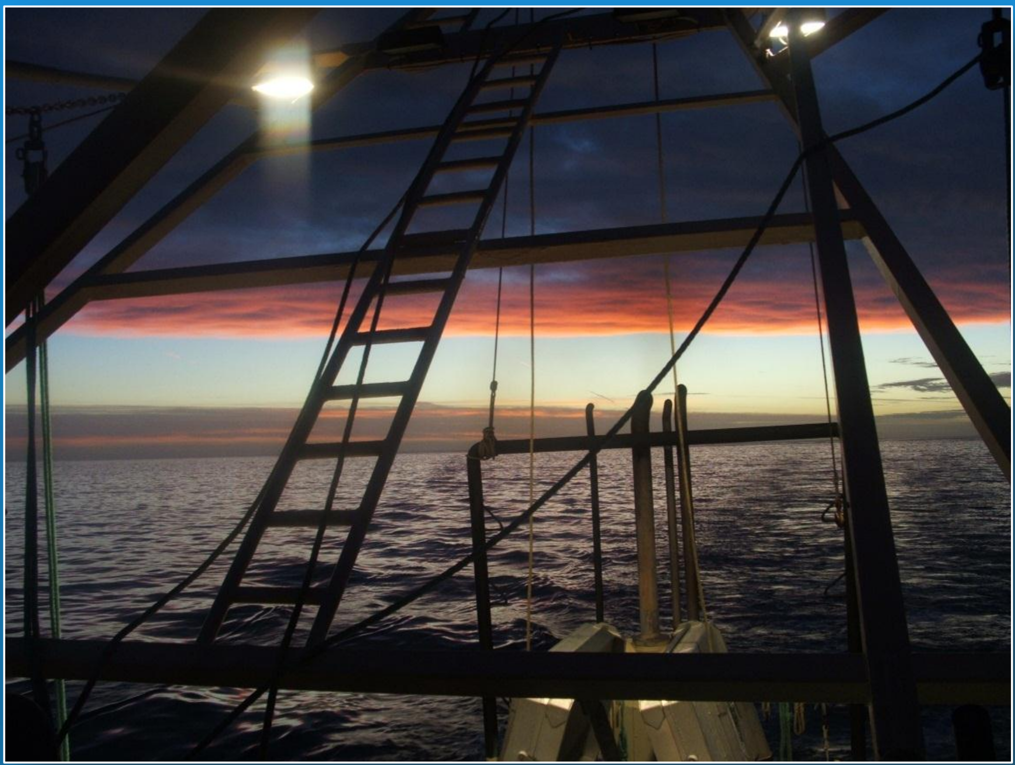
Fisheries

West Coast Prawn
Penaeus (Melicertus) latisulcatus
Fishery 2012–13



C.L. Beckmann, G. E. Hooper and C. J. Noell

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SARDI Aquatics Sciences
PO Box 120 Henley Beach SA 5022

November 2014

Fishery Assessment Report to PIRSA Fisheries and Aquaculture

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EXECUTIVE SUMMARY

This report updates the West Coast Prawn Fishery (WCPF) assessment report for 2006 and the status report for 2011 and provides new information for the 2012 and 2013 calendar years. The aims are to: (1) synthesise and assess the fisheries and biological information available for the WCPF; (2) assess the status of the resource and consider uncertainty associated with that assessment; (3) provide advice on a potential suite of performance indicators (PIs) and associated reference points (RPs) and discuss these PIs and RPs with respect to the 2012/13 fishing year; (4) provide advice on revision of the harvest strategy; and (5) identify future research priorities.

Since its inception in 1968, the WCPF has been characterised by fluctuations in catch. Most of the historic catch was harvested from Venus Bay, followed by Ceduna and Coffin Bay. Ceduna has not been commercially fished since 2009. During 2013, 114 t and 31 t, were harvested from Venus and Coffin Bay, respectively. Compared to 2012, the catch from Coffin Bay increased by 7% and from Venus Bay the catch decreased by 35%.

Nominal fishing effort in 2012 and 2013 was below the target RP (100–110 days) decreasing by 8 days to 73 days in 2013. Average size at capture was within the target RP (<40 prawns/kg) during 2012 and 2013 and decreased slightly in 2013 (32 prawns/kg). The mean recruitment index decreased to 14.0 in 2013 compared to 21.6 when last recorded in 2011. This was well below the target RP (40), however, the low number of shots sampled for recruitment data may affect the interpretation of this index.

Catch during the early spawning period, breached the suggested limit RP (>20 t) during 2012 and 2013 (28.5 and 31.0 t, respectively). Mean catch per unit effort (CPUE) decreased slightly in 2013 (70.6 $kg.hr^{-1}$) and was within the suggested limit RP (<50 $kg.hr^{-1}$). Survey catch rate did not breach the suggested limit RP (<40 $kg.hr^{-1}$) in 2012 and 2013 (57.5 and 57.0 kg.hr-1, respectively). Mean daily catch per vessel was above the suggested limit RP (<300 t) from 2012 and 2013 (760.3 and 717.2 kg, respectively).

The catch rates suggest the stock upon which the fishery is based has been in a relatively stable position since 2011. On the weight of evidence, the WCPF is not considered to be recruitment overfished, and the current level of fishing pressure is unlikely to cause the fishery to become overfished. The status of the resource supporting the WCPF is classified as ‘sustainable’. Continued independent fishery assessments are essential to provide further insight into trends in spawning success and recruitment, particularly in relation to fluctuating environmental variables.

1. INTRODUCTION

1.1. Overview

This fishery assessment report for the West Coast Prawn Fishery (WCPF) is a "living" document that is part of the South Australian Research and Development Institute (SARDI) Aquatic Sciences ongoing assessment programs for South Australian prawn fisheries. This report updates the fishery assessment report for 2006 and analyses data from the 2012 and 2013 fishing years. The aims of this report are to: (1) synthesise and assess the fisheries and biological information available for the WCPF; (2) assess the status of the resource and consider uncertainty associated with that assessment; (3) develop a suite of performance indicators (PIs) and associated reference points (RPs) and review the performance of the fishery with respect to these PIs and RPs; (4) provide advice on revision of the harvest strategy; and (5) identify future research priorities.

This report comprises four sections:

Section 1 provides a description of the WCPF, a summary of the management arrangements for the fishery, a synopsis of the biology of the western king prawn *Penaeus (Melicertus) latisulcatus*, and an overview of the information available to conduct the assessment.

Section 2 provides the methods for data collection and analyses used in the stock assessment survey (fishery-independent) and commercial logbook (fishery-dependent) data.

Section 3 provides an assessment of the stock using data from fishery-independent surveys and fishery-dependent data including catch, effort and prawn size data. It includes temporal and spatial analyses of survey catch per unit effort (CPUE) and prawn size, and derived calculations of egg production and recruitment. A suite of performance indicators are presented in line with the Management Policy.

Section 4 synthesises the information presented in the preceding sections to determine the status of the resource. This section also summarises how stock assessment surveys are used to develop fishing strategies and assess the performance of the fishery with respect to biological PIs in the current harvest strategy. This section also identifies future research priorities for the WCPF.

1.2. Description of the fishery

1.2.1. Fishery location

The WCPF is located in the eastern Great Australian Bight (GAB) in an oceanic environment that is different to South Australia's gulf prawn fisheries. There are three commercial prawn fisheries in South Australia: 1) Spencer Gulf Prawn Fishery (SGPF); 2) Gulf St Vincent Prawn Fishery (GSVPF); and 3) WCPF. All exclusively target the western king prawn *Penaeus (Melicertus) latisulcatus*. The WCPF is the smallest in terms of production, number of licence holders and vessels. The WCPF encompasses South Australian State waters within the meridians of longitude 131° East and 137° East. The three main fishing grounds of the WCPF are Venus Bay, Coffin Bay and Ceduna (Figure 1.1).

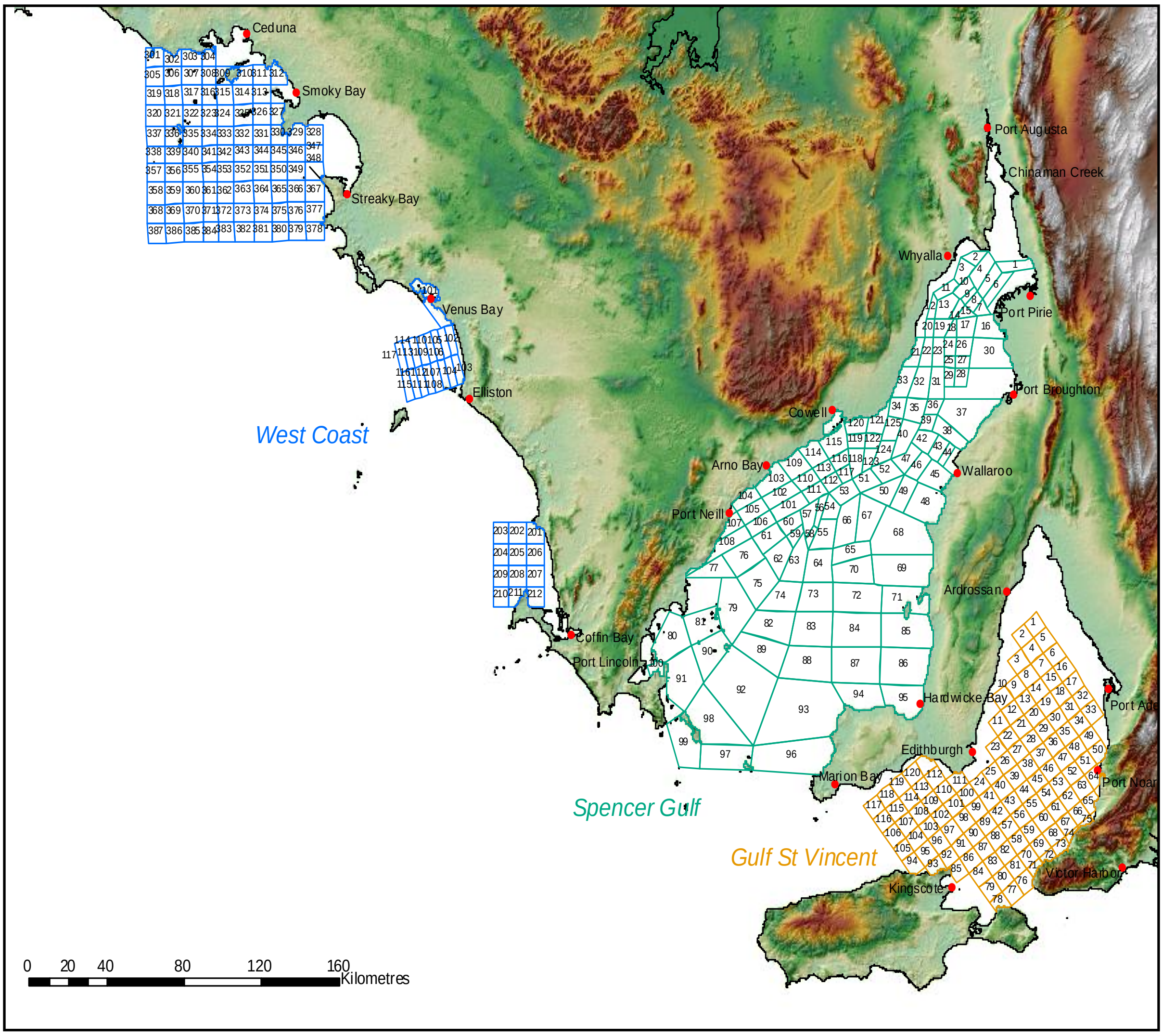

Figure 1.1 Location of South Australia's three commercial prawn fisheries.

1.2.2. The West Coast environment

The GAB is an immense, relatively flat, submarine plain that extends some 1300 km from Cape Pasley (Western Australia) to Cape Catastrophe (South Australia) and covers an area of almost 200,000 km^2 (James *et al.*, 2001). Fishing takes place on the inner continental shelf where the water is <50 m deep.

In general, the main oceanic currents of the region run north-west to south-east in the winter and south-east to north-west in the summer (Figure 1.2, Middleton and Platov, 2003). In summer there is wind-driven coastal upwelling, while in winter winds and shelf circulation shift, resulting in downwelling over the shelf break (Middleton and Platov, 2003). The Leeuwin Current is unique in the Southern Hemisphere as it transports warm tropical waters southward from northwest Australia and around Cape Leeuwin into the GAB (Feng *et al.*, 2003).

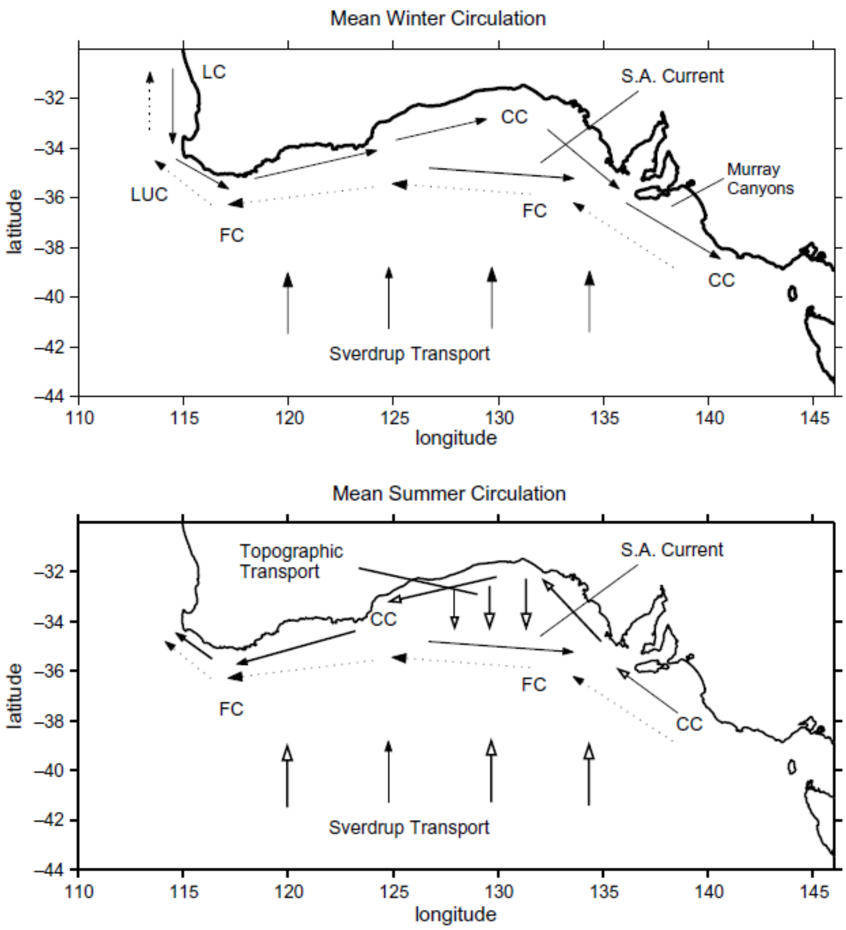

Figure 1.2 Upper panel: A schematic of some key circulation features for winter in the Great Australian Bight. The Leeuwin Current (LC), Leeuwin Undercurrent (LUC), Flinders Current (FC) and shelf-edge South Australian Current (SA Current) are show. Dense salty water is downwelled from the Gulfs. Lower panel: summertime circulation and upwelling occurs of Kangraroo Island and the Bonney Coast. Shelf-edge downwelling may occur in the western GAB. Source: Middleton and Bye (2007).

During winter, the Leeuwin Current and local winds drive warm, low salinity water from the west (Middleton and Bye, 2007). During summer, sea surface temperature (SST) anomalies occur with southeasterly winds along the coastline driving coastal upwelling of cold, low salinity water (Middleton and Bye, 2007). In South Australia, SSTs are lower and more variable than in northern fisheries that target western king prawns (e.g. Broome and Shark Bay, Figure 1.3). Figure 1.4 illustrates the generally cooler waters of the West Coast during summer, where only the major bays are of similar warmer temperatures to the Spencer Gulf and Gulf St Vincent. High salinity layers occur in shallow embayments because of high evaporation and reduced circulation (McClatchie *et al.*, 2006).

El Niño–Southern Oscillation (ENSO) events lead to enhanced upwelling, lowering the sea level and raising the thermocline (Middleton and Bye, 2007). During El Niño events, wintertime shelf-edge currents and the warm Leeuwin Current which flows from north-west to south-east are reduced (Middleton and Bye, 2007). Changes in the strength of the Leeuwin Current are correlated with sea level anomalies off Fremantle, Western Australia, with low sea level being indicative of weakened Leeuwin Current strength (Feng *et al.*, 2013). Between 1980 and 2010, there was a significant correlation between ENSO (El Niño 3.4 index), Fremantle sea level height (SLH) and SST (Zinke *et al.*, 2014). Prior to 1980, this correlation was weaker suggesting that other processes, such as eastern Indian Ocean meridonial winds, may play a role in controlling regional SST and Leeuwin Current strength (Zinke *et al.*, 2014).

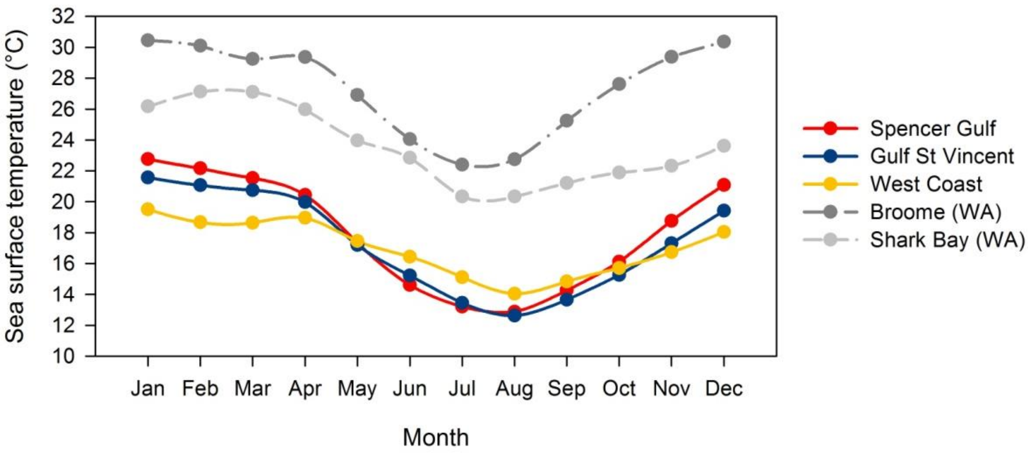

Figure 1.3 Mean monthly sea surface temperatures for the South Australian and Western Australian (WA) prawn fisheries that target western king prawn.

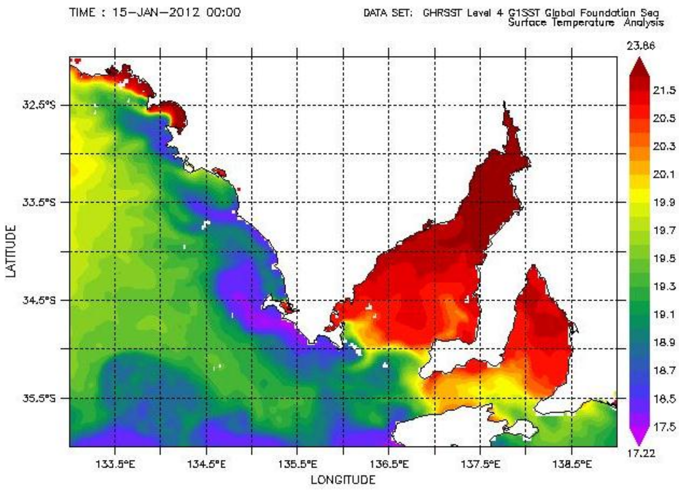

Figure 1.4 Sea surface temperatures (ºC) of the continental shelf and gulf waters of South Australia during January 2012. Source: Physical Oceanography Distributed Active Archive Center (NASA, 2013)

1.2.3. Nursery areas

In South Australia, juvenile western king prawns occur predominately on intertidal sand- and mud-flats, generally located between shallow subtidal or intertidal seagrass beds and mangroves higher on the shoreline (Kangas and Jackson, 1998; Tanner and Deakin, 2001). In a study of penaied prawn fisheries around the world, Pauly and Ingles (1999) demonstrated a significant relationship between mangrove area and fisheries production, thus supporting the widely held perception that intertidal vegetation (particularly mangroves) plays a major role in penaeid prawn recruitment.

Based on Bryars (2003) inventory of important coastal fishery habitats in South Australia, Dixon *et al.,* (2013) estimated that 27% of the West Coast’s 1,310 km coastline comprises appropriate habitat for prawn nursery areas, i.e. tidal flats (24%) and mangrove forests (3%, Table 1.1). Ceduna contained the greatest amount of juvenile prawn habitat (167 km of tidal flats and 6 km of mangrove forest), followed by Venus Bay (98 km of tidal flats and 6 km of mangrove forest, Figure 1.5). These data combined with data on prawn size and tag movement suggest that Ceduna is the main recruitment region for the WCPF.

Although the Spencer Gulf coastline had a comparative area of only 75% that of the West Coast, tidal flat and mangrove habitat were 180% and 444%, respectively, more abundant, respectively. The Gulf St Vincent coastline, including north-eastern Kangaroo Island from Cape Dutton to Kangaroo Head, totaled only 42% of that of the West Coast. Despite this, tidal flat habitat in Gulf St Vincent was similarly abundant (304 km Gulf St Vincent, 355 km West Coast), and mangrove habitat was almost twice as abundant (79 km Gulf St Vincent, 45 km West Coast). The extent of available juvenile habitat appears to correlate well with production from each fishery, particularly with respect to mangrove habitat. Of note, the importance of mangrove habitat for prawn recruitment has long been debated; (see Lee, 2004). The low production of the WCPF in comparison to the Gulf St Vincent fishery is likely due to oceanic influences on recruitment success.

Table 1.1 The number of Fishery Habitat Areas(FHAs; Bryars, 2003) and the estimated proportion and distance of coastline of tidal flat (TF) only and mangrove forest (+ TF) for each of South Australia's three prawn fisheries.

Fishery	# FHA's	Coastline	Tidal flat (TF) only		Mangrove (+ TF)	
			%	km	%	km
Spencer Gulf	15	992	51	508	25	245
Gulf St Vincent	11	551	41	225	14	79
West Coast	16	1310	24	310	3	45

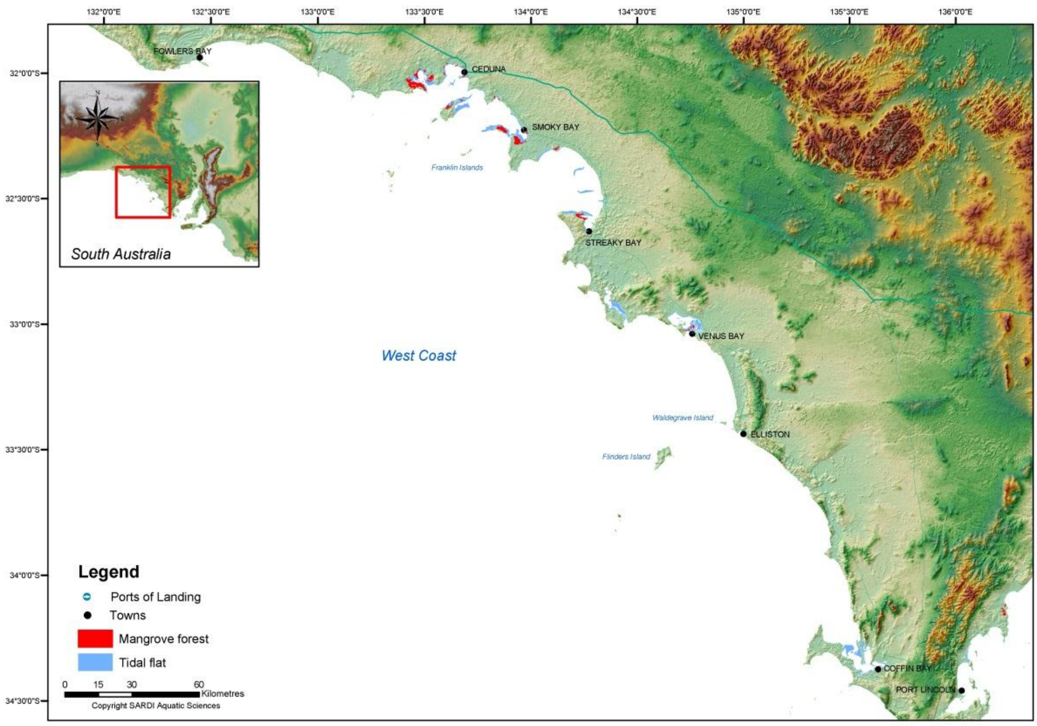

Figure 1.5 Important juvenile nursery habitat, mangrove forest and tidal flats, around the West Coast.

1.2.4. Commercial fishery

The western king prawn was first trawled in the west coast in 1968 by Tekoura and Osprey in Venus Bay (Wallner, 1985). In these early years of the fishery, Spencer Gulf trawlers made winter trips to this region as catch rates in Spencer Gulf declined during those months. In 1973, the annual production of Venus Bay peaked at approximately 290 t with up to 16 Spencer Gulf fishers operating at one time. After exploratory trawls in Ceduna identified good prawn trawling grounds, the first permit was granted for commercial trawling in this region in 1974. From 1974 onwards, catches in Venus Bay declined to 16.4 t in 1978. In this year it was agreed that the Spencer Gulf fleet would not fish in the West Coast, and in 1979 the WCPF became a limited permit fishery with three licence holders.

Prawns are harvested at night using demersal, otter-trawl, double-rig gear (Figure 1.6). Considerable technological advancements have been made in the fishery including the use of ‘crab bags’ to exclude mega-fauna by-catch (Figure 1.7), ‘hoppers’ for efficient sorting of the catch and rapid return of by-catch, and ‘graders’ to sort the prawns into marketable size categories. All three vessels in the prawn fleet are ‘factory vessels’ that process the catch on-board.

South Australia’s prawn fisheries are among the only single-species prawn fisheries in Australia. However, they are not the only fishery to target the western king prawn; 1,310 t (44%) and 97 t (10%) of western king prawns were caught from Western Australia’s Shark Bay and Exmouth Gulf prawn fisheries, respectively, in 2011 (Sporer *et al.*, 2012b; a). The WCPF, valued at $1.69 million is the sixth smallest prawn fishery in Australia in terms of production and has the least number of licences (Dixon *et al.*, 2013). In terms of value per licence, the WCPF ranks highly at $0.6M per licence, comparable with $0.5M and $0.6M, respectively in the WA Shark Bay and south-west fisheries and exceeded only by Spencer Gulf at $0.8M (Dixon *et al.*, 2013).

1.2.5. Recreational, traditional and illegal catch

Under current fisheries legislation, it is prohibited for any person to take *P. latisulcatus*, from waters <10 m in depth. As prawn trawl nets can only be used by the commercial fishing sector, the catch by the recreational and Indigenous sectors is negligible (Anon., 2003). The illegal take of prawns has not been quantified but is assumed to be negligible for the purposes of this assessment.

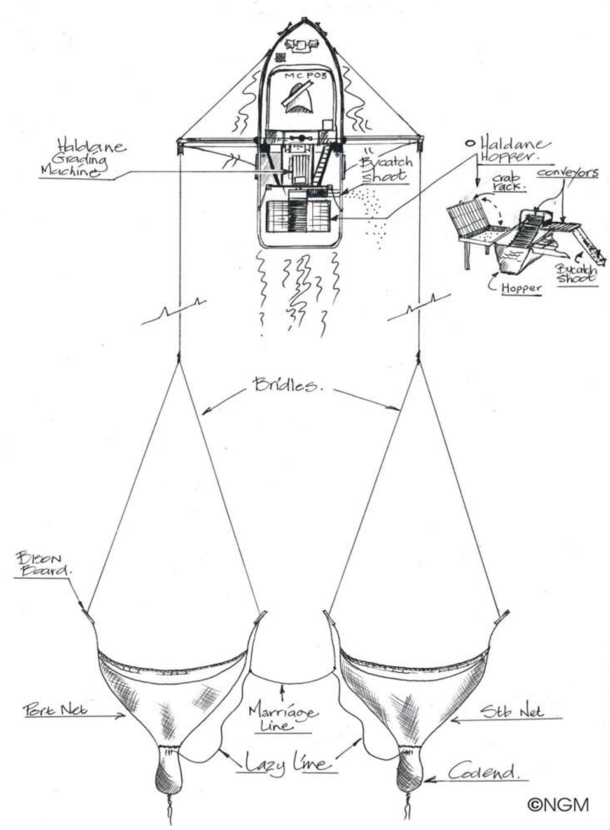

Figure 1.6 Double rig trawl gear and location of hopper sorting and prawn grading systems used in the WCPF. Figure from Carrick (2003).

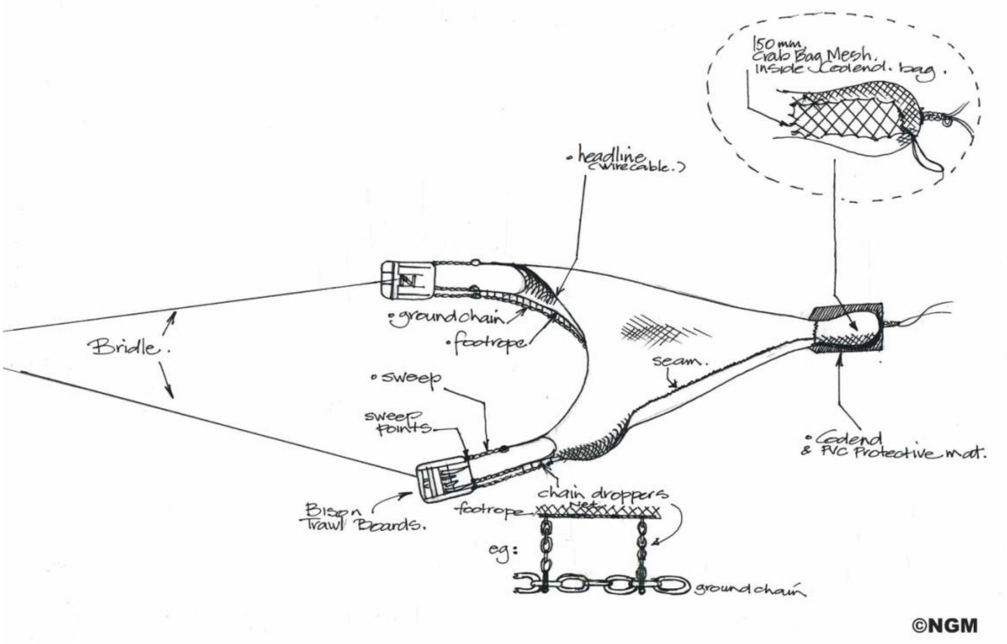

Figure 1.7 Trawl net configuration showing trawl boards, head rope, ground chain and cod end with crab bag. Figure from Carrick (2003).

1.3. Management of the fishery

1.3.1. Legislation

The WCPF is managed by Primary Industries and Regions South Australia (PIRSA) Fisheries and Aquaculture under the framework provided by the *Fisheries Management Act 2007.* General regulations for South Australia's prawn fisheries (commercial and recreational) are described in the *Fisheries (General) Regulations 2000*, with specific regulations located in the *Scheme of Management (Prawn Fisheries) Regulations 2006*. These three documents provide the statutory framework for management of the fishery.

1.3.2. Consultative process and co-management

Under the *Fisheries Act 1982*, Fisheries Management Committees (FMCs) were established to provide a consultative forum for commercial industry and other stakeholders to work with government in relation to each commercial fishery. Since the introduction of the *Fisheries Management Act 2007 ('the Act')*, FMCs were disbanded and a single expertise-based board, the Fisheries Council, was established to provide high-level advice to the Minister and perform a number of functions, including the promotion of co-management. Under this framework, industry associations have taken on greater responsibility for running the consultative process between industry and PIRSA. These changes have provided greater opportunities for well organised, representative fishing bodies, such as the Spencer Gulf and West Coast Prawn Fisherman's Association (SGWCPFA), to increase their role in co-management for a range of benefits (e.g. reduce administrative costs, increase stewardship of the resource).

1.3.3. Current management arrangements for the commercial sector

Management arrangements in the WCPF have evolved since the fisheries began in the late 1960s (Table 1.2). Now, the WCPF is a limited entry fishery with three licenced operators. Trawling is prohibited during daylight hours and in waters <10 m in depth. Effort is restricted through a range of input controls (i.e. spatial and temporal closures, vessel size and power, and configuration of trawl gear, including type and number of nets towed, maximum headline length and minimum mesh size; Table 1.3). Fishing generally occurs between the last and first quarters of the moon during the months of March, through to December

Two types of stock assessment surveys are conducted that include: 1) three fishery-independent (stock assessment) surveys in November (Venus Bay, Coffin Bay and Ceduna), March (Venus Bay and Ceduna), and June (Venus Bay); and 2) fishery-dependent (spot) surveys at various times throughout the fishing year. 'Fishing periods' are defined as the periods in which fishing has taken place separated by the end of the lunar period or a survey. There are generally six or seven fishing periods in a fishing year. Fishing strategies for these fishing periods are determined on the basis of data collected from the stock assessment surveys.

Table 1.2 Major management milestones for the West Coast Prawn Fishery.

Date	Management milestone
1968	Licence limitation. Trawling prohibited in waters of <10 metres. Commercial recording of catch and effort introduced
1969	*Prawn Resources Regulations 1969* established. West Coast divided into three zones
1976	West Coast Zone C fishery operators offered Spencer Gulf Zone D licences.
1979	Licences capped at 3
1984	*Fisheries Scheme of Management Regulations 198*4 introduced
1991	*Fisheries Scheme of Management Regulations 1991* introduced
1995	*Fisheries Scheme of Management Regulations 1995* introduced
1998	First management plan implemented
2006	*Fisheries Scheme of Management Regulations 2006* introduced
2007	Second management plan implemented. *Fisheries Management Act 2007* introduced.
2010	Third management plan implemented.
2014	Management Policy due to be updated

Table 1.3 Current management arrangements.

Prawn fishery management strategy	Specification
Permitted prawn species harvested	*Penaeus (Melicertus) latisulcatus*
Permitted by-product species harvested	*Ibacus* spp. (slipper lobsters), *Sepioteuthis australis* (southern calamary), *Nototodarus gouldi,* (arrow squid), *Octopus* spp., Pectinidae (scallop).
Limited entry	Yes
Number of licences	3
Corporate ownership of licences	Yes
Licence transferability	Yes
Minimum depth trawled	10 m
Method of capture	Demersal otter trawl
Trawl net configuration	Single or double
Maximum total headline length	29.26 m
Minimum mesh size	4.5 cm
Maximum length of vessel	22 m
Maximum engine capacity	336 kW
Catch and effort data	Daily logbook submitted monthly
Catch and disposal records	Daily CDR records
Recreational fishery	Depth >10 m, hand nets only
Recreational licence	Not required

1.3.4. Management Plan

MacDonald (1998) developed the first *Management Plan* for the SGPF and WCPF. A subsequent *Management Policy* was developed in 2010, the primary goals of which were to: 1) ensure the prawn resource is protected from over-exploitation; 2) optimise utilisation and equitable distribution of the resource; 3) minimise impacts on the ecosystem; and 4) achieve cost effective and participative management of the fishery.

1.3.5. Fishing strategy development

Harvest strategies are used to manage fishing effort using spatial and temporal closures. Specifically, this involves the legislation of appropriate temporal and spatial closures. The primary aim of the harvest strategy is for the fleet to target areas of high catch rate of appropriately sized prawns, ensuring biological sustainability and promoting economic efficiency through stability of the stock and stable catches.

The harvest strategy functions at two scales: harvest strategy development and harvest strategy management. Harvest strategies are developed prior to the commencement of fishing during each harvest period (March, April, June to September, November and December). Fishing does not occur during January or February and generally does not occur in May or October. The development phase involves the determination of suitable areas of the West Coast to open to prawn fishing, based on historical fishery information and data obtained from fishery-independent stock assessment surveys and industry-driven spot surveys.

Once established, the harvest strategy is managed on a daily basis during the fishing period and run by the SGWCPFA and PIRSA Fisheries and Aquaculture. Information is communicated both from and to the fleet by the ‘manager at-sea’. Adjustment of the harvest strategy is informed by assessment of data obtained during fishing and involves reducing or closing fished areas to avoid small prawns or unsuitable catch rates.

1.3.6. Performance indicators

The extent to which the fishery is achieving the range of stated goals and objectives of the *Management Policy* is assessed using a combination of PIs. The last stock assessment (Dixon and Roberts, 2006) and subsequent status reports (Roberts, 2007; Hooper *et al.*, 2009; 2010; 2011; Gorman *et al.*, 2012), reported on a suite of PIs including effective effort (days); mean size at capture (prawns/kg); recruitment (males <33 and females <35 mm (carapace length) CL per nautical mile); and percent virgin spawning biomass.

Biological PIs have been identified to provide measures of the status of a fishery and predictions about the future performance of the fishery. The current *Management Policy* (PIRSA, 2010), states that a suite of PIs and reference levels need to be developed that reflect the current management arrangements for the fishery.

Performance indicators, such as mean survey catch rate, appropriate recruitment measures for the fishery, total annual catch, catch during the early spawning period, mean daily catch per vessel, total effort, mean CPUE and prawn size, and appropriate limit reference points have been suggested for use in the harvest strategy.

1.4. Biology of the western king prawn

1.4.1. Distribution and taxonomy

The western king prawn was originally classified as *Penaeus latisulcatus* (Kishinouye, 1896), Pérez Farfante and Kensley (1997) proposed a taxonomic revision by raising former sub-genera in the genus *Penaeus* to generic rank, thus replacing *Penaeus* with the previously sub-genus *Melicertus* (i.e. *Melicertus latisulcatus*). Recently, Flegel (2007) revised the taxonomic name to *Penaeus (Melicertus) latisulcatus*. A smaller penaeid, *Metapenaeopsis crassima*, occurs in South Australian waters but is of no commercial value.

The western king prawn is distributed throughout the Indo-west Pacific (Grey *et al.*, 1983). Its distribution in South Australia is unique, as it is at its lowest temperature range, restricted to waters of Spencer Gulf, Gulf St Vincent and along the West Coast, including the commercially fished areas of Venus Bay, Coffin Bay and Ceduna.

The western king prawn is a benthic species that prefers sandy areas to seagrass or vegetated habitats (Tanner and Deakin, 2001). Both juvenile and adult prawns show a strong diel behavioral pattern of daytime burial and nocturnal activity (Rasheed and Bull, 1992; Primavera and Lebata, 2000). Strong lunar and seasonal differences in activity have also been reported, where prawn activity (and catchability) is greater during the dark phase of the lunar cycle and warmer months (Penn, 1976; Penn *et al.*, 1988).

Abundance of the western king prawn within the gulfs and estuaries is influenced by salinity, where higher abundances are associated with salinities above 30% (Potter *et al.*, 1991). In other physiological studies on this species, optimal salinity ranged from 22–34%, and 100% mortality occurred at salinities below 10% (Sang and Fotedar, 2004). Juvenile western king prawn are more efficient osmoregulators than adults, tolerating greater variation in salinity

(Dixon *et al.*, 2011). Important nursery areas in Western Australia and South Australia are characterised as being hypersaline (35–55%; Carrick, 1982; Penn *et al*., 1988).

1.4.2. Reproductive biology

In the WCPF, adult prawns aggregate, mature, mate and spawn in deep water (>10 m) between September and March, with a peak in November-December (Wallner, 1985). A minimum temperature of 17°C is required for western king prawn to spawn in Western Australia (Penn, 1980), and the peak spawning periods in Queensland were between June and July when water temperature dropped below 25°C (Courtney and Dredge, 1988). This temperature range for spawning of western king prawn (17–25°C) generally occurs from November to May in the main spawning area off Venus Bay.

During mating the male transfers a sperm capsule (spermatophore) to the female reproductive organ (thelycum). The success of insemination depends on the female prawn having recently moulted. Ovary development followed by spawning of fertile eggs occurs during a single intermoult period (Penn, 1980), where fertilisation occurs immediately prior to, or on release of, the eggs by the female.

The composition of western king prawns caught in Western Australia was shown to be female-biased in catches during the peak spawning period, attributed to higher catchability of females due to food requirements and increased foraging during ovarian development (Penn, 1976; 1980). Similarly, female-biased populations of western king prawn were observed during November and December in Gulf St Vincent (Svane, 2003a; Svane and Roberts, 2005).

The proportion of reproductively mature female western king prawns increases with size. In Spencer Gulf, Carrick (2003) defined the relationship between proportion mature (*P*) and carapace length (*CL*, in mm) with the logistic model:

$$P = 8.3 \times 10^{-6} + \left(\frac{1}{1 + e^{-0.277(CL - 36.45)}} \right),$$

Where, the length at which 50% of the female population are mature (CL_{50}) is estimated at 36.5 mm (Figure 1.8). While females can mature at a small size, differences between tropical and temperate populations are apparent. The smallest ripe female recorded in Western Australian populations was 29 mm CL (Penn, 1980), while in Spencer Gulf, the smallest ripe female was 24 mm CL (SARDI, unpublished data). Insemination rate affects fertilisation success and increases with size. Courtney and Dredge (1988) showed in Queensland populations that ~50% of females were inseminated at 34 mm CL, while ~95% were inseminated at 42 mm CL.

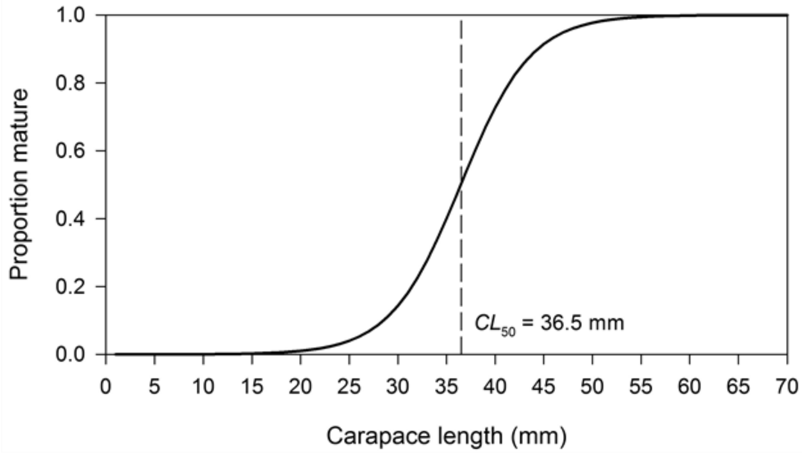

Figure 1.8 Logistic relationship between carapace length and sexual maturity for female western king prawns in Spencer Gulf. Source: Noell *et al.,* (2013).

There are currently no available data on the fecundity of the western king prawn in western South Australia; however, fecundity increases exponentially with carapace length in populations from Gulf St Vincent (Kangas unpublished, cited in Carrick 2003) and Shark Bay (Penn, 1980) (Figure 1.9). Thus, larger prawns make a greater contribution to total egg production due to greater insemination rates and greater fecundity (Penn, 1980; Carrick, 1996).

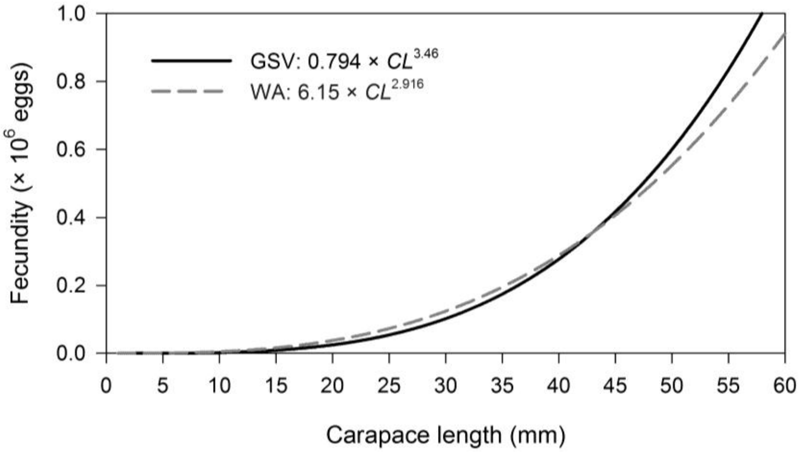

Figure 1.9 Relationship between carapace length and fecundity for female western king prawns in Gulf St Vincent (GSV) and Shark Bay, Western Australia (WA). Source: Noell *et al.,* (2013).

For the eastern king prawn (*P. plebejus*), females greater than 50 mm CL contribute little to egg production, with the bulk of the eggs produced by prawns in the middle to upper size ranges of 35–48 mm CL (Courtney *et al.*, 1995). Such ovarian senescence has not been documented for the western king prawn.

Spawning frequency for the western king prawn appears to be related to moulting frequency, as no recently moulted females were found with well-developed (stage 3 or 4) ovaries (Penn, 1980; Courtney and Dredge, 1988), females generally lose spermatophores with the exuvae at moult (Penn, 1980), and the average interval for both moulting and spawning was the same in tagging experiments (Penn, 1980). The average moult interval for mature untagged females in Western Australian populations during the spawning season was estimated at 30 to 40 days (Penn, 1980).

There are three lines of evidence supporting the concept of multiple spawning: 1) spent ovaries (stage 5) are difficult to identify since the rapid recommencement of ovary development meant they were often classified as developing (stage 2) (Penn, 1980; Courtney and Dredge, 1988); 2) in an experiment where ripe females were tagged and released, many recaptured individuals were found to have spawned and moulted, and had ovaries at an early stage of development during the same season (Penn, 1980); and 3) artificial spawning of *P. orientalis* in aquaria, using eyestalk ablation, demonstrated the multiple spawning capacity of penaeids (Arnstein and Beard, 1975). In addition to multiple spawning events within a season, females are likely to spawn for multiple seasons based on the observation of a large proportion of females in different size cohorts being reproductively active during the spawning season (Penn, 1980).

Prawn reproduction can be adversely affected by parasite load and disease status. Courtney *et al,.* (1995) showed that parasitisation by bopyrid isopods affected the reproductive output of the eastern king prawn. Bopyrid isopods have been observed to parasitise western king prawn (Roberts *et al.*, 2010). Viral infections have been shown to affect moulting and reproduction in another penaeid, the redleg banana prawn *Fenneropenaeus indicus* (formerly known as *P. indicus*) (Vijayan *et al.*, 2003). In addition, environmental pollution can increase the susceptibility of prawns to disease and reduce reproductive output (Nash *et al.*, 1988). These issues are poorly understood for western king prawn in South Australia.

1.4.3. Larval and juvenile stages

The life cycle of the western king prawn consists of two phases: 1) an offshore phase, where spawning of adults, and drift and growth of larvae occurs; and 2) an inshore phase, where settlement of post-larvae and growth through to the juvenile stage occurs (Figure 1.10).

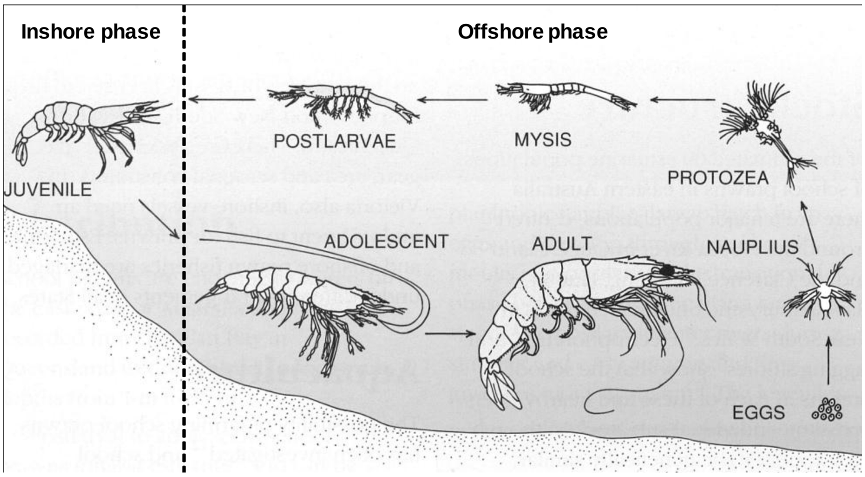

Figure 1.10 Life cycle of a penaeid prawn. Source: Kailola *et al.,* (1993).

Following hatching of the egg, prawn larvae undergo four main stages of metamorphosis, i.e. nauplii, zoea, mysis and post-larvae (Figure 1.11). Approximate sizes of the early life stages are: eggs 300 µm (diameter), nauplii >350 µm body length (BL), zoea >0.9 mm BL, mysis >2.0 mm BL and post-larvae >6.0 mm BL (Shokita, 1984; Roberts *et al.*, 2012).

Temperature, salinity and food availability are generally considered to have the most influence on larval growth and survival in penaeid prawns (Preston, 1985; Carrick, 2003; Jackson and Burford, 2003). Roberts *et al.* (2012) determined duration and survival of western king prawn larvae reared at different temperatures. An increase in temperature over a range of 17–25°C resulted in a shorter larval period (31.3 days at 17.1°C to 12.7 days at 24.4°C; Figure 1.12) and an increase in larval survival (36% at 17°C to 74% at 25°C), thus demonstrating the strong tropical affinity of this species. Wallner (1985) showed that post-larvae were present in the water column between December and March in fished regions of the West Coast.

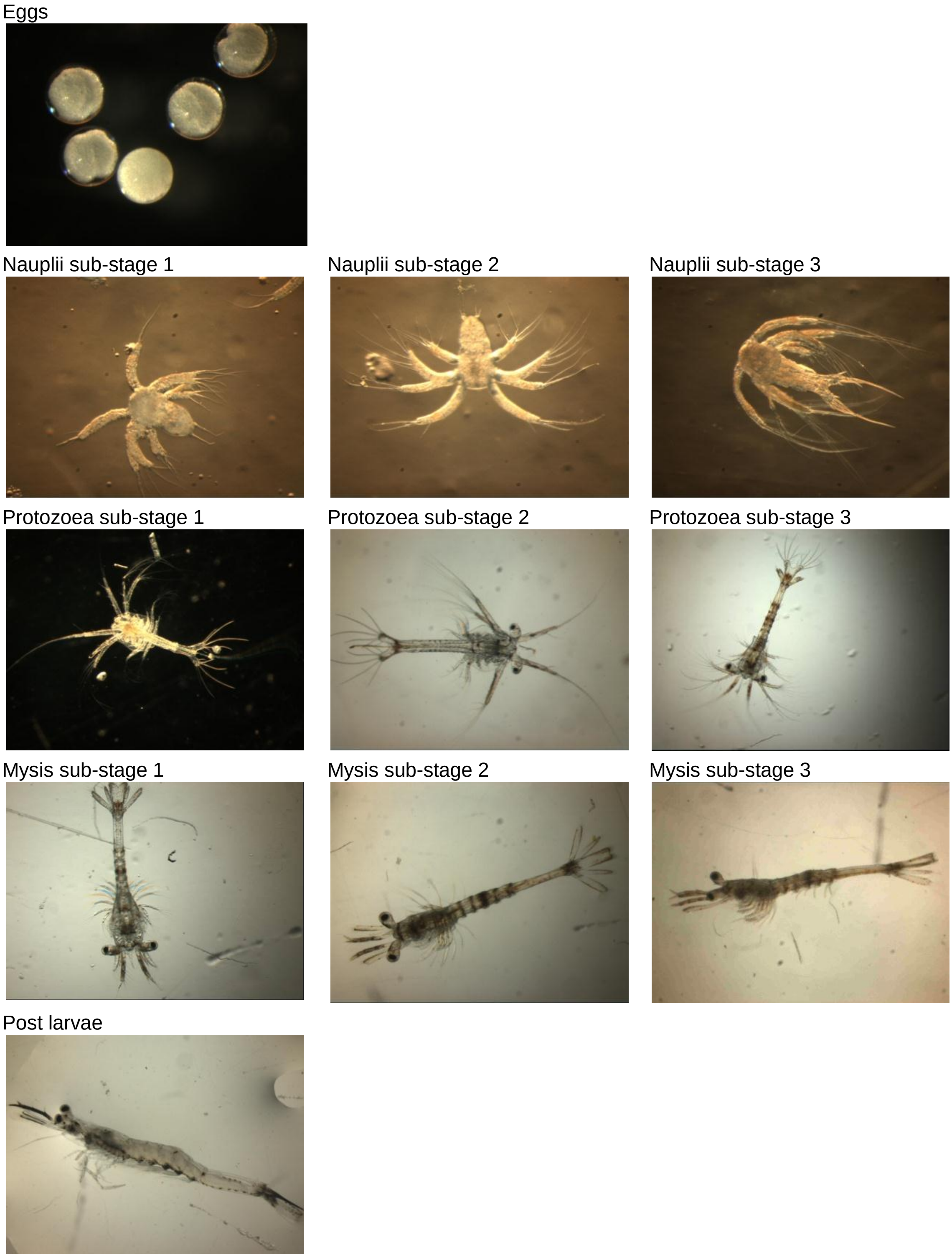

Figure 1.11 Western king prawn, *P. latisulcatus*, larval stages (egg to post larvae) (SARDI unpublished data as part of FRDC project 2008/011)

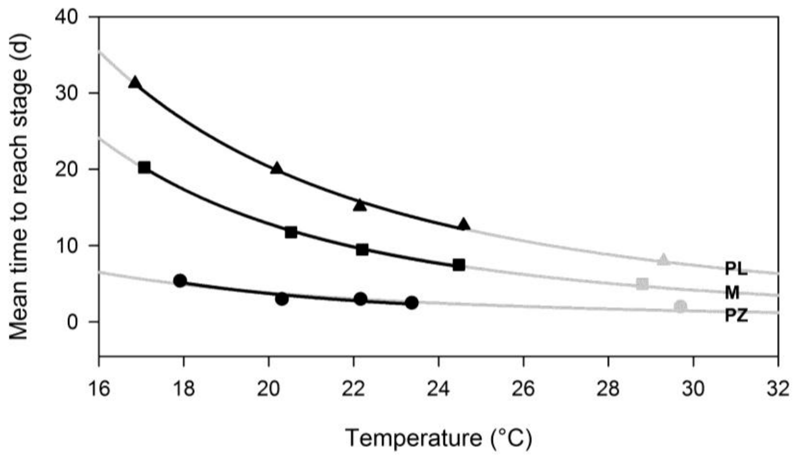

Figure 1.12 Effect of temperature on time days (d) to reach zoea (Z), mysis (M) and post-larval (PL) stages of the western king prawn from hatching. Black symbols and lines represent data from Roberts *et al.,* (2012), while data in grey sourced from Shokita (1984). Figure reproduced from Roberts *et al.,* (2012).

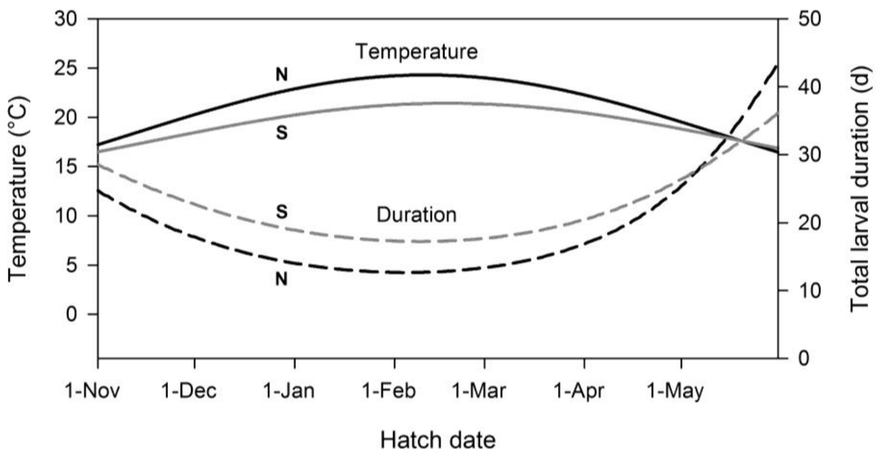

Figure 1.13 Predicted duration of larval developmental (dashed lines) for western king prawn in northern (N, black) and southern (S, grey) Spencer Gulf waters at-seasonal average water temperatures (solid lines). Figure reproduced from (Roberts *et al.*, 2012).

By incorporating average SST data for Spencer Gulf into a seasonal developmental model, Roberts *et al.* (2012) predicted total larval duration to be shorter at the beginning of the spawning season (26.8 days from hatch date of 9 November) due to increasing daily water temperatures, compared to later in the season (35.4 days from 29 May) (Figure 1.13). Furthermore, larval duration was predicted to be significantly shorter in warmer northern waters (minimum 12.7 days) compared to southern waters (minimum 17.2 days) separated by latitude 34°S. These optimal temporal and spatial influences for larval duration and survival reflect the distribution of spawning females observed in November.

Rodgers *et al.* (2013) examined the effect of temperature (range 17–25°C) on stage-specific size of western king prawn larvae, and showed that larval growth rate was dependent on temperature, with growth rate greater at higher temperatures. Despite this, larvae reared at 20°C reached the largest size, while those at either end of the experimental temperature range were smallest. The spawning time that would most likely maximise larval size on the West Coast is approximately December-January where SSTs are ~20°C.

The FRDC project (1999/142) "*Modelling prawn movement and spatial dynamics in the Spencer Gulf and West Coast Prawn Fisheries*," demonstrated that the recruitment variation was influenced by sea level height (SLH) and provided evidence that ENSO events influence recruitment strength in the WCPF (Carrick and Ostendorf, 2005). Further investigation in the FRDC project (2005/082) "*Determining the impact of environmental variability on the sustainability, fishery dynamics and economic performance of the West Coast Prawn Fishery*" demonstrated the impact of El Niño/cold water upwelling on the fishery by integrating environmental, fishery-independent and fishery-dependent catch effort and grade data (Carrick, 2008). El Niño driven changes (low SLH and cold water) were identified as important drivers in structuring recruitment in western South Australia (Carrick, 2008). Cold water was suggested to induce physiological stress to larvae and increased predation due to longer time in the planktonic environment (Carrick, 2008). Furthermore, cold water may affect behavioural activity including reproductive development and mating (Carrick, 2008). It was, therefore, hypothesised by Carrick (2008) that recruitment declines in the WCPF are caused by reduced larval survival and reduction of spawning due to cold water, change in currents reducing larval supply to nurseries due to unfavourable advection and change in the spatial distribution of stock whereby spawners spread and move offshore or away from trawl grounds.

1.4.4. Stock structure

Research undertaken by the South Australian Museum and SARDI (cited in Carrick, 2003) using rDNA demonstrated significant genetic differences in haplotype frequency between South Australian and Western Australian populations of western king prawns. Richardson (1982) examined the gene and genotype frequencies of western king prawns from Investigator Strait and Gulf St Vincent using electrophoretic techniques, and found no evidence of genetic isolation of the two stocks.

1.4.5. Growth

Prawns undergo a series of moults that lead to increases in body size incrementally. The shedding of hard body parts during moulting means that the age of individuals cannot be reliably determined. The inability to directly age prawns has increased the reliance on tag-recapture and cohort analysis for the determination of growth characteristics.

During 1983 and 1984, a total of 4,670 tagged and measured prawns were released in Venus Bay and Ceduna. Of these, 510 (11%) were recaptured within one year, from which the von Bertalanffy growth parameters were estimated using the equation $\Delta L=(L_\infty-L_t)\left(1-e^{-k\Delta t}\right)$ (Fabens, 1965), where ΔL is the growth increment in carapace length between release (L_t) and recapture, L_∞ is the asymptotic length, and k is the rate at which L_∞ is approached.

Analysis of length frequency cohorts obtained monthly between May 1984 and March 1985 in Venus Bay provided additional estimates of K and L_∞ (Table 1.4). Comparison of these estimates showed considerable differences between methods, with tagging data providing depressed estimates of growth rate compared to cohort analysis for both sexes (Figure 1.14). Uncertainties associated with each method of growth estimation included:

- growth suppression by the tagging process (Penn, 1975; Menz and Blake, 1980),
- short time at liberty for tag-recaptures influenced by seasonal growth,
- bias in size at release and time at liberty during tag-recapture experiments,
- ability to distinguish cohorts, effect of catchability, and net migration on cohort analysis,
- measurement error (both methods).

Carrick (2003) estimated growth rates from >9,000 tag-recaptures in Spencer Gulf and Kangas and Jackson (1997) estimated growth rates from 464 recaptures in Gulf St Vincent (Table 1.7). By re-parameterizing the von Bertalanffy function to include a seasonal oscillation in growth, Carrick (2003) demonstrated maximum growth rates occur during autumn (March-April), and negligible growth from winter to early summer (July-December).

The *omega* growth index (ω = KL_∞) (Gallucci and Quinn, 1979) obtained from growth parameters L_∞ and k derived from tagging studies in each of South Australia's prawn fisheries was compared (Wallner, 1985; Kangas and Jackson, 1997; Carrick, 2003). Female prawns attain a larger maximum size in all three fisheries, albeit at a slower rate, than males, and prawns on the West Coast attain a smaller maximum size than in the gulfs (Figure 1.14, Table 1.4).

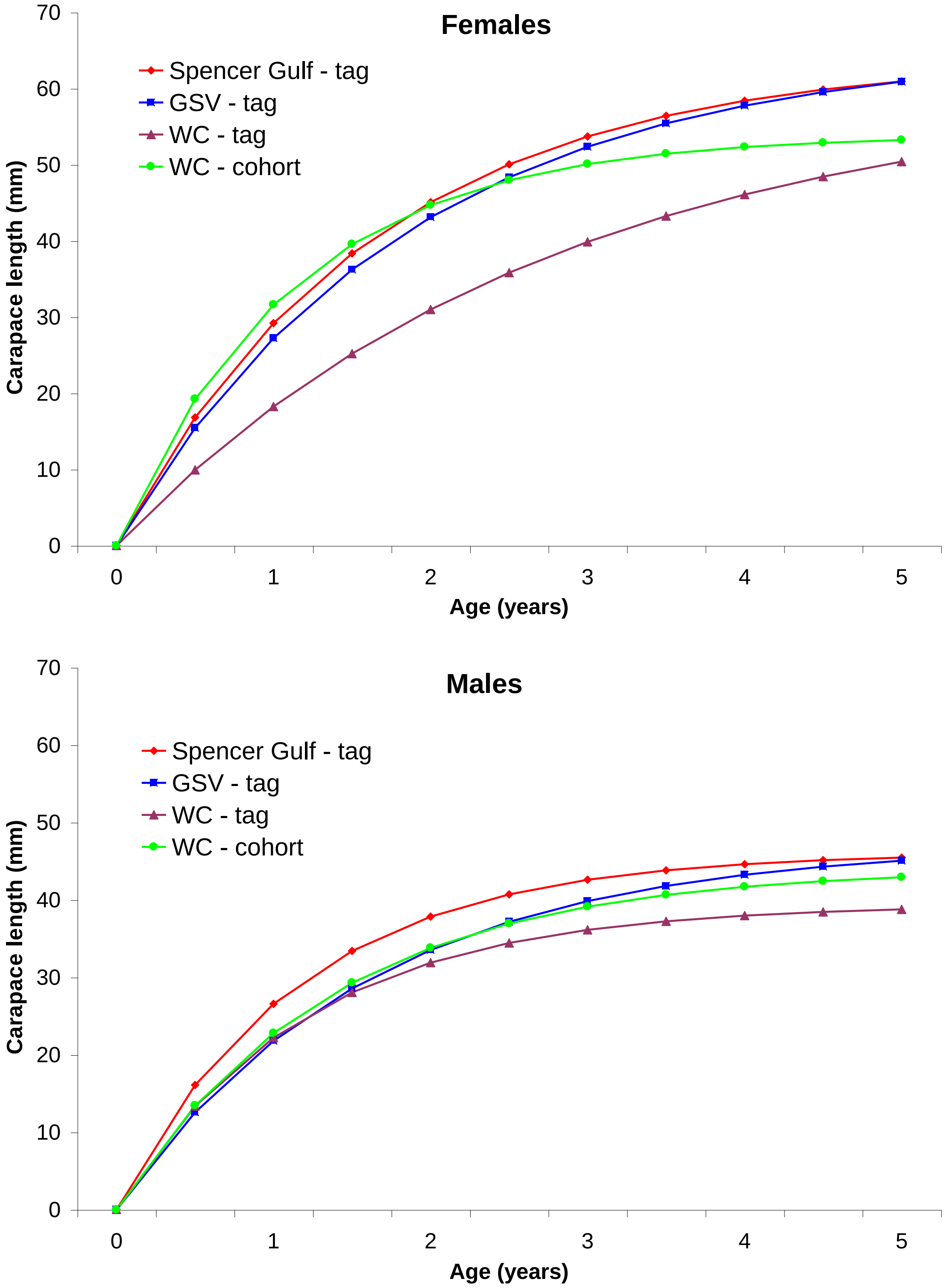

Figure 1.14 Sex-specific growth curves for western king prawns estimated from tag-recapture and cohort analysis in the West Coast (Wallner, 1985) and from tag-recapture in Spencer Gulf (Carrick, 2003) and Gulf St Vincent (Kangas and Jackson, 1997).

Table 1.4 Sex-specific von Bertalanffy growth parameters for western king prawns estimated from the West Coast (Wallner, 1985) Spencer Gulf (Carrick, 2003) and Gulf St Vincent (Kangas and Jackson, 1997).

Fishery	Sex	Growth parameters		
		K (yr^{-1})	L_∞ (mm)	ω
Spencer Gulf	Female	0.61	64.0	39.0
	Male	0.86	46.1	39.6
Gulf St Vincent	Female	0.54	65.3	35.3
	Male	0.62	47.2	29.3
West Coast	Female	0.36	60.4	21.7
	Male	0.83	39.4	32.7

1.4.6. Length-weight relationship

Length-weight relationships have not been documented for the WCPF. The relationship between carapace length (*CL*, mm) and weight (*W*, g) for the western king prawn from Spencer Gulf is described by the power function $W = 0.000124 \times CL^{2.76}$ for males, and $W = 0.000175 \times CL^{2.66}$ for females (Carrick, 2003). The relationship for juveniles (where sex cannot be easily distinguished) from Gulf St Vincent is $W = 0.00066 \times CL^{2.91}$ (Kangas, 1999).

1.4.7. Movement

Following the main spawning period in December-March, prawn larvae are expected to be advected (via inshore currents) from the Venus Bay spawning region to the north west towards the Ceduna nursery areas between February and May (Carrick, 2008). Tag returns and spatial size-distribution patterns suggest that very small prawns (>30/lb) from Ceduna then disperse in a south-east direction to join the spawning aggregation (Carrick, 2008). Transport of prawns from Ceduna is probably facilitated by the Leeuwin Current which extends from the western Australian coastline across the Great Australian Bight from May-October (Middleton and Bye, 2007).

Between October 1983 and February 1985, over 6,500 tagged prawns were released in Venus Bay and Ceduna (Wallner, 1985). Recaptures generally indicated a southerly offshore pattern of migration. A second tagging study was carried out in 1990, with 5,000 tagged prawns released in Venus Bay. Results showed a similar net offshore S/SE direction of movement (Carrick and Ostendorf, 2005).

In a larger scale tagging experiment, 10,000 tagged prawns were released in March 2002 in Ceduna. From 20 recaptures more than 8 months after release, 17 were caught in Venus Bay and Coffin Bay, again providing evidence for substantial migration south-eastward along the coast. A further 10,000 tagged prawns were released in March 2003 in Ceduna, with eight recaptures obtained more than 9 months after release. Of those recaptured, seven were caught in Ceduna and, despite the reduced distance of travel, a general S/SE direction of movement occurred. Approximate movements from these contemporary tag-recapture experiments are shown in Figure 1.15.

Each of these tag-recapture experiments was substantially affected by the magnitude and distribution of fishing effort following release. During each of the studies the status of the resource was poor relative to periods of good historical catches. This caused uncertainty in the interpretation of results including: the proportion and magnitude of movements within and between regions; the effect of population density on movement within and between regions; levels of dispersal and mortality; and the distribution of prawns outside of fished regions.

In summary, tag-recapture experiments in the West Coast indicated general localised inshore to offshore movement with a south-easterly direction of migration along the coastline that enables movements between regions. Future tagging experiments should be carried out when the fishery is not in decline to increase the chance of recapture during fishing and ensure that the results are pertinent to those of a healthy stock.

It should be noted that while the use of external tags improves tag-sighting probability, they have been associated with higher prawn mortality rates (Benzie *et al*., 1999) and suppressed growth rates (Penn, 1975; Menz and Blake, 1980), particularly for small prawns. These effects can be reduced with the use of antibiotic/antifungal ointment on the tag to reduce post-tag mortality from infection (Courtney *et al.* 2001) and selective tag colour to reduce prawn predation (Benzie *et al,*. 1995).

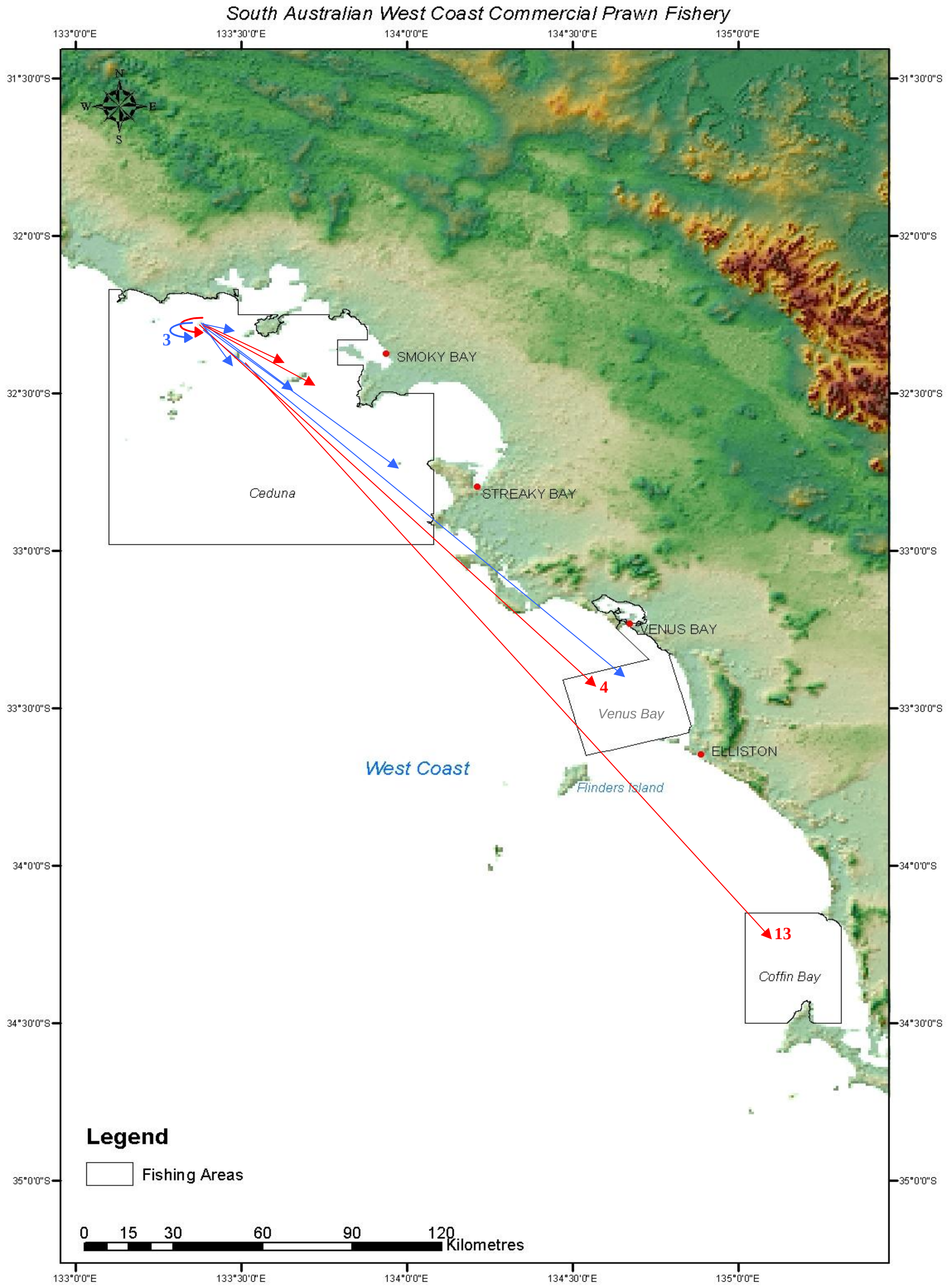

Figure 1.15 Approximate vectors indicating prawn movement from Ceduna during 2002 (red) and 2003 (blue) based on recaptures in the Venus Bay and Coffin Bay. Numbers indicate more than one recapture in that area, while circular arrows indicate recaptures caught close to the release site. Within region recapture positions were provided only for Ceduna (Dixon and Roberts, 2006).

1.4.8. Natural mortality

Wallner (1985) estimated daily instantaneous rates of natural mortality of prawns on the West Coast to be between 0.001 (inshore populations) and 0.014 (offshore populations). These values are consistent with other natural mortality values for this species in Spencer Gulf (0.003 to 0.005; King, 1977), Gulf St Vincent (0.003; Kangas and Jackson, 1997) and Western Australia (0.002 to 0.005; Penn, 1976).

Daily instantaneous rates of natural mortality for the western king prawn in Spencer Gulf range between 0.003 and 0.005 day^{-1} (King, 1977). These estimates of natural mortality are comparable with Gulf St Vincent at 0.003 day^{-1} (Kangas and Jackson, 1997; Xiao and McShane, 2000) and Western Australian populations 0.002-0.005 day^{-1}, (Penn, 1976), whereas estimates for prawns on the West Coast range more widely at between 0.001 and 0.014.day^{-1} (Wallner, 1985).

1.4.9. Biosecurity and prawn health

The health of West Coast population(s) of the western king prawn and the potential effects of coastal pollutants, parasites and disease on growth, survival and reproduction is poorly understood. In Spencer Gulf, reduced juvenile prawn abundance was observed possibly as a result of an oil spill during 1992 (Roberts *et al.*, 2005) and industrial effluent has been shown to influence juvenile habitat (Carrick, 2003). Common marine pollutants in South Australia include heavy metals, high nutrient loads from coastal industries, and petroleum (hydrocarbon) discharges (Edyvane, 1999). Although these sources of pollution are common, little research has been conducted to examine their impact on prawn nurseries. The WCPF is at a lower likelihood of risk from coastal pollutants, however, its small extent of suitable juvenile prawn habitat increases the consequence of such an event.

Disease status and parasite loads are limiting factors in marine animal populations, although they are generally overlooked in fisheries management (Harvell *et al.*, 2004). Climate change may increase the risks associated with spread of disease, and push species towards their physiological thresholds (Harvell *et al.*, 2002; Vilchis *et al.*, 2005; Pörtner and Knust, 2007).

Exotic (introduced) viral pathogens is considered one of the highest health risks for prawn populations due to their: 1) potential virulence; 2) rapid proliferation and infection; 3) general host non-specific nature; and 4) resistance and durability, which increases their chances of spread through national and international movements of prawns, prawn products (i.e. bait prawns) and other crustacean products. The ability for viral pathogens to survive the freezing process enabled one of the most virulent and financially-damaging penaeid viruses, White

Spot Syndrome Virus (WSSV), to spread from Asia into the USA (Lightner *et al.*, 1997). A naturally occurring (endemic), and likely harmless, MBV-like virus was observed in ~60% of prawns in Spencer Gulf and Gulf St Vincent (MBV is a common virus known to occur throughout Australia; (Roberts *et al.*, 2010), It was, however, concluded that juvenile prawn populations in South Australia are free of the key disease-causing (and notifiable) viruses found in Australia and overseas, which include IHHNV, WSSV, HPV and GAV. Nevertheless, the introduction of viruses through imported prawn and crustacean products remains a high risk, and regular monitoring of prawn nurseries is necessary to enable early detection and response. Under the current *Livestock Notice 2008* (Restrictions on Entry of Aquaculture Stock), aquaculture stock that do not have specific translocation protocols described in that notice can enter South Australia from interstate legally only under a Ministerial approval. The use of imported prawns as bait by recreational fishers was considered one of three major exposure pathways under an import risk assessment conducted by the Commonwealth Government (Biosecurity Australia, 2009)

1.5. Previous fishery assessments

Wallner (1985) produced the first stock assessment report for the WCPF. This comprehensive report included analyses of catch and effort data, as well as studies on prawn larvae, juvenile abundance and habitat, growth, mortality, recruitment, migration and reproduction. Stock assessments for the WCPF were combined with Spencer Gulf assessments in 1998, 2000 and 2001 (Carrick and McShane, 1998; Carrick and Williams, 2000; 2001), the latter two being the first to consider the biological PIs for the fishery.

Boxshall (2001) produced the first contemporary stock assessment report on the WCPF independent from the SGPF. The 2001 stock assessment contained background information on the fishery, management objectives, a brief biological overview of the western king prawn, catch and effort information for the 2000/01 season and the assessment of PIs (Boxshall, 2001). Subsequent status reports have been provided annually (Svane, 2003b; Svane and Barnett, 2004; 2005; Dixon *et al.*, 2005b; Dixon *et al.*, 2007; Roberts, 2007; Hooper *et al.*, 2009; 2010; 2011; Gorman *et al.*, 2012). Dixon and Roberts (2006) produced the second contemporary stock assessment report utilising information presented in previous reports and providing substantial updates on historic research, commercial logbook data, survey data, and prawn size data. The current report updates previous reports and incorporates increased survey data and incorporates environmental influences to examine trends in catch.

1.6. Research program

The current research program conducted by SARDI Aquatic Sciences comprises five components that include: (i) daily logbook program; (ii) catch and effort information; (iii) independent stock assessment surveys prior to, during and toward the end of the fishing-year; (iv) manage and analyse by-catch, juvenile sampling and tagging data; and (v) produce an annual report that assesses the status of the fishery against the PIs suggested in the *Management Policy* (PIRSA, 2010).

1.7. Information used for assessment

1.7.1. Stock assessment surveys

Stock assessment surveys, using industry vessels (with observers) have been undertaken since 1989. Venus Bay and Ceduna surveys have been conducted in accordance with the schedule in the Management Plan with the exception of the Ceduna survey in March 2012. Surveys have not been conducted in Coffin Bay since November 2009 due to logistical problems. A summary of the number of survey trawl shots conducted within regions of the WCPF is provided in Appendix 1. Surveys are conducted using industry vessels, skippers and crews, with independent observers placed on each vessel, to collect data on prawn size and catch rates. These data serve two purposes: 1) to determine relative biomass and stock status of the WCPF; and 2) to inform the development of fishing strategies within the decision rules in the *Management Policy* (PIRSA, 2010).

1.7.2. Catch and effort monitoring

Licence holders are required to complete and submit daily catch and effort logbook returns at the end of each month. A monthly logbook is also completed to enable validation and adjustment of daily catch estimates.

Since the reporting of catch and effort data began in 1968, there have been a number of modifications to improve the information available for assessment. From July 1987, the previously used regular grid for reporting catch and effort was replaced with 118 irregularly-shaped polygons, or fishing blocks; 12 in Coffin Bay, 17 in Venus Bay and 87 in Ceduna. More recent changes to the daily logbook include the requirements for licence holders to record GPS locations for at least three trawl shots per night, size-grade data of the prawn catch, and retained by-product (southern calamari, *Sepioteuthis australis*, slipper lobster, *Ibacus* spp., octopus *Octopus spp.,* arrow squid *Nototodarus gouldii* and scallop *Pectinidae*).

2. METHODS

2.1. Stock assessment surveys

2.1.1. Data collection

One or two vessels from the fishing fleet, with an observer onboard each vessel, were required to complete each survey in 2012–13. In 2012, surveys were conducted on March 24th (Venus Bay), June 19th (Venus Bay) and November 13th (Venus Bay and Ceduna). In 2013, surveys were conducted on March 11th (Venus Bay and Ceduna), June 9th (Venus Bay), and October 31st (Venus Bay and Ceduna). As with previous surveys, these dates were chosen to correspond with the dark moon. At each shot location, the survey vessel trawled along a pre-determined path for 30 minutes. The distance trawled at each location depends on trawl speed (3–5 knots), which is influenced by vessel power, tide and weather conditions. A complete list of survey dates and locations is available in Appendix 1.

Data collected for each shot location included total catch, catch of 20+ grade prawns, number of nets used, trawl duration, tide direction, and number of prawns in a '7 kg bucket' as a rapid measure of prawn size. A random sample of 100 prawns was also taken from each shot to obtain information on sex ratio and length frequency.

2.1.2. Egg production

An annual egg production model was developed in 2004/05 for the SGPF. Model calculations are based on biological data collected from the November survey, and rely on several assumptions:

- catchability of prawns is constant during the survey;
- female prawns spawn three times during the spawning period;
- spawning frequency does not vary with prawn size;
- natural mortality is zero;
- percentage of females within each grade does not vary during the spawning period; and
- sex-specific length frequency data from surveys are representative of the population.

The following calculations describe the application of the egg production model:

1) Mean weight of prawns for each prawn grade was obtained from commercial processors;
2) Mean size (mm, CL) of female prawns for each grade was derived from 1) using the length-weight relationship (Section 1.4.6);

3) Catch rate per grade was calculated (in $kg.h^{-1}$, adjusted for two nets);
4) Catch rate of females per grade per hour was derived from 3) and the mean proportion of females in the corresponding grade;
5) Number of females per grade per hour was derived from 1) and 4);
6) Number of mature females per grade per hour was derived from 2) and 5), and the proportion of mature females for each grade using the logistic equation was provided by Carrick (1996);
7) Number of fertilised eggs produced per grade per hour was derived from 2), the size-fecundity relationship for Gulf St Vincent (Kangas unpublished, cited in Carrick 2003), and the proportion of eggs successfully fertilised per grade (derived from Courtney and Dredge, 1988);
8) Number of fertilised eggs produced per hour was calculated as the sum of data from 7) across all grades; and
9) Total number of fertilised eggs produced per hour was calculated by multiplying the data from 8) by the assumed spawning frequency (three times per spawning period), and summing their products over all shots.

The final calculation of the mode, (i.e. step 9), is interpreted as the potential number of fertilised eggs per hour that females could have contributed to egg production throughout the spawning period.

2.1.3. Recruitment

The recruitment index developed by Carrick (2003) was calculated as the square root of the number of recruits per nautical mile trawled from March surveys in Ceduna. ‘Recruits’ are defined as prawns ≤32 mm CL for males and ≤35 mm CL for females. The recruitment index has been calculated for March surveys in 2007, 2010, 2011 and 2013 from 7–14 recruit shots.

The average number of recruits per trawl-hour was also determined for each survey period in each survey region from 2006 to 2013 to identify spatial and temporal (inter- and intra-annual) trends in relative abundance of recruits throughout the fishery.

2.2. Catch and effort statistics

2.2.1. Catch, Effort and CPUE

Catch and effort data includes fishery-dependent catch and effort from normal fishery operations (i.e. excludes survey catch and effort). Data were obtained from two sources: annual data from 1968 to 1972 and monthly data from January 1973 to June 1980 from the South Australian Fishing Industry Council (SAFIC) annual reports (1975 to 1980); and daily logbook data from July 1980 to December 2013 (SARDI). Daily logbook data from July 1980 to November 1986 are presented although they are not fully validated (discrepancies in annual catch between daily logbooks and various summaries were <5 t in all years). Estimated prawn catch for each shot was adjusted using validated post-harvest catches reported in monthly logbooks.

In this report, a “fishing-year” is defined as the calendar year to reflect the pattern of effort distribution of the fishery. Catch and effort data are presented for each fishing-year as a total and by regions defined in Figure 1.1. Currently, fishing occurs most months of the year as catch rates do not decrease dramatically during cooler periods. As the main spawning period for western king prawns in the West Coast extends from December to March, catch is also presented for the early spawning period (November–December) compared to all other fishing months. CPUE was calculated by dividing catch by effort, and expressed in $kg.h^{-1}$.

2.2.2. Prawn size

Data on prawn grades for the WCPF were obtained for the period 1996–2013. Grades were determined from the number of prawns to the pound (i.e. U10 = under 10 prawns per pound, etc.) and thus reflect mean prawn size. Daily catch was recorded as the number of cartons per prawn grade. All graded cartons weighed 10 kg each with the exception of those in the U8 and U10 categories after April 1999, when the carton weight was 9 kg.

From January 1996–March 1999, prawn grades included U8, U12, 12–18, 16–20, 19–25, 26+ and Soft & Broken (SB). Counts of the number of prawns in one 10 kg carton from each grade were obtained on a daily basis during this period. From April 1999–March 2004, prawn grades included U8, U10, 10–15, 10–20, 20–30 and SB. Counts of the number of prawns in 1 pound from each grade were obtained on some days during this period. These counts per graded carton and per graded pound were used to determine the mean number of prawns per kilogram (ppkg) for each prawn grade. Hereafter, prawns in the U8, U10 and U12 grades are referred to as the size category “extra-large”, those in the 10–15, 10–20, 12–18 and 16–20 grades as “medium-large”, and those in the 20–30, 19–25 and 26+ grades as “small”

(Table 2.1). SB prawns were excluded from all analyses, as were years and regions with less than five nights fished.

To facilitate interpretation of the prawn grade data among all fishing-years, the data from 1996 to 2014 were converted to four size categories based on the decision rules provided in Table 2.1. For analysis of trends within years, a fifth category, SB was established for prawns that were not graded. In this report, prawns in the U10, 10/15, 16/20, 20+ and SB categories are referred to as extra-large, large, medium, small and SB, respectively.

Table 2.1 Analytical categories assigned to reported prawn grades from the commercial logbook data.

Prawn grade	Categories in logbook
U10 (Extra-large)	U6, U8, U10, L, XL
10/15 (Large)	10/15, 9/12, U12, 13/15, LM, 10/20 (50%), 12/18 (50%)
16/20 (Medium)	16/20, M, 10/20 (50%), 12/18 (50%)
20+ (Small)	20+, 19/25, 21/25, 21/30, 26+, 30+, 31/40, S, SM
Soft & Broken (SB)	SB, B&D, MIX, REJ, SMS, blank, ERR

Estimates of the number of prawns captured per grade per day were obtained by multiplying the daily grade weight (kg) by the mean number of prawns.kg^{-1} for that grade (Table 2.2). From this, graded abundance of the catch was compared between years for each region. Mean annual prawn size (prawns/kg ± SE) was defined as the number of prawns captured in all grades per year/total weight of all grades per year, computed using the mean ratio estimator after Rice (1995). This estimator avoids the bias associated with calculating the average of mean daily prawn size.

The relative size composition of the total annual catch from the WCPF was compared between years for 1996–2004, and compared with prawn size data from Spencer Gulf during 2002/03 and 2003/04 (Dixon *et al.*, 2005a).

Mean daily prawn size was calculated as the number of prawns captured in all grades / total weight of all grades for each daily catch. Mean daily prawn size data from the WCPF during 1996–2004 were compared in relative terms to equivalent data obtained from the SGPF during 2002/03–2003/04.

Mean daily prawn size is a measure of the average size of prawns harvested by the fleet each day. The number of prawns per kilogram for each of the 23 prawn grades was estimated from the prawn grade name (i.e. prawn grade 10–15 was estimated as 12.5 prawns per pound equaling 27.5 prawns per kg) and are presented in Table 2.2.

Table 2.2 The number of prawns per kg estimated for reported prawn grades from the commercial logbook data.

Prawn Grade	Prawns per kg	Mean weight (g)
U6	13.2	75.8
U8	15.4	64.9
U10	19.8	50.5
10/15	27.5	36.4
10/20	33.0	30.3
16/20	39.6	25.3
21/25	50.6	19.8
21/30	56.1	17.8
26+	61.6	16.2
30+	78.1	12.8

The average number of prawns/7 kg (one bucket) for each vessel's daily catch was calculated from the catch-by-grade data provided in commercial logbooks and the number of prawns per kg for each grade (Table 2.2) using the equation:

$$\frac{\sum[catch(grade) \times \{ppkg(grade) \times 7\}]}{\sum[catch(grade)]}$$

where, catch is the total daily catch (kg), ppkg is the number of prawns per kg, and grade is the relevant prawn grade.

Mean annual prawn size (prawns/7 kg) was determined as the weighted mean prawn size from each daily catch using the equation:

$$\frac{\sum[\sum catch \times \sum(catch \times pp7kg)]}{\sum[catch]}$$

where, catch is the total daily catch (kg), andpp7kg is the mean daily prawns per 7 kg.

Target size criteria for fishing (as defined in the *Management Policy*) vary according to the at-sea decision rules which specify monthly and region specific limits. In Venus Bay, bucket counts of <250 prawns.kg^{-1} are targeted from March-May, while larger prawns (<240 prawns.kg^{-1}) are targeted from June–October. In Ceduna, smaller prawns are allowable all year (bucket counts < 270 prawns.kg^{-1}) and in Coffin Bay larger prawns are targeted all year (bucket counts less than 240 prawns.kg^{-1}). Data are presented on the number (and %) of vessel nights when prawns were caught at an average size smaller than 240, 250 and 270 prawns.7 kg^{-1} to assess how well the fishery achieved target size criteria.

2.3. Environmental variables

Data on SST, SLH, wind speed and direction were used to investigate potential environmental factors in the WCPF. SSTs were obtained from the DAAC live access server (http://thredds.jpl.nasa.gov/las/getUI.do) and the the Australian Bureau of Meteorology provided SLH (http://www.bom.gov.au/ntc/IDO70000/IDO70000_62230_SLD.shtml). The upwelling index was defined as the along shore component of wind stress (τ) from observed wind strength and direction at Neptune Island (Van Ruth *et al.*, 2010).

$$\tau = \rho_a C_D U|U|,$$

where, ρ is the density of air, C_D is the drag coefficient and (U) is the averaged three hourly wind data. Positive values of (τ) indicate upwelling favourable conditions.

2.4. Performance indicators

Performance of the fishery was assessed against three of the biological and economic RPs specified in the *Management Plan* (MacDonald, 1998):

1. Effort (days)
2. Recruitment index
3. Prawns per kilogram (ppkg)

The recruitment index was calculated using the updated methodology specified by Carrick (2003). In addition, the performance of the fishery was assessed against potential PIs as specified in the *Management Policy* (PIRSA, 2010):

1. Total effort (spatial, temporal)
2. Mean survey CPUE (spatial)
3. Mean CPUE (spatial)
4. Total annual catch
5. Mean daily catch per vessel
6. Catch during the early spawning period

Finally, the following additional performance indicators are suggested by SARDI based on those used in the SGPF (Dixon *et al.*, 2013):

1. Recruitment index (temporal and spatial)
2. Egg production
3. Prawn size (temporal)

2.5. Quality assurance of data

2.5.1. Research planning

The 2011-12 research requirements of PIRSA Fisheries and Aquaculture for the WCPF were developed in late 2010 and subsequently provided to industry representatives to confirm their understanding of proposed deliverables. This ensured that the research undertaken and deliverables provided were consistent with the needs of PIRSA Fisheries and Aquaculture to meet their obligations under the *Fisheries Management Act 2007.*

2.5.2. Data collection

Commercial fishers are advised on the procedures and requirements for conducting surveys and completion of the required SARDI fishery logbook on a regular basis, which is usually at the commencement of each fishing season. The data provided by commercial fishers were checked by SARDI prior to acceptance and potential errors corrected through direct correspondence with individual commercial fishers/licence holders. SARDI staff members are trained to undertake fishery-independent data collection using methods described in stock assessment reports for the fishery (Dixon and Roberts, 2006).

2.5.3. Data entry, validation, storage and security

All logbook data were entered and validated according to the quality assurance protocols identified for the WCPF in the SARDI Information Systems Quality Assurance and Data Integrity Report (Vainickis, 2010). Data were stored in an Oracle database, backed up daily, with access restricted to SARDI Information Systems staff. Extracts from the database were provided to SARDIstaff on request. All fishery-independent data were entered into a separate Oracle database. Accuracy of survey data entry was verified by: 1) running a series of checks for any inconsistencies or errors in the data file; and 2) checking a subset of the data (20%) against the original data sheets, including any errors that could not be resolved from examining the file alone. Once validated, data were uploaded and stored on a network drive with restricted access to SARDI staff involved in research projects in the Inshore Crustaceans Subprogram.

2.5.4. Data and statistical analyses

Data were extracted from the databases using established protocols. Accuracy of the data extracted was checked by comparing pivot table summaries with previous data extractions. To check for precision (repeatability), data analyses were carried out for multiple years at a time (where possible) to reproduce the results of previous years.

2.5.5. Data interpretation and report writing

The results, their interpretation and conclusions provided in the report were discussed with SARDI research peers, PIRSA Fisheries and Aquaculture and industry representatives (including some licence holders). All co-authors reviewed the report prior to the report being formally reviewed by two independent scientists at SARDI in accordance with the SARDI report review process.

3. RESULTS

3.1. Stock Assessment Surveys

3.1.1. Mean catch rate

Catch rates from prawn surveys have ranged from 5 kg.hr^{-1} (± 0.6 kg.hr^{-1}, SE) in 1993 to 74.4 kg.hr^{-1} (± 12.6 kg.hr^{-1}, SE) in 1996 (Figure 3.1). There is a general similarity in the temporal trends between survey and fishing catch rates (LR: r^2 = 0.456, df = 17, P = 0.002; Figure 3.2) and CPUE has closely followed trends in annual catch. Low catch rates observed during 1989, 1992–94, 2003–06 relate to years of low catch. In 2008, fishing catch rate was 43% higher than survey catch rate. This was correlated with low survey catch rates in 2008 in Coffin Bay (7.3 kg.hr^{-1} ± 1.1, SE; Figure 3.3). Similarly, higher fishing catch rates were observed compared to survey catch rates in 2004 and 2005. This was correlated with low survey catch rates in Venus Bay in 2004 (16.7 ± 2.6 kg.hr^{-1}, SE) and 2005 (19.1 ± 3.2 kg.hr^{-1}, SE) and Coffin Bay in 2004 (16.7 ± 2.5 kg.hr^{-1}, SE) and 2005 (19.1 ± 9.2 kg.hr^{-1}, SE; Figure 3.3). High levels of variation between regions were observed in survey catch rate from 2011–2013 correlated with lower survey catch rates in Ceduna in 2012 (34.2± 6.0 kg.hr^{-1}) and 2013 (41.4 ± 6.3 kg.hr^{-1}, Figure 3.3).

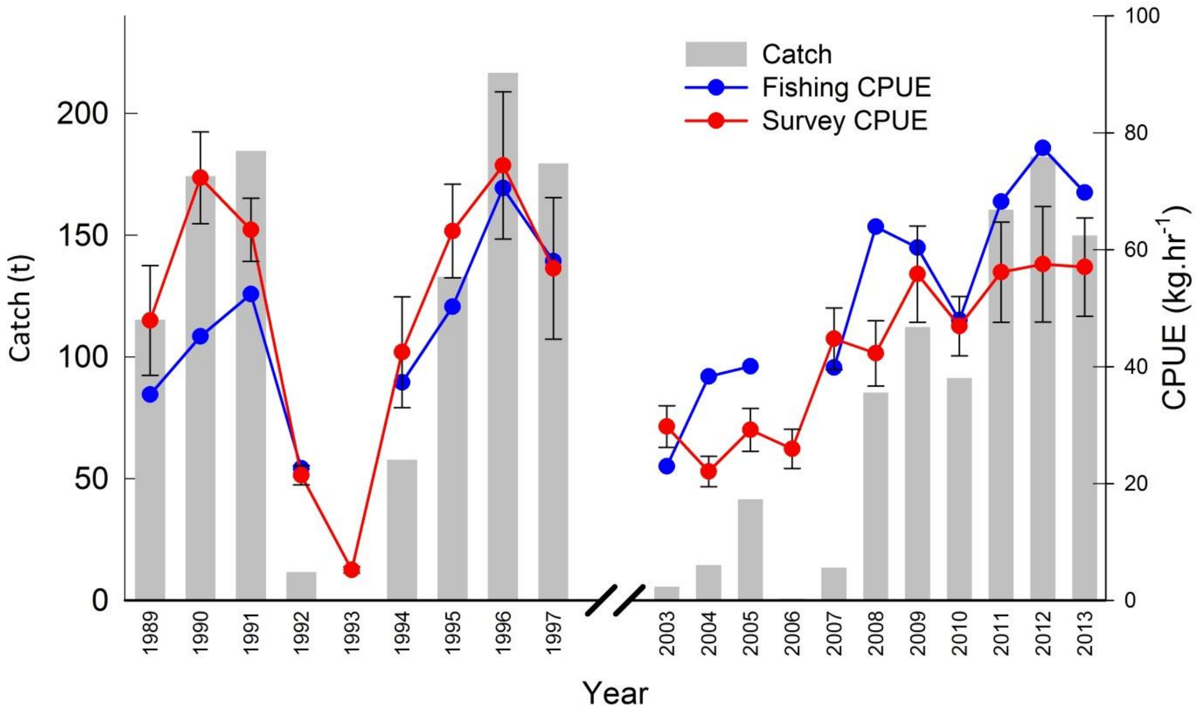

Figure 3.1 Total catch and mean survey catch per unit effort (CPUE) and fishing CPUE from the West Coast Prawn Fishery from 1989–2013. No fishing was done in 1993 or 2006.

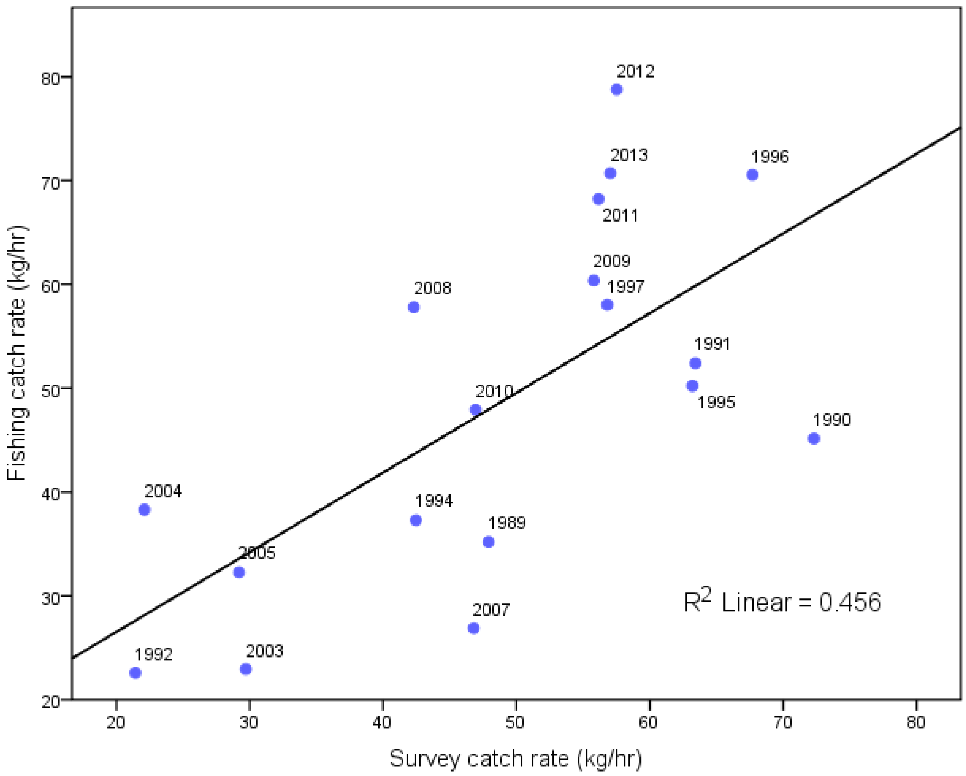

Figure 3.2 Correlation between survey and fishery catch rates for the years 1989–92, 1994–97, 2003–13.

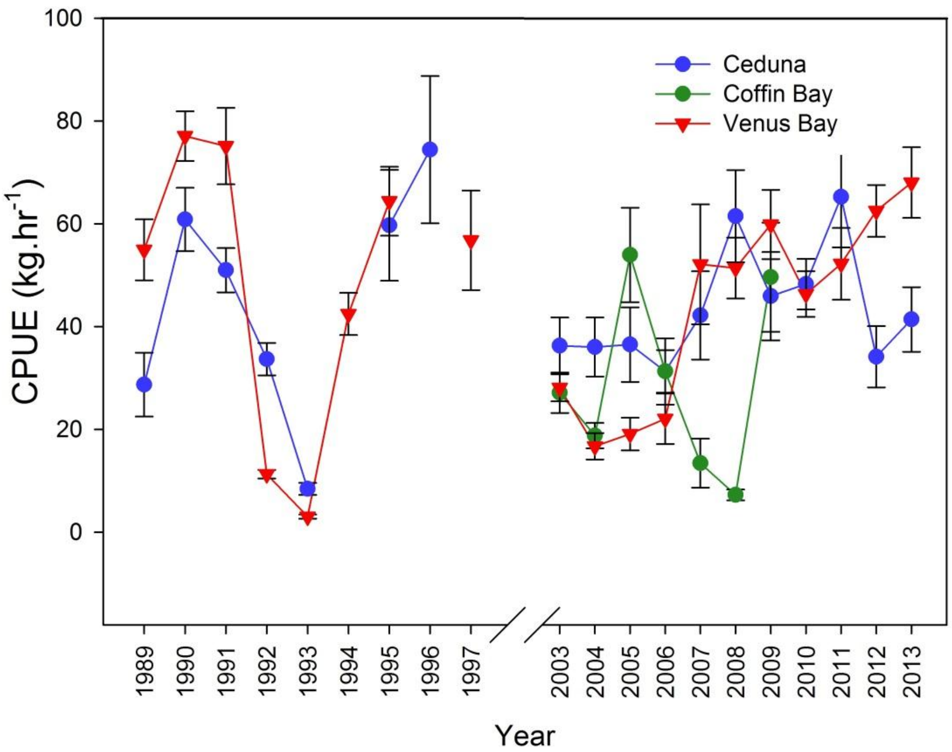

Figure 3.3 Mean survey catch per unit effort (CPUE) from the West Coast Prawn Fishery from 1989–2013. Survey catch rates not available for Coffin Bay from 1989–2000 and 2010–13, in Ceduna from 1994, 1997 and 1998 and Venus Bay in 1996.

3.1.2. Prawn size

The mean size of prawns measured on surveys varied between regions (Figure 3.4). Prawns in Ceduna were smaller than those in Venus Bay in all years. The difference in size was most apparent during 1990 and 1991. Surveys were only conducted in Coffin Bay from 2003–09 and during these years the mean size of prawns was similar to that observed in Venus Bay.

Each survey is characterised by fluctuating catch rates of small and mixed sized prawns. Following the fishery closure in 2006, there was a rapid increase in catch rates driven by increasing abundance of small prawns. Relative biomass appears to be stable from 2008 onwards (Figure 3.5).

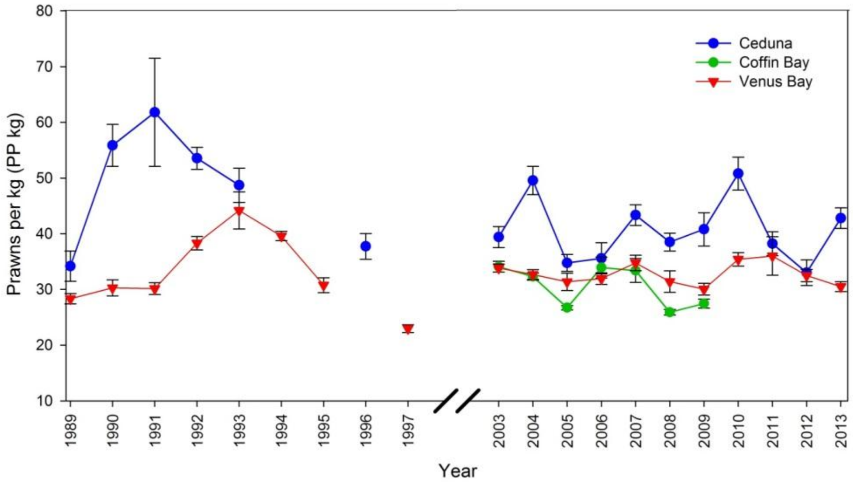

Figure 3.4 Mean size of prawns (± SE) measured during surveys from 1989–97 and 2003–13 in regions of the West Coast Prawn Fishery.

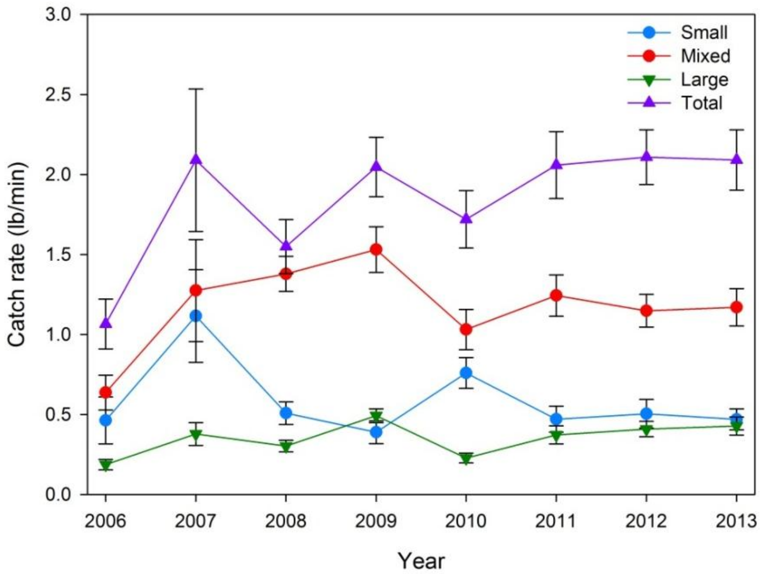

Figure 3.5 Mean catch rates of small (20+), mixed (10/20) and large (U10>) prawn grades, obtained from all surveys combined from 2006–13

3.1.3. Egg production

Mean egg production per hour trawled during the October 2013 survey (346 million.hr^{-1}) was greater than that from the previous November survey (2012: 187 million.hr^{-1}) and was above the previous six-year average (234 million.hr^{-1}, range 187–331 million.hr^{-1}; Figure 3.6).

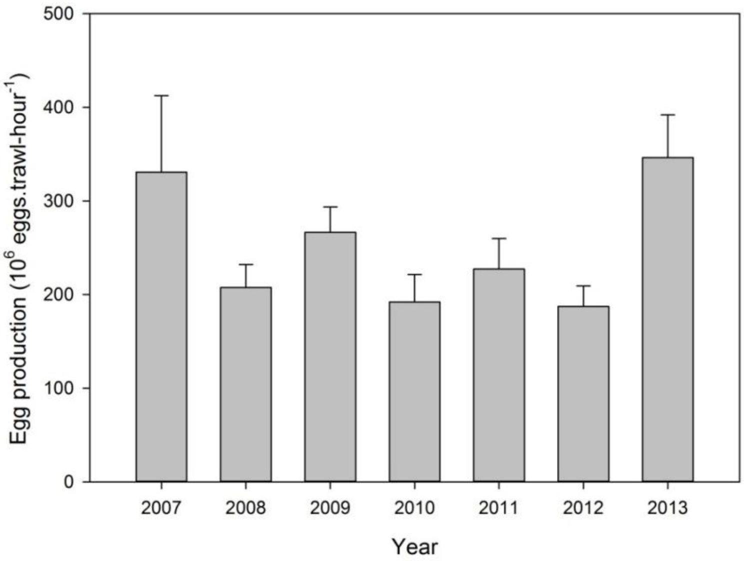

Figure 3.6 Egg production during November surveys from 2007–13 (2008 and 2013 surveys conducted in October).

3.1.4. Recruitment

In Ceduna, a decreasing recruitment index has been observed in March since 2007 (range 22.3–14.0 $\sqrt{\text{recruits.nm}^{-1}}$; Figure 3.7). The Ceduna recruitment index was low in 2013, however, this survey did not include sampling in shot 2025 (block 314) which had a historically high recruitment index (mean = 2007, 2010-11: 43.4). The decrease in recruitment index coincided with a 60% reduction in shot number 2014 from years 2011 to 2013 (Figure 3.8). The recruitment index in Venus Bay has increased in March since 2007 (range 7.5–13.7) and in 2013 March the recruitment index in Venus Bay was equivalent to Ceduna (Figure 3.7).

In November, the recruitment index was high in Ceduna in 2010 at 21.5 compared to only 9.4 in 2012 (Figure 3.7). Moderate recruitment index values were observed in November in Venus Bay, with a peak of 11.7 in 2010 and a low of 6.4 in 2006. As the index is square-root transformed, a two-fold increase in the index translates to a four-fold increase in the number of recruits per nautical mile. The recruitment index is below the limit RP (40) for all years, months and locations analysed.

Annual mean recruit abundance was higher in Ceduna than Venus Bay for all years analysed. Peaks in recruit abundance occurred in both Ceduna and Venus Bay in 2007 and 2010 (Figure 3.9). In March, a decreasing trend in recruits was observed at Ceduna (range: 84–196 rec.hour^{-1}) and Venus Bay (range: 43.4–76.2 rec.hr^{-1}) since 2006. Fluctuations in recruitment to Venus Bay were observed in June-July, with a peak in 2010 (range: 38.1–73.9 rec.hour^{-1}), while in most years, recruitment was lowest in October-November in Venus Bay (range: 10.2–49.5 rec.hour^{-1}). Increasing recruitment was observed in Ceduna from 2006–10 (range: 66.1–93.9 rec.hour^{-1}) followed by lower recruit abundance from 2011–12 (range: 39.7–53.5 rec.hour^{-1}).

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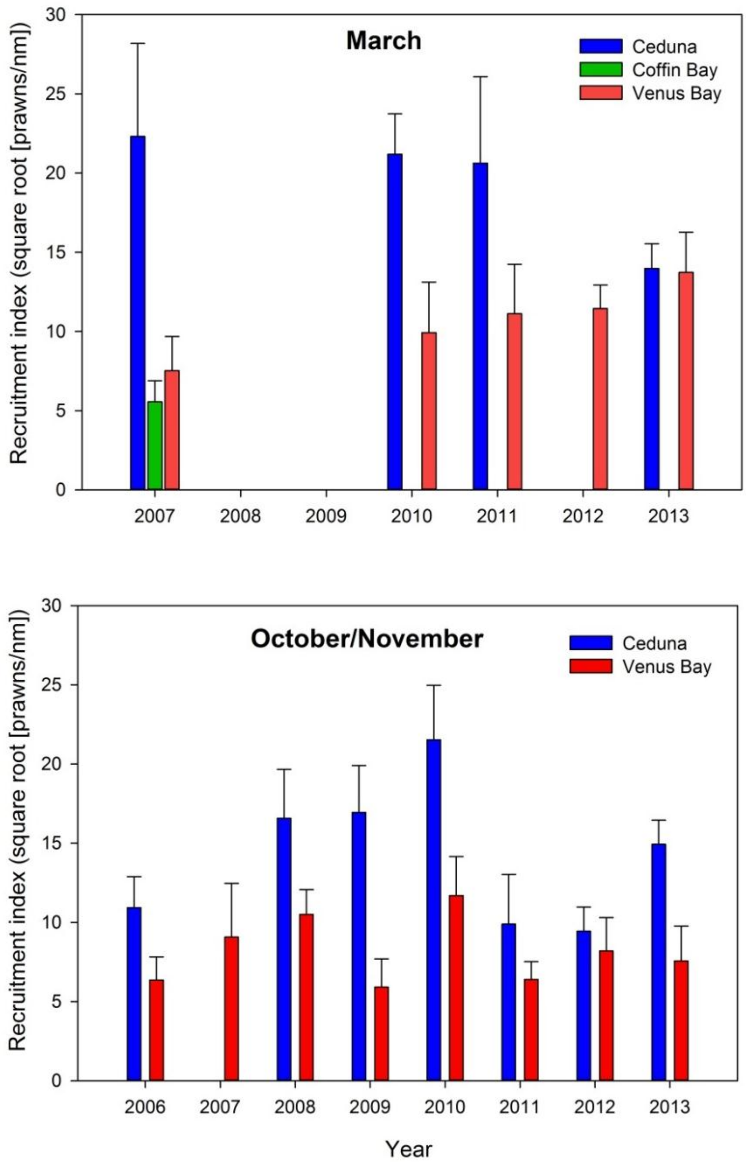

Figure 3.7 Mean (SE) recruitment index for Ceduna and Venus Bay surveyed in March and October-November from 2006-2013. Recruitment indexes could not be calculated due to lack of data in March 2006, 2008, 2009, 2012 (Ceduna) and November 2007 (Ceduna) and 2009. October surveys were conducted in 2008 and 2013.

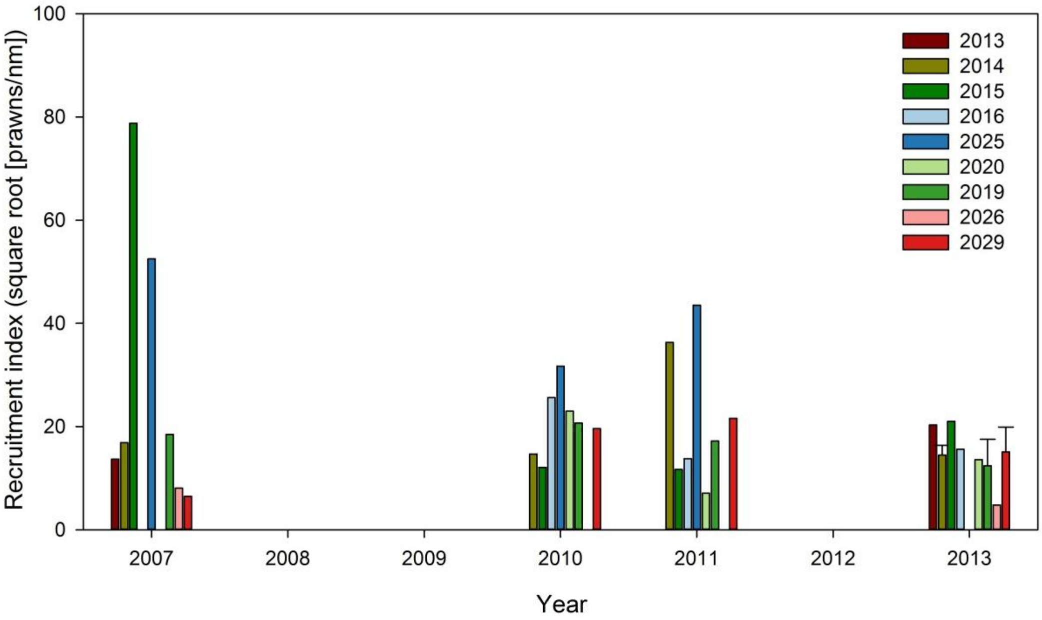

Figure 3.8 Mean (SE) recruitment indices for shots repeatedly surveyed in Ceduna from March 2007–13. Recruitment indexes could not be calculated due to lack of data in 2008, 2009 and 2012.

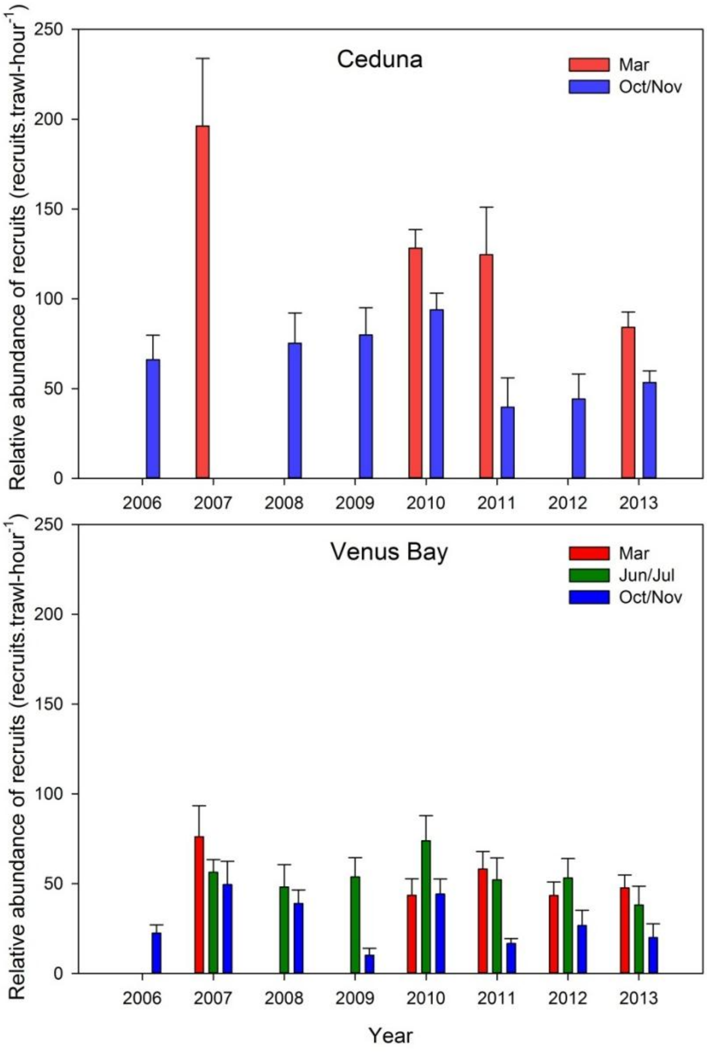

Figure 3.9 Mean (SE) recruit abundance (recruits.trawl–hour^{-1}) for (a) Ceduna and (b) Venus Bay surveyed from 2006-13.

3.2. Catch and effort statistics

3.2.1. Annual trends

Historically, there have been three low catch periods (<50 t) and four high catch periods (>80 t). Catches of prawns were low on the West Coast in 1968 (Figure 3.10). Both catch and effort increased rapidly, with effort peaking at ~10,000 hours in 1970 and catch peaking at ~290 t in 1973. The first high catch period from 1969–76 was followed by a 3-year low catch period. Catches recovered rapidly and were above 50 t from 1980–91. In 1991 catches declined from ~190 t to <10 t in 1992. Catches were high from 1994–2001 (mean annual catch = 134.1 ± 17.2 t. SE) before declining steeply from ~140 t in 2001 to ~30 t in 2002 and <5 t in 2003. The fishery produced low catches (reduced effort, maximum 1000 hours in 2005) during 2004–07, with no fishing undertaken in 2006. From 2008–10, high catches were obtained (mean annual catch = 95.1 ± 8.6 t, SE) and the highest catch since 1997 was recorded in 2011 with 159.3 t which was exceeded by the 2012 catch of 181.2 t. Effort increased by over 1,000 hours from 2007 to 2008 and continued increasing until 2012 where over 2,000 hours were fished. The total catch of 148.5 t for 2013 is within the historical range and at the 65th percentile since 1973–74 (range: 4.6–289.9 t; mean = 115.8 ± 73.3 t, SE; Figure 3.10).

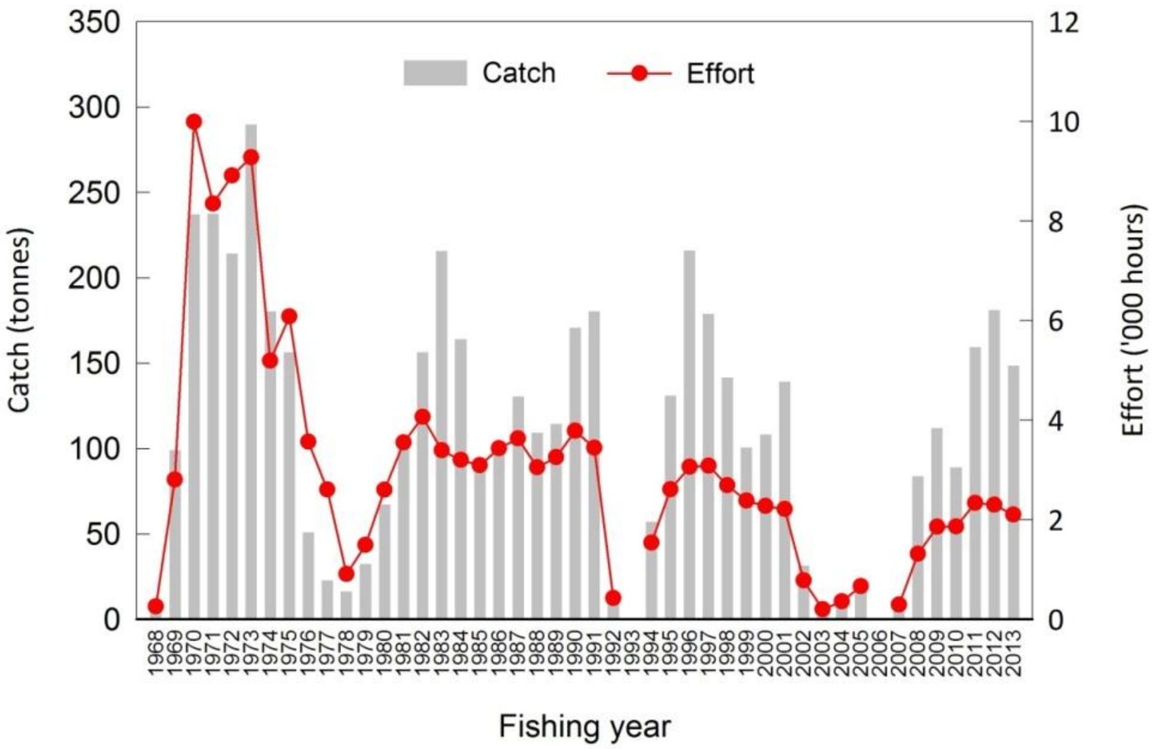

Figure 3.10 Catch (t) and effort (hrs) for the West Coast Prawn Fishery from 1968–2013.

From 1968–76, annual CPUE varied between 14 and 35 $kg.hr^{-1}$ before declining rapidly until 1977 (Figure 3.11). From 1981–1991, CPUE varied between 29 and 64 $kg.hr^{-1}$ before again declining in 1992. From 1995–2001, CPUE varied between 42 and 71 $kg.hr^{-1}$ before declining in 2002. Annual CPUE did not exceed 41 $kg.hr^{-1}$ from 2002–07. CPUE exceeded 60 $kg.hr^{-1}$ in 2008 and 2009, peaking in 2012 at 77 $kg.hr^{-1}$ which is the highest recorded CPUE.

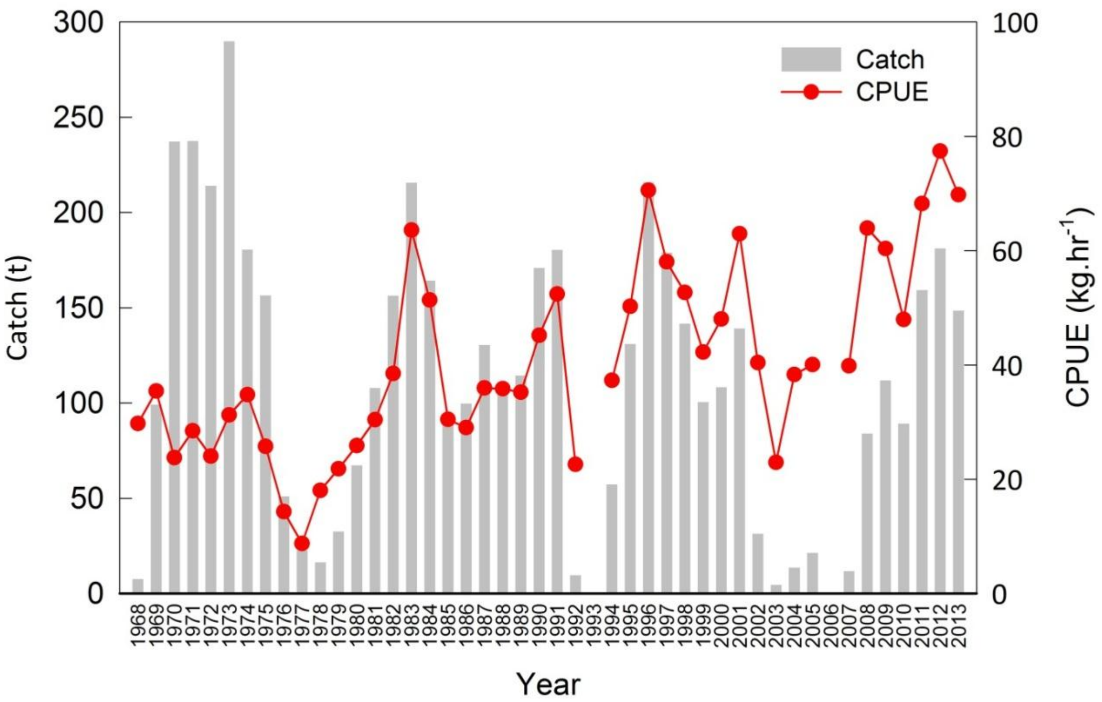

Figure 3.11 Annual catch and catch-per-unit-effort (CPUE) for the West Coast Prawn Fishery from 1968–2013.

3.2.2. Spawning periods

From 1973, ~39% of the total catch from the WCPF was harvested during the spawning period (November to March). From 1973–2013, 16% of the catch was harvested during early spawning (November and December) and ~23% during late spawning (January–March, Figure 3.12). High levels of catch during early spawning (>20 t) were observed in 1973–74, 1982–85, 1995–2001 and from 2012-13. Late spawning catch was high (>20 t) during 1974–76, 1980–91 and 1995–2000.

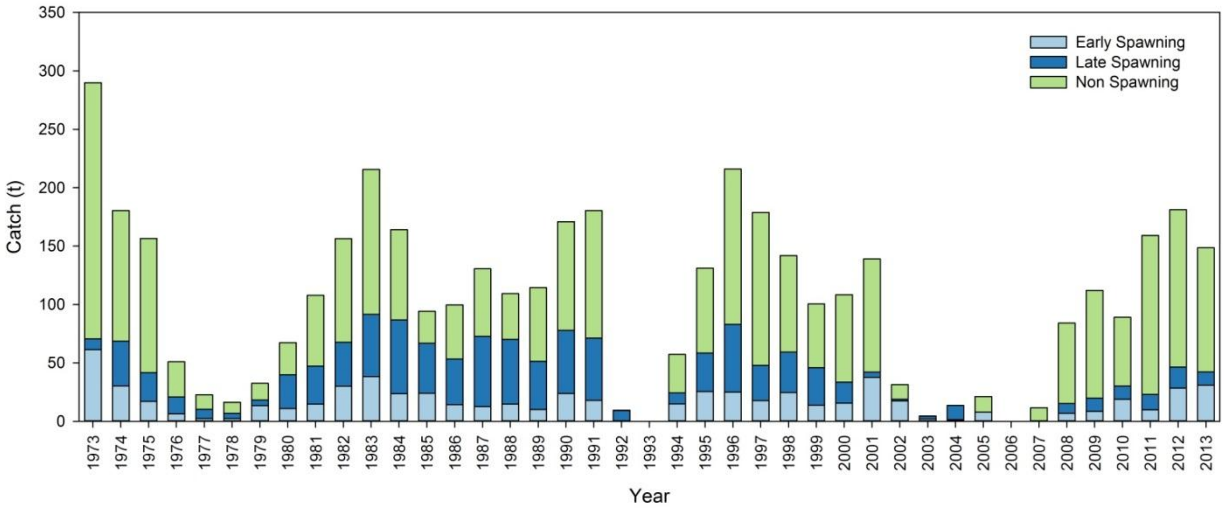

Figure 3.12 Catches during early spawning (November–December), late spawning (January–March) and non-spawning (April–October) periods from 1973–2013 for the West Coast Prawn Fishery.

3.2.3. Regional catch

The regional distribution of catches from the WCPF has varied since 1980 (Figure 3.13). Since 1980, >65% of the total catch occurred in Venus Bay, ~28% from Ceduna and ~6% from Coffin Bay. Between 1981 and 1991, annual catches ranged from 47–180 t in Venus Bay and 25–62 t in Ceduna. Catches from Coffin Bay during this period exceeded 2 t only during 1991 (9 t), the year prior to the dramatic declines in total catch.

Following the low catch period of the early 1990s, catch from Venus Bay increased to ~39 t in 1994. Between 1995 and 2001, catches ranged from 48–150 t, and declined to 9 t in 2002. During 2003 and 2004, <1 t was harvested from Venus Bay and while catch increased to ~12 t in 2005 and 2007, no catch was reported from Venus Bay in 2006. High catches occurred from Venus Bay from 2008–13, peaking at 152 t in 2012.

Catch from Coffin Bay ranged from 0–13 t from 1994–2000. During 2001 78 t was harvested from Coffin Bay, an annual catch 13 times greater than the previous 7–year average. Catches in Coffin Bay were again well above historic averages during 2002 (22 t), yet did not exceed 2 t during 2003 and 2004. A small increase in catch in Coffin Bay occurred in 2005 (9 t), however, from 2006-08 no catch was reported. In 2009, catch returned to 8 t in Coffin Bay and ranged from 21–36 t between 2010 and 2013.

Catch from Ceduna remained historically low until 1995. Catches ranged from 24–70 t between 1995 and 2000, but declined steadily from 1998–2002. A small increase in catch occurred in 2004 (13.3 t), however, catch from Ceduna has not exceeded 15 t since 2000.

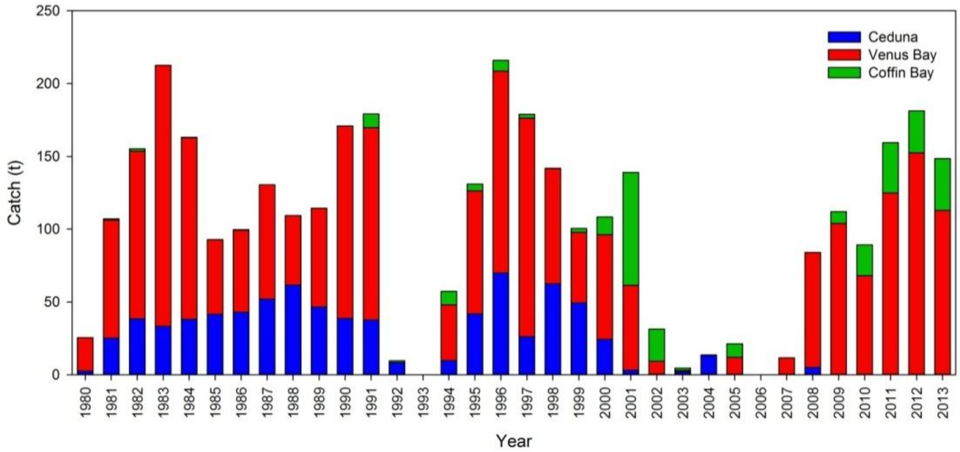

Figure 3.13 Annual catches by region in the West Coast Prawn Fishery from 1980–2013 (1980 catch from July to December only).

3.2.4. Regional effort

The distribution of mean monthly effort within regions has varied substantially throughout the history of the fishery during periods of high catch. Prior to 1992, mean effort was generally spread across the year, peaking during June and lowest during May. In Venus Bay, effort was highest in winter and lowest in summer. In Ceduna, mean effort was highest from January–March and lowest from May–October. Effort in Coffin Bay was low compared to other regions, with a peak in December. From 1995–2001, total effort peaked during June–August and was lowest during October and May (Figure 3.14). The highest levels of effort occurred during June-August in Venus Bay, from November–April in Ceduna and from June–September and November–January in Coffin Bay. From 2008–13, mean effort was concentrated in Venus Bay, peaking in June-July (Figure 3.14). In Ceduna, the highest effort occurred in October–December, with a peak in November and no effort in other months.

Historically, effort in Venus Bay has been focused in the middle zone (Blocks 106–109, see Appendix, Figure 6.1 for block locations). Block 109 contributed to >40% of effort from 1989 to 1995, while effort was more evenly spread throughout the middle zone from 1996 to 1997 (Figure 3.14). More than 40% of effort took place in Block 107 from 1999–2000 and 2002–07 with high levels of effort (>25%) continuing in this Block from 2008–13. In 2001, 2004, 2007 and 2011, effort also increased by >30% in Block 106. In 2013, effort increased in Block 109 (36%) and was comparable to the 1995 levels. High effort (>30%) in the inner zone (Blocks

101-105) occurred in 1997 and 2008–10 with most effort concentrated in Blocks 104 and 105. The outer zone (Blocks 110–117) contributed only a minor amount to overall effort.

In Coffin Bay, >30% of effort was located in nearshore Blocks (206–208, see Appendix Figure 6.2 for Block locations) from 1987–92. In 1994-95, effort increased to >20% in the southern Blocks (211 and 212). From 1996 onward the majority of effort occurred near-shore in Block 207 (range: 38–100%, Figure 3.14).

Ceduna has not been commercially fished since 2009. Historically, a majority of effort occurred near-shore from 1987–95 and 1999–2005 (74–100%), with a concentration of effort in Blocks 307–308, 314–317, 323–327 and 336–337 (Figure 3.15, see Appendix, 6.3 for Block locations). In 1996–97 and 2008, effort shifted offshore with increases in in Blocks 367 and 377.

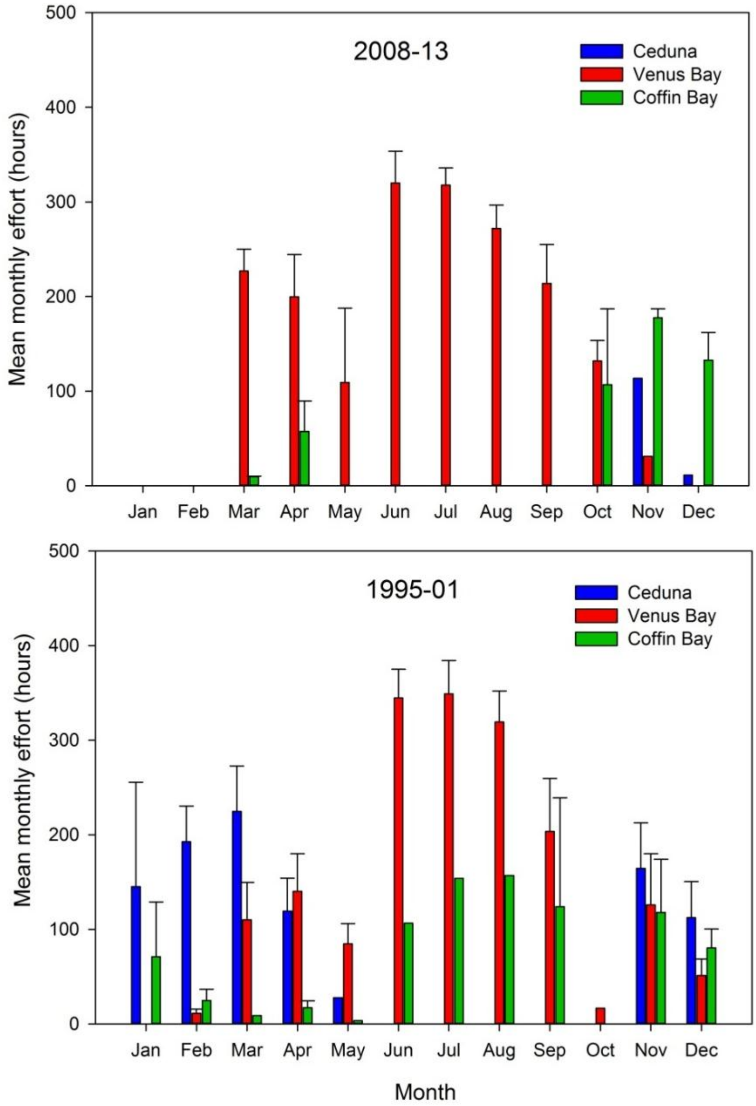

Figure 3.14. Mean monthly effort since 1995 from regions of the West Coast Prawn Fishery for high catch periods (annual catch >80 t).

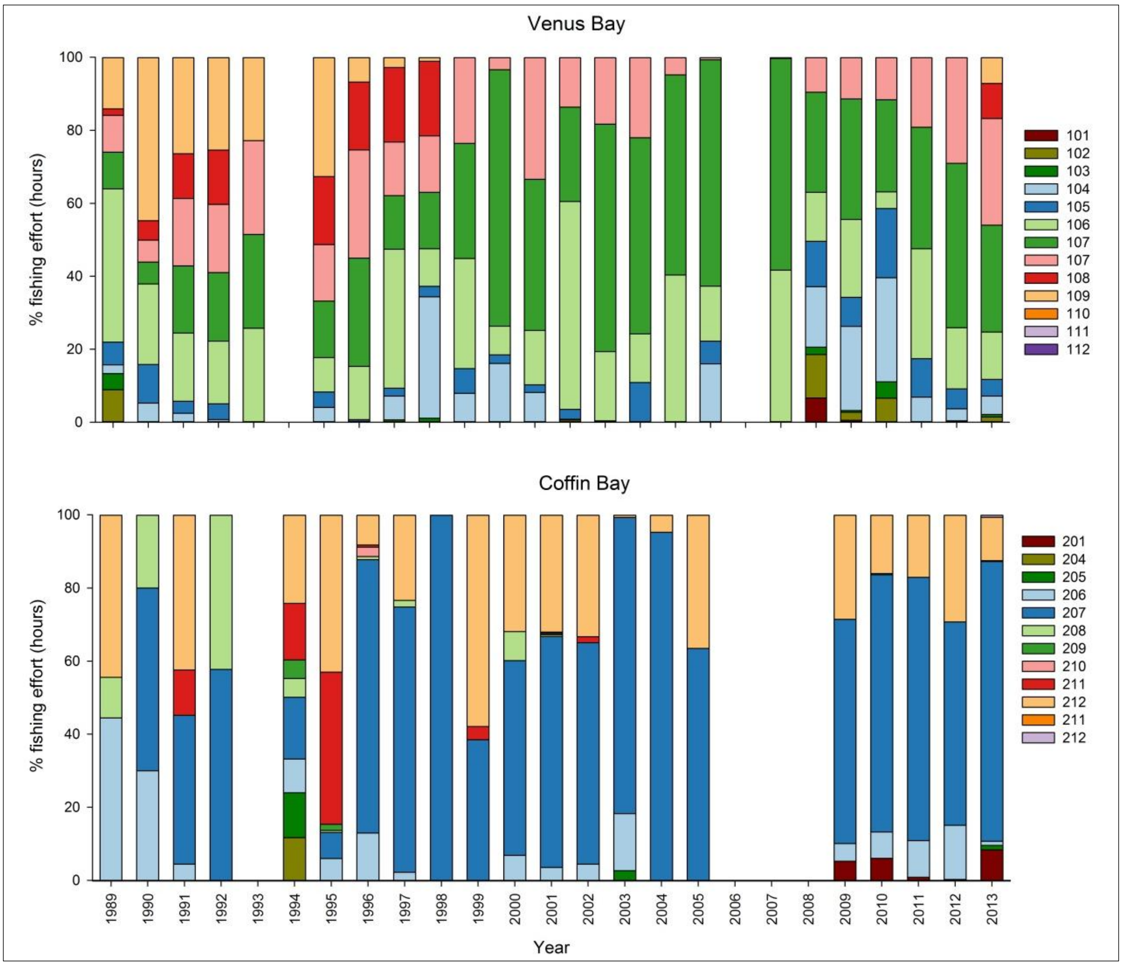

Figure 3.15 Effort (% of total hours) by block number in Venus Bay and Coffin Bay from 1989–2013

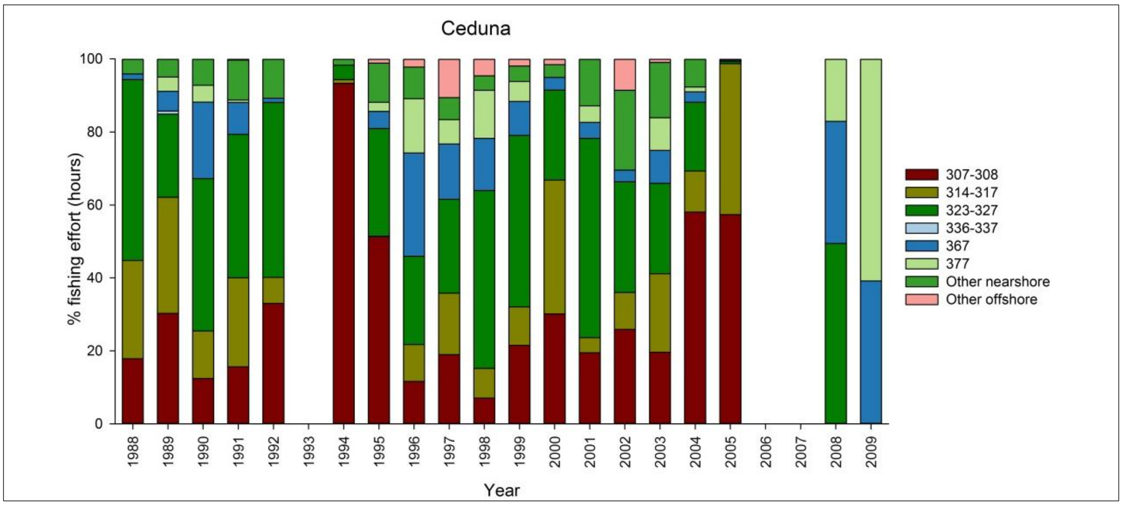

Figure 3.16. Effort (% of total hours) by grouped blocks in Ceduna from 1988–2009. Other near-shore blocks include 301-306, 310-312, 318-322, 329-335 and 344-346. Other offshore blocks include 363-366 and 372-376.

3.2.5. Prawn size

In 1996, small grade prawns represented 23% of the catch compared to 11% in 2013 (Figure 3.17). The proportion of small grade prawns has fluctuated over time, with peaks of ≤20% in 1998–2001, 2004–05, 2008 and 2010. Medium grade prawns comprised 14–23% of catch from 1996–2007 and since 2008, the proportion of medium grade size prawns has been higher at 29–34% of total catch. Peak catches of large grade prawns were observed in 1996–97 (50–51%) and 2004 (51%). In all other years, catches of large grade prawns ranged from 26–40% with catch in 2012 and 2013 reaching a historical low of 26%. The proportion of extra-large grade prawns was low from 1996–2001, ranging from 3–20%. A peak in the proportion of extra-large grade prawns occurred in 2002 at 38%, followed by a substantial decrease to 6% the following year. From 2005–12, extra-large grade prawns contributed between 17–28% of the catch increasing to 31% of total catch in 2013.

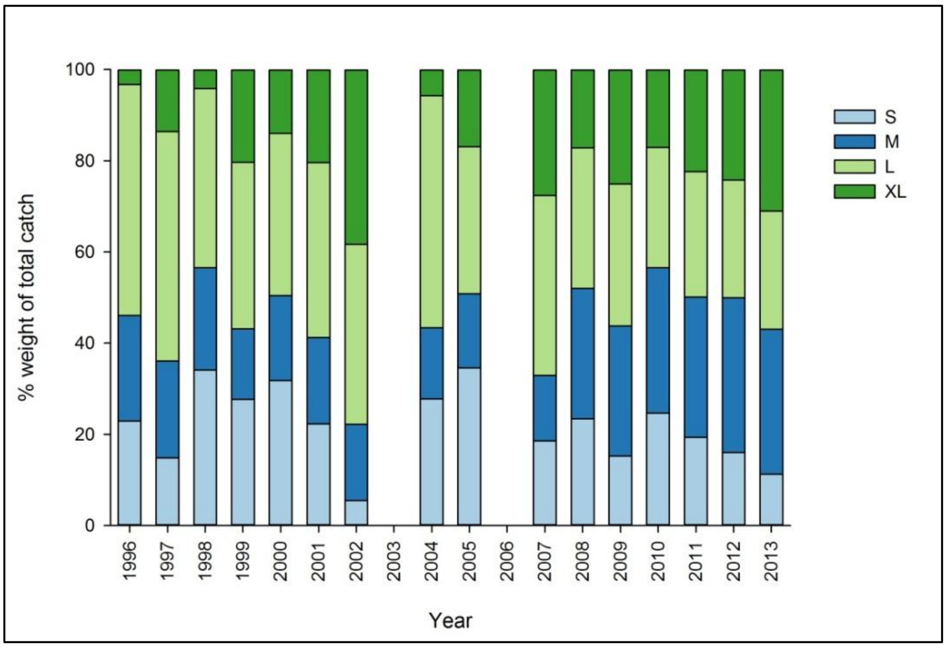

Figure 3.17 Size composition of the commercial catch from the West Coast Prawn Fishery during 1996–2013.

Catch composition in Coffin Bay was dominated historically by large grade prawns (Figure 3.18). Catches of large grade prawns peaked at 64% of total catch in 1996, decreasing to a low of 26% in 2013. Extra-large grade prawns were also caught in high proportions in 2002 (40%) and 2011–2013 (range: 30–40%). Medium grade prawns made up a lower proportion of the total catch from 1996–2002 (range: 13–23%) and increased in recent years (2009–13, range: 26–33%). Small grade prawns made up the smallest proportion of total catch in most years, with a maximum of 31% recorded in 1998. In all other years, the proportion of small grade prawns ranged from 5–24%, and in 2013 was the third lowest proportion was recorded at 7% of total catch.

In Venus Bay, small grade prawns contributed a high proportion of the total catch in 1998 (26%), 2000–01 (34 and 27%), 2008 (23%) and 2010–11 (26% and 22%, Figure 3.18). In 2012 and 2013, catches of small grade prawns were 17% and 13%, respectively, which was equivalent to 2009 levels. Catches of medium grade prawns were historically high in Venus Bay, peaking at 49% of total catch in 1998. Since 1999, medium grade prawns have contributed 27–40% of the total catch, including 34% in 2013 (Figure 3.18). The proportion of large grade prawns in the total catch was historically high in 1996 (57%) and declined to 36% in 2001. The proportion of large grade prawns in the total catch was high in 2002 (42%) and 2007 (39%), but declined to 31% in 2008. Large prawns contributed less of the total catch since 2009 (range: 25–27%). Extra-large grade prawns generally made up the smallest proportion of the total catch in Venus Bay, with high proportions observed in 1999, 2002 and 2004 (range: 30–40%) compared to the moderate proportions observed from 2007 (range: 16–28%).

In Ceduna, small grade prawns comprised >30% of catches in all years, except 2004 and 2009 (Figure 3.18). Large grade prawns also comprised (>30%) of the total catch in all years, except in 2008. The catch of small grade prawns peaked at 40% of total catch in 1996 and 51% of the total catch in 2004. Medium grade prawns comprised <25% of catches but increased to 37% and 36% in 2012 and 2013, respectively. Extra-large grade prawns comprised <20% of catches in all years, with peaks of 16% and 17% in 2001 and 2005, respectively.

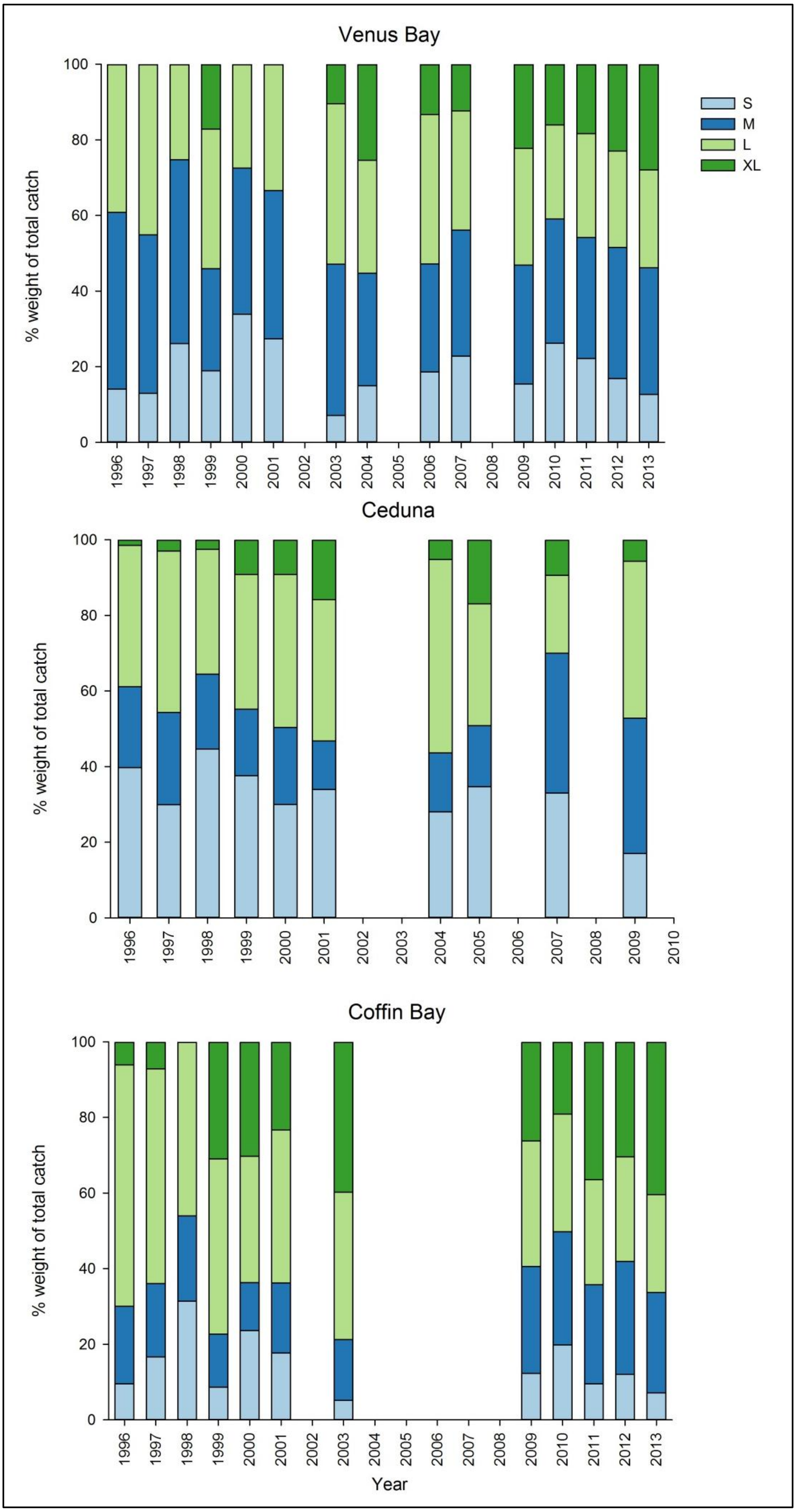

Figure 3.18 Size composition of the total catch from the West Coast Prawn Fishery in Venus Bay, Ceduna and Coffin Bay during 1996–2013.

3.3. Environmental variables

Sea surface temperature (SST) in Venus Bay was lower than 17ºC for more than 30 days (50%) of the early spawning period in 1987, 1991, 1992, 1994, 1995 and 2004 (Figure 3.19). In addition, the SST in Venus Bay was lower than 17ºC for more than 20 days (30%) during the spawning period in 1986/87, 2002/03 and 2007/08 The upwelling index did not show a strong correlation with low temperatures, however, 1988–89, 1989–90, 1998–99 and 2011–12 showed higher levels of upwelling favourable winds (wind stress >0.06).

In Fremantle, low SLH was recorded during March–July in 1987, 1992 and 1997 (Table 3.1). All years where low SST and SLH occurred were also classified as El Niño years by the Bureau of Meteorology.

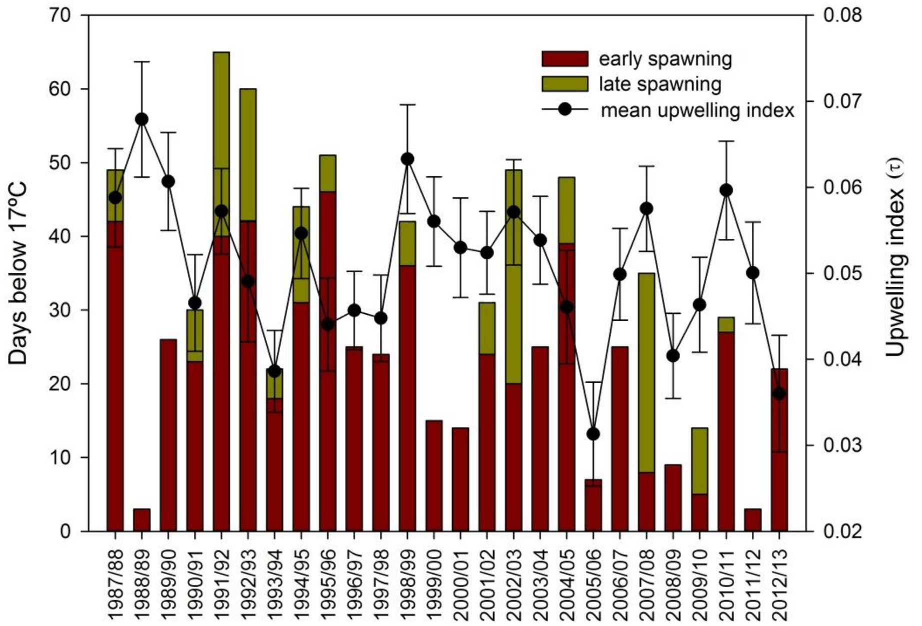

Figure 3.19 The number of days below 17ºC in Venus Bay during the during the early (November–December) and late spawning period (January-March) and the mean upwelling index (wind stress, November-March) from 1987/88–2012/13.

Table 3.1 Environmental variables and El Niño events from 1987–2013. El niño events affect the Leeuwin Current flows from March to July in Western Australia and this is indicated by lowered sea level height (SLH). Source: Bureau of Meteorology.

Year	Mean SOI	Mean Niño 3.4 Index	ENSO Events		Mean SOI (Mar-Jul)	Mean Niño 3.4 (Mar-Jul)	Fremantle sea level (Mar-Jul)
1987	-13.1	1.2	El Niño		-20.3	1.2	74.5
1988	7.8	-1.0		La Niña	3.7	-1.0	83.7
1989	6.8	-0.9		La Niña	11.8	-0.9	86.0
1990	-2.2	0.1			2.1	0.1	75.7
1991	-8.8	0.4	El Niño		-10.0	0.4	82.6
1992	-10.4	1.0	El Niño		-12.4	1.0	78.1
1993	-9.5	0.6			-12.9	0.6	70.9
1994	-11.9	0.2	El Niño		-15.0	0.2	77.6
1995	-2.3	0.0	El Niño		-3.8	0.0	79.8
1996	5.7	-0.4			7.2	-0.4	88.2
1997	-11.7	0.8	El Niño		-16.1	0.8	76.9
1998	-1.1	0.1	El Niño	La Niña	-5.6	0.1	83.3
1999	8.0	-0.9		La Niña	6.9	-0.9	98.2
2000	7.8	-0.8		La Niña	4.1	-0.8	95.1
2001	0.5	-0.2		La Niña	-0.6	-0.2	86.9
2002	-6.1	0.4	El Niño		-7.5	0.4	81.7
2003	-3.1	0.0	El Niño		-5.8	0.0	83.0
2004	-4.8	0.1			-4.7	0.1	81.9
2005	-3.6	0.3			-4.4	0.3	85.0
2006	-1.9	-0.1	El Niño	La Niña	1.0	-0.1	83.0
2007	1.5	-0.2	El Niño	La Niña	-1.3	-0.2	84.1
2008	10.2	-0.7		La Niña	3.9	-0.7	95.3
2009	-0.2	0.1	El Niño	La Niña	0.6	0.1	87.9
2010	9.8	-0.1	El Niño	La Niña	7.4	-0.1	82.7
2011	13.3	-0.5		La Niña	11.9	-0.5	97.3
2012	-0.8	0.0		La Niña	-3.8	0.0	97.2
2013	4.0	-0.2			8.4	-0.2	N/A

N/A data not available.
Southern oscillation index (SOI): sustained negative values below -8 (above +8) indicate El Niño (La Niña) episodes.
Nino 3.4 Index: El Niño (La Niña) events identified if the 3 month running mean is above (below) +0.5 (-0.5)

3.4. Fishery performance

3.4.1. Current performance indicators

The current management policy does not provide reference points for performance indicators and therefore reference points from Macdonald (1998) have been used to assess fishery performance annually since 1998 (Table 3.2).

Table 3.2 Summary of Performance Indicators (PI) and reference Points (RP) from 2010–2013 for the West Coast Prawn Fishery as defined by MacDonald (1998). Recruitment index is calculated after Carrick (2003).

Performance indicator	Target RP	Limit RP	2010	2011	2012	2013
Effort (days)	100–110	120	65	80	81	73
Size at capture (prawns/kg)	<40/kg	>40/kg	36	35	34	32
Recruitment indices ($\sqrt{\text{recruits.nm}^{-1}}$)	40	35	**21.2**	**21.6**	N/A	**14.0**

Fishing effort

Fishing effort was reported as nominal effort for each vessel over the calendar year and does not include survey nights. From 2010–13, effort was below the target RP and limit RPs (100–110 days). During this period, effort was highest during 2012 (81 days) and lowest in 2010 (65 days). Fishing effort in 2013 (73 days) was only marginally lower than during 2012 (Table 3.2).

Average size at capture

Average size at capture was within the target RP (<40 prawns/kg) for this PI during 2010–2013. Mean prawn weight was highest during 2010 (36 prawns/kg) and lowest in 2013 (32 prawns/kg; Table 3.2). The limit RP of >40 prawns/kg was not exceeded on any individual night for which there were data during this period.

Recruitment indices

Recruitment indices were calculated as the square-root transformed abundance of prawns (males <33 and females <35 mm carapace length) per nautical mile trawled (after Carrick 2003) in Ceduna during surveys conducted in February or March. Twelve shots were conducted in Ceduna in March 2013. The mean recruitment index was 14.0 in 2013, which was lower than the estimate in 2010–2011, and below the limit RP (35; Table 3.2).

3.4.2. Suggested performance indicators: Management Policy

The *WCPF Management Policy* (2010) identified several potential biological PIs. Six of these PIs were investigated and potential limit RPs have been suggested by SARDI based on the historical trends (Table 3.3). The potential limit RPs are discussed in more detail to assist with the review of the harvest strategy.

Table 3.3 Summary of additional biological performance indicators (PIs) suggested in the WCPF management policy (PIRSA, 2010) and suggested reference points (RP) based on historical data.

Performance indicator	Potential Limit RP	2010	2011	2012	2013
Effort (days) Venus Bay	>70	50	65	67	59
Effort (days) Coffin Bay	>20	18	15	15	19
Effort (days) Coffin Bay (Pre-Christmas)	>15	14	7	14	7
Mean survey CPUE (kg.hr^{-1})	<40	46.9	56.2	57.5	57.0
Ceduna mean survey CPUE (kg.hr^{-1})	<40	48.3	65.2	**34.2**	41.4
Venus Bay mean survey CPUE (kg.hr^{-1})	<50	**46.3**	52.2	62.5	68.0
Mean fishing CPUE (kg.hr^{-1})	<50	**48.5**	70.5	79.2	70.6
Venus Bay mean CPUE (kg.hr^{-1})	<50	**47.1**	65.0	78.4	67.5
Coffin Bay mean CPUE (kg.hr^{-1})	<50	53.1	92.3	84.1	81.7
Total annual catch (t)	<80	89.2	159.3	181.2	148.5
Mean daily catch per vessel (kg)	<300	468.7	710.4	760.3	717.2
Catch during the early spawning period (t)	>20	18.9	10.0	**28.5**	**31.0**

Temporal and spatial effort

The limit RP for spatial effort was suggested at >70 days in Venus bay based on historical high effort periods which preceded historical catch rate declines (1997: 85 days, 1988–1991: 77–90 days). The limit RP for spatial effort has not breached in Venus Bay since 1997 (85 days, Table 3.3).

In Coffin Bay, the limit RP for spatial effort was suggested at >20 days (>15 days pre-Christmas) based on the historically high levels in 2001 and 2002 (23 and 48 days, respectively) which preceded the recent low catch period. The limit RP for overall effort has not been breached in Coffin Bay since 2002 (23 days) and since 2001 (21 days) for Pre-Christmas fishing (Table 3.3).

Mean survey CPUE

The limit RP for mean survey CPUE was suggested as <40 kg.hr^{-1} based on catch rate during low catch periods in 1992–93 (range: 5.2–21.4 kg.hr^{-1}) and 2003–06 (range: 22.1–29.7 kg.hr^{-1}). Survey catch rate has been relatively stable since 2007 (range: 42.3–57.5 kg.h^{-1}), and has not breached the limit RP since 2006 (Table 3.3).

The limit RP was breached in Ceduna in 2012 (34.2 kg.h^{-1}) but in 2013 increased above the limit RP (41.4 kg.h^{-1}). In Venus Bay the limit RP for mean survey CPUE was suggested at

50 kg.hr^{-1} based on historically higher catch rates than Ceduna. The limit RP was breached in 2010 (46.3 kg.hr^{-1}) but has been above the limit RP for the past three years (Table 3.3)

Mean fishing CPUE

The limit RP for mean fishing CPUE was suggested as <50 kg.hr^{-1} based on catch rate during low catch periods in 1992–94 (range: 23.1–37.4 kg.hr^{-1}) and 2002–07 (range: 22.3–40.1 kg.hr^{-1}). In 2010, CPUE was below the limit (48.5 kg.hr^{-1}) and this corresponded to a 19% decrease in total catch. Mean CPUE has been above the limit RP since 2011, peaking at 79.2 kg.hr^{-1} in 2012 (Table 3.3).

In Venus Bay the limit RP for mean CPUE was breached in 2010 (47.1 kg.hr^{-1}) but CPUE has remained above 50 kg.hr^{-1} since 2011 (Table 3.3). In Coffin Bay, mean CPUE has been above the limit RP since 2010, peaking at 92.3 kg.hr^{-1} in 2011

Total annual catch

The limit RP for total annual catch was suggested as <80 t based on total catch during low catch periods in 1992–94 (range: 9.6–57.3 t) and 2002–07 (range: 4.6–40.6 t). From 2008–13, total catch did not breach the limit RP and has generally increased (range: 84.0–181.2 t; Table 3.3).

Mean daily catch per vessel

The limit RP for mean daily catch per vessel was based on catch during low catch periods of 1992–1994 (183–363 kg) and 2002-08 (range: 156–384 kg). Mean daily catch increased to above the limit RP in 2008 and has remained at high levels since 2008 (range: 594–760 kg) (Table 3.3).

Catch during the early spawning period

The limit RP for catch during the early spawning period was suggested as >20 t based on catch during low catch periods in 1994 (15 t) and 2002–2009 (range: 7–18 t). From 2008–11, the limit RP was not breached during early spawning (range: 7–19 t). Recently, catch during the early spawning period has increased (28 t in 2012 and 31 t in 2013) resulting in breaches of the limit RP (Table 3.3).

3.4.3. Suggested performance indicators: Spencer Gulf Prawn Fishery

In response to the *Management Policy* (2010) suggesting advice on PIs was needed in the stock assessment, additional PIs proposed by SARDI based on the use of these indicators in the Spencer Gulf Prawn Fishery have also been evaluated (Dixon *et al.*, 2013). Limit RPs are also proposed based on historical lows in each PI (Table 3.4).

Table 3.4 Assessment of performance indicators used in the Spencer Gulf Prawn Fishery for the West Coast Gulf Prawn Fishery for 2010–2013

Performance indicator	Suggested limit RP	2010	2011	2012	2013
Oct/Nov survey recruitment index Venus Bay ($\sqrt{\text{recruits.m}^{-1}}$)	>8	11.7	**6.4**	8.2	**7.6**
Oct/Nov survey recruitment index Ceduna ($\sqrt{\text{recruits.m}^{-1}}$)	>10	21.5	**9.9**	**9.4**	14.9
Mar survey recruitment index Venus Bay($\sqrt{\text{recruits.m}^{-1}}$)	>8	9.9	11.1	11.5	13.7
Mar survey recruitment index Ceduna ($\sqrt{\text{recruits.m}^{-1}}$)	>15	21.2	21.6	N/A	**14.0**
Jun/Jul survey recruitment index Venus Bay	>12	17.6	12.2	14.8	**8.5**
Oct/Nov survey egg production ($\times10^6$ eggs.trawl-hour^{-1})	>200	**192**	227	187	346
% of 20+ in the catch – Nov and Dec	<25%	18%	10%	12%	7%
% of 20+ in the catch – Mar to Jun	<25%	**26%**	24%	18%	15%
% of 16/20 in the catch – Nov and Dec	<35%	10%	24%	30%	26%
% of 16/20 in the catch – Mar to Jun	<35%	32%	32%	33%	33%

Recruitment

The recruitment index in Venus Bay was below the limit RP (>8) in October/November 2011 (6.4) and 2013 (7.6, Table 3.4). In October/November 2011 and 2012, the recruitment index in Ceduna was below the suggested limit RP (>10) but increased to 14.9; during 2013. In March, the recruitment index in Venus Bay has been above the suggested limit RP (>8) since 2007. Recruitment has been historically high in Ceduna during March with an index value of >20 in 2007–11. In 2013, a low recruitment index value of 14.0 meant that the year fell below the limit RP (>15). In June/July, the recruitment index in Venus Bay was moderate (range: 12.2–17.6) from 2008–12. In 2013, the June/July recruitment index in Venus Bay fell to 8.5 which was below the suggested limit RP.

Egg production

Egg production was assessed for the first time in the WCPF. Since 2007, egg production has fluctuated (range: 187–346). Egg production was below the suggested limit RP (<200 eggs.trawl-hour^{-1}) in 2010 and 2012 (Table 3.4).

Proportion of 16/20 and 20+ prawns

The proportion of 20+ prawns in the catch from November to December was within the suggested limit RP (>25%) during 2010–13 (Table 3.4). Historically, the suggested November-December limit RP would have been breached in 1998 (36%) and 2008 (30%), however, since 2009 the proportion of 20+ prawns has been consistently lower (range: 7–18%). In March-June, the proportion of 20+ prawns was above the limit RP (<25%) from 1998–2005 (range: 31–36%), and in 2010 (26%) but was relatively low in 2012 and 2013 (Table 3.6). The proportion of 16/20 prawns has been low in most years, but the suggested limit RP (>35%) was only triggered once, in November/December 2008 (Table 3.4).

4. DISCUSSION

4.1. Current status of the West Coast Prawn Fishery

Substantial information was available to assess the WCPF for 2013, including: 1) documentation of management arrangements of the fishery; 2) annual stock status reports (Roberts, 2007; Hooper *et al.*, 2009; 2010; 2011; Gorman *et al.*, 2012) and periodic stock assessment reports for the past decade (Dixon and Roberts, 2006); and 3) a comprehensive biological synopsis of the western king prawn.

The primary measures of stock status in the WCPF are total catch from fishery-dependent data and average catch rates obtained during fishery-independent surveys conducted in March, June and November. Consistent with recent status reports, there are several lines of evidence that suggest the WCPF has recovered from the period of stock depletion experienced from 2002–07 (Hooper *et al.*, 2010; 2011; Gorman *et al.*, 2012). Annual catch has exceeded 80 t since 2008 and mean fishing catch rate has exceeded 70 $kg.hr^{-1}$ since 2011. During 2013, the total catch of 148 t was considerably higher than during the most recent period of collapse (2002–07; mean = 20 t ± 7) and survey and commercial catch rates were among the highest on record. On the weight of evidence, the WCPF is not considered to be recruitment overfished, and the current level of fishing pressure is unlikely to cause the fishery to become overfished. Therefore, using the national framework for stock status reporting (Flood *et al.*, 2012), the WCPF is 'sustainable'.

Careful monitoring of the fishery in future years using both a consistent survey sampling design and commercial catch rates will be necessary to ensure sustainability of the fishery. This is because increased catch from Coffin Bay in 2012 and 2013 during the early spawning period may have resulted in reduced egg production and subsequent reduced larval settlement in Ceduna. Surveys have not been conducted in Coffin Bay since 2009, however, recent high catch rates suggest that there has been an increase in abundance in this region. Although the sampling design was inconsistent among years, there are some indications of decreased recruitment and survey catch rates in Ceduna.

Previous reports have also suggested that environmental parameters may explain the fluctuations in catch rate and recruitment (Wallner, 1985; Carrick and Williams, 2000; Svane and Barnett, 2004; Carrick and Ostendorf, 2005; Dixon and Roberts, 2006). Although preliminary comparisons of catch rates in relation to SST and the strength of the Leeuwin Current (Fremantle SLH) were investigated in this report, recruitment data are patchy and a longer time series is required to confirm these environmental relationships. Nevertheless, an El Niño event is predicted in late 2014 and this may reduce Leeuwin Current flow (Feng *et* *al.*, 2003; Ludescher *et al.*, 2014), which in turn has a major role in the movement and distribution of larval fish and invertebrates (Maxwell and Cresswell, 1981; Gopurenko *et al.*, 2003; Muhling *et al.*, 2008; Beckley *et al.*, 2009). If this also affects western king prawns, the transport of prawns from recruitment grounds in Ceduna to spawning grounds in Venus Bay could be disrupted, reducing potential spawning biomass. In addition, variations in wind stress will continue to drive fluctuations in upwelling intensity, with strong events resulting in lower SSTs (Middleton and Platov, 2003), which may impact the survival of prawn larvae (Rodgers *et al.*, 2013).

4.2. Harvest strategy for the WCPF

4.2.1. Current management arrangements

The Management Policy, including the WCPF harvest strategy, is due for review. Currently, the fishing strategy is developed prior to the commencement of fishing each month with fishing effort subsequently managed via spatial and temporal closures. Development of the fishing strategy is informed by data obtained from fishery-independent stock assessment surveys and industry-driven spot surveys. The current management policy suggests that three stock assessment surveys are to be conducted annually in November (Venus Bay, Ceduna and Coffin Bay), March (Venus Bay and Ceduna), and June (Venus Bay).

Once established, the fishing strategy is managed on a daily basis by the SGWCPFA and PIRSA Fisheries and Aquaculture. Adjustment of the fishing strategy is informed from data obtained during commercial fishing and involves reducing or closing fished areas to avoid small prawns or unsuitable catch rates. The decision rules used to close regions of the fishery where prawns are of an unacceptable size are outlined in the harvest strategy (Dixon and Sloan, 2007).

There are several advantages of the current harvest strategy. These include controls on effort and/or catch on a monthly and annual basis (e.g. season limits on fishing nights) and this adaptive approach is a critical element of the fishery's success that should be maintained. There are, however, some limitations. Firstly, the harvest strategy does not provide a definition of recruitment over-fished, in part because survey catch rate is not explicitly linked to an annual assessment of stock status. The RPs are not defined as traditional measures and there is no threshold RP below which the stock is considered to be recruitment over-fished. Second, it does not explicitly aim to control catch at an annual scale that is appropriate to the size of the harvestable biomass. Third, there are no decision rules that control exploitation (e.g. target prawn size) and inform the development of monthly strategies.

4.2.2. Assessment of stock status

Australian harvest strategies are usually underpinned by an annual assessment of stock status, with associated management actions that aim to ensure that fishing effort and/or catch for the upcoming year is maintained at levels that will achieve the maximum economic or sustainable yield (DAFF, 2007; Sloan *et al.*, 2014). One management option for the WCPF, that is in line with the approach taken in the SGPF, may be to define management of the fishery at three temporal scales: 1) annual harvest strategy based on stock status; 2) monthly fishing strategies; and 3) daily at-sea management strategy.

The benefits to this approach include: increased certainty in the likely fishing outcomes of the season; reduced variability in monthly fishing strategies due to a decreased reliance on individual survey results; and alignment with standard harvest strategy approaches. Figure 4.1 provides a description of how annual stock status and subsequent surveys can be used to inform fishing strategies. A challenge that arises when assessing this fishery is the uncertainties relating to environmental influence on the stock status, and uncoupling those factors from potential fishery impacts. Consequently, if this approach was adopted, there would also be the need to maintain flexibility in terms of management arrangements.

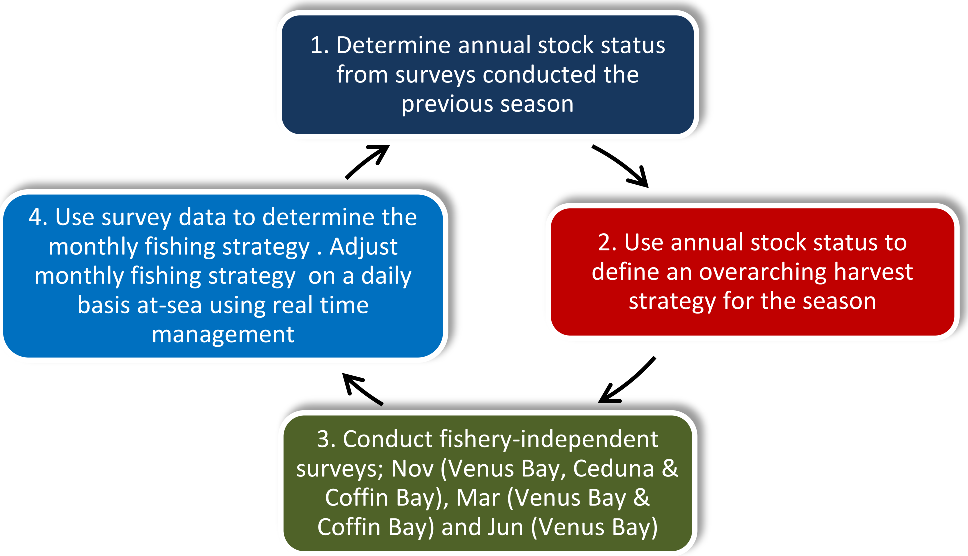

Figure 4.1 A potential harvest strategy cycle for the WCPF.

Given the national stock status reporting framework (Flood *et al.,* 2012) and the harvest strategy development guidelines (Sloan *et al.*, 2014) that are being broadly implemented across SA-managed fisheries, there is a need for the stock status of the WCPF to be clearly defined using limit and threshold reference points that reflect historical trends (Figure 4.2). One approach to define the annual stock status would be to classify levels of relative abundance above the threshold RP as "sustainably fished", levels of relative abundance between the threshold and limit RP as "transitional" and levels of relative abundance below the threshold RP as "overfished".

Once stock status has been determined, it is important that the annual fishing strategy selected is representative of the stock status classification. Thus, assessment of annual stock status should provide guidance for an overarching, annual harvest strategy for the fishery. It is also critical that management of the fishery is responsive to changes in the status of the stock and decision rules should be designed to maintain stock sustainability. To achieve this, one outcome from the stock status determination should be defined bounds of annual catch and/or effort for each level of stock status and an assessment to determine whether a stock is adequately controlled through management (Flood *et al.*, 2012). Under this approach, the annual harvest strategy should: 1) prevent targeted fishing when the status is overfished; 2) reduce catch or effort when the status is transitional; and 3) maintain normal practices when the status is sustainable. Where there is a high degree of uncertainty associated with the status of the stock, a more conservative harvest strategy should be adopted (Sloan *et al.*, 2014).

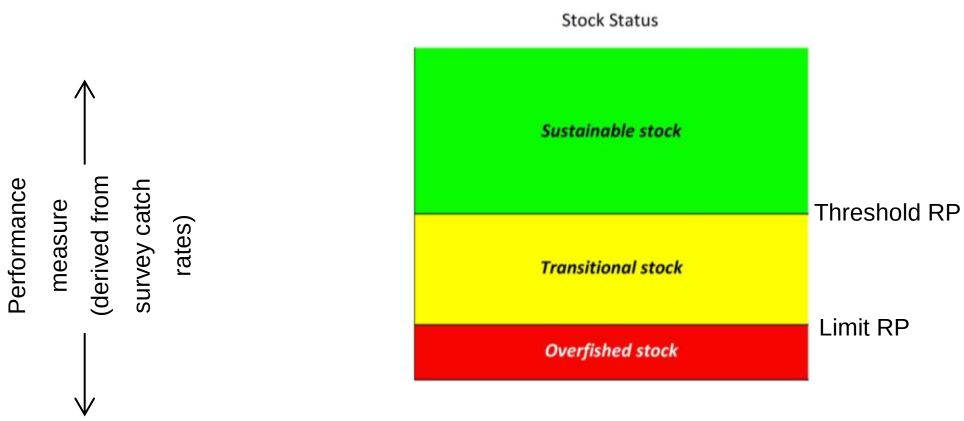

Figure 4.2 Assessment of stock status using survey catch rate as a key biological performance indicators (PIs), with reference points (RPs) based on stock assessment survey results.

4.2.3. Indicators of stock status

Biological PIs provide guidance as to whether stock abundance is too low or fishing pressure too high and limit RPs are used to determine the stock status to invoke a management response (Flood *et al.*, 2012). The source of data for these PIs can be either fishery-dependent or fishery-independent. One approach to determine stock status would be to focus on fishery-independent surveys which can be used to understand fluctuations in stock size and limit the risks of fishery-driven stock declines (Sloan *et al.*, 2014). Alternatively, a range of PIs could be considered that would require integration to a single index of stock status. This would, however, further complicate assessments, especially if PIs provided inconsistent inferences about stock status. Thus, there are potentially several different approaches for using performance indicators to determine stock status in the WCPF.

An index of stock status could be derived from the fishery-independent surveys (e.g. mean survey catch rate of all three surveys combined) as a proxy for relative adult abundance. This is consistent with other inshore crustacean fisheries such as the SGPF and blue crab fishery (Brown *et al.*, 2008; Dixon *et al.*, 2013; Harris *et al.*, 2014; Noell *et al.*, 2014). The limit and threshold RP could consider the range of mean survey catch rate estimates obtained over the past 11 years when the survey design has provided robust estimates of relative abundance for the fishery. Subsequent survey results could then be used to adjust monthly fishing strategies within the bounds of the annual harvest strategy. Such a tiered approach is supported by the correlation observed between survey and commercial catch rates (Dixon *et al.*, 2013). The key strength with this approach is the use of a simple index that could be routinely obtained in a consistent manner on an annual basis. However, one of the main weaknesses with this approach is the inconsistency of historical surveys (i.e. limited spatial and temporal replication), for which standardisation approaches may be required to determine appropriate threshold and limit reference points.

Given the spatio-temporal inconsistencies in the historical fishery-independent survey data, it may be useful to link the outcomes from the fishery-independent surveys to other PIs to develop an integrated index of stock status. There are several options available for this approach including using the abundance of small prawns in the commercial catch or from fishery-independent surveys, a recruitment index from fishery-independent surveys and/or estimates of egg production.

The abundance of small prawns is a useful indicator of future biomass. The limit RP for this PI would be designed to reduce the potential impact on the spawning biomass through overfishing of recruits. By monitoring prawn size using fishery-independent data, areas that are not currently commercially fished, including important recruitment grounds such as Ceduna can still be assessed. Size grade data provided by commercial fishers can yield important information on the size of prawns captured, however, there is some uncertainty surrounding the consistency of grading practices over time and among licence holders. The application of calculations of prawns per kilogram from fishery-dependent data may be limited until appropriate standardisation of grade sizes used by the fleet is achieved.

Fishery-independent surveys provide more detailed information on prawn size through length frequency measurements. Recruitment needs to be monitored as reductions can result in impaired stock productivity and may lead to collapse. The major benefit of using the recruitment index to monitor prawn size is that it does not rely upon commercial grading practices and includes survey information from the main nursery area in Ceduna. However, it relies on randomly-collected samples, which is difficult to monitor or test. The primary index of recruitment is calculated from shots sampled in March in Ceduna and additional indices are presented from each survey period and location. To improve calculations of the recruitment index, effort should be made to increase the number of shots sampled and ensure that the same shots are sampled each year. This will provide for a far more robust and reliable interpretation of recruitment.

In order for successful recruitment to occur, adequate levels of egg production need to be maintained. An egg production model has been developed for the SGPF and applied to survey catch data from the WCPF. The advantage of the egg production model is that it estimates that the potential number of fertilised eggs that females could contribute to egg production throughout the spawning period (Dixon *et al.*, 2013). The model, however, relies upon a number of assumptions including; catchability of prawns is constant during the survey, female prawns spawn three times during the spawning period, spawning frequency does not vary with prawn size, natural mortality is zero, percentage of females within each grade does not vary during the spawning period, and sex-specific length-frequency data from surveys are representative for the population. Thus, formal use of the egg production model will require substantial development and refinement specific to this fishery (following completion of FRDC project 2008/011).

4.3. Future research needs

The most pressing research need for assessment and management of the WCPF is to determine the relationships between spawning location, recruitment success, adult transport and environmental parameters including ENSO, SST and upwelling strength including ocean currents. This information is needed to optimise fishing and harvest strategies for the fishery.

There is also a need to revise the management policy and develop a harvest strategy which provides a definition of recruitment over-fished including limit reference points at which the stock is considered to be recruitment over-fished. One option for achieving this would be to link survey catch rate to an annual stock status and would likely require spatially and temporally consistent surveys across all three fishing grounds. Finally, there is also a need to collect information on the fishing power of the fleet in order to more accurately interpret indices of effort and catch rate over time. This would also facilitate more effective evaluation of exploitation rates.

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6. APPENDIX 1

Table 6.1 Number of stock assessment survey shots done in fishing regions of the West Coast Prawn Fishery from November 1989 to December 2013.

Year	Month	Ceduna	Coffin Bay	Venus Bay	Total
1989	Nov	7		19	26
1990	Feb	6		20	26
	Apr	6		20	26
	Jun	6			6
	Nov	7		20	27
1991	Feb	17		20	37
	Apr	17		20	37
	Jun	17		20	37
	Nov	16		11	27
1992	Feb	17		20	37
	Apr	17		20	37
	Jun	17		20	37
	Jul	9		12	21
	Oct	16		20	36
1993	Feb	17		20	37
	Apr			11	11
	Jun	17		20	37
1994	Jun			20	20
1995	Jan	16			16
	Feb			20	20
	Jul			26	26
1996	Feb	16		19	35
1997	Feb			22	22
1998	Mar			16	16
	Jun			18	18
2000	Feb			10	10
	Dec			9	9
2003	Jul			14	14
	Oct	9	10	10	29
	Nov	7	10	9	26
2004	Apr			13	13
	Jun	9	8	13	30
	Oct	9	9	11	29
2005	Feb	8		11	19
	Jun			14	14
	Nov	6	8	10	24
	Dec	7			7
2006	Feb	8		11	19
	Jun			13	13
	Nov	7	10	11	28
2007	Mar	14	8	11	33
	Aug			10	10
	Nov	6		10	16

2008	Mar	7	5	10	22
	Jun			8	8
	Oct	7	10	10	27
2009	Mar			10	10
	Jun			10	10
	Nov	6	10	10	36
2010	Mar	7		10	17
	Jun			10	10
	Nov	6		10	16
2011	Mar	7		10	17
	Jun			10	10
	Nov	6		10	16
2012	Mar			10	10
	Jun			9	9
	Nov	6		9	15
2013	Mar	13		9	22
	Jun			9	9
	Oct	6		9	15

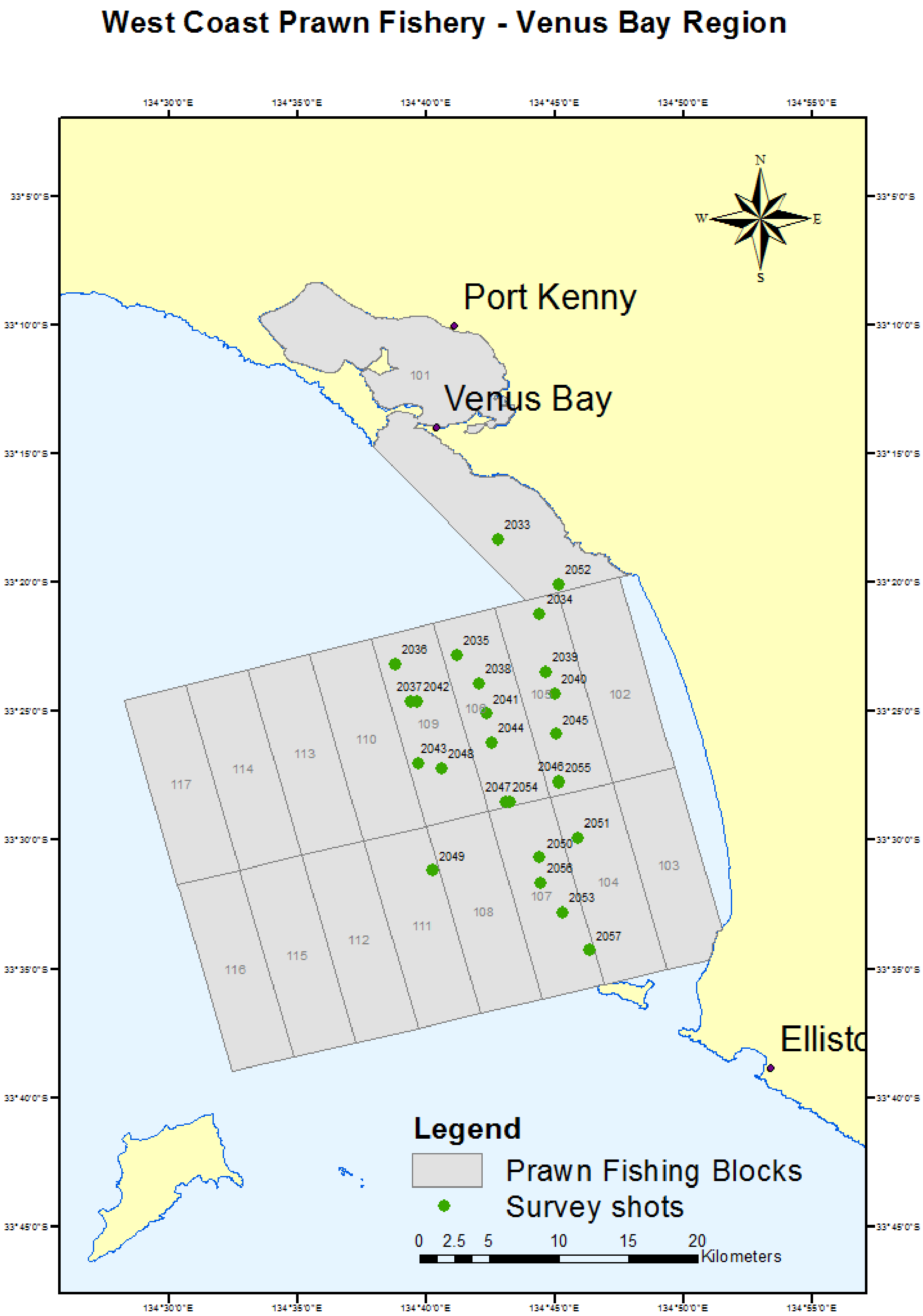

Figure 6.1 Fishing blocks and survey shots of the South Australia's West Coast commercial western king prawn fishery– - Venus Bay region

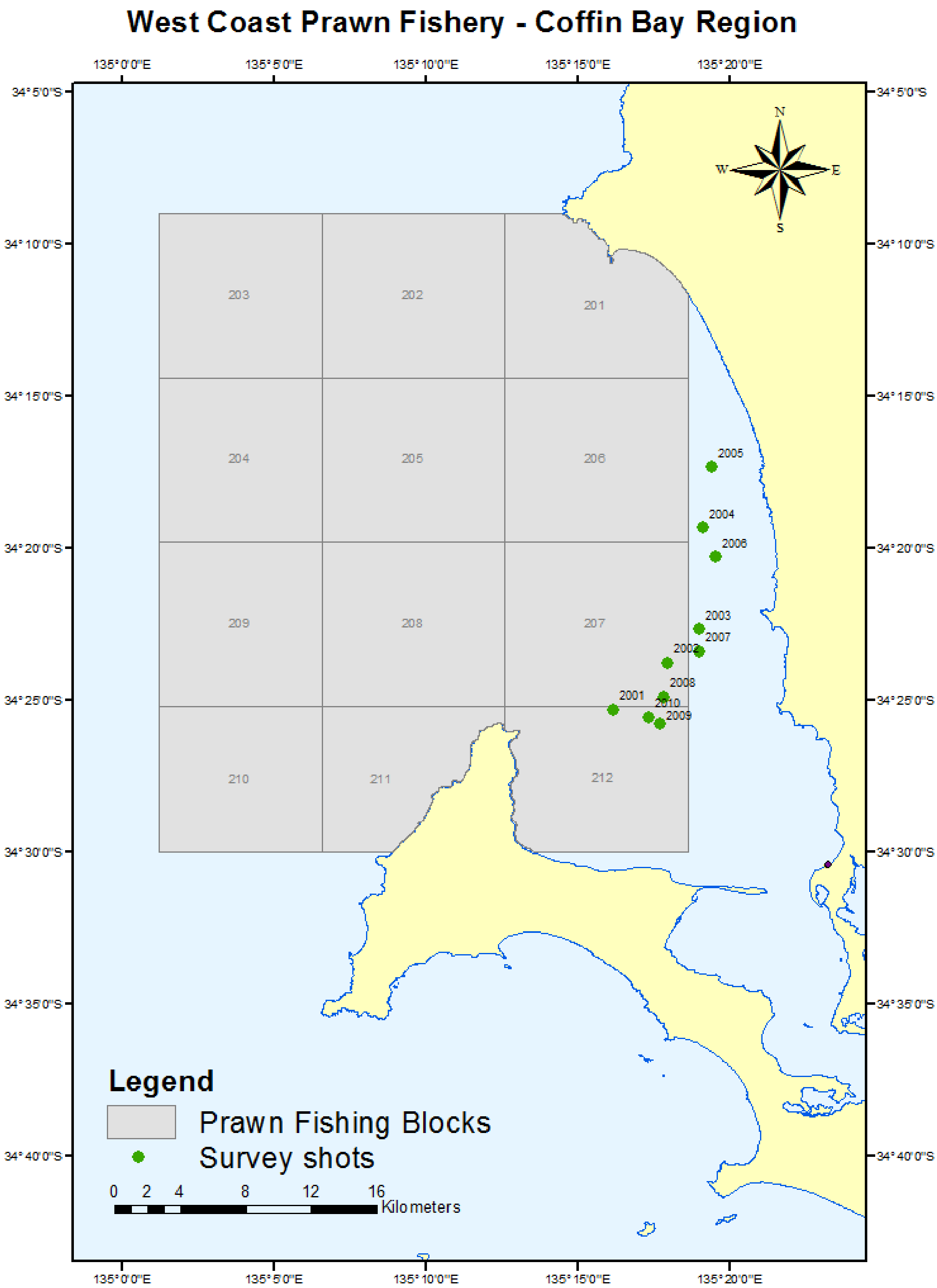

Figure 6.2 Fishing blocks and survey shots of the South Australia's West Coast commercial western king prawn fishery–-Coffin Bay region

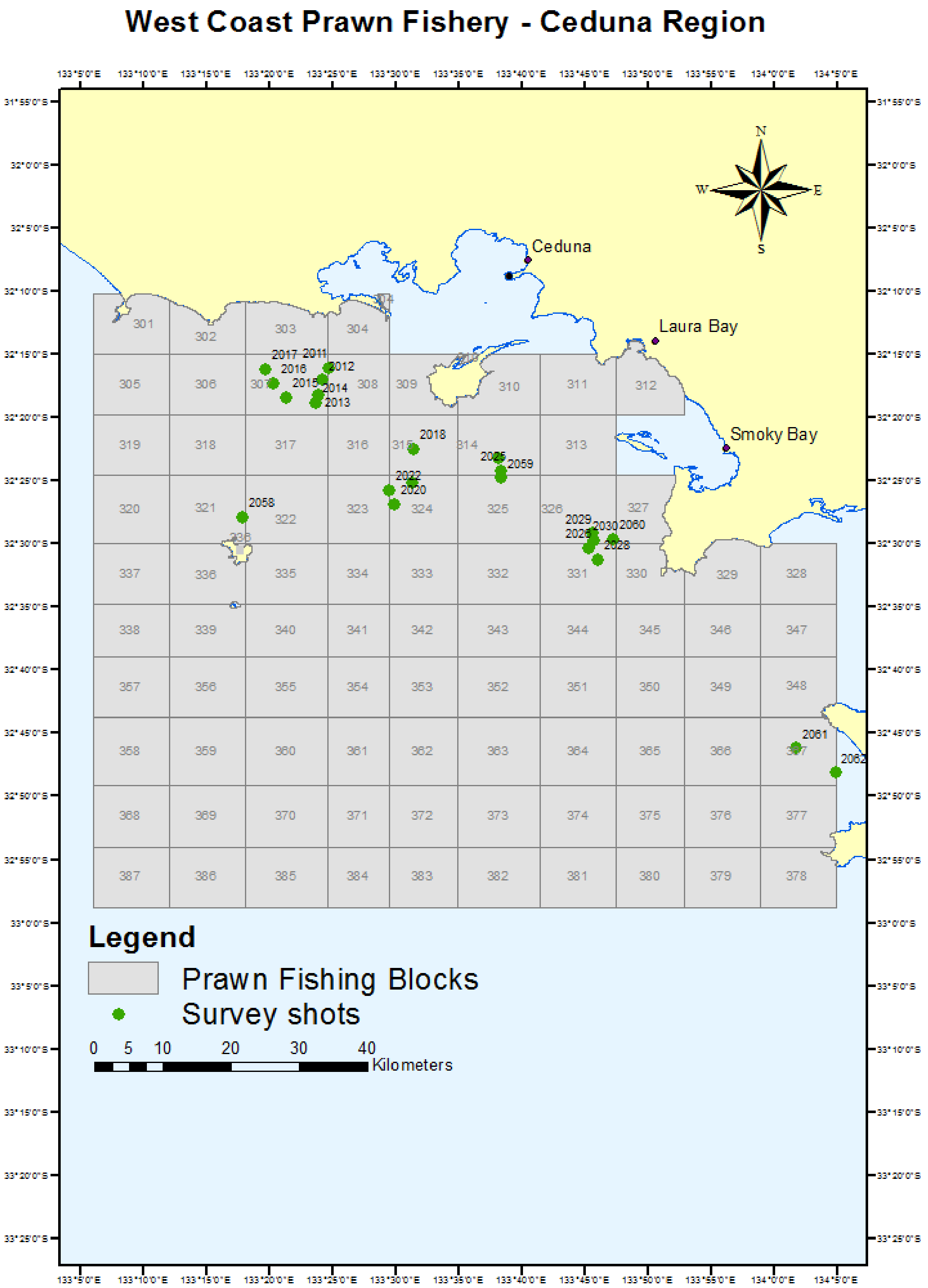

Figure 6.3 Fishing blocks and survey shots of the South Australia's West Coast commercial western king prawn fishery–Ceduna region