy
Swan R.
Canning R.
35
35
41
34
32
33
31
36
Rous Head
Catherine Point
Woodman Point
d'Ervaise Bay
Cockburn Sound
James Point
Mangles Bay
Garden Island
CAPE PERON
Shoalwater Bay
Penguin Isl.
Safety Bay
Warnbro Sound
Birdport Point
Becher Point
Carnac Isl.
Straggler Reef
Coventry Reef
Rottnest Isl.
0
5
10
15 km
N
E
S
W



Perth North
Fishing
Regions
51
Wreck Point
Yanchep
46
35
Alkimos
Quinns Rocks
45
Mindarie Keys
N
W
E
S
44
Burns Beach
Ocean Reef
43
Mullaloo
Whitford
Pinnaroo Point
Hillarys
Sorrento
Marmion
North Beach
Trigg
Scarborough
Brighton Beach
42
0
5
10
15 km
Floreat
City Beach
36
Swanbourne
Cottesloe
Rottnest Isl.
41
35
Leighton
Port Beach
Fremantle
34


Mid West Fishing Regions
0 30 60 90 120 km
N
S
E
W
61
62
63
57
56
55
54
53
52
51
46
90
Murchison River
Greenough River
Irwin River
Moore River
Houtman Abrolhos Islands
Gantheaume Bay
Kalbarri
Bluff Point
Wagoe Beach
Lucky Bay
Sandalwood Bay
Shoal Point
Port Gregory
Broken Anchor Bay
Horrocks
Champion Bay
Separation Point
Geraldton
CAPE BURNEY
S Bend
7 Mile Beach
Arurine Bay
Leander Point
White Point
Dongara
Cliff Head
Freshwater Point
Knobby Head
Leeman
Point Louise
Green Head
South Bay
Sandy Point
Jurien Bay
Jurien
Ronsard Bay
Hansen Bay
Cervantes
Hangover Bay
Lawry Bay
Wedge Island
Dide Bay
Lancelin
Ledge Point
CAPE LESCHENAULT
Guilderton
Wreck Point
Two Rocks


Gascoyne Fishing Regions
0 20 40 60 80 km
N
S
E
W
NORTH WEST CAPE
Exmouth
Mangrove Bay
T Bone Bay
Turquoise Bay
Sandy Bay
Osprey Bay
Hope Pt
Sandy Pt
Winderbandi Pt
Lefroy Bay
71
67
Ashburton River
Jane Bay
Bruboodjoo Pt
Bateman Bay
Point Maud
Coral Bay
66
Amherst Pt
CAPE FARQUHAR
Gnarraloo Bay
65
CAPE CUVIER
90
Pt Quobba
CAPE RONSARD
Bernier Isl.
CAPE COUTURE
CAPE BOULLANGER
64
Gascoyne River
Carnarvon
New Beach
Dorre Isl.
CAPE ST CRICQ
Bush Bay
61
CAPE INSCRIPTION
Turtle Bay
CAPE PERON NORTH
Eastern Gulf
Wooramel River
Dirk Hartog Isl.
Denham Sound
Faure Isl.
61
Denham
Gladstone
63
Steep Point
62
Thunder Bay
False Entrance
Freycinet Estuary
57

Appendix J – Parameter inputs of proportion of white lobsters in each length class in each region and time-step for the stock assessment model.

PropWhite_11_regions_11_timesteps

55

#region	new	mn	mn.se	a	a.se	sdev	sdev.se	xscal	xscal.se
1	1	-39.76360208	25.48007793	0.06432006	0.012833165	-113.1915815	25.48494906	28.8228342	1.156389377
1	2	411.8049405	23.44384701	-0.163419268	0.011751274	343.0949196	23.52367227	27.07647368	0.408760283
1	3	411.8049405	23.44384701	-0.163419268	0.011751274	343.0949196	23.52367227	27.07647368	0.408760283
1	4	432.945801	36.57248662	-0.172196177	0.018295179	357.4692304	36.61322037	9.281792809	0.189008444
1	5	432.945801	36.57248662	-0.172196177	0.018295179	357.4692304	36.61322037	9.281792809	0.189008444
2	1	-39.76360208	25.48007793	0.06432006	0.012833165	-113.1915815	25.48494906	28.8228342	1.156389377
2	2	411.8049405	23.44384701	-0.163419268	0.011751274	343.0949196	23.52367227	27.07647368	0.408760283
2	3	411.8049405	23.44384701	-0.163419268	0.011751274	343.0949196	23.52367227	27.07647368	0.408760283
2	4	432.945801	36.57248662	-0.172196177	0.018295179	357.4692304	36.61322037	9.281792809	0.189008444
2	5	432.945801	36.57248662	-0.172196177	0.018295179	357.4692304	36.61322037	9.281792809	0.189008444
3	1	401.1489013	54.24232335	-0.156772837	0.026851363	330.7578052	54.17745963	29.27167041	2.690817917
3	2	370.4327591	37.03550054	-0.144277877	0.018554768	309.9719435	37.30654035	33.67393692	1.354320037
3	3	370.4327591	37.03550054	-0.144277877	0.018554768	309.9719435	37.30654035	33.67393692	1.354320037
3	4	99.01060552	86.30983038	-0.006458125	0.043279298	33.23788759	86.41129165	9.37684402	0.580662484
3	5	99.01060552	86.30983038	-0.006458125	0.043279298	33.23788759	86.41129165	9.37684402	0.580662484
4	1	401.1489013	54.24232335	-0.156772837	0.026851363	330.7578052	54.17745963	29.27167041	2.690817917
4	2	370.4327591	37.03550054	-0.144277877	0.018554768	309.9719435	37.30654035	33.67393692	1.354320037
4	3	370.4327591	37.03550054	-0.144277877	0.018554768	309.9719435	37.30654035	33.67393692	1.354320037
4	4	99.01060552	86.30983038	-0.006458125	0.043279298	33.23788759	86.41129165	9.37684402	0.580662484
4	5	99.01060552	86.30983038	-0.006458125	0.043279298	33.23788759	86.41129165	9.37684402	0.580662484
5	1	-184.047543	40.90263712	0.136219484	0.020714118	-254.1178906			

							40.93360727	23.58962415	1.599106668
5	2	275.8169172	33.39742295	-0.097550941	0.016746964	213.9111386	33.57381481	26.97959174	0.725696905
5	3	275.8169172	33.39742295	-0.097550941	0.016746964	213.9111386	33.57381481	26.97959174	0.725696905
5	4	482.6329026	56.58555977	-0.201394767	0.028315295	416.4957273	56.79914145	6.935299034	0.269803571
5	5	482.6329026	56.58555977	-0.201394767	0.028315295	416.4957273	56.79914145	6.935299034	0.269803571
6	1	-184.047543	40.90263712	0.136219484	0.020714118	-254.1178906	40.93360727	23.58962415	1.599106668
6	2	275.8169172	33.39742295	-0.097550941	0.016746964	213.9111386	33.57381481	26.97959174	0.725696905
6	3	275.8169172	33.39742295	-0.097550941	0.016746964	213.9111386	33.57381481	26.97959174	0.725696905
6	4	482.6329026	56.58555977	-0.201394767	0.028315295	416.4957273	56.79914145	6.935299034	0.269803571
6	5	482.6329026	56.58555977	-0.201394767	0.028315295	416.4957273	56.79914145	6.935299034	0.269803571
7	1	-184.047543	40.90263712	0.136219484	0.020714118	-254.1178906	40.93360727	23.58962415	1.599106668
7	2	275.8169172	33.39742295	-0.097550941	0.016746964	213.9111386	33.57381481	26.97959174	0.725696905
7	3	275.8169172	33.39742295	-0.097550941	0.016746964	213.9111386	33.57381481	26.97959174	0.725696905
7	4	482.6329026	56.58555977	-0.201394767	0.028315295	416.4957273	56.79914145	6.935299034	0.269803571
7	5	482.6329026	56.58555977	-0.201394767	0.028315295	416.4957273	56.79914145	6.935299034	0.269803571
8	1	-184.047543	40.90263712	0.136219484	0.020714118	-254.1178906	40.93360727	23.58962415	1.599106668
8	2	275.8169172	33.39742295	-0.097550941	0.016746964	213.9111386	33.57381481	26.97959174	0.725696905
8	3	275.8169172	33.39742295	-0.097550941	0.016746964	213.9111386	33.57381481	26.97959174	0.725696905
8	4	482.6329026	56.58555977	-0.201394767	0.028315295	416.4957273	56.79914145	6.935299034	0.269803571
8	5	482.6329026	56.58555977	-0.201394767	0.028315295	416.4957273	56.79914145	6.935299034	0.269803571
9	1	-184.047543	40.90263712	0.136219484	0.020714118	-254.1178906	40.93360727	23.58962415	1.599106668
9	2	275.8169172	33.39742295	-0.097550941	0.016746964	213.9111386	33.57381481	26.97959174	0.725696905
9	3	275.8169172	33.39742295	-0.097550941	0.016746964	213.9111386	33.57381481	26.97959174	0.725696905
9	4	482.6329026	56.58555977	-0.201394767	0.028315295	416.4957273	56.79914145	6.935299034	0.269803571
9	5	482.6329026	56.58555977	-0.201394767	0.028315295	416.4957273	56.79914145	6.935299034	0.269803571

10	1	-184.047543	40.90263712	0.136219484	0.020714118	-254.1178906	40.93360727	23.58962415	1.599106668
10	2	275.8169172	33.39742295	-0.097550941	0.016746964	213.9111386	33.57381481	26.97959174	0.725696905
10	3	275.8169172	33.39742295	-0.097550941	0.016746964	213.9111386	33.57381481	26.97959174	0.725696905
10	4	482.6329026	56.58555977	-0.201394767	0.028315295	416.4957273	56.79914145	6.935299034	0.269803571
10	5	482.6329026	56.58555977	-0.201394767	0.028315295	416.4957273	56.79914145	6.935299034	0.269803571
11	1	-184.047543	40.90263712	0.136219484	0.020714118	-254.1178906	40.93360727	23.58962415	1.599106668
11	2	275.8169172	33.39742295	-0.097550941	0.016746964	213.9111386	33.57381481	26.97959174	0.725696905
11	3	275.8169172	33.39742295	-0.097550941	0.016746964	213.9111386	33.57381481	26.97959174	0.725696905
11	4	482.6329026	56.58555977	-0.201394767	0.028315295	416.4957273	56.79914145	6.935299034	0.269803571
11	5	482.6329026	56.58555977	-0.201394767	0.028315295	416.4957273	56.79914145	6.935299034	0.269803571

Appendix K – Parameter inputs of the size at 50 and 95% maturity in each region and year for the stock assessment model.

#	Simes	estimate	with	adrians	CV	from	SAMtrendV5		
451	#								
#_area	year	sb50	sb50_se	sb95	sb95_se	db50	db50_se	db95	db95_se
1	1975	96.96192481	3.469688466	109.0356026	7.633585569	108.2278456	3.872828519	126.4508016	8.852824134
1	1976	96.61694869	3.365258311	108.6476701	7.355040967	107.842787	3.756264715	126.0009085	8.529790315
1	1977	96.27197258	3.264082922	108.2597377	7.086742512	107.4577284	3.643333846	125.5510153	8.218639146
1	1978	95.92699647	3.166528783	107.8718052	6.829324681	107.0726698	3.534444977	125.1011222	7.920106457
1	1979	95.58202036	3.072998251	107.4838727	6.583478748	106.6876112	3.430047216	124.651229	7.634993946
1	1980	95.23704424	2.983930276	107.0959403	6.349951931	106.3025527	3.330630511	124.2013359	7.364168152
1	1981	94.89206813	2.899799898	106.7080078	6.129543852	105.9174941	3.236725097	123.7514427	7.108556424
1	1982	94.54709202	2.821116036	106.3200754	5.923099549	105.5324355	3.148899028	123.3015496	6.869138782
1	1983	94.20211591	2.748417087	105.9321429	5.731498095	105.1473769	3.067753252	122.8516564	6.646934683
1	1984	93.85713979	2.682263787	105.5442104	5.555635932	104.7623183	2.993913657	122.4017633	6.442983764
1	1985	93.51216368	2.623228946	105.156278	5.396404422	104.3772597	2.92801961	121.9518701	6.258319752
1	1986	93.16718757	2.571883831	104.7683455	5.254661419	103.9922012	2.87070875	121.501977	6.09393751
1	1987	92.82221146	2.528781311	104.380413	5.131197403	103.6071426	2.822598188	121.0520838	5.950753786
1	1988	92.47723534	2.494436403	103.9924806	5.026697792	103.222084	2.784262775	120.6021907	5.829563467
1	1989	92.13225923	2.469305331	103.6045481	4.941703923	102.8370254	2.756211746	120.1522975	5.73099435
1	1990	91.78728312	2.453764834	103.2166157	4.876576181	102.4519668	2.738865611	119.7024044	5.655464384
1	1991	91.44230701	2.448093744	102.8286832	4.831463327	102.0669082	2.732535604	119.2525112	5.603146095
1	1992	91.0973309	2.452458959	102.4407507	4.806281905	101.6818497	2.737408008	118.8026181	5.57394269
1	1993	90.75235478	2.46690752	102.0528183	4.80070861	101.2967911	2.753535335	118.3527249	5.567479224
1	1994	87.37911556	2.283060428	98.25954403	4.182540976	97.53161814	2.548327212	113.9535878	4.850577671
1	1995	87.03413944	2.229947569	97.87161156	4.055615041	97.14655956	2.489043216	113.5036946	4.703379086
1	1996	86.68916333	2.186697339	97.4836791	3.947995394	96.76150098	2.44076778	113.0538015	4.578570401
1	1997	86.34418722	2.154024233	97.09574664	3.86056506	96.37644239	2.404298415	112.6039083	4.477175666
1	1998	85.99921111	2.132539304	96.70781418	3.793987834	95.99138381	2.38031717	112.1540152	4.399964703
1	1999	85.654235	2.122711135	96.31988171	3.748646415	95.60632523	2.369347074	111.704122	4.347381342
1	2000	85.30925888	2.124833717	95.93194925	3.72459566	95.22126664	2.371716278	111.2542289	4.319489192
1	2001	84.96428277	2.13900646	95.54401679	3.721539334	94.83620806	2.387535739	110.8043357	4.315944708
1	2002	84.61930666	2.165129798	95.15608432	3.738835278	94.45114947	2.416694325	110.3544426	4.336003168
1	2003	84.27433055	2.2029171	94.76815186	3.775528748	94.06609089	2.458872101	109.9045494	4.378557327
1	2004	83.92935443	2.251920554	94.3802194	3.830408454	93.68103231	2.513569222	109.4546563	4.442202437
1	2005	83.58437832	2.311566476	93.99228694	3.902076426	93.29597372	2.580145352	109.0047631	4.52531724
1	2006	83.23940221	2.381194581	93.60435447	3.98902169	92.91091514	2.657863485	108.55487	4.626149426
1	2007	82.8944261	2.460096165	93.21642201	4.089689051	92.52585656	2.745932575	108.1049768	4.742895408
1	2008	82.54944998	2.547547582	92.82848955	4.202537118	92.14079797	2.843544895	107.6550836	4.873767604
1	2009	82.20447387	2.64283698	92.44055708	4.326082769	91.75573939	2.949905884	107.2051905	5.017046004
1	2010	82.20447387	2.64283698	92.44055708	4.326082769	91.75573939	2.949905884	107.2051905	5.017046004
1	2011	82.20447387	2.64283698	92.44055708	4.326082769	91.75573939	2.949905884	107.2051905	5.017046004
1	2012	82.20447387	2.64283698	92.44055708	4.326082769	91.75573939	2.949905884	107.2051905	5.017046004
1	2013	82.20447387	2.64283698	92.44055708	4.326082769	91.75573939	2.949905884	107.2051905	5.017046004
1	2014	82.20447387	2.64283698	92.44055708	4.326082769	91.75573939	2.949905884	107.2051905	5.017046004
1	2015	82.20447387	2.64283698	92.44055708	4.326082769	91.75573939	2.949905884	107.2051905	5.017046004
2	1975	96.96192481	3.469688466	109.0356026	7.633585569	108.2278456	3.872828519	126.4508016	8.852824134
2	1976	96.61694869	3.365258311	108.6476701	7.355040967	107.842787	3.756264715	126.0009085	8.529790315
2	1977	96.27197258	3.264082922	108.2597377	7.086742512	107.4577284	3.643333846	125.5510153	8.218639146
2	1978	95.92699647	3.166528783	107.8718052	6.829324681	107.0726698	3.534444977	125.1011222	7.920106457
2	1979	95.58202036	3.072998251	107.4838727	6.583478748	106.6876112	3.430047216	124.651229	7.634993946
2	1980	95.23704424	2.983930276	107.0959403	6.349951931	106.3025527	3.330630511	124.2013359	7.364168152
2	1981	94.89206813	2.899799898	106.7080078	6.129543852	105.9174941	3.236725097	123.7514427	7.108556424
2	1982	94.54709202	2.821116036	106.3200754	5.923099549	105.5324355	3.148899028	123.3015496	6.869138782
2	1983	94.20211591	2.748417087	105.9321429	5.731498095	105.1473769	3.067753252	122.8516564	6.646934683
2	1984	93.85713979	2.682263787	105.5442104	5.555635932	104.7623183	2.993913657	122.4017633	6.442983764
2	1985	93.51216368	2.623228946	105.156278	5.396404422	104.3772597	2.92801961	121.9518701	6.258319752
2	1986	93.16718757	2.571883831	104.7683455	5.254661419	103.9922012	2.87070875	121.501977	6.09393751
2	1987	92.82221146	2.528781311	104.380413	5.131197403	103.6071426	2.822598188	121.0520838	5.950753786
2	1988	92.47723534	2.494436403	103.9924806	5.026697792	103.222084	2.784262775	120.6021907	5.829563467
2	1989	92.13225923	2.469305331	103.6045481	4.941703923	102.8370254	2.756211746	120.1522975	5.73099435
2	1990	91.78728312	2.453764834	103.2166157	4.876576181	102.4519668	2.738865611	119.7024044	5.655464384
2	1991	91.44230701	2.448093744	102.8286832	4.831463327	102.0669082	2.732535604	119.2525112	5.603146095

2	1992	91.0973309	2.452458959	102.4407507	4.806281905	101.6818497	2.737408008	118.8026181	5.57394269
2	1993	90.75235478	2.46690752	102.0528183	4.80070861	101.2967911	2.753535335	118.3527249	5.567479224
2	1994	87.37911556	2.283060428	98.25954403	4.182540976	97.53161814	2.548327212	113.9535878	4.850577671
2	1995	87.03413944	2.229947569	97.87161156	4.055615041	97.14655956	2.489043216	113.5036946	4.703379086
2	1996	86.68916333	2.186697339	97.4836791	3.947995394	96.76150098	2.44076778	113.0538015	4.578570401
2	1997	86.34418722	2.154024233	97.09574664	3.86056506	96.37644239	2.404298415	112.6039083	4.477175666
2	1998	85.99921111	2.132539304	96.70781418	3.793987834	95.99138381	2.38031717	112.1540152	4.399964703
2	1999	85.654235	2.122711135	96.31988171	3.748646415	95.60632523	2.369347074	111.704122	4.347381342
2	2000	85.30925888	2.124833717	95.93194925	3.72459566	95.22126664	2.371716278	111.2542289	4.319489192
2	2001	84.96428277	2.13900646	95.54401679	3.721539334	94.83620806	2.387535739	110.8043357	4.315944708
2	2002	84.61930666	2.165129798	95.15608432	3.738835278	94.45114947	2.416694325	110.3544426	4.336003168
2	2003	84.27433055	2.2029171	94.76815186	3.775528748	94.06609089	2.458872101	109.9045494	4.378557327
2	2004	83.92935443	2.251920554	94.3802194	3.830408454	93.68103231	2.513569222	109.4546563	4.442202437
2	2005	83.58437832	2.311566476	93.99228694	3.902076426	93.29597372	2.580145352	109.0047631	4.52531724
2	2006	83.23940221	2.381194581	93.60435447	3.98902169	92.91091514	2.657863485	108.55487	4.626149426
2	2007	82.8944261	2.460096165	93.21642201	4.089689051	92.52585656	2.745932575	108.1049768	4.742895408
2	2008	82.54944998	2.547547582	92.82848955	4.202537118	92.14079797	2.843544895	107.6550836	4.873767604
2	2009	82.20447387	2.64283698	92.44055708	4.326082769	91.75573939	2.949905884	107.2051905	5.017046004
2	2010	82.20447387	2.64283698	92.44055708	4.326082769	91.75573939	2.949905884	107.2051905	5.017046004
2	2011	82.20447387	2.64283698	92.44055708	4.326082769	91.75573939	2.949905884	107.2051905	5.017046004
2	2012	82.20447387	2.64283698	92.44055708	4.326082769	91.75573939	2.949905884	107.2051905	5.017046004
2	2013	82.20447387	2.64283698	92.44055708	4.326082769	91.75573939	2.949905884	107.2051905	5.017046004
2	2014	82.20447387	2.64283698	92.44055708	4.326082769	91.75573939	2.949905884	107.2051905	5.017046004
2	2015	82.20447387	2.64283698	92.44055708	4.326082769	91.75573939	2.949905884	107.2051905	5.017046004
3	1975	92.58658272	3.565929167	104.1154439	10.36106943	103.3441363	3.980251341	120.7447937	12.01594254
3	1976	92.24160661	3.459421278	103.7275114	9.980049143	102.9590778	3.861368393	120.2949005	11.57406558
3	1977	91.8966305	3.355399512	103.3395789	9.61084981	102.5740192	3.74526043	119.8450074	11.14589761
3	1978	91.55165438	3.254144504	102.9516465	9.254086699	102.1889606	3.632240691	119.3951142	10.73215219
3	1979	91.20667827	3.155967098	102.563714	8.910439006	101.803902	3.52265614	118.9452211	10.33361698
3	1980	90.86170216	3.061210397	102.1757816	8.580652727	101.4188434	3.416889741	118.4953279	9.951157147
3	1981	90.51672605	2.970251353	101.7878491	8.265542066	101.0337848	3.315362245	118.0454348	9.585716915
3	1982	90.17174993	2.883501617	101.3999166	7.965988669	100.6487263	3.218533134	117.5955416	9.238318757
3	1983	89.82677382	2.801407308	101.0119842	7.68293777	100.2636677	3.126900359	117.1456485	8.910058888
3	1984	89.48179771	2.724447247	100.6240517	7.41739028	99.87860909	3.040998376	116.6957553	8.60209807
3	1985	89.1368216	2.653129196	100.2361192	7.170389707	99.4935505	2.961393944	116.2458622	8.315646497
3	1986	88.79184549	2.587983603	99.84818678	6.943002882	99.10849192	2.888679142	115.795969	8.051941377
3	1987	88.44686937	2.529554439	99.46025432	6.736293693	98.72343334	2.823461144	115.3460759	7.812216531
3	1988	88.10189326	2.478386857	99.07232185	6.551289557	98.33837475	2.766348446	114.8961827	7.597663484
3	1989	87.75691715	2.435011743	98.68438939	6.388941163	97.95331617	2.717933616	114.4462896	7.409384754
3	1990	87.41194104	2.399927612	98.29645693	6.250077124	97.56825758	2.67877309	113.9963964	7.248341314
3	1991	87.06696492	2.373580848	97.90852447	6.135356443	97.183199	2.649365119	113.5465033	7.115297408
3	1992	86.72198881	2.356345808	97.520592	6.045222851	96.79814042	2.630127556	113.0966101	7.01076765
3	1993	86.3770127	2.348506669	97.13265954	5.979865855	96.41308183	2.621377593	112.646717	6.934971818
3	1994	83.00377347	2.076802488	93.3393853	4.950933162	92.64790891	2.318104342	108.2475798	5.741697689
3	1995	82.65879736	1.9979013	92.95145284	4.726013255	92.26285033	2.230035695	107.7976867	5.480853505
3	1996	82.31382125	1.927106657	92.56352037	4.523170314	91.87779174	2.151015484	107.3477935	5.245612427
3	1997	81.96884514	1.865450701	92.17558791	4.344345123	91.49273316	2.082195778	106.8979004	5.038225225
3	1998	81.62386902	1.81398061	91.78765545	4.191441677	91.10767458	2.024745421	106.4480072	4.860899993
3	1999	81.27889291	1.773704207	91.39972298	4.066201881	90.72261599	1.979789339	105.9981141	4.71565686
3	2000	80.9339168	1.745522681	91.01179052	3.970056756	90.33755741	1.948333426	105.5482209	4.604155407
3	2001	80.58894069	1.7301579	90.62385806	3.903972719	89.95249883	1.931183424	105.0983278	4.527516407
3	2002	80.24396457	1.728086262	90.2359256	3.868320166	89.56744024	1.928871084	104.6484346	4.486169421
3	2003	79.89898846	1.739492552	89.84799313	3.862793386	89.18238166	1.941602662	104.1985415	4.479759901
3	2004	79.55401235	1.764254497	89.46006067	3.886402731	88.79732308	1.969241675	103.7486483	4.507140136
3	2005	79.20903624	1.8019616	89.07212821	3.937543072	88.41226449	2.011329934	103.2987552	4.566448629
3	2006	78.86406012	1.85196338	88.68419574	4.014123621	88.02720591	2.067141377	102.848862	4.655260645
3	2007	78.51908401	1.913435635	88.29626328	4.113731166	87.64214732	2.135756039	102.3989688	4.77077754
3	2008	78.1741079	1.985451421	87.90833082	4.233796131	87.25708874	2.216139275	101.9490757	4.910019314
3	2009	77.82913179	2.067045587	87.52039836	4.37173741	86.87203016	2.307213796	101.4991825	5.069992615
3	2010	77.82913179	2.067045587	87.52039836	4.37173741	86.87203016	2.307213796	101.4991825	5.069992615
3	2011	77.82913179	2.067045587	87.52039836	4.37173741	86.87203016	2.307213796	101.4991825	5.069992615
3	2012	77.82913179	2.067045587	87.52039836	4.37173741	86.87203016	2.307213796	101.4991825	5.069992615
3	2013	77.82913179	2.067045587	87.52039836	4.37173741	86.87203016	2.307213796	101.4991825	5.069992615
3	2014	77.82913179	2.067045587	87.52039836	4.37173741	86.87203016	2.307213796	101.4991825	5.069992615
3	2015	77.82913179	2.067045587	87.52039836	4.37173741	86.87203016	2.307213796	101.4991825	5.069992615

4	1975	92.58658272	3.565929167	104.1154439	10.36106943	103.3441363	3.980251341	120.7447937	12.01594254
4	1976	92.24160661	3.459421278	103.7275114	9.980049143	102.9590778	3.861368393	120.2949005	11.57406558
4	1977	91.8966305	3.355399512	103.3395789	9.61084981	102.5740192	3.74526043	119.8450074	11.14589761
4	1978	91.55165438	3.254144504	102.9516465	9.254086699	102.1889606	3.632240691	119.3951142	10.73215219
4	1979	91.20667827	3.155967098	102.563714	8.910439006	101.803902	3.52265614	118.9452211	10.33361698
4	1980	90.86170216	3.061210397	102.1757816	8.580652727	101.4188434	3.416889741	118.4953279	9.951157147
4	1981	90.51672605	2.970251353	101.7878491	8.265542066	101.0337848	3.315362245	118.0454348	9.585716915
4	1982	90.17174993	2.883501617	101.3999166	7.965988669	100.6487263	3.218533134	117.5955416	9.238318757
4	1983	89.82677382	2.801407308	101.0119842	7.68293777	100.2636677	3.126900359	117.1456485	8.910058888
4	1984	89.48179771	2.724447247	100.6240517	7.41739028	99.87860909	3.040998376	116.6957553	8.60209807
4	1985	89.1368216	2.653129196	100.2361192	7.170389707	99.4935505	2.961393944	116.2458622	8.315646497
4	1986	88.79184549	2.587983603	99.84818678	6.943002882	99.10849192	2.888679142	115.795969	8.051941377
4	1987	88.44686937	2.529554439	99.46025432	6.736293693	98.72343334	2.823461144	115.3460759	7.812216531
4	1988	88.10189326	2.478386857	99.07232185	6.551289557	98.33837475	2.766348446	114.8961827	7.597663484
4	1989	87.75691715	2.435011743	98.68438939	6.388941163	97.95331617	2.717933616	114.4462896	7.409384754
4	1990	87.41194104	2.399927612	98.29645693	6.250077124	97.56825758	2.67877309	113.9963964	7.248341314
4	1991	87.06696492	2.373580848	97.90852447	6.135356443	97.183199	2.649365119	113.5465033	7.115297408
4	1992	86.72198881	2.356345808	97.520592	6.045222851	96.79814042	2.630127556	113.0966101	7.01076765
4	1993	86.3770127	2.348506669	97.13265954	5.979865855	96.41308183	2.621377593	112.646717	6.934971818
4	1994	83.00377347	2.076802488	93.3393853	4.950933162	92.64790891	2.318104342	108.2475798	5.741697689
4	1995	82.65879736	1.9979013	92.95145284	4.726013255	92.26285033	2.230035695	107.7976867	5.480853505
4	1996	82.31382125	1.927106657	92.56352037	4.523170314	91.87779174	2.151015484	107.3477935	5.245612427
4	1997	81.96884514	1.865450701	92.17558791	4.344345123	91.49273316	2.082195778	106.8979004	5.038225225
4	1998	81.62386902	1.81398061	91.78765545	4.191441677	91.10767458	2.024745421	106.4480072	4.860899993
4	1999	81.27889291	1.773704207	91.39972298	4.066201881	90.72261599	1.979789339	105.9981141	4.71565686
4	2000	80.9339168	1.745522681	91.01179052	3.970056756	90.33755741	1.948333426	105.5482209	4.604155407
4	2001	80.58894069	1.7301579	90.62385806	3.903972719	89.95249883	1.931183424	105.0983278	4.527516407
4	2002	80.24396457	1.728086262	90.2359256	3.868320166	89.56744024	1.928871084	104.6484346	4.486169421
4	2003	79.89898846	1.739492552	89.84799313	3.862793386	89.18238166	1.941602662	104.1985415	4.479759901
4	2004	79.55401235	1.764254497	89.46006067	3.886402731	88.79732308	1.969241675	103.7486483	4.507140136
4	2005	79.20903624	1.8019616	89.07212821	3.937543072	88.41226449	2.011329934	103.2987552	4.566448629
4	2006	78.86406012	1.85196338	88.68419574	4.014123621	88.02720591	2.067141377	102.848862	4.655260645
4	2007	78.51908401	1.913435635	88.29626328	4.113731166	87.64214732	2.135756039	102.3989688	4.77077754
4	2008	78.1741079	1.985451421	87.90833082	4.233796131	87.25708874	2.216139275	101.9490757	4.910019314
4	2009	77.82913179	2.067045587	87.52039836	4.37173741	86.87203016	2.307213796	101.4991825	5.069992615
4	2010	77.82913179	2.067045587	87.52039836	4.37173741	86.87203016	2.307213796	101.4991825	5.069992615
4	2011	77.82913179	2.067045587	87.52039836	4.37173741	86.87203016	2.307213796	101.4991825	5.069992615
4	2012	77.82913179	2.067045587	87.52039836	4.37173741	86.87203016	2.307213796	101.4991825	5.069992615
4	2013	77.82913179	2.067045587	87.52039836	4.37173741	86.87203016	2.307213796	101.4991825	5.069992615
4	2014	77.82913179	2.067045587	87.52039836	4.37173741	86.87203016	2.307213796	101.4991825	5.069992615
4	2015	77.82913179	2.067045587	87.52039836	4.37173741	86.87203016	2.307213796	101.4991825	5.069992615
5	1975	88.45535704	3.398681228	99.46979887	9.263400156	98.73290718	3.793571011	115.3571449	10.7429532
5	1976	88.11038093	3.29531123	99.0818664	8.915972392	98.34784859	3.678190544	114.9072517	10.34003416
5	1977	87.76540482	3.194778508	98.69393394	8.580550673	97.96279001	3.565977013	114.4573586	9.951038793
5	1978	87.4204287	3.097406159	98.30600148	8.257800809	97.57773143	3.457291056	114.0074654	9.576739221
5	1979	87.07545259	3.00355102	97.91806902	7.948454076	97.19267284	3.352530971	113.5575723	9.217983543
5	1980	86.73047648	2.913605229	97.53013655	7.653308265	96.80761426	3.252134458	113.1076791	8.875696949
5	1981	86.38550037	2.827996951	97.14220409	7.373226379	96.42255568	3.156579429	112.657786	8.550880298
5	1982	86.04052425	2.747189859	96.75427163	7.109132112	96.03749709	3.066383432	112.2078928	8.24460482
5	1983	85.69554814	2.671680911	96.36633916	6.862000992	95.65243851	2.982101166	111.7579997	7.958001841
5	1984	85.35057203	2.601995882	95.9784067	6.632846156	95.26737993	2.904319494	111.3081065	7.692246325
5	1985	85.00559592	2.538682158	95.59047424	6.422697704	94.88232134	2.833649405	110.8582134	7.448532902
5	1986	84.66061981	2.482298352	95.20254178	6.232574939	94.49726276	2.770714415	110.4083202	7.22804367
5	1987	84.31564369	2.433400538	94.81460931	6.063451407	94.11220418	2.716135205	109.9584271	7.031907682
5	1988	83.97066758	2.39252526	94.42667685	5.916213523	93.72714559	2.670510665	109.5085339	6.861152916
5	1989	83.62569147	2.360169968	94.03874439	5.791614796	93.34208701	2.634396041	109.0586408	6.716653239
5	1990	83.28071536	2.336772099	93.65081192	5.690228935	92.95702843	2.608279594	108.6087476	6.599074003
5	1991	82.93573924	2.322688559	93.26287946	5.612406255	92.57196984	2.5925597	108.1588544	6.508821459
5	1992	82.59076313	2.318177728	92.874947	5.558238321	92.18691126	2.58752476	107.7089613	6.446001805
5	1993	82.24578702	2.323386102	92.48701454	5.527535557	91.80185268	2.59333829	107.2590681	6.410395189
5	1994	78.87254779	1.91569027	88.69374029	4.259040063	88.03667975	2.138272638	102.859931	4.939295216
5	1995	78.52757168	1.845931302	88.30580783	4.071090374	87.65162117	2.060408436	102.4100379	4.721326146
5	1996	78.18259557	1.785807531	87.91787537	3.906827263	87.26656258	1.993298937	101.9601447	4.53082688
5	1997	77.83761946	1.736446282	87.52994291	3.768171247	86.881504	1.938202449	101.5102516	4.370024686
5	1998	77.49264334	1.698918546	87.14201044	3.656846371	86.49644542	1.896314398	101.0603584	4.240918966

5	1999	77.14766723	1.674158713	86.75407798	3.574214511	86.11138683	1.868677741	100.6104652	4.145089123
5	2000	76.80269112	1.662880563	86.36614552	3.521110093	85.72632825	1.856089193	100.1605721	4.083502848
5	2001	76.45771501	1.665505233	85.97821305	3.497708583	85.34126967	1.859018821	99.71067895	4.056363643
5	2002	76.11273889	1.682117644	85.59028059	3.503461513	84.95621108	1.877561413	99.26078579	4.063035434
5	2003	75.76776278	1.71246239	85.20234813	3.537117219	84.5711525	1.911431889	98.81089264	4.102066638
5	2004	75.42278667	1.755979909	84.81441567	3.596824172	84.18609392	1.96000567	98.36099949	4.171310006
5	2005	75.07781056	1.811873179	84.4264832	3.680292278	83.80103533	2.02239313	97.91110634	4.268109661
5	2006	74.73283444	1.879189047	84.03855074	3.784976506	83.41597675	2.09753037	97.46121319	4.389514083
5	2007	74.38785833	1.956898264	83.65061828	3.908249421	83.03091817	2.184268552	97.01132003	4.532476188
5	2008	74.04288222	2.043962906	83.26268581	4.047540471	82.64585958	2.281449158	96.56142688	4.694014845
5	2009	73.69790611	2.139385991	82.87475335	4.200433429	82.260801	2.387959368	96.11153373	4.871327909
5	2010	73.69790611	2.139385991	82.87475335	4.200433429	82.260801	2.387959368	96.11153373	4.871327909
5	2011	73.69790611	2.139385991	82.87475335	4.200433429	82.260801	2.387959368	96.11153373	4.871327909
5	2012	73.69790611	2.139385991	82.87475335	4.200433429	82.260801	2.387959368	96.11153373	4.871327909
5	2013	73.69790611	2.139385991	82.87475335	4.200433429	82.260801	2.387959368	96.11153373	4.871327909
5	2014	73.69790611	2.139385991	82.87475335	4.200433429	82.260801	2.387959368	96.11153373	4.871327909
5	2015	73.69790611	2.139385991	82.87475335	4.200433429	82.260801	2.387959368	96.11153373	4.871327909
6	1975	88.45535704	3.398681228	99.46979887	9.263400156	98.73290718	3.793571011	115.3571449	10.7429532
6	1976	88.11038093	3.29531123	99.0818664	8.915972392	98.34784859	3.678190544	114.9072517	10.34003416
6	1977	87.76540482	3.194778508	98.69393394	8.580550673	97.96279001	3.565977013	114.4573586	9.951038793
6	1978	87.4204287	3.097406159	98.30600148	8.257800809	97.57773143	3.457291056	114.0074654	9.576739221
6	1979	87.07545259	3.00355102	97.91806902	7.948454076	97.19267284	3.352530971	113.5575723	9.217983543
6	1980	86.73047648	2.913605229	97.53013655	7.653308265	96.80761426	3.252134458	113.1076791	8.875696949
6	1981	86.38550037	2.827996951	97.14220409	7.373226379	96.42255568	3.156579429	112.657786	8.550880298
6	1982	86.04052425	2.747189859	96.75427163	7.109132112	96.03749709	3.066383432	112.2078928	8.24460482
6	1983	85.69554814	2.671680911	96.36633916	6.862000992	95.65243851	2.982101166	111.7579997	7.958001841
6	1984	85.35057203	2.601995882	95.9784067	6.632846156	95.26737993	2.904319494	111.3081065	7.692246325
6	1985	85.00559592	2.538682158	95.59047424	6.422697704	94.88232134	2.833649405	110.8582134	7.448532902
6	1986	84.66061981	2.482298352	95.20254178	6.232574939	94.49726276	2.770714415	110.4083202	7.22804367
6	1987	84.31564369	2.433400538	94.81460931	6.063451407	94.11220418	2.716135205	109.9584271	7.031907682
6	1988	83.97066758	2.39252526	94.42667685	5.916213523	93.72714559	2.670510665	109.5085339	6.861152916
6	1989	83.62569147	2.360169968	94.03874439	5.791614796	93.34208701	2.634396041	109.0586408	6.716653239
6	1990	83.28071536	2.336772099	93.65081192	5.690228935	92.95702843	2.608279594	108.6087476	6.599074003
6	1991	82.93573924	2.322688559	93.26287946	5.612406255	92.57196984	2.5925597	108.1588544	6.508821459
6	1992	82.59076313	2.318177728	92.874947	5.558238321	92.18691126	2.58752476	107.7089613	6.446001805
6	1993	82.24578702	2.323386102	92.48701454	5.527535557	91.80185268	2.59333829	107.2590681	6.410395189
6	1994	78.87254779	1.91569027	88.69374029	4.259040063	88.03667975	2.138272638	102.859931	4.939295216
6	1995	78.52757168	1.845931302	88.30580783	4.071090374	87.65162117	2.060408436	102.4100379	4.721326146
6	1996	78.18259557	1.785807531	87.91787537	3.906827263	87.26656258	1.993298937	101.9601447	4.53082688
6	1997	77.83761946	1.736446282	87.52994291	3.768171247	86.881504	1.938202449	101.5102516	4.370024686
6	1998	77.49264334	1.698918546	87.14201044	3.656846371	86.49644542	1.896314398	101.0603584	4.240918966
6	1999	77.14766723	1.674158713	86.75407798	3.574214511	86.11138683	1.868677741	100.6104652	4.145089123
6	2000	76.80269112	1.662880563	86.36614552	3.521110093	85.72632825	1.856089193	100.1605721	4.083502848
6	2001	76.45771501	1.665505233	85.97821305	3.497708583	85.34126967	1.859018821	99.71067895	4.056363643
6	2002	76.11273889	1.682117644	85.59028059	3.503461513	84.95621108	1.877561413	99.26078579	4.063035434
6	2003	75.76776278	1.71246239	85.20234813	3.537117219	84.5711525	1.911431889	98.81089264	4.102066638
6	2004	75.42278667	1.755979909	84.81441567	3.596824172	84.18609392	1.96000567	98.36099949	4.171310006
6	2005	75.07781056	1.811873179	84.4264832	3.680292278	83.80103533	2.02239313	97.91110634	4.268109661
6	2006	74.73283444	1.879189047	84.03855074	3.784976506	83.41597675	2.09753037	97.46121319	4.389514083
6	2007	74.38785833	1.956898264	83.65061828	3.908249421	83.03091817	2.184268552	97.01132003	4.532476188
6	2008	74.04288222	2.043962906	83.26268581	4.047540471	82.64585958	2.281449158	96.56142688	4.694014845
6	2009	73.69790611	2.139385991	82.87475335	4.200433429	82.260801	2.387959368	96.11153373	4.871327909
6	2010	73.69790611	2.139385991	82.87475335	4.200433429	82.260801	2.387959368	96.11153373	4.871327909
6	2011	73.69790611	2.139385991	82.87475335	4.200433429	82.260801	2.387959368	96.11153373	4.871327909
6	2012	73.69790611	2.139385991	82.87475335	4.200433429	82.260801	2.387959368	96.11153373	4.871327909
6	2013	73.69790611	2.139385991	82.87475335	4.200433429	82.260801	2.387959368	96.11153373	4.871327909
6	2014	73.69790611	2.139385991	82.87475335	4.200433429	82.260801	2.387959368	96.11153373	4.871327909
6	2015	73.69790611	2.139385991	82.87475335	4.200433429	82.260801	2.387959368	96.11153373	4.871327909
7	1975	91.01208096	3.642183279	102.3448855	10.46232086	101.5866946	4.06536535	118.6914412	12.13336587
7	1976	90.66710485	3.548540041	101.956953	10.11969105	101.201636	3.960841788	118.241548	11.73601113
7	1977	90.32212874	3.458114565	101.5690206	9.790363458	100.8165774	3.859909855	117.7916549	11.35408324
7	1978	89.97715262	3.371208395	101.1810881	9.474960209	100.4315189	3.762906133	117.3417617	10.98830369
7	1979	89.63217651	3.288145303	100.7931556	9.174142638	100.0464603	3.670192014	116.8918686	10.63943944
7	1980	89.2872004	3.209270606	100.4052232	8.888607384	99.66140168	3.582152935	116.4419754	10.30829841
7	1981	88.94222429	3.134949611	100.0172907	8.619080194	99.2763431	3.49919665	115.9920823	9.995722259

7	1982	88.59724817	3.06556501	99.62935825	8.366307046	98.89128452	3.421750313	115.5421891	9.702576108
7	1983	88.25227206	3.001512999	99.24142579	8.131042186	98.50622593	3.350256155	115.092296	9.42973467
7	1984	87.90729595	2.943197994	98.85349333	7.914032856	98.12116735	3.28516558	114.6424028	9.17806455
7	1985	87.56231984	2.891025828	98.46556086	7.716000628	97.73610877	3.226931576	114.1925097	8.948402552
7	1986	87.21734372	2.845395473	98.0776284	7.537619633	97.35105018	3.17599947	113.7426165	8.741530497
7	1987	86.87236761	2.806689432	97.68969594	7.379492292	96.9659916	3.132796208	113.2927234	8.558147007
7	1988	86.5273915	2.775263164	97.30176348	7.242123638	96.58093302	3.09771855	112.8428302	8.398837788
7	1989	86.18241539	2.751434076	96.91383101	7.125895741	96.19587443	3.071120781	112.3929371	8.264045942
7	1990	85.83743927	2.735470778	96.52589855	7.031044064	95.81081585	3.053302722	111.9430439	8.154044522
7	1991	85.49246316	2.727583413	96.13796609	6.957637773	95.42575727	3.04449893	111.4931508	8.068913762
7	1992	85.14748705	2.727915889	95.75003362	6.905565916	95.04069868	3.044870037	111.0432576	8.00852497
7	1993	84.80251094	2.736540709	95.36210116	6.874530968	94.6556401	3.054496967	110.5933645	7.972533107
7	1994	81.42927171	2.348015349	91.56882692	5.516789159	90.89046717	2.620829188	106.1942273	6.397932371
7	1995	81.0842956	2.296430091	91.18089446	5.353151785	90.50540859	2.563250282	105.7443342	6.208158791
7	1996	80.73931949	2.253511268	90.79296199	5.21163012	90.12035001	2.515344761	105.294441	6.044033242
7	1997	80.39434337	2.219858319	90.40502953	5.093110426	89.73529142	2.477781704	104.8445479	5.906583545
7	1998	80.04936726	2.195997712	90.01709707	4.998273021	89.35023284	2.451148754	104.3946547	5.796598684
7	1999	79.70439115	2.182354517	89.62916461	4.927535112	88.96517426	2.435920369	103.9447616	5.714562493
7	2000	79.35941504	2.179227529	89.24123214	4.881004611	88.58011567	2.43243006	103.4948684	5.660600126
7	2001	79.01443893	2.186771355	88.85329968	4.85845198	88.19505709	2.440850395	103.0449753	5.634445384
7	2002	78.66946281	2.204988108	88.46536722	4.859305063	87.80999851	2.461183737	102.5950821	5.635434719
7	2003	78.3244867	2.233729996	88.07743475	4.882668443	87.42493992	2.493265121	102.145189	5.662529708
7	2004	77.97951059	2.272712279	87.68950229	4.927364851	87.03988134	2.536776721	101.6952958	5.714365038
7	2005	77.63453448	2.321534503	87.30156983	4.991992851	86.65482276	2.591271555	101.2454027	5.789315439
7	2006	77.28955836	2.379706892	86.91363737	5.074993096	86.26976417	2.656202942	100.7955095	5.885572512
7	2007	76.94458225	2.446678488	86.5257049	5.174715406	85.88470559	2.730955909	100.3456164	6.001222498
7	2008	76.59960614	2.521864084	86.13777244	5.289480237	85.49964701	2.814877253	99.8957232	6.134317599
7	2009	76.25463003	2.604667817	85.74983998	5.417630332	85.11458842	2.90730188	99.44583005	6.28293587
7	2010	76.25463003	2.604667817	85.74983998	5.417630332	85.11458842	2.90730188	99.44583005	6.28293587
7	2011	76.25463003	2.604667817	85.74983998	5.417630332	85.11458842	2.90730188	99.44583005	6.28293587
7	2012	76.25463003	2.604667817	85.74983998	5.417630332	85.11458842	2.90730188	99.44583005	6.28293587
7	2013	76.25463003	2.604667817	85.74983998	5.417630332	85.11458842	2.90730188	99.44583005	6.28293587
7	2014	76.25463003	2.604667817	85.74983998	5.417630332	85.11458842	2.90730188	99.44583005	6.28293587
7	2015	76.25463003	2.604667817	85.74983998	5.417630332	85.11458842	2.90730188	99.44583005	6.28293587
8	1975	91.01208096	3.642183279	102.3448855	10.46232086	101.5866946	4.06536535	118.6914412	12.13336587
8	1976	90.66710485	3.548540041	101.956953	10.11969105	101.201636	3.960841788	118.241548	11.73601113
8	1977	90.32212874	3.458114565	101.5690206	9.790363458	100.8165774	3.859909855	117.7916549	11.35408324
8	1978	89.97715262	3.371208395	101.1810881	9.474960209	100.4315189	3.762906133	117.3417617	10.98830369
8	1979	89.63217651	3.288145303	100.7931556	9.174142638	100.0464603	3.670192014	116.8918686	10.63943944
8	1980	89.2872004	3.209270606	100.4052232	8.888607384	99.66140168	3.582152935	116.4419754	10.30829841
8	1981	88.94222429	3.134949611	100.0172907	8.619080194	99.2763431	3.49919665	115.9920823	9.995722259
8	1982	88.59724817	3.06556501	99.62935825	8.366307046	98.89128452	3.421750313	115.5421891	9.702576108
8	1983	88.25227206	3.001512999	99.24142579	8.131042186	98.50622593	3.350256155	115.092296	9.42973467
8	1984	87.90729595	2.943197994	98.85349333	7.914032856	98.12116735	3.28516558	114.6424028	9.17806455
8	1985	87.56231984	2.891025828	98.46556086	7.716000628	97.73610877	3.226931576	114.1925097	8.948402552
8	1986	87.21734372	2.845395473	98.0776284	7.537619633	97.35105018	3.17599947	113.7426165	8.741530497
8	1987	86.87236761	2.806689432	97.68969594	7.379492292	96.9659916	3.132796208	113.2927234	8.558147007
8	1988	86.5273915	2.775263164	97.30176348	7.242123638	96.58093302	3.09771855	112.8428302	8.398837788
8	1989	86.18241539	2.751434076	96.91383101	7.125895741	96.19587443	3.071120781	112.3929371	8.264045942
8	1990	85.83743927	2.735470778	96.52589855	7.031044064	95.81081585	3.053302722	111.9430439	8.154044522
8	1991	85.49246316	2.727583413	96.13796609	6.957637773	95.42575727	3.04449893	111.4931508	8.068913762
8	1992	85.14748705	2.727915889	95.75003362	6.905565916	95.04069868	3.044870037	111.0432576	8.00852497
8	1993	84.80251094	2.736540709	95.36210116	6.874530968	94.6556401	3.054496967	110.5933645	7.972533107
8	1994	81.42927171	2.348015349	91.56882692	5.516789159	90.89046717	2.620829188	106.1942273	6.397932371
8	1995	81.0842956	2.296430091	91.18089446	5.353151785	90.50540859	2.563250282	105.7443342	6.208158791
8	1996	80.73931949	2.253511268	90.79296199	5.21163012	90.12035001	2.515344761	105.294441	6.044033242
8	1997	80.39434337	2.219858319	90.40502953	5.093110426	89.73529142	2.477781704	104.8445479	5.906583545
8	1998	80.04936726	2.195997712	90.01709707	4.998273021	89.35023284	2.451148754	104.3946547	5.796598684
8	1999	79.70439115	2.182354517	89.62916461	4.927535112	88.96517426	2.435920369	103.9447616	5.714562493
8	2000	79.35941504	2.179227529	89.24123214	4.881004611	88.58011567	2.43243006	103.4948684	5.660600126
8	2001	79.01443893	2.186771355	88.85329968	4.85845198	88.19505709	2.440850395	103.0449753	5.634445384
8	2002	78.66946281	2.204988108	88.46536722	4.859305063	87.80999851	2.461183737	102.5950821	5.635434719
8	2003	78.3244867	2.233729996	88.07743475	4.882668443	87.42493992	2.493265121	102.145189	5.662529708
8	2004	77.97951059	2.272712279	87.68950229	4.927364851	87.03988134	2.536776721	101.6952958	5.714365038
8	2005	77.63453448	2.321534503	87.30156983	4.991992851	86.65482276	2.591271555	101.2454027	5.789315439

8	2006	77.28955836	2.379706892	86.91363737	5.074993096	86.26976417	2.656202942	100.7955095	5.885572512
8	2007	76.94458225	2.446678488	86.5257049	5.174715406	85.88470559	2.730955909	100.3456164	6.001222498
8	2008	76.59960614	2.521864084	86.13777244	5.289480237	85.49964701	2.814877253	99.8957232	6.134317599
8	2009	76.25463003	2.604667817	85.74983998	5.417630332	85.11458842	2.90730188	99.44583005	6.28293587
8	2010	76.25463003	2.604667817	85.74983998	5.417630332	85.11458842	2.90730188	99.44583005	6.28293587
8	2011	76.25463003	2.604667817	85.74983998	5.417630332	85.11458842	2.90730188	99.44583005	6.28293587
8	2012	76.25463003	2.604667817	85.74983998	5.417630332	85.11458842	2.90730188	99.44583005	6.28293587
8	2013	76.25463003	2.604667817	85.74983998	5.417630332	85.11458842	2.90730188	99.44583005	6.28293587
8	2014	76.25463003	2.604667817	85.74983998	5.417630332	85.11458842	2.90730188	99.44583005	6.28293587
8	2015	76.25463003	2.604667817	85.74983998	5.417630332	85.11458842	2.90730188	99.44583005	6.28293587
9	1975	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	1976	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	1977	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
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9	1979	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	1980	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	1981	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	1982	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	1983	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	1984	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	1985	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	1986	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	1987	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	1988	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	1989	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	1990	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	1991	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	1992	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	1993	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	1994	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	1995	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	1996	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
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9	2001	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	2002	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	2003	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	2004	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	2005	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	2006	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	2007	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	2008	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	2009	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	2010	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	2011	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	2012	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	2013	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	2014	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
9	2015	64.14	2.29	72.13	5.309075966	71.59881801	2.562509162	83.65433024	6.157043166
10	1975	73.19023223	3.319051143	82.30386403	9.54091047	81.69414094	3.704688776	95.4494618	11.06478754
10	1976	72.84525612	3.215718302	81.91593157	9.161036569	81.30908236	3.589349784	94.99956865	10.62424007
10	1977	72.50028	3.115195179	81.52799911	8.794843031	80.92402377	3.477146967	94.54967549	10.19955799
10	1978	72.15530389	3.017818436	81.14006664	8.443011382	80.53896519	3.368456105	94.09978234	9.791531684
10	1979	71.81032778	2.923961805	80.75213418	8.106294528	80.1539066	3.263694356	93.64988919	9.401034314
10	1980	71.46535167	2.834038108	80.36420172	7.785518018	79.76884802	3.163322504	93.19999604	9.029023283
10	1981	71.12037555	2.748500367	79.97626925	7.48157864	79.38378944	3.067846207	92.75010289	8.676538617
10	1982	70.77539944	2.667841555	79.58833679	7.195439228	78.99873085	2.977815719	92.30020974	8.344696932
10	1983	70.43042333	2.592592425	79.20040433	6.928118437	78.61367227	2.893823459	91.85031658	8.034679583
10	1984	70.08544722	2.52331677	78.81247187	6.680674114	78.22861369	2.816498726	91.40042343	7.747713381
10	1985	69.7404711	2.460603487	78.4245394	6.454179065	77.8435551	2.746498842	90.95053028	7.485042475
10	1986	69.39549499	2.405054916	78.03660694	6.249688317	77.45849652	2.684496132	90.50063713	7.247890402
10	1987	69.05051888	2.357271174	77.64867448	6.068197851	77.07343794	2.631160438	90.05074398	7.037412226
10	1988	68.70554277	2.317830673	77.26074201	5.910595886	76.68837935	2.58713738	89.60085082	6.854638027

10	1989	68.36056666	2.287267637	76.87280955	5.777609345	76.30332077	2.553023251	89.15095767	6.700410838
10	1990	68.01559054	2.266048129	76.48487709	5.669749825	75.91826219	2.529338268	88.70106452	6.575323963
10	1991	67.67061443	2.254546802	76.09694463	5.587264651	75.5332036	2.516500611	88.25117137	6.479664231
10	1992	67.32563832	2.253026954	75.70901216	5.530099251	75.14814502	2.514804175	87.80127822	6.413368357
10	1993	66.98066221	2.261626446	75.3210797	5.497876395	74.76308644	2.524402834	87.35138507	6.375998856
10	1994	63.60742298	1.992580814	71.52780546	4.451726492	70.99791351	2.224097026	82.95224793	5.162757578
10	1995	63.26244687	1.928922435	71.139873	4.266433236	70.61285493	2.153042237	82.50235478	4.947869228
10	1996	62.91747075	1.874960099	70.75194053	4.105417964	70.22779634	2.092810063	82.05246163	4.76113655
10	1997	62.57249464	1.831703688	70.36400807	3.970204042	69.84273776	2.044527729	81.60256847	4.604326219
10	1998	62.22751853	1.800086134	69.97607561	3.862067353	69.45767918	2.009236558	81.15267532	4.478917906
10	1999	61.88254242	1.780895985	69.58814314	3.781902554	69.07262059	1.987816723	80.70278217	4.385949161
10	2000	61.53756631	1.774711668	69.20021068	3.73010153	68.68756201	1.980913856	80.25288902	4.325874461
10	2001	61.19259019	1.781849511	68.81227822	3.706468793	68.30250343	1.98888104	79.80299587	4.298467096
10	2002	60.84761408	1.802336656	68.42434576	3.710194519	67.91744484	2.011748567	79.35310271	4.302787897
10	2003	60.50263797	1.835915025	68.03641329	3.739893907	67.53238626	2.049228377	78.90320956	4.337230879
10	2004	60.15766186	1.882075086	67.64848083	3.793705634	67.14732768	2.100751736	78.45331641	4.399637432
10	2005	59.81268574	1.940111308	67.26054837	3.869428835	66.76226909	2.165531134	78.00342326	4.487455166
10	2006	59.46770963	2.009187589	66.8726159	3.964672343	66.37721051	2.242633328	77.55353011	4.597910995
10	2007	59.12273352	2.088401339	66.48468344	4.076992726	65.99215193	2.331050854	77.10363696	4.728171224
10	2008	58.77775741	2.176838122	66.09675098	4.204005869	65.60709334	2.429763029	76.6537438	4.875470943
10	2009	58.43278129	2.273612964	65.70881852	4.343466135	65.22203476	2.537782054	76.20385065	5.037205844
10	2010	58.43278129	2.273612964	65.70881852	4.343466135	65.22203476	2.537782054	76.20385065	5.037205844
10	2011	58.43278129	2.273612964	65.70881852	4.343466135	65.22203476	2.537782054	76.20385065	5.037205844
10	2012	58.43278129	2.273612964	65.70881852	4.343466135	65.22203476	2.537782054	76.20385065	5.037205844
10	2013	58.43278129	2.273612964	65.70881852	4.343466135	65.22203476	2.537782054	76.20385065	5.037205844
10	2014	58.43278129	2.273612964	65.70881852	4.343466135	65.22203476	2.537782054	76.20385065	5.037205844
10	2015	58.43278129	2.273612964	65.70881852	4.343466135	65.22203476	2.537782054	76.20385065	5.037205844
11	1975	73.19023223	3.319051143	82.30386403	9.54091047	81.69414094	3.704688776	95.4494618	11.06478754
11	1976	72.84525612	3.215718302	81.91593157	9.161036569	81.30908236	3.589349784	94.99956865	10.62424007
11	1977	72.50028	3.115195179	81.52799911	8.794843031	80.92402377	3.477146967	94.54967549	10.19955799
11	1978	72.15530389	3.017818436	81.14006664	8.443011382	80.53896519	3.368456105	94.09978234	9.791531684
11	1979	71.81032778	2.923961805	80.75213418	8.106294528	80.1539066	3.263694356	93.64988919	9.401034314
11	1980	71.46535167	2.834038108	80.36420172	7.785518018	79.76884802	3.163322504	93.19999604	9.029023283
11	1981	71.12037555	2.748500367	79.97626925	7.48157864	79.38378944	3.067846207	92.75010289	8.676538617
11	1982	70.77539944	2.667841555	79.58833679	7.195439228	78.99873085	2.977815719	92.30020974	8.344696932
11	1983	70.43042333	2.592592425	79.20040433	6.928118437	78.61367227	2.893823459	91.85031658	8.034679583
11	1984	70.08544722	2.52331677	78.81247187	6.680674114	78.22861369	2.816498726	91.40042343	7.747713381
11	1985	69.7404711	2.460603487	78.4245394	6.454179065	77.8435551	2.746498842	90.95053028	7.485042475
11	1986	69.39549499	2.405054916	78.03660694	6.249688317	77.45849652	2.684496132	90.50063713	7.247890402
11	1987	69.05051888	2.357271174	77.64867448	6.068197851	77.07343794	2.631160438	90.05074398	7.037412226
11	1988	68.70554277	2.317830673	77.26074201	5.910595886	76.68837935	2.58713738	89.60085082	6.854638027
11	1989	68.36056666	2.287267637	76.87280955	5.777609345	76.30332077	2.553023251	89.15095767	6.700410838
11	1990	68.01559054	2.266048129	76.48487709	5.669749825	75.91826219	2.529338268	88.70106452	6.575323963
11	1991	67.67061443	2.254546802	76.09694463	5.587264651	75.5332036	2.516500611	88.25117137	6.479664231
11	1992	67.32563832	2.253026954	75.70901216	5.530099251	75.14814502	2.514804175	87.80127822	6.413368357
11	1993	66.98066221	2.261626446	75.3210797	5.497876395	74.76308644	2.524402834	87.35138507	6.375998856
11	1994	63.60742298	1.992580814	71.52780546	4.451726492	70.99791351	2.224097026	82.95224793	5.162757578
11	1995	63.26244687	1.928922435	71.139873	4.266433236	70.61285493	2.153042237	82.50235478	4.947869228
11	1996	62.91747075	1.874960099	70.75194053	4.105417964	70.22779634	2.092810063	82.05246163	4.76113655
11	1997	62.57249464	1.831703688	70.36400807	3.970204042	69.84273776	2.044527729	81.60256847	4.604326219
11	1998	62.22751853	1.800086134	69.97607561	3.862067353	69.45767918	2.009236558	81.15267532	4.478917906
11	1999	61.88254242	1.780895985	69.58814314	3.781902554	69.07262059	1.987816723	80.70278217	4.385949161
11	2000	61.53756631	1.774711668	69.20021068	3.73010153	68.68756201	1.980913856	80.25288902	4.325874461
11	2001	61.19259019	1.781849511	68.81227822	3.706468793	68.30250343	1.98888104	79.80299587	4.298467096
11	2002	60.84761408	1.802336656	68.42434576	3.710194519	67.91744484	2.011748567	79.35310271	4.302787897
11	2003	60.50263797	1.835915025	68.03641329	3.739893907	67.53238626	2.049228377	78.90320956	4.337230879
11	2004	60.15766186	1.882075086	67.64848083	3.793705634	67.14732768	2.100751736	78.45331641	4.399637432
11	2005	59.81268574	1.940111308	67.26054837	3.869428835	66.76226909	2.165531134	78.00342326	4.487455166
11	2006	59.46770963	2.009187589	66.8726159	3.964672343	66.37721051	2.242633328	77.55353011	4.597910995
11	2007	59.12273352	2.088401339	66.48468344	4.076992726	65.99215193	2.331050854	77.10363696	4.728171224
11	2008	58.77775741	2.176838122	66.09675098	4.204005869	65.60709334	2.429763029	76.6537438	4.875470943
11	2009	58.43278129	2.273612964	65.70881852	4.343466135	65.22203476	2.537782054	76.20385065	5.037205844
11	2010	58.43278129	2.273612964	65.70881852	4.343466135	65.22203476	2.537782054	76.20385065	5.037205844
11	2011	58.43278129	2.273612964	65.70881852	4.343466135	65.22203476	2.537782054	76.20385065	5.037205844
11	2012	58.43278129	2.273612964	65.70881852	4.343466135	65.22203476	2.537782054	76.20385065	5.037205844

11	2013	58.43278129	2.273612964	65.70881852	4.343466135	65.22203476	2.537782054	76.20385065	5.037205844
11	2014	58.43278129	2.273612964	65.70881852	4.343466135	65.22203476	2.537782054	76.20385065	5.037205844
11	2015	58.43278129	2.273612964	65.70881852	4.343466135	65.22203476	2.537782054	76.20385065	5.037205844

Appendix L – Parameter inputs of proportion of ovigerous females in each region and time-step for the stock assessment model.

#	ovigorous_4_ areas_11_ timesteps								
121									
#region	tstep	mx	mx.se	a	a.se	l50	l50.se	l95	l95.se
1	1	0.67186687	0.008757903	-0.335219499	0.024166916	755.8692933	48.21923919	771.5627756	48.31538248
1	2	0.67186687	0.008757903	-0.335219499	0.024166916	755.8692933	48.21923919	771.5627756	48.31538248
1	3	0.67186687	0.008757903	-0.335219499	0.024166916	755.8692933	48.21923919	771.5627756	48.31538248
1	4	0.405844927	0.004911713	-0.394605792	0.022975843	877.6773119	45.91688872	894.3653327	45.9425108
1	5	0.405844927	0.004911713	-0.394605792	0.022975843	877.6773119	45.91688872	894.3653327	45.9425108
1	6	1.00E-04	1.00E-06	1	0	400	1	450	1
1	7	1.00E-04	1.00E-06	1	0	400	1	450	1
1	8	1.00E-04	1.00E-06	1	0	400	1	450	1
1	9	1.00E-04	1.00E-06	1	0	400	1	450	1
1	10	1.00E-04	1.00E-06	1	0	400	1	450	1
1	11	0.67186687	0.008757903	-0.335219499	0.024166916	755.8692933	48.21923919	771.5627756	48.31538248
2	1	0.67186687	0.008757903	-0.335219499	0.024166916	755.8692933	48.21923919	771.5627756	48.31538248
2	2	0.67186687	0.008757903	-0.335219499	0.024166916	755.8692933	48.21923919	771.5627756	48.31538248
2	3	0.67186687	0.008757903	-0.335219499	0.024166916	755.8692933	48.21923919	771.5627756	48.31538248
2	4	0.405844927	0.004911713	-0.394605792	0.022975843	877.6773119	45.91688872	894.3653327	45.9425108
2	5	0.405844927	0.004911713	-0.394605792	0.022975843	877.6773119	45.91688872	894.3653327	45.9425108
2	6	1.00E-04	1.00E-06	1	0	400	1	450	1
2	7	1.00E-04	1.00E-06	1	0	400	1	450	1
2	8	1.00E-04	1.00E-06	1	0	400	1	450	1
2	9	1.00E-04	1.00E-06	1	0	400	1	450	1
2	10	1.00E-04	1.00E-06	1	0	400	1	450	1
2	11	0.67186687	0.008757903	-0.335219499	0.024166916	755.8692933	48.21923919	771.5627756	48.31538248
3	1	0.686029713	0.04011139	-0.188365858	0.037969455	462.1068791	75.84966274	486.1861275	76.13945039
3	2	0.686029713	0.04011139	-0.188365858	0.037969455	462.1068791	75.84966274	486.1861275	76.13945039
3	3	0.686029713	0.04011139	-0.188365858	0.037969455	462.1068791	75.84966274	486.1861275	76.13945039
3	4	0.360975624	0.014000243	-0.267540172	0.035291994	618.8384098	70.60304745	643.2022266	70.95660944
3	5	0.360975624	0.014000243	-0.267540172	0.035291994	618.8384098	70.60304745	643.2022266	70.95660944
3	6	1.00E-04	1.00E-06	1	0	400	1	450	1
3	7	1.00E-04	1.00E-06	1	0	400	1	450	1
3	8	1.00E-04	1.00E-06	1	0	400	1	450	1
3	9	1.00E-04	1.00E-06	1	0	400	1	450	1
3	10	1.00E-04	1.00E-06	1	0	400	1	450	1
3	11	0.686029713	0.04011139	-0.188365858	0.037969455	462.1068791	75.84966274	486.1861275	76.13945039
4	1	0.686029713	0.04011139	-0.188365858	0.037969455	462.1068791	75.84966274	486.1861275	76.13945039
4	2	0.686029713	0.04011139	-0.188365858	0.037969455	462.1068791	75.84966274	486.1861275	76.13945039
4	3	0.686029713	0.04011139	-0.188365858	0.037969455	462.1068791	75.84966274	486.1861275	76.13945039
4	4	0.360975624	0.014000243	-0.267540172	0.035291994	618.8384098	70.60304745	643.2022266	70.95660944
4	5	0.360975624	0.014000243	-0.267540172	0.035291994	618.8384098	70.60304745	643.2022266	70.95660944
4	6	1.00E-04	1.00E-06	1	0	400	1	450	1
4	7	1.00E-04	1.00E-06	1	0	400	1	450	1
4	8	1.00E-04	1.00E-06	1	0	400	1	450	1
4	9	1.00E-04	1.00E-06	1	0	400	1	450	1
4	10	1.00E-04	1.00E-06	1	0	400	1	450	1
4	11	0.686029713	0.04011139	-0.188365858	0.037969455	462.1068791	75.84966274	486.1861275	76.13945039
5	1	0.685178711	0.016850361	-0.39042819	0.032831172	861.752137	65.66936822	880.6342223	65.98948452
5	2	0.685178711	0.016850361	-0.39042819	0.032831172	861.752137	65.66936822	880.6342223	65.98948452
5	3	0.685178711	0.016850361	-0.39042819	0.032831172	861.752137	65.66936822	880.6342223	65.98948452
5	4	0.440809646	0.008645877	-0.221834028	0.021936275	526.2886861	43.85257337	544.5078918	43.94594793
5	5	0.440809646	0.008645877	-0.221834028	0.021936275	526.2886861	43.85257337	544.5078918	43.94594793
5	6	1.00E-04	1.00E-06	1	0	400	1	450	1
5	7	1.00E-04	1.00E-06	1	0	400	1	450	1
5	8	1.00E-04	1.00E-06	1	0	400	1	450	1
5	9	1.00E-04	1.00E-06	1	0	400	1	450	1
5	10	1.00E-04	1.00E-06	1	0	400	1	450	1
5	11	0.685178711	0.016850361	-0.39042819	0.032831172	861.752137	65.66936822	880.6342223	65.98948452
6	1	0.685178711	0.016850361	-0.39042819	0.032831172	861.752137	65.66936822	880.6342223	65.98948452

6	2	0.685178711	0.016850361	-0.39042819	0.032831172	861.752137	65.66936822	880.6342223	65.98948452
6	3	0.685178711	0.016850361	-0.39042819	0.032831172	861.752137	65.66936822	880.6342223	65.98948452
6	4	0.440809646	0.008645877	-0.221834028	0.021936275	526.2886861	43.85257337	544.5078918	43.94594793
6	5	0.440809646	0.008645877	-0.221834028	0.021936275	526.2886861	43.85257337	544.5078918	43.94594793
6	6	1.00E-04	1.00E-06	1	0	400	1	450	1
6	7	1.00E-04	1.00E-06	1	0	400	1	450	1
6	8	1.00E-04	1.00E-06	1	0	400	1	450	1
6	9	1.00E-04	1.00E-06	1	0	400	1	450	1
6	10	1.00E-04	1.00E-06	1	0	400	1	450	1
6	11	0.685178711	0.016850361	-0.39042819	0.032831172	861.752137	65.66936822	880.6342223	65.98948452
7	1	0.685178711	0.016850361	-0.39042819	0.032831172	861.752137	65.66936822	880.6342223	65.98948452
7	2	0.685178711	0.016850361	-0.39042819	0.032831172	861.752137	65.66936822	880.6342223	65.98948452
7	3	0.685178711	0.016850361	-0.39042819	0.032831172	861.752137	65.66936822	880.6342223	65.98948452
7	4	0.440809646	0.008645877	-0.221834028	0.021936275	526.2886861	43.85257337	544.5078918	43.94594793
7	5	0.440809646	0.008645877	-0.221834028	0.021936275	526.2886861	43.85257337	544.5078918	43.94594793
7	6	1.00E-04	1.00E-06	1	0	400	1	450	1
7	7	1.00E-04	1.00E-06	1	0	400	1	450	1
7	8	1.00E-04	1.00E-06	1	0	400	1	450	1
7	9	1.00E-04	1.00E-06	1	0	400	1	450	1
7	10	1.00E-04	1.00E-06	1	0	400	1	450	1
7	11	0.685178711	0.016850361	-0.39042819	0.032831172	861.752137	65.66936822	880.6342223	65.98948452
8	1	0.685178711	0.016850361	-0.39042819	0.032831172	861.752137	65.66936822	880.6342223	65.98948452
8	2	0.685178711	0.016850361	-0.39042819	0.032831172	861.752137	65.66936822	880.6342223	65.98948452
8	3	0.685178711	0.016850361	-0.39042819	0.032831172	861.752137	65.66936822	880.6342223	65.98948452
8	4	0.440809646	0.008645877	-0.221834028	0.021936275	526.2886861	43.85257337	544.5078918	43.94594793
8	5	0.440809646	0.008645877	-0.221834028	0.021936275	526.2886861	43.85257337	544.5078918	43.94594793
8	6	1.00E-04	1.00E-06	1	0	400	1	450	1
8	7	1.00E-04	1.00E-06	1	0	400	1	450	1
8	8	1.00E-04	1.00E-06	1	0	400	1	450	1
8	9	1.00E-04	1.00E-06	1	0	400	1	450	1
8	10	1.00E-04	1.00E-06	1	0	400	1	450	1
8	11	0.685178711	0.016850361	-0.39042819	0.032831172	861.752137	65.66936822	880.6342223	65.98948452
9	1	1.00E-04	1.00E-06	1	0	400	1	450	1
9	2	1.00E-04	1.00E-06	1	0	400	1	450	1
9	3	1.00E-04	1.00E-06	1	0	400	1	450	1
9	4	1.00E-04	1.00E-06	1	0	400	1	450	1
9	5	1.00E-04	1.00E-06	1	0	400	1	450	1
9	6	1.00E-04	1.00E-06	1	0	400	1	450	1
9	7	1.00E-04	1.00E-06	1	0	400	1	450	1
9	8	1.00E-04	1.00E-06	1	0	400	1	450	1
9	9	1.00E-04	1.00E-06	1	0	400	1	450	1
9	10	1.00E-04	1.00E-06	1	0	400	1	450	1
9	11	1.00E-04	1.00E-06	1	0	400	1	450	1
10	1	0.685178711	0.016850361	-0.39042819	0.032831172	861.752137	65.66936822	880.6342223	65.98948452
10	2	0.685178711	0.016850361	-0.39042819	0.032831172	861.752137	65.66936822	880.6342223	65.98948452
10	3	0.685178711	0.016850361	-0.39042819	0.032831172	861.752137	65.66936822	880.6342223	65.98948452
10	4	0.440809646	0.008645877	-0.221834028	0.021936275	526.2886861	43.85257337	544.5078918	43.94594793
10	5	0.440809646	0.008645877	-0.221834028	0.021936275	526.2886861	43.85257337	544.5078918	43.94594793
10	6	1.00E-04	1.00E-06	1	0	400	1	450	1
10	7	1.00E-04	1.00E-06	1	0	400	1	450	1
10	8	1.00E-04	1.00E-06	1	0	400	1	450	1
10	9	1.00E-04	1.00E-06	1	0	400	1	450	1
10	10	1.00E-04	1.00E-06	1	0	400	1	450	1
10	11	0.685178711	0.016850361	-0.39042819	0.032831172	861.752137	65.66936822	880.6342223	65.98948452
11	1	0.685178711	0.016850361	-0.39042819	0.032831172	861.752137	65.66936822	880.6342223	65.98948452
11	2	0.685178711	0.016850361	-0.39042819	0.032831172	861.752137	65.66936822	880.6342223	65.98948452
11	3	0.685178711	0.016850361	-0.39042819	0.032831172	861.752137	65.66936822	880.6342223	65.98948452
11	4	0.440809646	0.008645877	-0.221834028	0.021936275	526.2886861	43.85257337	544.5078918	43.94594793
11	5	0.440809646	0.008645877	-0.221834028	0.021936275	526.2886861	43.85257337	544.5078918	43.94594793
11	6	1.00E-04	1.00E-06	1	0	400	1	450	1
11	7	1.00E-04	1.00E-06	1	0	400	1	450	1
11	8	1.00E-04	1.00E-06	1	0	400	1	450	1
11	9	1.00E-04	1.00E-06	1	0	400	1	450	1
11	10	1.00E-04	1.00E-06	1	0	400	1	450	1
11	11	0.685178711	0.016850361	-0.39042819	0.032831172	861.752137	65.66936822	880.6342223	65.98948452

Appendix M – Parameter inputs of proportion of setose females in each region and time-step for the stock assessment model.

#	setose_11_ regions_11_ timesteps								
121									
#region	tstep	mx	mx.se	a	a.se	l50	l50.se	l95	l95.se
1	1	0.976677803	0.006038957	-0.470157173	0.030422259	1018.533774	60.83981177	1030.995753	60.91603671
1	2	0.976677803	0.006038957	-0.470157173	0.030422259	1018.533774	60.83981177	1030.995753	60.91603671
1	3	0.976677803	0.006038957	-0.470157173	0.030422259	1018.533774	60.83981177	1030.995753	60.91603671
1	4	0.970807934	0.00501376	-0.57199268	0.021432717	1228.736551	42.91373201	1246.108073	42.95617054
1	5	0.970807934	0.00501376	-0.57199268	0.021432717	1228.736551	42.91373201	1246.108073	42.95617054
1	6	0.730593879	0.010410686	-0.410919966	0.054834481	913.460846	109.8372416	935.2604897	109.9106503
1	7	0.36431393	0.00592852	-0.290658205	0.061707531	661.8179872	123.5355968	670.2612506	123.593009
1	8	0.703964765	0.009817966	-0.193091805	0.045876372	471.1734695	91.81591923	491.9092865	91.8344739
1	9	0.976677803	0.006038957	-0.470157173	0.030422259	1018.533774	60.83981177	1030.995753	60.91603671
1	10	0.976677803	0.006038957	-0.470157173	0.030422259	1018.533774	60.83981177	1030.995753	60.91603671
1	11	0.976677803	0.006038957	-0.470157173	0.030422259	1018.533774	60.83981177	1030.995753	60.91603671
2	1	0.976677803	0.006038957	-0.470157173	0.030422259	1018.533774	60.83981177	1030.995753	60.91603671
2	2	0.976677803	0.006038957	-0.470157173	0.030422259	1018.533774	60.83981177	1030.995753	60.91603671
2	3	0.976677803	0.006038957	-0.470157173	0.030422259	1018.533774	60.83981177	1030.995753	60.91603671
2	4	0.970807934	0.00501376	-0.57199268	0.021432717	1228.736551	42.91373201	1246.108073	42.95617054
2	5	0.970807934	0.00501376	-0.57199268	0.021432717	1228.736551	42.91373201	1246.108073	42.95617054
2	6	0.730593879	0.010410686	-0.410919966	0.054834481	913.460846	109.8372416	935.2604897	109.9106503
2	7	0.36431393	0.00592852	-0.290658205	0.061707531	661.8179872	123.5355968	670.2612506	123.593009
2	8	0.703964765	0.009817966	-0.193091805	0.045876372	471.1734695	91.81591923	491.9092865	91.8344739
2	9	0.976677803	0.006038957	-0.470157173	0.030422259	1018.533774	60.83981177	1030.995753	60.91603671
2	10	0.976677803	0.006038957	-0.470157173	0.030422259	1018.533774	60.83981177	1030.995753	60.91603671
2	11	0.976677803	0.006038957	-0.470157173	0.030422259	1018.533774	60.83981177	1030.995753	60.91603671
3	1	0.915051774	0.018187907	-0.272647983	0.045405055	618.6765295	90.81894652	630.5709631	90.92409735
3	2	0.915051774	0.018187907	-0.272647983	0.045405055	618.6765295	90.81894652	630.5709631	90.92409735
3	3	0.915051774	0.018187907	-0.272647983	0.045405055	618.6765295	90.81894652	630.5709631	90.92409735
3	4	0.916729754	0.012121323	-0.353810561	0.028000147	785.0719609	56.04379296	801.7486238	56.15338391
3	5	0.916729754	0.012121323	-0.353810561	0.028000147	785.0719609	56.04379296	801.7486238	56.15338391
3	6	0.47838198	0.011069235	-0.37849256	0.061197255	835.3976562	122.5338988	844.1322145	122.6863275
3	7	0.340227244	0.007385519	-0.179527994	0.046708196	435.101236	93.51420391	438.4750254	93.52193266
3	8	0.49126894	0.008165292	-0.135502562	0.043243972	346.3248548	86.58571825	353.9505615	86.63532603
3	9	0.915051774	0.018187907	-0.272647983	0.045405055	618.6765295	90.81894652	630.5709631	90.92409735
3	10	0.915051774	0.018187907	-0.272647983	0.045405055	618.6765295	90.81894652	630.5709631	90.92409735
3	11	0.915051774	0.018187907	-0.272647983	0.045405055	618.6765295	90.81894652	630.5709631	90.92409735
4	1	0.915051774	0.018187907	-0.272647983	0.045405055	618.6765295	90.81894652	630.5709631	90.92409735
4	2	0.915051774	0.018187907	-0.272647983	0.045405055	618.6765295	90.81894652	630.5709631	90.92409735
4	3	0.915051774	0.018187907	-0.272647983	0.045405055	618.6765295	90.81894652	630.5709631	90.92409735
4	4	0.916729754	0.012121323	-0.353810561	0.028000147	785.0719609	56.04379296	801.7486238	56.15338391
4	5	0.916729754	0.012121323	-0.353810561	0.028000147	785.0719609	56.04379296	801.7486238	56.15338391
4	6	0.47838198	0.011069235	-0.37849256	0.061197255	835.3976562	122.5338988	844.1322145	122.6863275
4	7	0.340227244	0.007385519	-0.179527994	0.046708196	435.101236	93.51420391	438.4750254	93.52193266
4	8	0.49126894	0.008165292	-0.135502562	0.043243972	346.3248548	86.58571825	353.9505615	86.63532603
4	9	0.915051774	0.018187907	-0.272647983	0.045405055	618.6765295	90.81894652	630.5709631	90.92409735
4	10	0.915051774	0.018187907	-0.272647983	0.045405055	618.6765295	90.81894652	630.5709631	90.92409735
4	11	0.915051774	0.018187907	-0.272647983	0.045405055	618.6765295	90.81894652	630.5709631	90.92409735
5	1	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
5	2	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
5	3	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
5	4	0.930452342	0.00797743	-0.323490816	0.02566093	724.918208	51.3910572	739.3762522	51.4686476
5	5	0.930452342	0.00797743	-0.323490816	0.02566093	724.918208	51.3910572	739.3762522	51.4686476
5	6	0.386083259	0.0097473	-0.528588541	0.075570932	1135.494702	151.3567309	1145.929245	151.5792773
5	7	0.317613299	0.005798023	-0.01565989	0.039346657	105.146909	78.804623	107.3084802	78.80970522
5	8	0.395800858	0.00607437	-0.028142283	0.038354765	130.3446465	76.82241378	135.256211	76.8274305
5	9	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
5	10	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
5	11	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
6	1	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
6	2	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502

6	3	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
6	4	0.930452342	0.00797743	-0.323490816	0.02566093	724.918208	51.3910572	739.3762522	51.4686476
6	5	0.930452342	0.00797743	-0.323490816	0.02566093	724.918208	51.3910572	739.3762522	51.4686476
6	6	0.386083259	0.0097473	-0.528588541	0.075570932	1135.494702	151.3567309	1145.929245	151.5792773
6	7	0.317613299	0.005798023	-0.01565989	0.039346657	105.146909	78.804623	107.3084802	78.80970522
6	8	0.395800858	0.00607437	-0.028142283	0.038354765	130.3446465	76.82241378	135.256211	76.8274305
6	9	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
6	10	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
6	11	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
7	1	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
7	2	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
7	3	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
7	4	0.930452342	0.00797743	-0.323490816	0.02566093	724.918208	51.3910572	739.3762522	51.4686476
7	5	0.930452342	0.00797743	-0.323490816	0.02566093	724.918208	51.3910572	739.3762522	51.4686476
7	6	0.386083259	0.0097473	-0.528588541	0.075570932	1135.494702	151.3567309	1145.929245	151.5792773
7	7	0.317613299	0.005798023	-0.01565989	0.039346657	105.146909	78.804623	107.3084802	78.80970522
7	8	0.395800858	0.00607437	-0.028142283	0.038354765	130.3446465	76.82241378	135.256211	76.8274305
7	9	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
7	10	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
7	11	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
8	1	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
8	2	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
8	3	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
8	4	0.930452342	0.00797743	-0.323490816	0.02566093	724.918208	51.3910572	739.3762522	51.4686476
8	5	0.930452342	0.00797743	-0.323490816	0.02566093	724.918208	51.3910572	739.3762522	51.4686476
8	6	0.386083259	0.0097473	-0.528588541	0.075570932	1135.494702	151.3567309	1145.929245	151.5792773
8	7	0.317613299	0.005798023	-0.01565989	0.039346657	105.146909	78.804623	107.3084802	78.80970522
8	8	0.395800858	0.00607437	-0.028142283	0.038354765	130.3446465	76.82241378	135.256211	76.8274305
8	9	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
8	10	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
8	11	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
9	1	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
9	2	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
9	3	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
9	4	0.930452342	0.00797743	-0.323490816	0.02566093	724.918208	51.3910572	739.3762522	51.4686476
9	5	0.930452342	0.00797743	-0.323490816	0.02566093	724.918208	51.3910572	739.3762522	51.4686476
9	6	0.436340907	0.007293295	0.097682158	0.048901633	-125.7727333	97.87395871	-122.1951893	97.86709762
9	7	0.351592829	0.008414678	0.046634182	0.072879144	-21.43652895	146.1705052	-19.61166455	146.1623252
9	8	0.385898387	0.008154042	0.017454987	0.080087582	36.56007938	160.6335834	39.07287165	160.604731
9	9	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
9	10	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
9	11	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
10	1	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
10	2	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
10	3	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
10	4	0.930452342	0.00797743	-0.323490816	0.02566093	724.918208	51.3910572	739.3762522	51.4686476
10	5	0.930452342	0.00797743	-0.323490816	0.02566093	724.918208	51.3910572	739.3762522	51.4686476
10	6	0.386083259	0.0097473	-0.528588541	0.075570932	1135.494702	151.3567309	1145.929245	151.5792773
10	7	0.317613299	0.005798023	-0.01565989	0.039346657	105.146909	78.804623	107.3084802	78.80970522
10	8	0.395800858	0.00607437	-0.028142283	0.038354765	130.3446465	76.82241378	135.256211	76.8274305
10	9	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
10	10	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
10	11	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
11	1	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
11	2	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
11	3	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
11	4	0.930452342	0.00797743	-0.323490816	0.02566093	724.918208	51.3910572	739.3762522	51.4686476
11	5	0.930452342	0.00797743	-0.323490816	0.02566093	724.918208	51.3910572	739.3762522	51.4686476
11	6	0.386083259	0.0097473	-0.528588541	0.075570932	1135.494702	151.3567309	1145.929245	151.5792773
11	7	0.317613299	0.005798023	-0.01565989	0.039346657	105.146909	78.804623	107.3084802	78.80970522
11	8	0.395800858	0.00607437	-0.028142283	0.038354765	130.3446465	76.82241378	135.256211	76.8274305
11	9	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
11	10	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502
11	11	0.943176266	0.00772945	-0.452197154	0.034290437	978.289559	68.57723138	987.2364205	68.71504502

Appendix N – List of length bins the selectivity of lobsters due to management rules and the proportions of lobsters retained in pots due to escape gaps.

Lbins

#1	2	3	4	5	6	7	8	9	10	11	12	13
	14	15	16	17	18	19	20	21	22	23	24	25
	26	27	28	29	30	31	32	33	34	35	36	37
	38	39	40	41	42	43	44	45	46			

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FM76 Selectivity of lobsters based on minimum and maximum size limits

0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0.5	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1			

FM77

0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1			

F76_95

0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0.5	1	1	1	1	1	1	1	1	1
	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0			

F77_95

0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	1	1	1	1	1	1	1	1	1
	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0			

F76_105

0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0.5	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0			

F77_105

0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0			

F76_115

0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0.5	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	0	0
	0	0	0	0	0	0	0	0	0			

F77_115

0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	0	0
	0	0	0	0	0	0	0	0	0			

Nbins

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#	IncrementsLower	Mean	upper									
	2	2	2	2	2	2	2	2	2	2	2	2
	2	2	2	2	2	2	2	2	2	2	2	2
	2	2	2	2	2	2	2	2	2	2	2	2
	2	2	2	2	2	2	2	2	2	65		
	45	47	49	51	53	55	57	59	61	63	65	67
	69	71	73	75	77	79	81	83	85	87	89	91
	93	95	97	99	101	103	105	107	109	111	113	115
	117	119	121	123	125	127	129	131	133	135		
	46	48	50	52	54	56	58	60	62	64	66	68
	70	72	74	76	78	80	82	84	86	88	90	92
	94	96	98	100	102	104	106	108	110	112	114	116
	118	120	122	124	126	128	130	132	134	136		
	47	49	51	53	55	57	59	61	63	65	67	69
	71	73	75	77	79	81	83	85	87	89	91	93
	95	97	99	101	103	105	107	109	111	113	115	117
	119	121	123	125	127	129	131	133	135	200		

#	Discards_R1_54/55	- Escape gaps										
	0	0	0	0	0	0	0	0	0	0	0	0
	0.05	0.15	0.3	0.6	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1		
	0	0	0	0	0	0	0	0	0	0	0	0
	0	0.05	0.2	0.4	0.9	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1		