Fisheries

Spencer Gulf Prawn *Penaeus* (*Melicertus*) *latisulcatus* Fishery 2011/12

C.D. Dixon, C.J. Noell and G.E. Hooper

SARDI Publication No. F2007/000770-6
SARDI Research Report Series No. 685

SARDI Aquatic Sciences
PO Box 120 Henley Beach SA 5022

March 2013

Fishery Assessment Report to PIRSA Fisheries and Aquaculture

Government of South Australia

Spencer Gulf Prawn
Penaeus (*Melicertus*) *latisulcatus* Fishery
2011/12

Fishery Assessment Report to PIRSA Fisheries and Aquaculture

C.D. Dixon, C.J. Noell and G.E. Hooper

SARDI Publication No. F2007/000770-6
SARDI Research Report Series No. 685

March 2013

This report may be cited as:
Dixon, C.D., Noell, C.J. and Hooper, G.E. (2013). Spencer Gulf Prawn *Penaeus* (*Melicertus*) *latisulcatus* Fishery 2011/12. Fishery Assessment Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007/000770-6. SARDI Research Report Series No. 685. 115pp.

South Australian Research and Development Institute
SARDI Aquatic Sciences
2 Hamra Avenue
West Beach SA 5024

Telephone: (08) 8207 5400
Facsimile: (08) 8207 5406
http://www.sardi.sa.gov.au

Printed in Adelaide: March 2013

SARDI Publication No. F2007/000770-6
SARDI Research Report Series No. 685

Author(s): C.D. Dixon, C.J. Noell and G.E. Hooper

Reviewer(s): S. Mayfield and M. Steer

Approved by: Assoc Prof T. Ward
Science Leader - Fisheries

Signed:

Date: 7 March 2013

Distribution: PIRSA Fisheries and Aquaculture, Spencer Gulf and West Coast Prawn Fisherman's Association, Spencer Gulf Prawn Fishery licence holders, SAASC Library, University of Adelaide Library, Parliamentary Library, State Library and National Library

Circulation: Public Domain

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

Funds for this research were provided by PIRSA Fisheries and Aquaculture, obtained through licence fees. The South Australian Research and Development Institute (SARDI) Aquatic Sciences provided substantial in-kind support. We are grateful to the numerous scientific observers, industry observers, SARDI staff and volunteers that have assisted with Spencer Gulf prawn surveys. Considerable thanks go to the Spencer Gulf and West Coast Prawn Fishing Association, in particular Simon Clark, Greg Palmer and Kelly Tape. The catch and effort data were provided by Angelo Tsolos of the Fisheries Statistics Unit (FSU) at SARDI Aquatic Sciences. The report was reviewed by Dr Stephen Mayfield and Dr Mike Steer of SARDI Aquatic Sciences. Dr Annabel Jones of PIRSA Fisheries and Aquaculture provided valuable comments on the manuscript and Assoc. Prof. Tim Ward (SARDI Aquatic Sciences) formally approved the report for release.

EXECUTIVE SUMMARY

This report updates the fishery assessment report for 2010/11 and analyses data from the 2011/12 fishing-year as part of SARDI Aquatic Sciences' ongoing assessment program for the Spencer Gulf Prawn Fishery (SGPF). The aims are to: (1) synthesise and assess the information available for the SGPF; (2) assess the status of the resource and consider uncertainty associated with that assessment; (3) comment on the performance of the fishery with respect to the current biological performance indicators (PIs) and reference points (RPs); (4) provide advice on revision of the harvest strategy; and (5) identify future research priorities.

The SGPF was established in 1968 and catches increased rapidly to reach 2,287 t in 1973/74. Annual catches between 1,048 and 2,522 t have been harvested since. Nominal fishing effort peaked in 1978/79 (45,786 hrs) and is now 40% of this level. Increases in commercial catch per unit effort (CPUE) during this period reflect increases in fishing power.

Commercial catch in 2011/12 was 1,675 t, the lowest catch recorded since 2002/03. The catch of 556 t harvested from the Wallaroo region was the lowest since 1996/97. Both commercial catch and CPUE (91 kg/h) have declined by about 50% from the levels observed in 2009/10.

Trends in relative biomass (survey catch) have been stable over the last eight fishing-years. Standardisation of survey catch had minimal effect on nominal measures because of the consistent approach to surveys undertaken in recent years. The identification of several statistically significant external factors that affect survey catch will aid standardisation of historic survey data.

The mean size of prawns harvested during 2011/12 was similar to the mean size of prawns harvested over the previous nine years.

Six of the seven primary performance indicators (PIs) were achieved during 2011/12. The total commercial catch of 1,675 t fell short of the limit RP (1,800 t). Of the eight secondary PIs, only the % of 16/20 grade prawns harvested from March to June (32.9%) was not met (<30%).

A revised management plan and harvest strategy is due to be completed for the fishery in 2013. Several elements of the harvest strategy require amendment. Principally, key biological PI(s) are required to assess annual stock status. Adult

biomass could be a suitable PI, with appropriate RPs initially determined from survey CPUE data and in the future, potentially outputs from a bio-economic model which is currently being developed for South Australia's prawn fisheries. Stock status could then be used to determine the extent of catch or fishing effort applied for the upcoming season, with survey data collected throughout the season used to adjust catch or effort levels.

Historical reductions in effort, relatively stable catches and increases in prawn size over time indicate that the SGPF has been fished within sustainable limits for much of its history. Stable measures of biomass by size class indicate that the fishery continued to be harvested sustainably in recent years. Future research and management could now focus on establishing harvest and management strategies that aim to maximise the economic returns to industry while continuing to ensure the resource is harvested within sustainable limits.

1. GENERAL INTRODUCTION

1.1 Overview

This fishery assessment report for the Spencer Gulf Prawn Fishery (SGPF) is the seventh version of 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. The aims of the fishery assessment report are to: (1) synthesise and assess the information available for the SGPF; (2) assess the status of the resource and consider uncertainty associated with that assessment; (3) comment on the performance of the fishery with respect to the current biological performance indicators (PIs) and reference points (RPs); (4) provide advice on revision of the harvest strategy; and (5) identify future research priorities.

Since 2004, this report has documented the biology and management of the primary harvest species, presented analyses of commercial logbook and fishery-independent survey data, and provided assessment against the performance indicators of the Management Plan (Dixon and Sloan 2007). More recent reports have also provided detailed spatial and temporal assessments linking survey data with subsequent commercial catch. These analyses provide critical information for the assessment and improvement of the “Real Time Management” system that is the cornerstone of the SGPF’s success.

This report updates the analysis in last year’s stock assessment of factors that affect survey catch, with a standardisation of survey catch conducted on data obtained from 2004/05. The report also provides refined analyses on recruitment to the fishery and assessment of various measures of prawn size. These new analyses will assist in the development of a bio-economic model for the fishery. In 2012, the Australian Seafood CRC funded SARDI to develop a model, which primarily aims to examine and optimise the biological and economic outcomes from a range of alternative fishing strategies for the fishery.

1.2 Description of the fishery

1.2.1 Fishery location

There are three commercial prawn *Penaeus* (*Melicertus*) *latisulcatus* fisheries in South Australia: Spencer Gulf, Gulf St Vincent and the West Coast (Figure 1.1). The SGPF is the largest of these in terms of total area, production, and number of licence holders.

Fishing is permitted in all waters north of the geodesic joining Cape Catastrophe (Latitude 34º 35.4'S, Longitude 136º 36.0'E) on Eyre Peninsula and Cape Spencer (Latitude 34º 9.6'S, Longitude 135º 31.2'E) on Yorke Peninsula, with the exception of several permanently closed areas. Spencer Gulf is divided into 125 prawn fishing blocks aggregated into regions reflective of the main trawl grounds of the fishery (Figure 1.2).

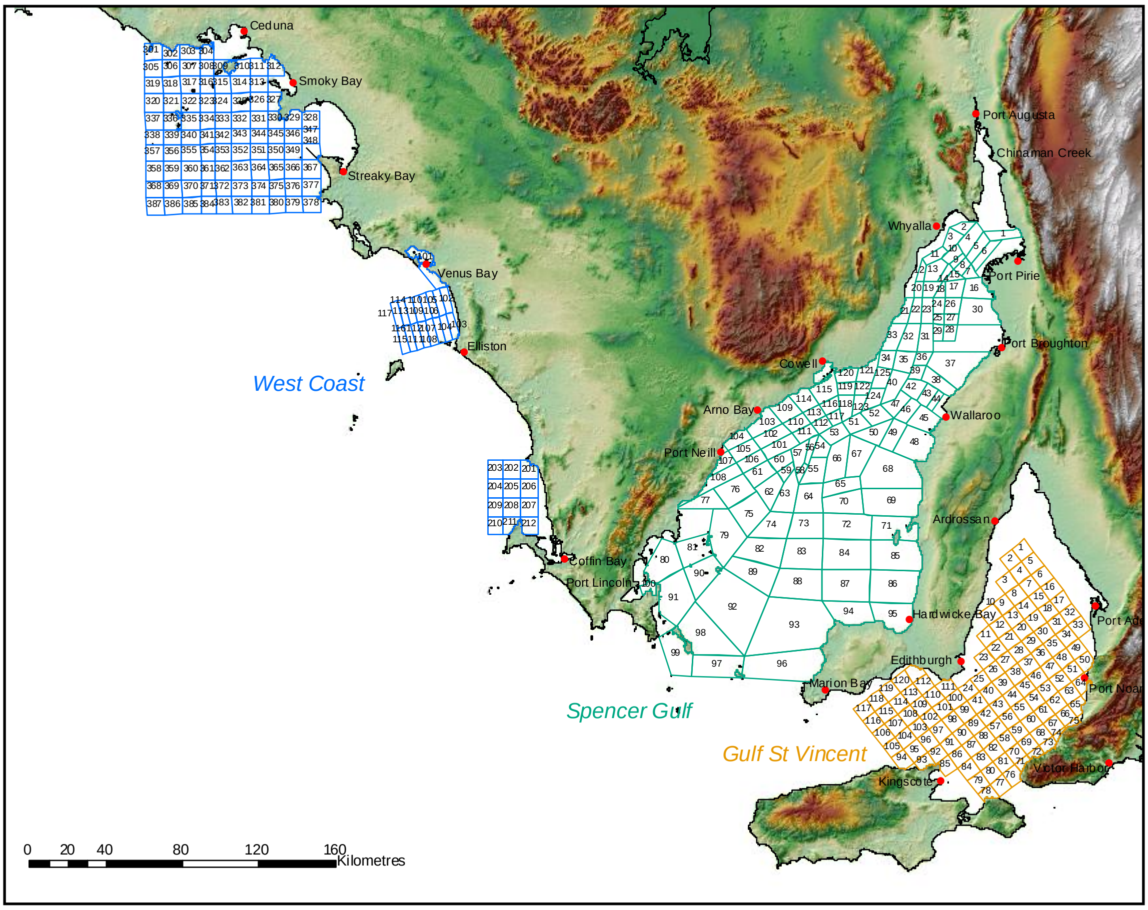


Figure 1.1 Location of South Australia's three commercial prawn fisheries.

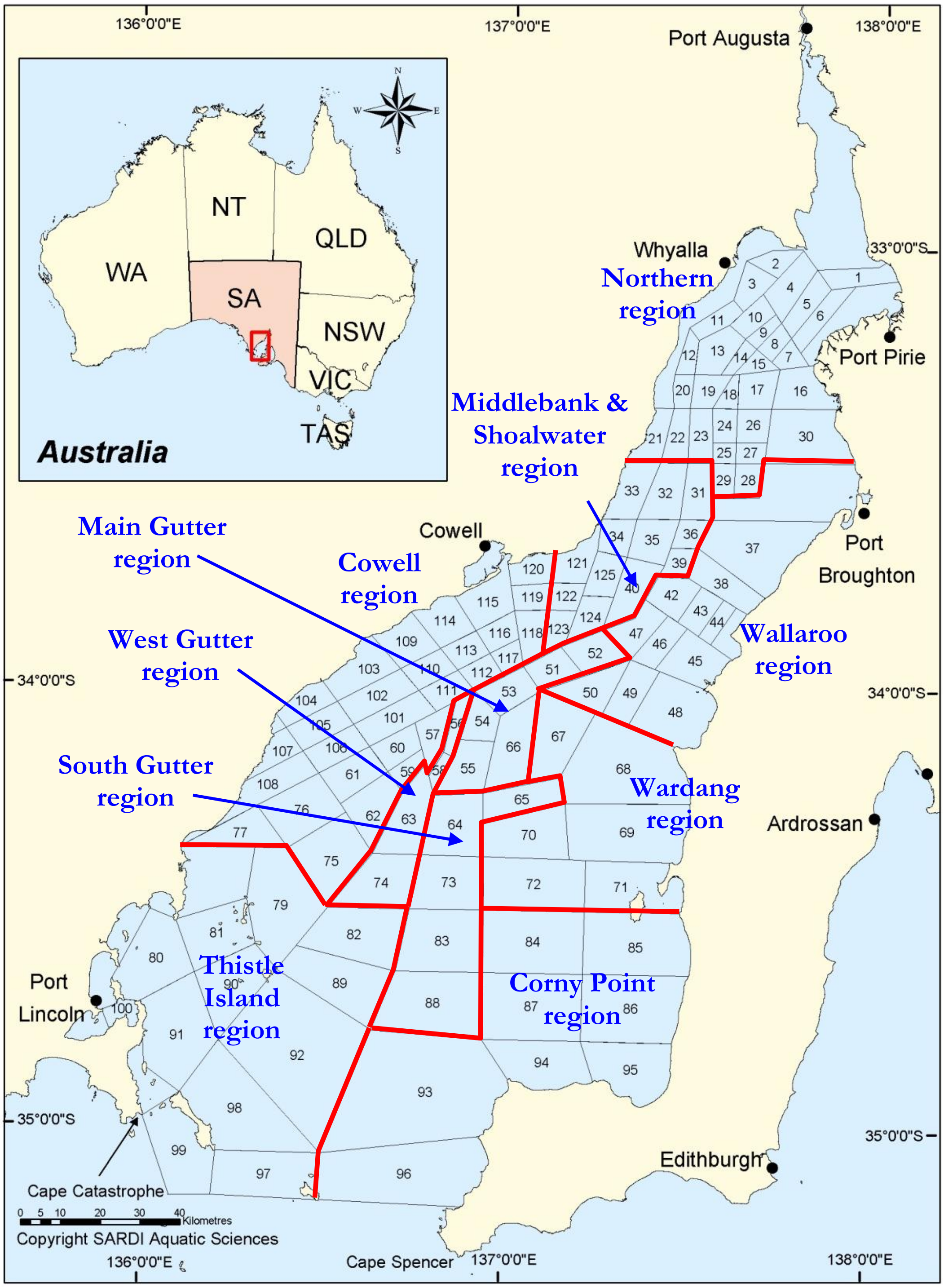


Figure 1.2 Fishing blocks (numbers) and reporting regions of the SGPF.

1.2.2 Spencer Gulf environment

The Spencer Gulf is a shallow embayment <40 m deep in the northern areas and up to 60 m deep in the southern areas (Figure 1.5). Sediments are predominately sand and mud, and seagrass habitats are common at depths <10 m. Due to minimal freshwater input and high summer evaporation rates, it is an inverse estuary, with salinity increasing towards the head of the gulf (Nunes and Lennon 1986).

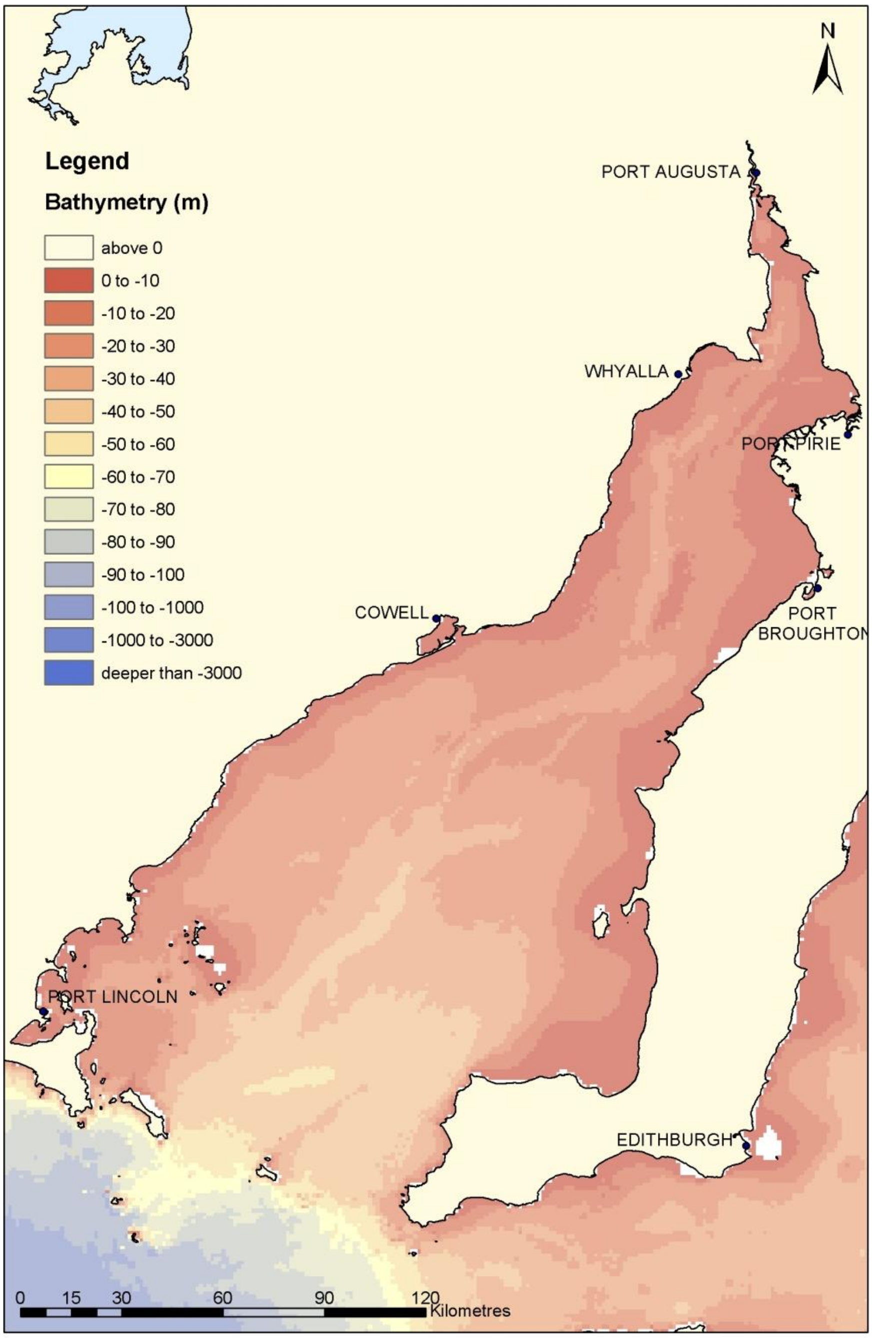


Figure 1.3 The bathymetry of Spencer Gulf.

Sea surface temperatures (SSTs) in South Australia are lower and more variable than in northern fisheries that target *P. latisulcatus* (eg. Broome and Shark Bay, Figure 1.6). In Spencer Gulf, SST fluctuates seasonally between ~12°C and ~24°C (Nunes and Lennon 1986) with warmer SSTs in the north, cooler surface waters in the south, and considerably lower temperatures in the surrounding open ocean (Figure 1.7).

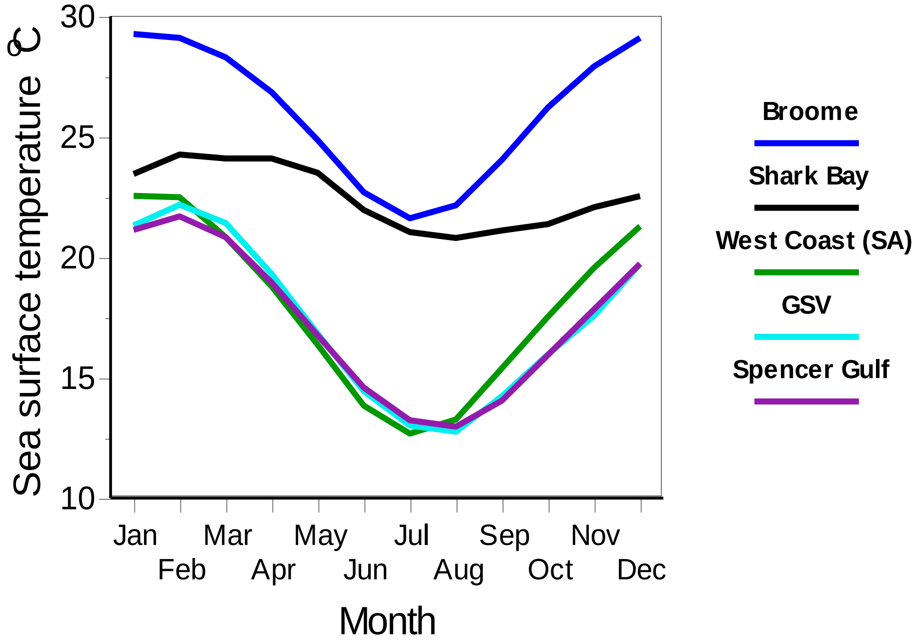


Figure 1.4 Comparison of mean monthly sea surface temperature (SST, ºC) for the Australian prawn fisheries that target *P. latisulcatus*. Figure reproduced from Carrick (2003).

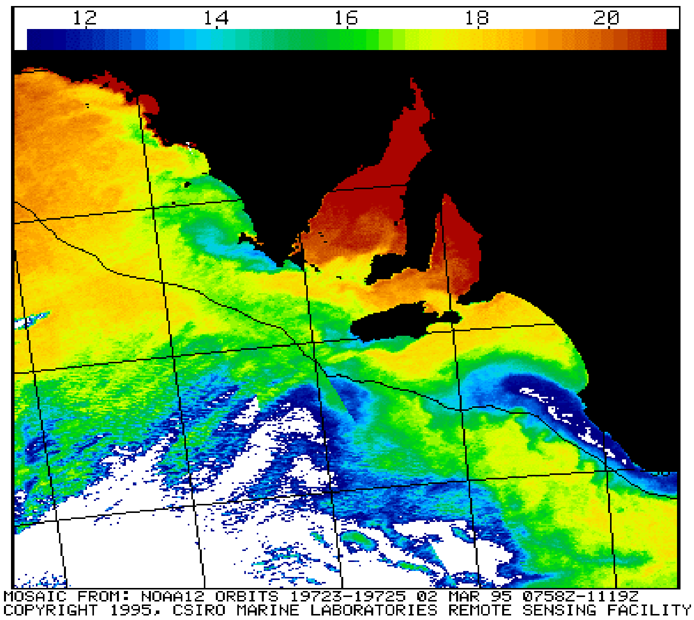


Figure 1.5 Sea surface temperatures over the continental shelf of South Australia during late summer/early autumn, 1995. A colour-coded key in degree Celsius is situated at the top of the map. Figure from Linnane et al. (2005), sourced from CSIRO.

1.2.3 Nursery areas

In South Australia, juvenile *P. latisulcatus* occur predominately on intertidal sand- and mud-flats, generally located between shallow subtidal / intertidal seagrass beds and mangroves higher on the shoreline (Kangas and Jackson 1998; Tanner and Deakin 2001). In Spencer Gulf, juvenile abundance was significantly greater in the mid intertidal zone compared to lower and upper zones (Roberts *et al.* 2005), while in Gulf St Vincent abundance was similar within intertidal zones (Kangas and Jackson 1998).

Following Bryars (2003), the Spencer Gulf coastline was divided into a number of Fisheries Habitat Areas (FHA 20, 23, 25–37 - Thorny Passage to Formby Bay). Each FHA has a comprehensive description, including colour-coded maps of up to 12 habitat types. Of these, the habitat types ‘tidal flats’ and ‘mangrove forests’ were determined as appropriate juvenile prawn habitat. The proportion of the coastline for each FHA containing tidal flat only and mangrove forest (+ tidal flat) was estimated to the nearest 10% from the maps (Bryars 2003). This enabled estimation of the percent length of coast for each habitat type. The total length of coastline was calculated from satellite imagery (http://earth.google.com). Table 1.1 provides summary estimates for each South Australian prawn fishery (see also Dixon *et al.* 2006a, 2006b).

Table 1.1 The number of Fishery Habitat Areas (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 (km)	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

The Spencer Gulf coastline was approximated at 992 km, with 508 km (51%) of tidal flat only and 245 km (25%) of mangrove forest (+ tidal flat) (Table 1.6). Areas with the greatest juvenile prawn nursery habitat were the Far Northern Spencer Gulf (~201 km of tidal flat only and 67 km of mangrove forests (+ tidal flat)), Germein Bay (~95 km of tidal flat only and 57 km of mangrove forests (+ tidal flat)) and False Bay (~63 km of tidal flat only and 49 km of mangrove forests (+ tidal flat)) (Figure 1.8). These areas of identified nursery habitat correspond well with sites in Spencer Gulf previously found to contain the greatest abundances of juvenile prawns. Juvenile abundance was significantly greater in the north, with False Bay found to have the greatest abundance (Roberts *et al.* 2005).

While the importance of mangrove habitat for prawn recruitment has been debated for some time (see Lee 2004), the extent of available juvenile habitat appears to correlate well with production from each fishery, particularly that of mangroves (Table 1.1).

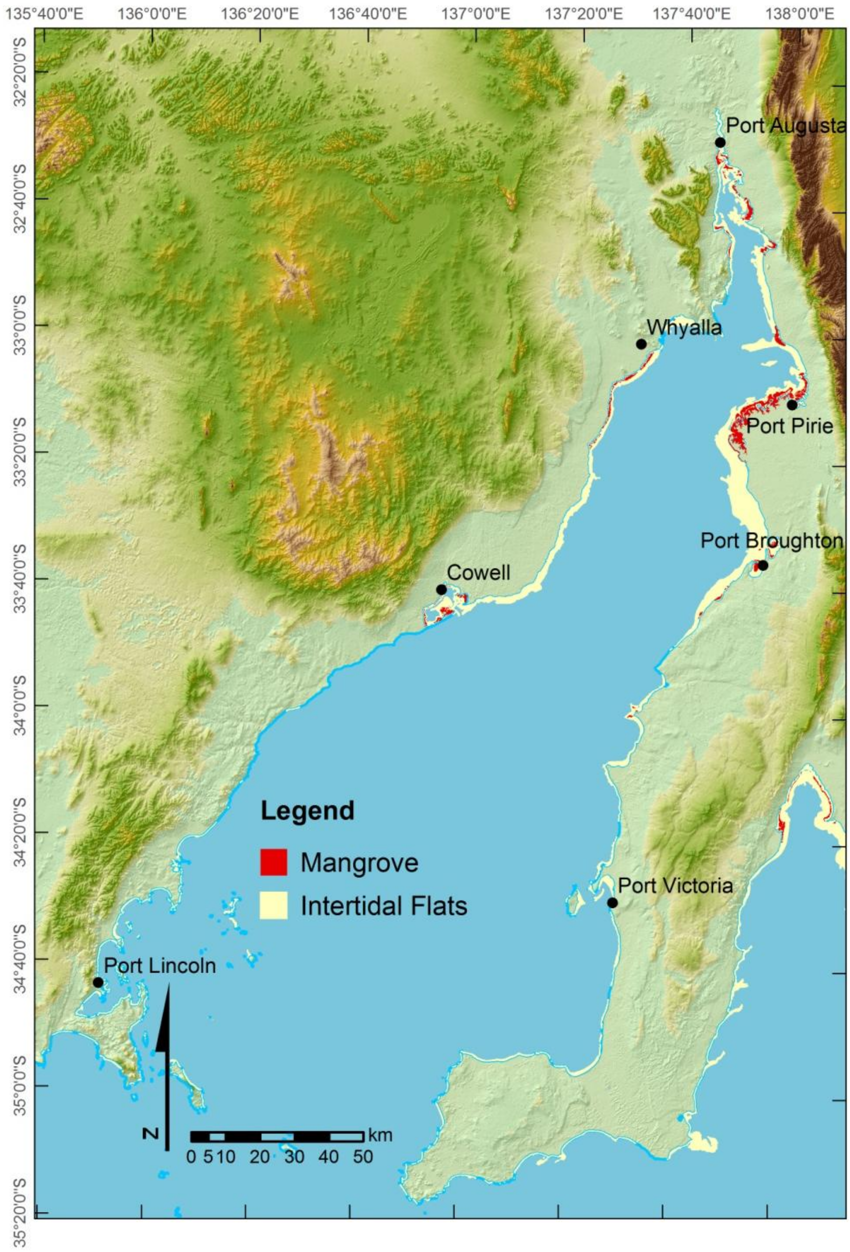


Figure 1.6 Important juvenile nursery habitat, mangrove forest and tidal flats, around coastal Spencer Gulf. Reproduced from Bryars (2003).

1.2.4 Commercial fishery

The SGPF is a single species fishery that targets the Western King Prawn*.* This species was initially classified as *Penaeus latisulcatus* (Kishinouye, 1896), then subsequently reclassified by Perez Farfante and Kensley (1997) to raise the sub-genus *Melicertus* to generic rank (ie. *Melicertus latisulcatus*). Recently, Flegel (2007) revised the taxonomic name to *Penaeus (Melicertus) latisulcatus*. A smaller penaeid, *Metapenaeopsis crassima*, occurs in Spencer Gulf but is of no commercial value.

P. latisulcatus was first trawled in Spencer Gulf in 1909 by the FIS *Endeavour*. The first commercial prawn trawling attempts occurred in 1948 but the first commercial quantity of prawns was not harvested until October 1968 (Carrick 2003). Prawns are harvested at night using demersal, otter-trawl, double-rig gear (Figure 1.3). Considerable technological advancements have been made in the fishery including the use of “crab bags” to exclude mega-fauna by-catch (Figure 1.4), “hoppers” for efficient sorting of the catch and rapid return of by-catch (Figure 1.3), and “graders” to sort the prawns into marketable size categories (Figure 1.3). Many vessels in the prawn fleet are “factory vessels” that process the catch on-board.

The SGPF is the third most valuable prawn fishery in Australia ($30.3M in 2010/11) behind the Queensland East Coast Prawn Fishery ($90M) and Northern Prawn Fishery ($62.2M in 2008; Table 1.2). In terms of value per licence holder, the SGPF is ranked second (39 licences, $0.78M per licence) behind the Northern Prawn Fishery (52 licences, $1.20M per licence), and the Queensland East Coast Prawn Fishery (498 licences, $0.18M per licence).

South Australia’s prawn fisheries are the only substantial single species prawn fisheries in Australia. However, it is not the only fishery to target *P. latisulcatus*, as this species comprises 62% of the Shark Bay prawn catch, 46% of the Broome prawn catch and 43% of the Exmouth Gulf prawn catch (Table 1.2).

The SGPF was recently awarded third party certification for sustainability by the Marine Stewardship Council (MSC, http://www.msc.org), becoming the first prawn trawl fishery in the southern hemisphere to achieve this.

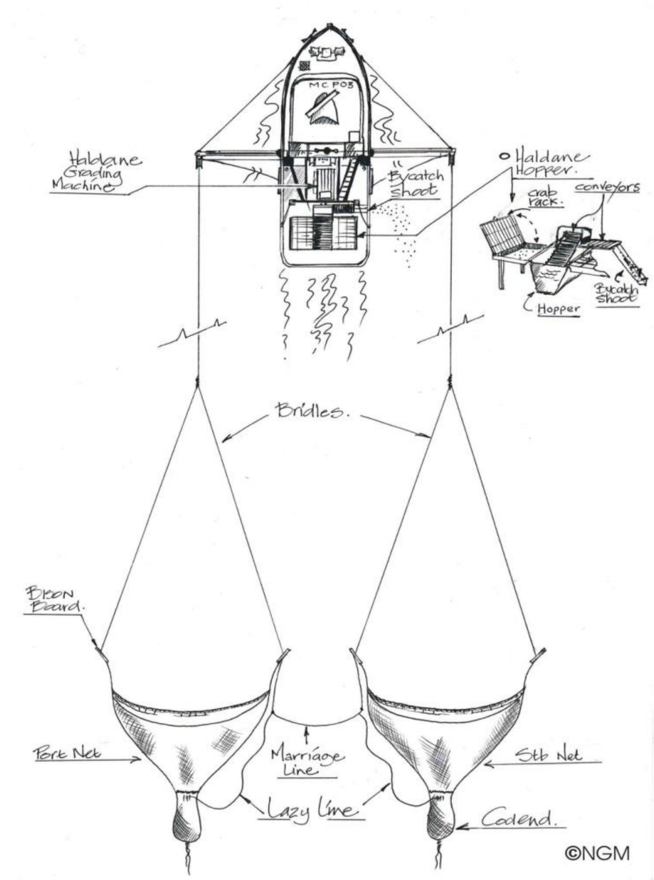


Figure 1.7 Double rig trawl gear and location of hopper sorting and prawn grading systems used in the SGPF. Figure from Carrick (2003).

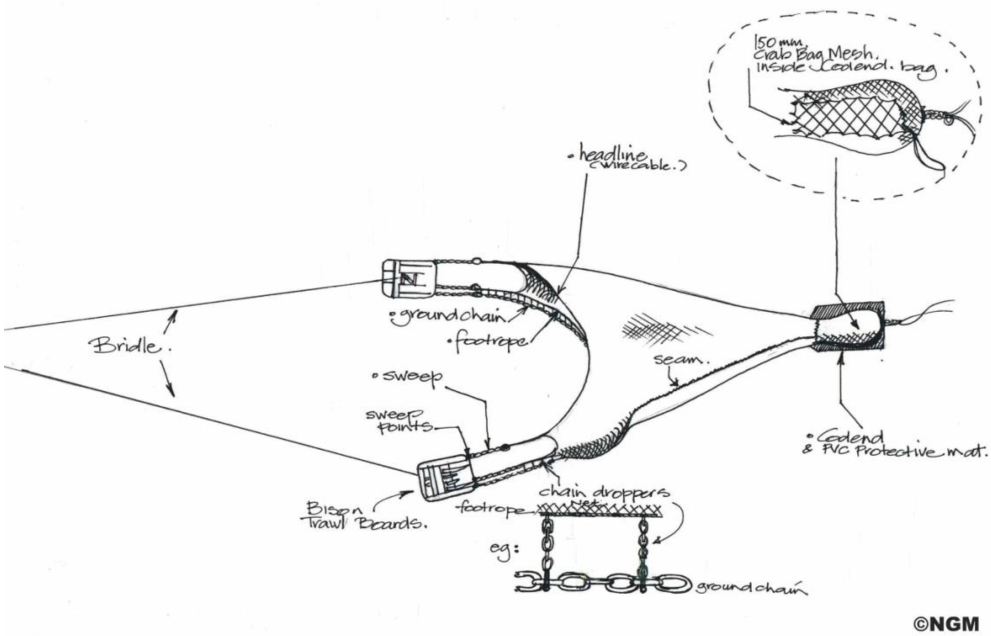


Figure 1.8 Trawl net configuration showing trawl boards, head rope, ground chain and cod end with crab bag. Figure from Carrick (2003).

Table 1.2 Production figures and species harvested in all Australian prawn fisheries. * NSW production and value is calculated from total reported commercial wild harvest (includes by-product). ** only one vessel fished in 2007.

Fishery	Year	Production (t, % King)	Value ($M)	Licences	Prawn species harvested
South Australia					
Spencer Gulf [1]	2010/11	1979 (100%)	30.3	39	Western king
Gulf St Vincent [1]	2010/11	178(100%)	2.12	10	Western king
West Coast[1]	2010/11	136 (100%)	1.69	3	Western king
Commonwealth					
Northern[2]	2009	7483 (0.1%)	na	55	Banana, Tiger, Endeavour and King
Torres Strait[3]	2007	1078 (4%)	11	61	Tiger, Endeavour and Red Spot King
Other States					
NSW–Ocean Trawl[4]*	2006/07	3476 (13%)	21.5	306	Eastern King, School, Royal Red, Brown Tiger
NSW–Estuary General[4]*	2006/07	3657 (1.1%)	20.8	685	Eastern King, School, Brown Tiger, Greentail
NSW–Estuary Trawl[4]*	2006/07	522 (0.4%)	3.9	216	Eastern King, School, Brown Tiger, Greentail
QLD–East Coast[5]	2006	5635 (35%)	90	498	Tiger, Banana, Red Spot King, Endeavour, Eastern King and Bay
QLD–River & Inshore[6]	2007	364 (0%)	4.8	143	Banana, Bay and Tiger
WA–Shark Bay[7]	2007	1250 (62%)	14.3	27	Western King, Brown Tiger, Coral and Endeavour
WA–Exmouth[7]	2007	790 (43%)	9.1	16	Western King, Brown Tiger, Banana and Endeavour
WA–South West[7]	2007	6 (100%)	-	14	Western King
WA–Onslow[7]**	2007	4 (<25%)	-	Up to 31	Western King, Brown Tiger, Banana and Endeavour
WA–Nickol Bay[7]	2007	44 (0.2%)	0.3	14	Western King, Brown Tiger, Banana and Endeavour
WA–Kimberley[7]	2007	271 (0.4%)	2.2	137	Banana, Tiger, Endeavour and Western King
WA–Broome[7]	2007	72 (46%)	0.5	5	Western King and Coral
Victoria[8]	2006/07	56 (82%)	0.675	60	Eastern King and School

Sources: 1. Knight and Tsolos (2012); 2. Evans (2010); 3. Wallis *et al.* (2009); 4. Scandol *et al.* (2008); 5. Anon (2007a); 6. Anon (2008a); 7. Kangas *et al*. (2008); 8. Anon (2008b).

1.2.5 Recreational, indigenous and illegal catch

Significant recreational catches of *P. latisulcatus* are precluded by current fisheries regulations that require recreational prawn catches to be taken from waters >10 m in depth using hand held nets. Levels of indigenous and illegal fishing are considered negligible (Anon 2003).

1.3 Management of the fishery

The SGPF is managed by Primary Industries and Regions South Australia (PIRSA) 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.

The introduction of the *Fisheries (Management Committees) Regulations 1995* provided a forum for South Australia's fishing industries to participate in the active management of their respective fishery. The introduction of the *Fisheries Management Act 2007* saw the abolishment of fisheries management committees (FMCs), and establishment of the Fisheries Council of South Australia. These changes aim to provide well organised, representative fishing bodies, such as the Spencer Gulf and West Coast Prawn Fisherman's Association, greater opportunities to increase responsibility in co-management, while reducing administrative costs.

1.3.1 Management history

Management arrangements have evolved in the SGPF since its inception in the late 1960s, with key milestones presented in Table 1.3.

Table 1.3 Major management milestones for the SGPF.

Date	Management milestone
1968	Licence limitation. Trawling prohibited in waters of <10 metres. Commercial recording of catch and effort introduced
1969	Prawn Resources Regulations established. Spencer Gulf divided into two zones
1971	Spencer Gulf zones removed
1974	Spatial closure north of Point Lowly implemented
1976	Licences capped at 39
1981	Spatial closure adjacent to Port Broughton implemented
1991	Scheme of Management (Prawn Fisheries) Regulations introduced
1995	The *Fisheries (Management Committees) Regulations 1995* are introduced
1998	First management plan implemented
2007	Management plan reviewed and updated

1.3.2 Current management arrangements

The SGPF is a limited entry fishery with 39 licensed operators. Trawling activities are banned during daylight hours and must be conducted in waters >10 m depth. Effort is restricted both spatially and temporally throughout the fishing-year by closures. Effective effort (fishing power) is restricted by gear restrictions including vessel size and power, type and number of trawl nets towed, maximum headline length and minimum mesh sizes (Table 1.4).

Table 1.4 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)
Limited entry	Yes
Number of licences	39
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

There are generally 6 fishing periods within each fishing-year. Each fishing period lasts a maximum of 18 nights from the last to first quarters of the moon in November, December, March, April, May and June. Harvest strategies for each period are determined on the basis of data collected during fishery-independent and fishery-dependent surveys.

1.3.3 Management Plan

MacDonald (1998) developed the first Spencer Gulf and West Coast Prawn Fishery Management Plan, documenting the management history, policy framework and performance indicators for these two fisheries. Recently, a review of the Management Plan was undertaken and an updated plan specific to the SGPF was documented (Dixon and Sloan 2007, hereafter referred to as ‘the Plan’).

The Plan provides an overarching framework for management decision making that is underpinned by four key goals and a series of objectives and strategies. The primary aim for the SGPF for the life of the Plan is to maintain ecologically sustainable stock levels. The Plan also aims to identify an appropriate balance between long-term ecological sustainability and the optimum utilisation and equitable distribution of resources between all stakeholder groups and future generations. The four goals are:

1. Maintain ecologically sustainable stock levels
2. Ensure optimum utilisation and equitable distribution
3. Minimise impacts on the ecosystem
4. Enable effective management with greater industry involvement.

The Plan is the first to contain specific guidelines for the development and assessment of harvest strategies for the fishery. Harvest strategies are the mechanisms for managing fishing effort using a combination of prawn size, catch rate, and spatial and temporal closures. The aim of the harvest strategies is to define fishing areas for the fleet to target areas that are characterised by high catch rate of appropriately sized prawns, thereby ensuring biological sustainability and promoting economic efficiency. The Plan provides details on the data required and the decisions rules for harvest strategy determination, both of which can be audited against the Plan.

1.3.4 Performance indicators

The extent to which the fishery is achieving the range of stated goals and objectives of the Plan is assessed using a combination of performance indicators (PIs). The key biological and management PIs of the Plan assessed in this report are presented in Table 1.5. The full suite of PIs is documented in the Plan.

The recruitment index is measured as the square root of the number of juvenile prawns (males <33 and females <35 mm CL) captured per nautical mile trawled, following Carrick (2003). Total commercial catch and mean commercial CPUE are calculated from commercial logbook catch and effort data for the fishing-year from November to June inclusive. Data on mean prawn size (weighted by catch) are obtained from commercial logbook size grade data. Indices of future and current biomass are based on catch rates obtained during each of the three fishery independent surveys conducted annually. The limit for future biomass is a mean catch rate for the 20+ prawn grade of 10, 50 and 40 kg/hr during November, February and April surveys, respectively. The threshold limit for current biomass is a mean total catch rate of 95, 120 and 160 kg/hr during November, February and April surveys, respectively. Committee compliance with harvest strategy decision rules is assessed by comparing survey results in light of the decision rules of the Plan against the determined harvest strategy.

Table 1.5 Biological and management performance indicators and limit reference points for the SGPF.

Performance indicator	**Limit reference point**
Fishery independent surveys	3 surveys completed
Recruitment index (juveniles$^{0.5}$.nm^{-1})	<35
Total commercial catch (t)	<1800
Mean commercial CPUE (kg/hr)	<80
% vessel nights with mean size >280 prawns/7 kg	>2%
Indices of future and current biomass (defined in the Plan)	Neither index is below lower threshold levels in 2 consecutive surveys
Committee comply with harvest strategy decision rules	Committee develops all harvest strategies based on results of surveys and in accordance with decision rules

Limit reference points (LRPs) define the minimum acceptable level of performance. If the LRP is not achieved for any PI, measures to improve performance must be developed, following the management responses outlined in the Plan. These responses include detailed assessment of a series of additional performance measures (Table 1.6). Triggering additional performance measures does not evoke a management response.

Table 1.6 Summary of the additional biological and management performance measures and associated limit reference points for the SGPF.

Performance measure	**Limit reference point**
Recruit index November survey all shots	>12
Recruit index February survey all shots	>19
Recruit index April survey all shots	>15
Egg production (eggs*10^6/ hr trawled)	>500
% of 20+ in the catch – Nov & Dec	<12%
% of 20+ in the catch – March to June	<7%
% of 16–20 in the catch – Nov & Dec	25–35%
% of 16–20 in the catch – March to June	<30%

Additional performance measures include recruitment indices for each stock assessment survey, calculated as for the recruitment index in Table 1.5, but for all surveyed sites throughout Spencer Gulf. Egg production is calculated following

Section 3.6 of this report. The percentage of 20+ and 16–20 grade prawns in the catch is calculated from commercial logbook data following Section 2.3 of this report.

1.4 Biology of the Western King Prawn

1.4.1 Distribution and taxonomy

P. latisulcatus 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 Ceduna, Venus Bay and Coffin Bay. King (1977), Sluczanowski (1980) and Carrick (1982, 1996) provide detailed accounts of the distribution of Western King Prawn in Spencer Gulf.

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 behavioural pattern of daytime burial and nocturnal activity (Rasheed and Bull 1992; Primavera and Lebata 2000). Strong lunar and seasonal differences in activity are also exhibited, where prawn activity (and catchability) is greater during the dark phase of the lunar cycle and during warmer months.

The distribution and abundance of *P. latisulcatus* within the gulfs and estuaries is affected by salinity and the presence of sandy substrate (Potter *et al*. 1991). Higher abundances are associated with salinities above 30 ‰ (Potter *et al*. 1991). In physiological studies on *P. latisulcatus*, optimal salinity ranged from 22 to 34 ‰, and 100% mortality occurred at salinities below 10 ‰ (Sang and Fotedar 2004). Juvenile *P. latisulcatus* are more efficient osmoregulators than adults, tolerating greater variation in salinity. Important nursery areas in Western Australia and South Australia are characterised as being hyper-saline (35–55 ‰) (Carrick 1982; Penn *et al*. 1988).

1.4.2 Reproductive biology

In the SGPF adult prawns aggregate, mature, mate and spawn in deep water (>10 metres) between October and April, with the main spawning period being earlier in the fishing-year (October–January in 2008/09), peaking in November (Figure 1.9). Spawning and fecundity are affected by water temperature, with the minimum for spawning being 17 °C for *P. latisulcatus* in WA (Penn 1980). The peak reproductive period in Queensland (QLD) populations of *P. latisulcatus* was between June and July when water temperature dropped below 25 °C (Courtney and Dredge 1988). While the ideal temperature range (17–25 °C) for spawning generally occurs from ~1 November to 31 May, the majority of spawning in Spencer Gulf is restricted to earlier in the fishing-year, which is likely associated with optimising reproductive success due to shorter larval durations and higher larval survival at that time of year (Roberts *et al.* 2012).

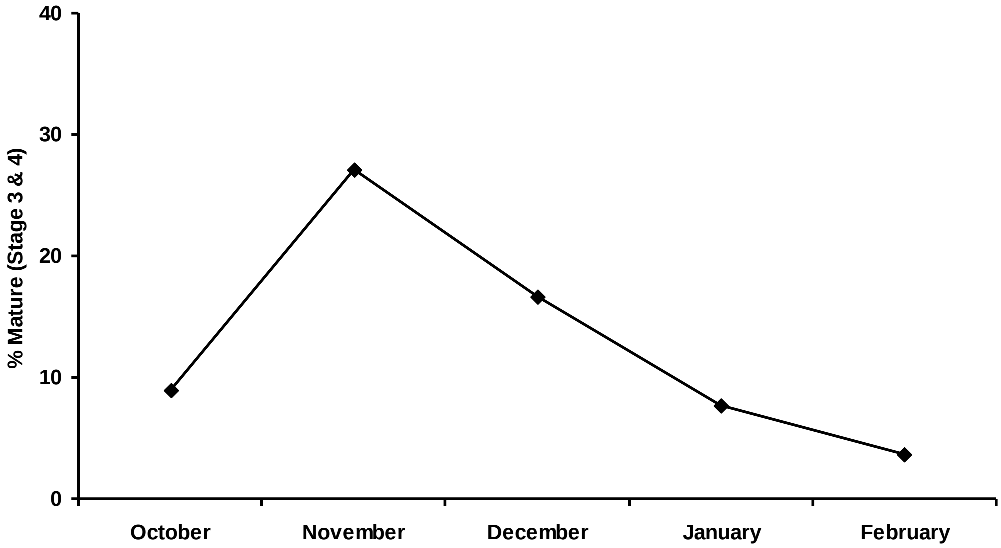


Figure 1.9 Female prawn reproductive maturation based on the percentage of ripe (Stage 3 and 4) prawns collected from northern Spencer Gulf during the summer of 2008/09 (SARDI unpublished data as part of N. Hackett PhD).

During mating the male transfers a sperm capsule (spermatophore) to the female reproductive organ (thelycum). The success of this 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 presumably occurs immediately prior to, or on release of, the eggs by the female.

During the peak spawning period, the sex ratio of *P. latisulcatus* caught in Western Australia (WA) was shown to significantly change to that of a female-biased catch. This was attributed to higher catchability of females due to increased foraging-feeding activity necessitated by food requirements during ovary development (Penn 1976; Penn 1980). Similarly during November and December, female-biased populations of *P. latisulcatus* were documented in Gulf St Vincent (Svane 2003; Svane and Roberts 2005).

The proportion of reproductively mature female *P. latisulcatus* increases with size. In Spencer Gulf, Carrick (2003) defined the relationship between maturity and size with the logistic equation:

$$\text{Proportion mature} = 8.3 \times 10^{-6} + \left[\frac{1}{1 + e^{-\{0.277(CL - 36.45)\}}} \right]$$

While females can mature at a small size, differences between tropical and temperate populations are apparent. The smallest ripe female recorded in WA populations was 29 mm carapace length (CL) (Penn 1980). In Spencer Gulf, the smallest ripe female was 24 mm CL (SARDI unpublished data). Insemination rate is indicative of fertilisation success and also increases with size. Courtney and Dredge (1988) showed that ~50% of females were inseminated at 34 mm CL, while ~95% were inseminated at 42 mm CL in QLD populations of *P. latisulcatus*. There are no data on the fecundity of *P. latisulcatus* in Spencer Gulf. Table 1.7 and Figure 1.10 presents the results of fecundity studies for *P. latisulcatus* in Gulf St Vincent (Kangas unpublished, cited in Carrick 2003), Shark Bay (Penn 1980) and the north east coast of QLD (Courtney and Dredge 1988). In all three fisheries, fecundity increases exponentially with carapace length, however this is more pronounced in the cooler waters of Gulf St Vincent (see Figure 1.10). Thus, larger prawns make a greater contribution to total egg production due to both greater insemination rates, as well as greater fecundity (Penn 1980; Courtney and Dredge 1988; Carrick 1996).

Table 1.7 Fecundity relationships for *P. latisulcatus* in Gulf St Vincent, Western Australia and Queensland. Fecundity = a × carapace length^ b

Location	*a*	*b*
Gulf St Vincent, SA	7.94×10^{-6}	3.462
Shark Bay, WA	6.95×10^{-5}	2.916
Nth East Coast, QLD	4.8×10^{-6}	3.52

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 in old female *P. latisulcatus* has not been documented.

Spawning frequency for *P. latisulcatus* 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 and hence spawning interval, for mature untagged females in WA populations during the spawning season was estimated at 30–40 days (Penn 1980).

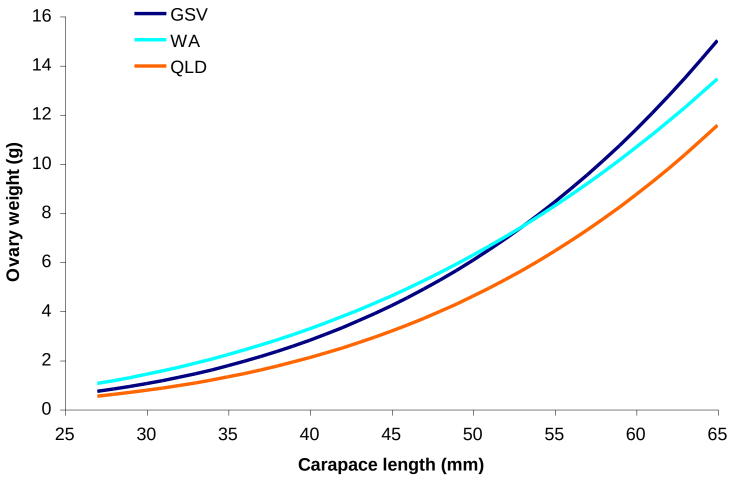


Figure 1.10 The relationship between fecundity (ovary weight) and carapace length (CL) for *P. latisulcatus* in Gulf St Vincent, Western Australia and Queensland.

Multiple spawning events can occur in *P. latisulcatus* as spawning frequency is related to moulting frequency. There are three lines of evidence supporting the concept of multiple spawning: (1) spent ovaries are difficult to identify since immediate ovary development meant they were often classified as Stage 2 (Penn 1980; Courtney and Dredge 1988); (2) in an experiment where ripe females were tagged and released, 15 re-captured 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, provided direct evidence for the multiple spawning capacity of Penaeids (Arnstein and Beard 1975). In addition to multiple spawning within a season, females are likely to spawn for multiple seasons. This was determined by the large proportion of females in different size cohorts being reproductively active during the spawning season (Penn 1980).

Prawn reproduction can also be affected by parasite load and disease status. Courtney *et. al.* (1995) showed that parasitisation by bopyrid isopods affected the reproductive output of *P. plebejus*. Bopyrid isopods have been observed to parasitise individuals of the South Australian population of *P. latisulcatus* (Roberts *et al.*, 2010). In *Fenneropenaeus indicus* (formerly known as *P. indicus*), it was shown that viral infections affected moulting and reproduction in Penaeid shrimp (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 *P. latisulcatus* in South Australia.

1.4.3 Larval and juvenile phase

P. latisulcatus has an offshore adult life and an inshore juvenile phase (Figure 1.11).

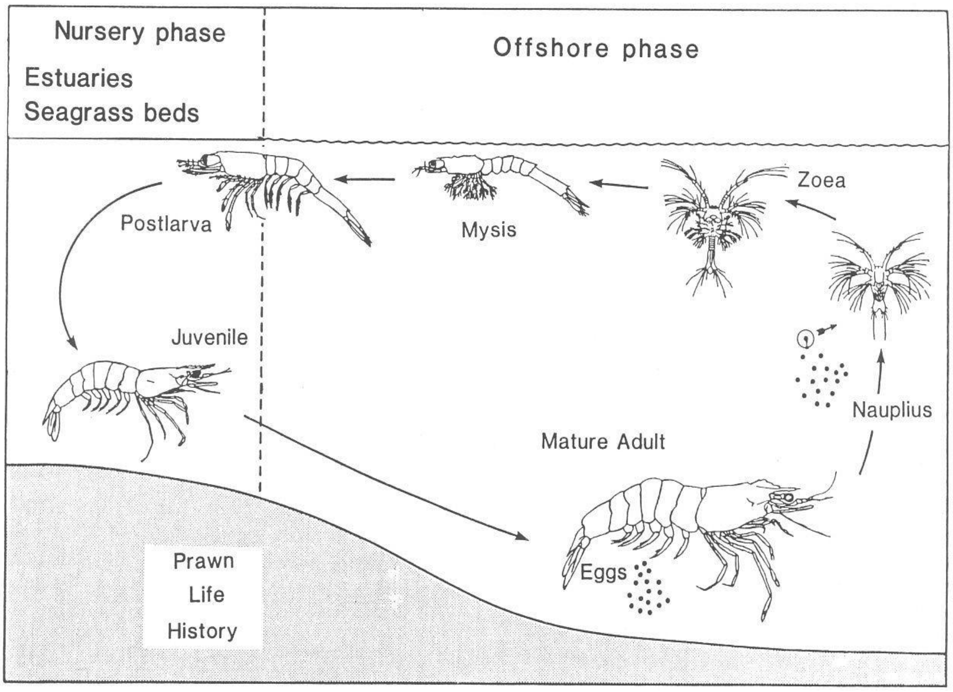


Figure 1.11 Life cycle of *P. latisulcatus* (King unpublished thesis).

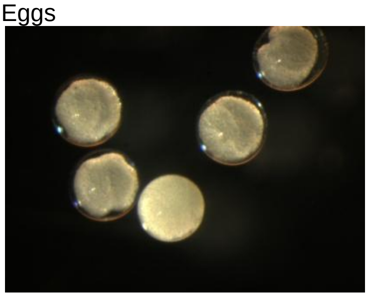
Prawn larvae undergo metamorphosis through four main stages: nauplii, zoea, mysis and post-larvae (Figure 1.12). Stage specific sizes (body length) are approximately: egg ~300 µm (diameter), nauplii >350 µm, zoea >0.9 mm, mysis >2.0 mm and post-larvae >6.0 mm (Shokita, 1984; Roberts *et al.* 2012). Key parameters that affect larval development and survival are generally considered to be: temperature, salinity and food availability (Preston 1985; Jackson and Burford 2003; Bryars and Havenhand 2006; Lober and Zeng 2009). The effect of water temperature is an important factor, with faster development and higher survival in warmer water (Hudinaga 1942; Roberts *et al*. 2012). As part of the FRDC project 2008/011 “Prawn and crab harvest optimisation: a biophysical management tool”, Roberts *et al.* (2012) found that the total larval period varies from 12.7 days (at 24.4°C) to 31.3 days (at 17.1°C) under constant laboratory conditions, while larval survival was greatest at 25°C (74%) and lowest at 17°C (36%), demonstrating the strong tropical affinity of this species (Figure 1.13). 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: 9 November hatch date at 17°C), due to increasing daily water temperatures, compared to later in the season (35.4 days: 29 May hatch date at 17°C). Furthermore, larval duration was predicted to be significantly shorter in northern (min. 12.7 days) compared to southern (min. 17.2 days) spawning grounds (separated by latitude 34°S) (Figure 1.14). These temporal and spatial optimums for larval duration and survival accord with the distribution of spawning females observed in November.

In marine invertebrate populations, larval dispersal, distribution and abundance are controlled by a combination of factors including reproductive dynamics of the adults, their physiological tolerances, behaviour (i.e. vertical migration), and hydro-meteorological dynamics such as wind-driven and tidal currents (Roberts *et al*. 2012). Bio-physical models that aim to incorporate these parameters to predict larval dispersal and settlement provide useful tools for fisheries management (Pedersen *et al.* 2003; Queiroga *et al.* 2007). Plankton sampling in Spencer Gulf has shown that larvae are broadly distributed (Figure 1.15), but highest densities were found north of Cowell (Carrick 1996). Latitude, water temperature and salinity all influenced the distribution and abundance of larvae (Carrick 2003). Larval densities varied significantly among years, probably due to differences in environmental conditions and spawning stock status.

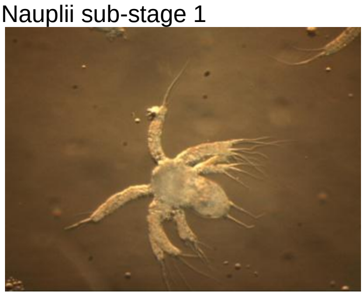
Key factors that are yet to be determined for *P. latisulcatus* that may affect larval duration, survival, dispersal and recruitment strength in Spencer Gulf include: salinity, temperature effects on larval size, stage-specific behaviour (vertical vs tidal stream migration), effects of natural food availability and oceanographic processes.

Post-larvae settle in inshore nursery areas when 2-3 mm CL and can remain there for up to 10 months, depending on the time of settlement (Carrick *et al*. 1996). The post-larvae produced from early spawning events settle in nursery areas during December or January where they grow rapidly before emigrating to deeper water in May or June. Alternatively, post-larvae produced from spawning after January settle in nurseries from March and then grow slowly. They “over-winter” in the nursery areas before recruiting to the trawl grounds in February of the following year (Carrick 2003). The effect of over-wintering on adult growth and survival are unquantified.

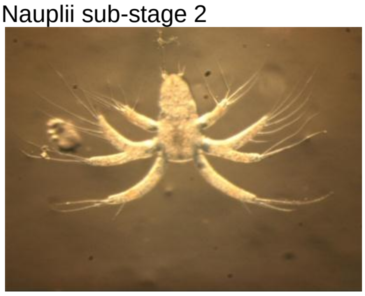
Eggs



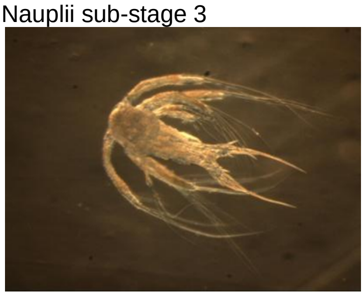
Nauplii sub-stage 1



Nauplii sub-stage 2



Nauplii sub-stage 3



Protozoea sub-stage 1

Protozoea sub-stage 2

Protozoea sub-stage 3

Mysis sub-stage 1

Mysis sub-stage 2

Mysis sub-stage 3

Post larvae

Figure 1.12 Western King Prawn, *P. latisulcatus*, larval stages (egg to post larvae) (SARDI unpublished data as part of FRDC project 2008/011).

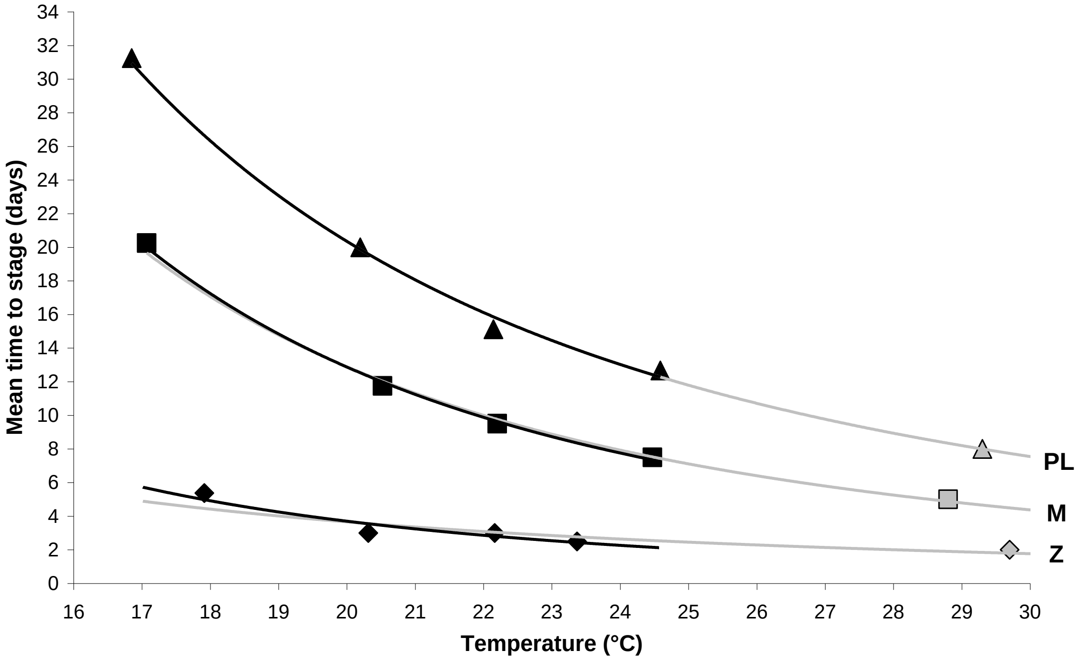


Figure 1.13: Mean time (days) to reach zoea (Z), mysis (M) and post-larvae (PL, total duration) stages from hatching at constant temperatures. Black data points and black fitted power curves indicate data from this study, while grey indicates data for higher temperatures sourced from Shokita (1984) (Roberts *et al.* 2012).

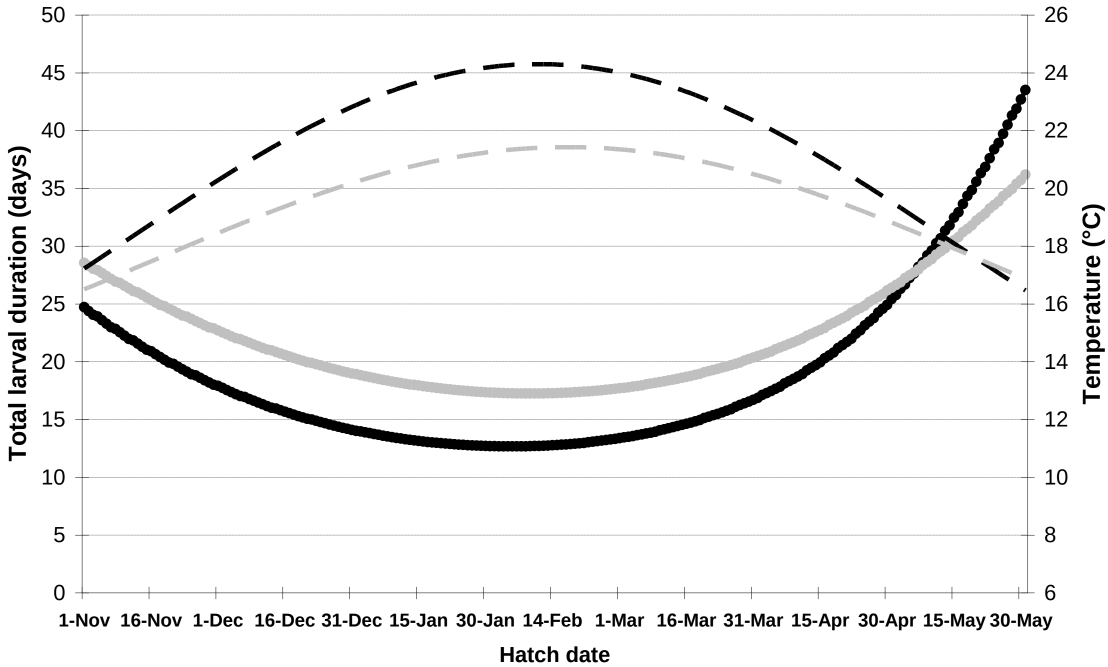


Figure 1.14: Predicted larval developmental duration (full lines) for *P.latisulcatus* in north (dark lines) and south (light lines) Spencer Gulf waters under seasonally average water temperature (hatched lines) conditions (Roberts *et al.* 2012).

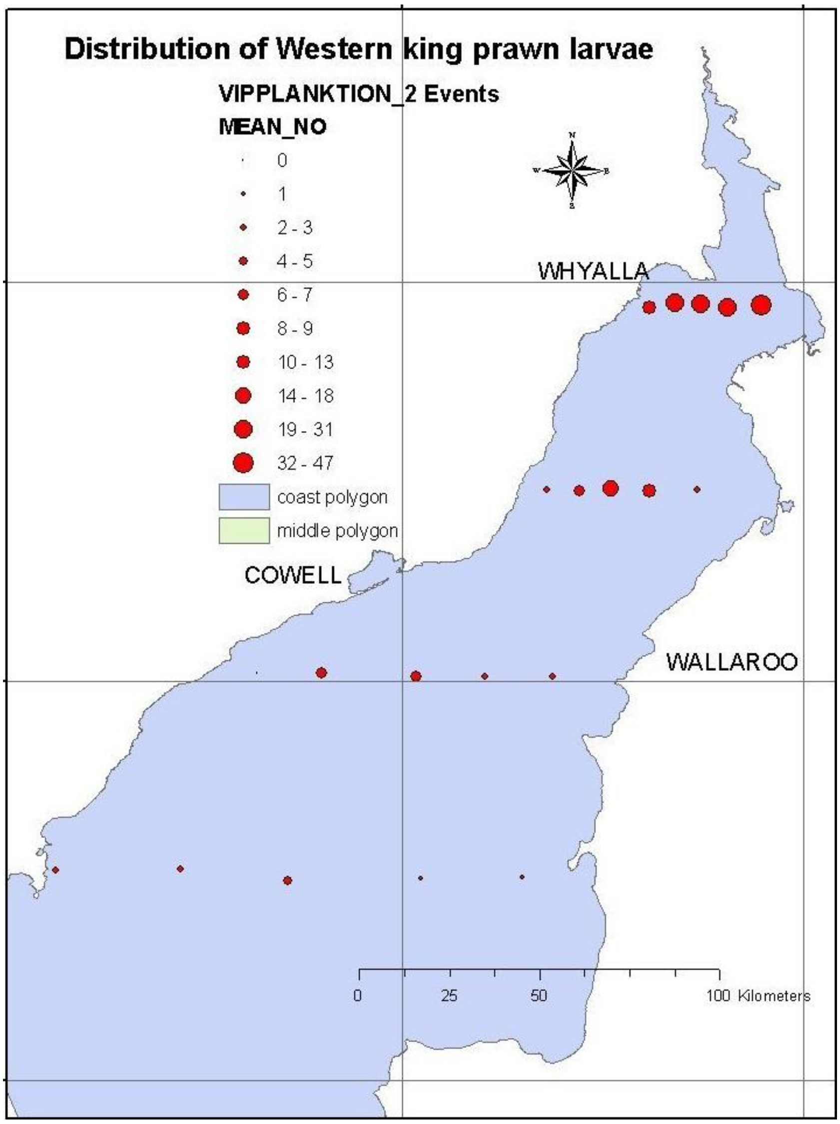


Figure 1.15 Mean larval density (√no./100 m3) in Spencer Gulf during 1993 and 1994 (Carrick 2003).

Over-wintering mortalities in nurseries ranged from 0.2–16.5% (mean = 7.9%) per week, with evidence of density dependent mortality (Kangas 1999). The mean natural mortality in Spencer Gulf nurseries during winter was estimated at 5% per week (Carrick 2003). These estimates of natural mortality for juvenile *P. latisulcatus* are considerably lower than for other prawn species (Carrick 1996).

In Spencer Gulf, spatial and temporal differences in juvenile prawn abundances were evident (Roberts *et al.* 2005). Even so, inter-annual patterns were generally consistent across sites. Abundances were greatest between February and May, with key nursery sites identified as False Bay, Shoalwater Pt, Plank Pt, Mt Young, 5th Creek and Port Pirie, all in the north of the gulf (Carrick 1996; Roberts *et al.* 2005). Five of these key nursery sites were recently surveyed during March 2009, with estimates of relative abundance comparable to historical data (Roberts *et al*. 2010). Juveniles were abundant at all sites surveyed during 2009, with the highest densities observed at False Bay, which was consistent with previous assessments.

1.4.4 Stock structure

Analyses using r-DNA have shown significant genetic differences in haplotype distribution of *P. latisulcatus* between South Australia and Western Australia (South Australian Museum/SARDI cited in Carrick 2003). However, an analysis of the genetic structure of *P. latisulcatus* within South Australia using electrophoresis suggested a homogenous stock (Richardson 1982, cited in Carrick 2003).

1.4.5 Growth

Prawns undergo a series of moults to increase their size incrementally. The shedding of hard body parts during moulting means that the age of individuals cannot be reliably determined as is possible for teleost and cartilaginous fishes, through the examination of otoliths and vertebrae. The inability to directly age prawns has increased the reliance on tag-recapture and cohort analysis for the determination of growth rate.

Uncertainties associated with each method of growth estimation include:

- 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,
- inability to distinguish cohorts, effect of catchability, and net migration on cohort analysis,
- measurement error (both methods).

Between 1984 and 1991, more than 150,000 prawns were individually tagged with streamer tags in Spencer Gulf. The CL of each prawn was measured and the tag and location details recorded prior to release. Some 9,000 tagged prawns were recaptured between 1985 and 1992. Sex-specific growth parameters, derived using a modified von Bertalanffy growth model (Carrick 2003), showed that male prawns grew slower and attained a smaller maximum size than females (Table 1.8).

Maximum growth rates occurred during late summer and autumn, and growth was negligible from July to December (Carrick 2003). Growth was strongly seasonal because winter water temperatures in Spencer Gulf are at the lower limits of their preferred temperature range (Wu 1990). The von Bertalanffy limited growth model is $dL/dt = k(L_\infty - L)$, where k is a function of temperature. The formula for growth is usually re-written as $L(t) = L_\infty\ (1\text{-}e^r(t\text{-}t_0))$, where r is the specific growth rate, t is time, and $k = r$. The constant r is species (and gender) dependent and determines the rate of growth.

Growth estimates from Spencer Gulf are compared to those estimated from Gulf St Vincent and the West Coast Fishery in Table 1.9 and Figure 1.16. Kangas and Jackson (1997) estimated growth rates from 464 tag-recaptures in Gulf St Vincent, while in the West Coast Prawn Fishery, growth was estimated from 510 tag-recaptures as well as from length-frequency cohort analyses (Wallner 1985).

Seasonal growth and differences between genders were evident in each fishery. Prawns in Spencer Gulf attained a similar size to Gulf St Vincent prawns, although a slower growth rate was evident for male prawns in Gulf St Vincent (Figure 1.16). Also, prawns in both gulfs attain a greater size and growth rate than those in the West Coast. Whilst this may be an artefact of the uncertainty associated with West Coast prawn growth estimates (see Dixon and Roberts 2006), growth may be slower due to the cooler summer water temperatures of the West Coast's oceanic environment.

A more complex model for estimating penaeid prawn growth was published by Franco *et al.* (2006), which considers physiological processes such as ingestion, assimilation, faeces production, respiration and female reproduction. The model can be used to quantify the most important physiological processes involved in growth for several life stages and also to examine the effect of food availability, water temperature, disease and anthropogenic factors on predicted size (CL) and biomass. Analyses of growth data in South Australia have not considered this suite of factors to date.

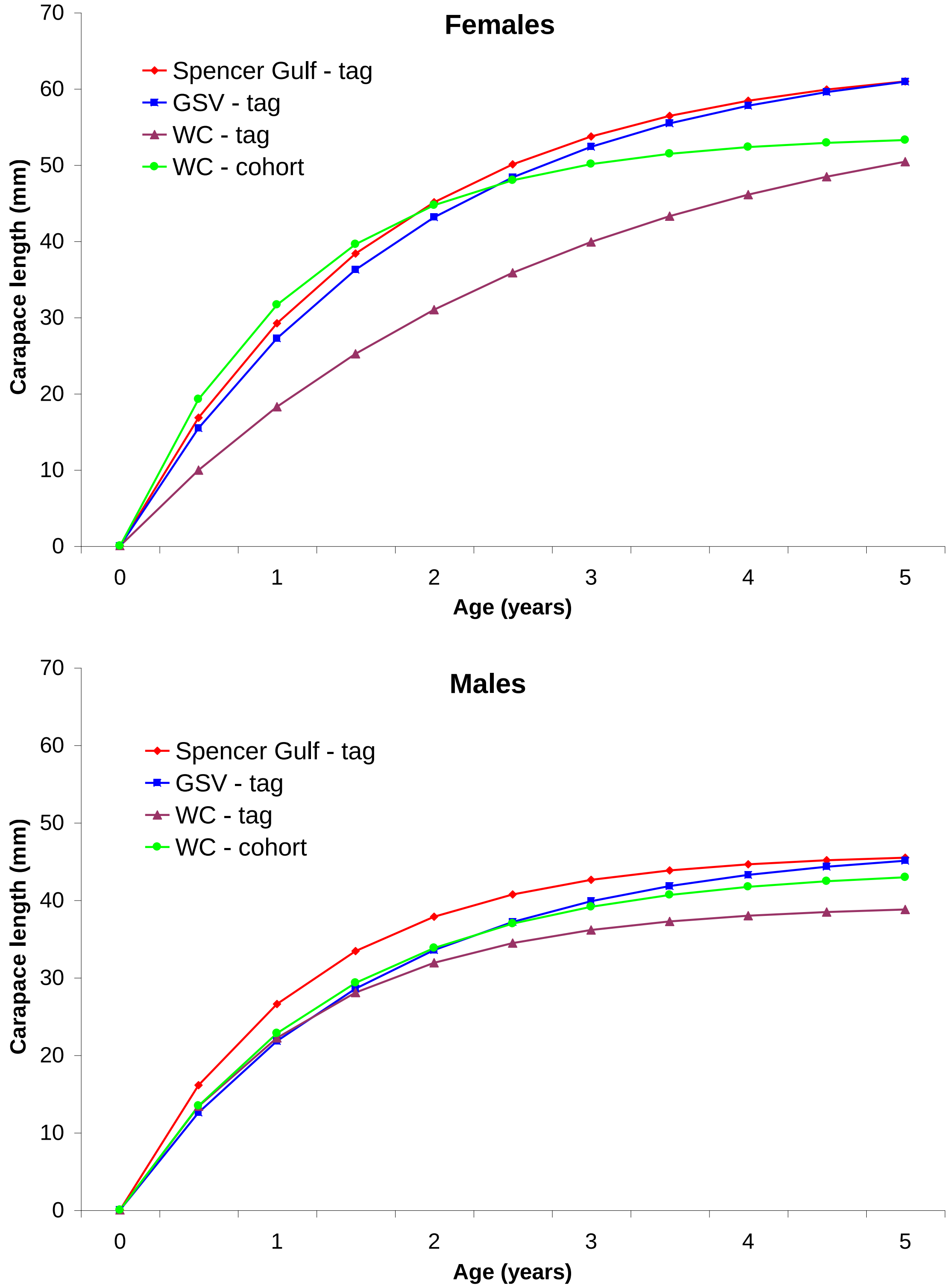


Figure 1.16 Sex-specific growth curves for *P. latisulcatus* estimated from tag-recapture and cohort analysis in the West Coast (Wallner 1985) and from tag-recapture in Spencer Gulf (Carrick 2003) and Gulf St Vincent (Kangas and Jackson 1997).

Table 1.8 Sex-specific growth parameters for *P. latisulcatus* 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).

Fishery	Method	Sex	Growth parameters	
			K (yr^{-1})	L_∞ (mm)
West Coast	Cohort	Male	0.73	44.1
		Female	0.88	53.9
West Coast	Tag	Male	0.83	39.4
		Female	0.36	60.4
Spencer Gulf	Tag	Male	0.86	46.1
		Female	0.61	64.0
Gulf St Vincent	Tag	Male	0.62	47.2
		Female	0.54	65.3

1.4.6 Length weight relationship

The relationship between prawn carapace length (CL, mm) and weight (g) was determined from a sample of over 2000 prawns from Spencer Gulf (Carrick 2003). The power relationship described by the equation "Weight = $a \times$ carapace length^{b}" varies between males (a = 0.00124, b = 2.76) and females (a = 0.00175, b = 2.66). Kangas (1999) determined the length weight relationship for juvenile prawns in Gulf St Vincent (a = 0.00066, b = 2.91, N = 325). The size range of individuals was 2.4–20.4 mm CL, where sexes could not be distinguished at such small sizes.

1.4.7 Movement determined from tagging studies

Tag-recapture data (see 1.5.5) were analysed to determine the movement patterns of prawns in Spencer Gulf (Carrick 2003). The generalised movement patterns were: (1) a net movement from north to south in northern Spencer Gulf, (2) a general east to north-east movement from northern Cowell and the top of the Gutter, (3) south-east movement from southern Cowell and the Gutter towards Corny Pt., and (4) negligible movement from Wallaroo (Figure 1.17, Carrick 2003).

While the use of external tags (as used for prawns in South Australia) has been associated with higher prawn mortality rates (Benzie *et al*. 1995) and suppressed growth rates (Penn 1975; Menz and Blake 1980), particularly for small individuals, it is unclear how these tags affect prawn movement. Potential effects on growth and mortality 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).

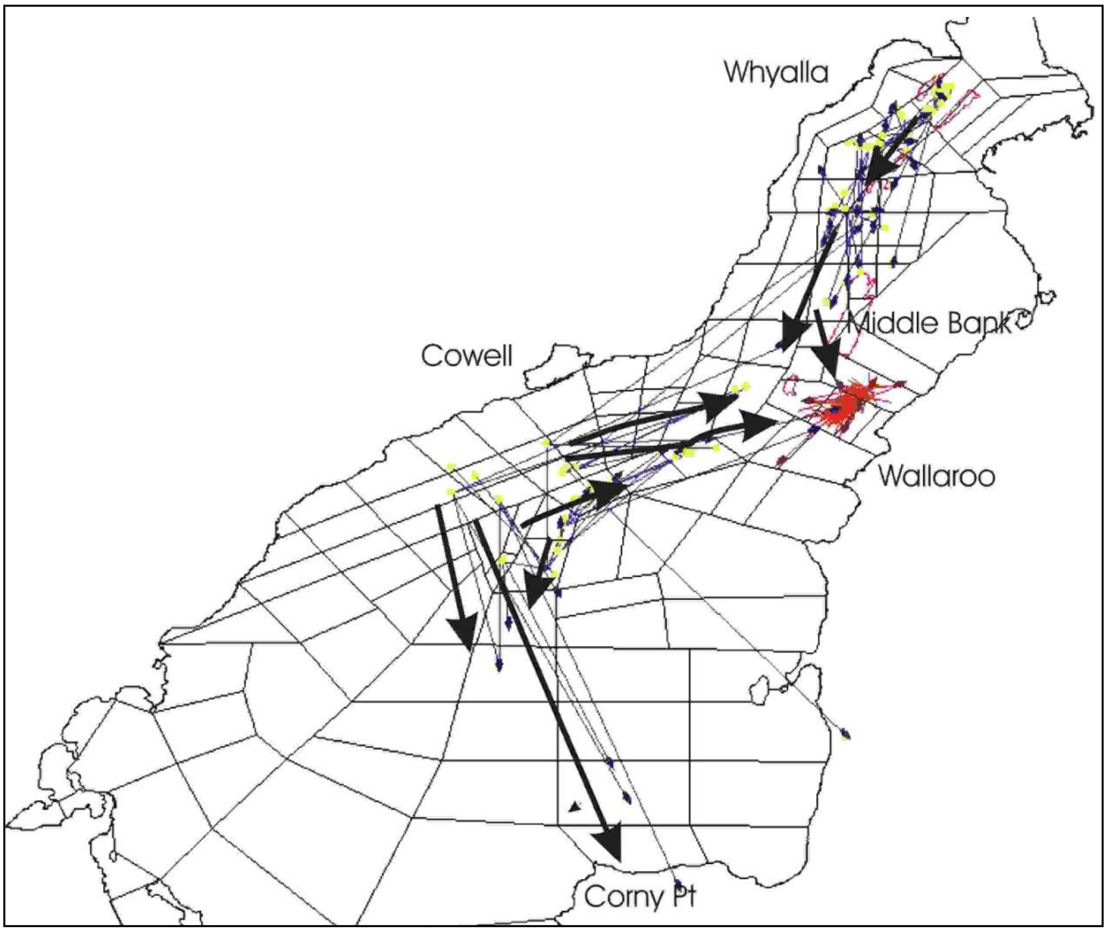


Figure 1.17 Generalised movement patterns of tagged *P. latisulcatus* in Spencer Gulf (Carrick 2003).

1.4.8 Natural mortality

Daily instantaneous rate of natural mortality for *P. latisulcatus* in Spencer Gulf ranges between 0.003 and 0.005.day^{-1} (King 1977). This value was similar to that estimated for *P. latisulcatus* in Gulf St Vincent (0.003.day^{-1}; Kangas and Jackson 1997, Xiao and McShane 2000) the West Coast Prawn Fishery (0.001 to 0.014.day^{-1}; Wallner 1985) and Western Australia (0.002 to 0.005.day^{-1}; Penn 1976).

1.4.9 Biosecurity and prawn health

Invasive species are a major threat to coastal ecosystems and are second only to habitat destruction as a cause for environmental decline (Crookes and Soulé 1999). The most susceptible prawn habitat to invasive pests is that of juvenile prawn nurseries. Information is emerging that some marine pests, particularly the invasive alga *Caulerpa taxifolia* can modify inshore environments in ways that may decrease prawn recruitment (Fernandes *et al.* submitted for publication). In a recent (2009) survey of key prawn nursery sites in both Spencer Gulf and Gulf St Vincent, no marine pest species were observed (Roberts *et al.* 2010).

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.* 1999; Harvell, 2002; Ignacio Vilchis *et al.* 2005; Portner and Knust 2007). Furthermore, environmental pollution from coastal industries can increase the susceptibility of aquatic animals to disease and reduce reproductive output (Nash *et al.*, 1988).

Exotic (“introduced”) viral pathogens may be considered one of the highest health risks for a prawn population 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 economically damaging penaeid viruses (White Spot Syndrome Virus, WSSV) to spread from Asia into the USA (Lightner *et al.* 1997).

Roberts *et al.* (2010) assessed the disease status of prawns (focussing on viruses) collected from key nursery sites in both Spencer Gulf and Gulf St Vincent. A naturally occurring (endemic), and likely harmless, MBV-like virus was observed in ~60% of prawns, which is a common virus known to occur throughout Australia. However, it was concluded that juvenile prawn populations in South Australia (SA) are free of the key disease-causing (and notifiable) viruses found both in other States and internationally. These include: IHHNV, WSSV, HPV and GAV. This highlights the risks associated with prawn and crustacean products sourced from outside of the State and provide important information that will improve early detection and response to any disease issues to the fishery.

In Spencer Gulf, juvenile habitats appear to have been influenced by oil spills (Roberts *et al.* 2005) and industrial effluent Carrick (2003). In Gulf St Vincent, anecdotal evidence suggests that juvenile prawn abundances at Barker Inlet have significantly declined since the early 1970s, probably due to human factors including increased nutrient loading (Kangas 1999). The disturbance of acid sulfate soils as a result of coastal development were recently identified as a major cause of habitat degradation in Gulf St Vincent, including mangrove dieback at St Kilda and contaminated tidal flats in Barker Inlet (SA Coast Protection Board, 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, and potentially directly affect juvenile prawn nurseries, little research has been conducted to examine these issues.

Coastal pollutants, parasites and disease can affect populations through mortality, as well as suppression of growth and reproduction, and have yet to be determined for SA prawn populations. Franco *et al.* (2006) suggests that these factors can be incorporated into their growth model to predict effects on size (CL) and biomass.

1.5 Stock assessment

The first stock assessment for the SGPF was completed in 1998 (Carrick and McShane 1998). Subsequent stock assessments in 2000 and 2001 were the first to consider the biological PIs of the fishery (Carrick and Williams 2000, 2001). The 2003 stock assessment report was the first version of a “living” document (Carrick 2003) that constituted a considerable advance on previous assessments. This included a description of the life history of prawns and management of the fishery, detailed spatial and temporal analyses of fishery-dependent and fishery-independent data, assessment of the fishery against the performance indicators defined in the Plan, and a review of the biology of *P. latisulcatus*. Subsequent assessments (Dixon *et al*. 2005a; Dixon *et al*. 2007; Dixon and Hooper 2008; Dixon *et al*. 2009; Dixon *et al.* 2010) have built considerably on previous reports to include a comprehensive assessment of all available fishery-dependent and fishery-independent data, comparisons of survey results and fishing activities at the scale of fishing block and fishing period, development of an egg production model, and information on the extent and status of suitable juvenile habitats.

The production of annual stock assessment reports over at least a decade has not only provided managers and industry the necessary information to make sound decisions to ensure biological sustainability of the resource, it provides a strong basis for further research into and gaining a better understanding of the bio-economic aspects of the fishery in response to increasing cost/price pressures.

1.6 Current research and monitoring program

The current research program conducted by SARDI Aquatic Sciences in support of the SGPF comprises five components. These are: (i) administer a daily logbook program; (ii) collate catch and effort information; (iii) conduct independent stock assessment surveys prior to, during and toward the end of the fishing-year, to inform fishing strategy decisions and to assess the fishery against the PI's; (iv) manage and analyse by-catch, juvenile sampling and tagging data; and (v) produce an annual report that assesses the status of the fishery, including assessment of the fishery against the PIs defined in the Plan.

1.6.1 Catch and effort research logbook

Licence holders are required to complete a daily and monthly logbook after the completion of fishing in each month. The logbook has undergone several modifications throughout time to improve the information available for assessment. During 1986 the catch and effort reporting blocks were modified to better reflect the fishing grounds and distribution of effort. More recent changes to the logbook include incorporation of the location (GPS position) of at least 3 trawl shots per night, size-grade data of the prawn catch, and reporting of retained by-product.

1.6.2 Stock assessment surveys

The first stock assessment surveys were done in Spencer Gulf in February 1982. Surveys are conducted using industry vessels with independent observers, to assess stock status and provide data for the development of harvest strategies following the decision rules in the Management Plan. The survey design was altered in 2007 by adopting spatial and temporal consistency among surveys to improve the robustness of surveys as a measure of relative biomass.

1.7 Discussion

Generally, aspects of the biology of *P. latisulcatus*, the environment in which they are distributed and the management of the commercial fisheries that harvest them within

South Australia are well documented. However, some key elements of the SGPF are poorly understood, particularly regarding spawning, larval biology, dispersal, recruitment success and prawn health. Notably, several current and recently completed projects have begun to address these knowledge gaps.

There is a need for an improved understanding of several aspects of reproduction and recruitment of *P. latisulcatus* in Spencer Gulf. In particular, this includes knowledge of fertilisation success and the frequency of individual spawning events during the spawning season. Also, an improved understanding of larval dispersal, settlement and subsequent recruitment is required. These are controlled by a combination of factors including reproductive dynamics of the adults, their physiological tolerances (food availability, salinity and temperature), behaviour (i.e. vertical migration), and hydro-meteorological dynamics such as wind-driven and tidal currents. Bio-physical models that aim to incorporate these parameters to predict larval dispersal and settlement provide useful tools for fisheries management. The current FRDC project 2008/011 “Prawn and crab harvest optimisation: a biophysical management tool” aims to address many of these issues. The project also aims to address key knowledge gaps in the reproductive biology of female prawns in Spencer Gulf. When the biological and physical models are combined, the outputs will 1) provide an improved understanding of the spawner–recruit relationship, 2) enable the determination of environmental conditions that result in favourable recruitment and 3) provide advice on optimal harvest strategies during the spawning season to maximise pre-Christmas catch and minimise the effect on future recruitment to the fishery.

Juvenile prawn surveys conducted during 2009 provided important information on the biosecurity and disease status of nursery habitats, as well as data on juvenile prawn abundance. Prawn nurseries (the highest risk habitat for prawn species) were clear of marine pests and four key disease-causing (notifiable) viruses. The continuation of juvenile surveys would enable on-going monitoring of nursery habitats to ensure this disease free status. However it is notable that the health status of adult prawn populations, which occur in separate (deeper water) habitat, is still poorly understood. Awareness of the need for understanding the effects of coastal pollutants, parasites and disease on growth, survival and reproduction of prawns in Spencer Gulf has increased in recent years, due largely to issues regarding the risks of disease introduction associated with the use of imported prawns for bait and the proposed development of a desalination plant in northern Spencer Gulf. It is recommended that juvenile habitats continue to be surveyed to enable 1) the identification of risks to the fishery, 2) the early detection and response to pests or disease and 3) an improved understanding of the stock-recruitment relationship to inform appropriate fishery management.

A growth model for penaeids that determines the effects of food availability, environmental parameters (salinity and temperature), disease and anthropogenic factors on predicted size (CL) and biomass (Franco *et al.* 2006) may be a useful tool for SA prawn fisheries to consider in the future. Knowledge of these influencing factors has the potential to improve our understanding of the appropriate sizes to target throughout the season and the appropriate timing of harvest to enable maximum annual yield and economic return.

Throughout its history, substantial data have been gathered on the biology, abundance and distribution of prawns in Spencer Gulf. Combined with information on the economics of the fishery, these data provide a sound foundation for the development of a bio-economic model. The Australian Seafood CRC has approved and provided funding for the development of such a model for the Spencer Gulf and Gulf St Vincent prawn fisheries. The project commenced in mid 2012 and is due to be completed late 2014.

2. FISHERY STATISTICS

2.1 Introduction

Fishery-dependent catch and effort logbook data are available from 1968. Since July 1987 detailed daily commercial logbooks have been provided to SARDI. Monthly logbooks are also completed that enable validation and adjustment of daily catch estimates. In the following sections, trends in catch, effort and commercial CPUE are analysed from commercial logbook data.

Information on prawn size was obtained from commercial-grade data available from 1978/79, 1998/99 and 2002/03 to 2011/12. Data were used to examine annual trends in the size of commercially harvested prawns and to evaluate the average size of prawns caught by each vessel each day, which is hereafter referred to as “mean daily prawn size”.

2.2 Methods

2.2.1 Catch, effort and CPUE

Catch and effort data includes only commercial catch and effort (i.e. excludes survey catch and effort). Data were obtained from two sources: annual data from 1968 to 1973 and monthly data from January 1973 to June 1988 were obtained from the South Australian Fishing Industry Council (SAFIC) annual reports (1973 to 1988); data from 1988/89 to 2011/12 were obtained from daily logbooks. 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 period from November to October the following year. Catch and effort data are presented for each fishing-year as a total and by regions defined in Figure 1.2. Currently, most fishing is done from November to June, in “fishing periods” of varying length between the last and first quarter of the moon (maximum length 18 days). Monthly trends disregard fishing periods during a fishing-year, which may extend across two months. As the main spawning period for *P. latisulcatus* in Spencer Gulf extends from November to March, catch is also presented for the early spawning period (November and December) compared to all other fishing months (March to June).

Annual nominal CPUE was estimated by dividing total annual catch by total annual effort (including commercial and survey catch and effort).

2.2.2 Prawn size

Prawn-grade data were available from 1978/79, 1998/99 and 2002/03 to 2011/12. The grade was determined from the number of prawns to the pound (i.e. U10 = under 10 prawns per pound, etc). In 1978/79 and 1998/99, data were reported as the proportion of the commercial catch that was comprised of four size categories (U10, 10/15, 16/20 and 20+, Carrick 2003). From 2002/03, data were reported as the proportion of the commercial catch occurring in each of 29 size classes (see Table 2.1). To facilitate interpretation of the prawn-grade data among all fishing-years, the data from 2002/03 to 2008/09 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 (Soft and Broken) was established for prawns that were not graded. In this report, prawns in the U10, 10/15, 16/20, 20+ and Soft and Broken categories are referred to as XL, 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 (XL)	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)	S/B, B&D, MIX, REJ, SMS, blank, ERR

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 equalling 27.5 prawns per kg) and are presented in Table 2.2.

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

Prawn grade	Prawns per kg	Prawn grade	Prawns per kg	Prawn grade	Prawns per kg
U6	13.2	10/15	27.5	21/25	50.6
U8	15.4	13/15	30.8	S	56.1
XL	15.4	10/20	33.0	20+	56.1
U10	19.8	12/18	33.0	21/30	56.1
L	19.8	M	39.6	26+	61.6
9/12	23.1	16/20	39.6	30+	78.1
U12	24.2	SM	48.4	31/40	78.1
LM	27.5	19/25	48.4		

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,
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),
pp7kg is the mean daily prawns/7 kg.

Target size criteria for fishing (as defined in the Management Plan) vary according to the status of the resource (determined from survey catch rates) and the time of the year. Most fishing periods during 2011/12 targeted prawns larger than 220 prawns/7 kg. Some periods allowed catches of smaller prawns up to 250 prawns/7 kg to be caught. Data are presented on the number (and %) of vessel nights when prawns were caught at an average size smaller than 220, 250 and 280 prawns/7 kg to assess how well the fishery achieved target size criteria.

2.3 Results

2.3.1 Inter-annual trends in catch

The total catch of 1,675 t in 2011/12 was within the historical range since the mid 1970s; however, it was the lowest recorded since 2002/03 and represents a decline in catch of ~30% since 2009/10 (2,361 t) (Figure 2.1). In the nine fishing-years since the low catch of 2002/03 (1,479 t), annual catch has averaged 1,959 t, which is 50 t greater than the average catch during the previous 30 fishing-years (1973/74 to 2002/03: 1,909 t).

Commercial effort increased rapidly from 6,795 hr in 1968 to 45,786 hr during 1978/79 (Figure 2.1) but has declined steadily and significantly in the years since (Linear Regression: r^2 = 0.92, df = 33, P < 0.01) at a rate of 803 hours per year. During 2011/12, trawl effort was 18,336 h which represented 40% of peak trawl effort.

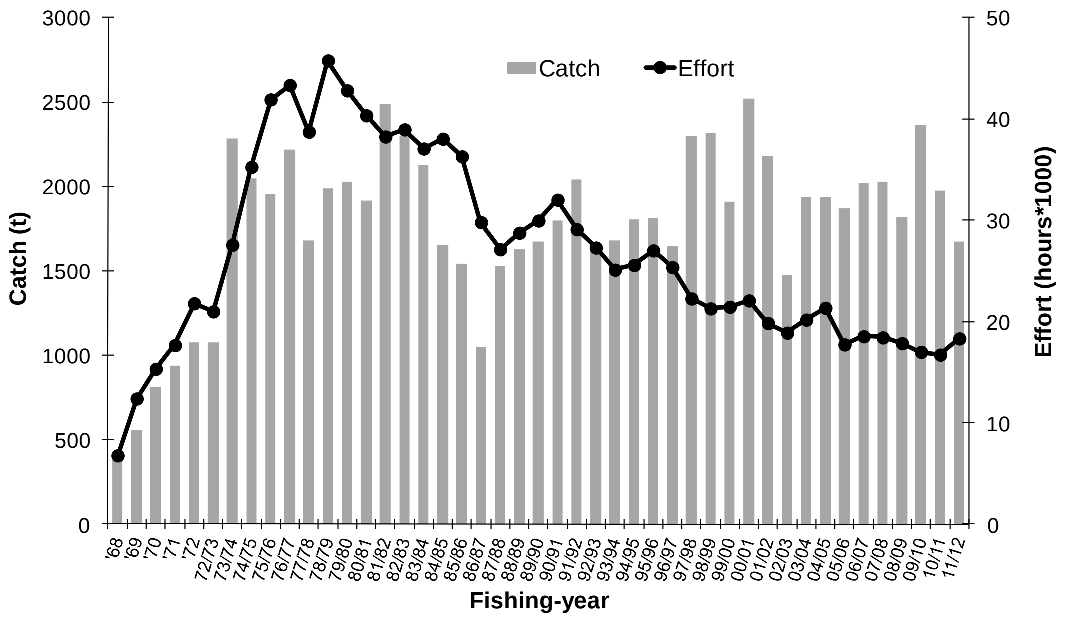


Figure 2.1 Total catch (t) and effort (hrs) for Spencer Gulf from 1968 to 2011/12. Data for 1968–1972 are reported as calendar year. Data for 1972/73 are from January to October 1973. From 1973/74 data are reported in fishing-years.

2.3.2 Regional trends in catch

The spatial distribution of catches from Spencer Gulf has changed since 1988/89 (Figure 2.2). The annual catch from the North region peaked at 933 t in 1991/92 but has not exceeded 250 t over the last 13 fishing-years. Peak catches in the North region coincided with the lowest annual catch from the Wallaroo region (206 t). During the past ten fishing-years, the Wallaroo and Middlebank/Shoalwater regions have produced 46% and 28% of the total catch, respectively. During 2011/12, the catch of 556 t from the Wallaroo region was the lowest catch recorded for this region since 1996/97 (457 t). Similarly, the catch in the Main Gutter during 2011/12 (93 t) was the lowest recorded since 1988/89 (83 t).

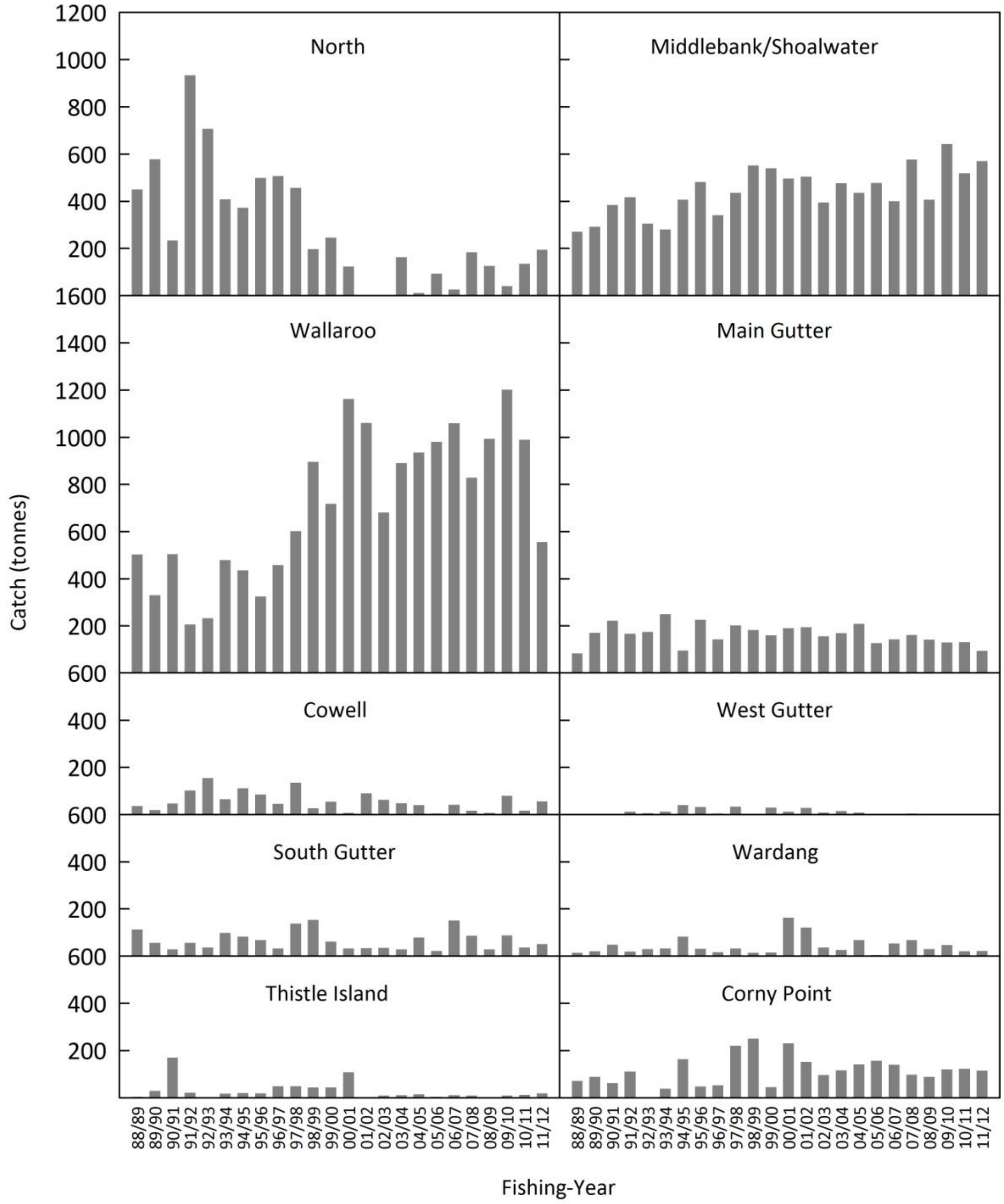


Figure 2.2 Average annual catches from regions of Spencer Gulf from 1988/89 to 2011/12.

2.3.3 Trends in catch within years

The distribution of monthly catches has also changed over the last 37 fishing-years (Figure 2.3). Prior to the introduction of temporal closures in 1978/79, prawns were captured in all months, with peak catches taken during April and the low catches taken from July to September. From 1984/85 to 1993/94, most of the catch was taken from March to May and there was no fishing during January, August or September in any year. Since 1994/95, fishing has generally been undertaken during six months of the year with peak catches in April and May and low catches in June. During 2011/12, catches in October were high compared to most previous years, whereas catches in December, May and June were much lower.

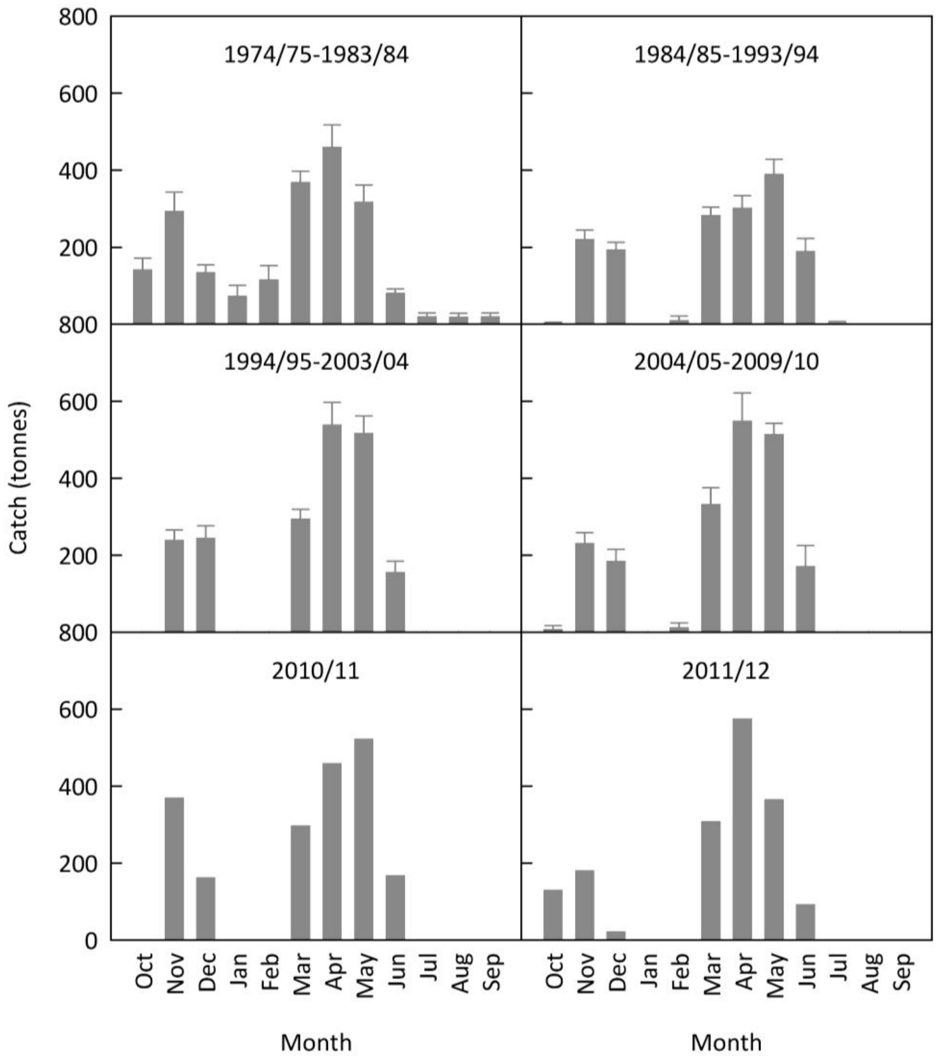


Figure 2.3 Average monthly catches from Spencer Gulf for 10-year periods from 1974/75 to 2003/04, the 6-year period from 2004/05 to 2009/10 and for the fishing-years 2010/11 and 2011/12. Note: SE bars are shown for multi-year periods.

2.3.4 Catches during the early spawning season

From 1981/82 to 1986/87, the total annual catch declined from 2,491 t to the record low of 1,048 t (Figure 2.4). This record low catch followed increases in the pre-Christmas catch from 297 t in 1979/80 to 833 t in 1983/84. This is the only period in the history of the fishery that pre-Christmas catch has exceeded 500 t in three consecutive years (1981/82, 1982/83, 1983/84). In recent years, the pre-Christmas harvest has been stabilised to maintain high levels of annual recruitment. Pre-Christmas catch during 2011/12 was 333 t, the lowest recorded since 2003/04 (311 t).

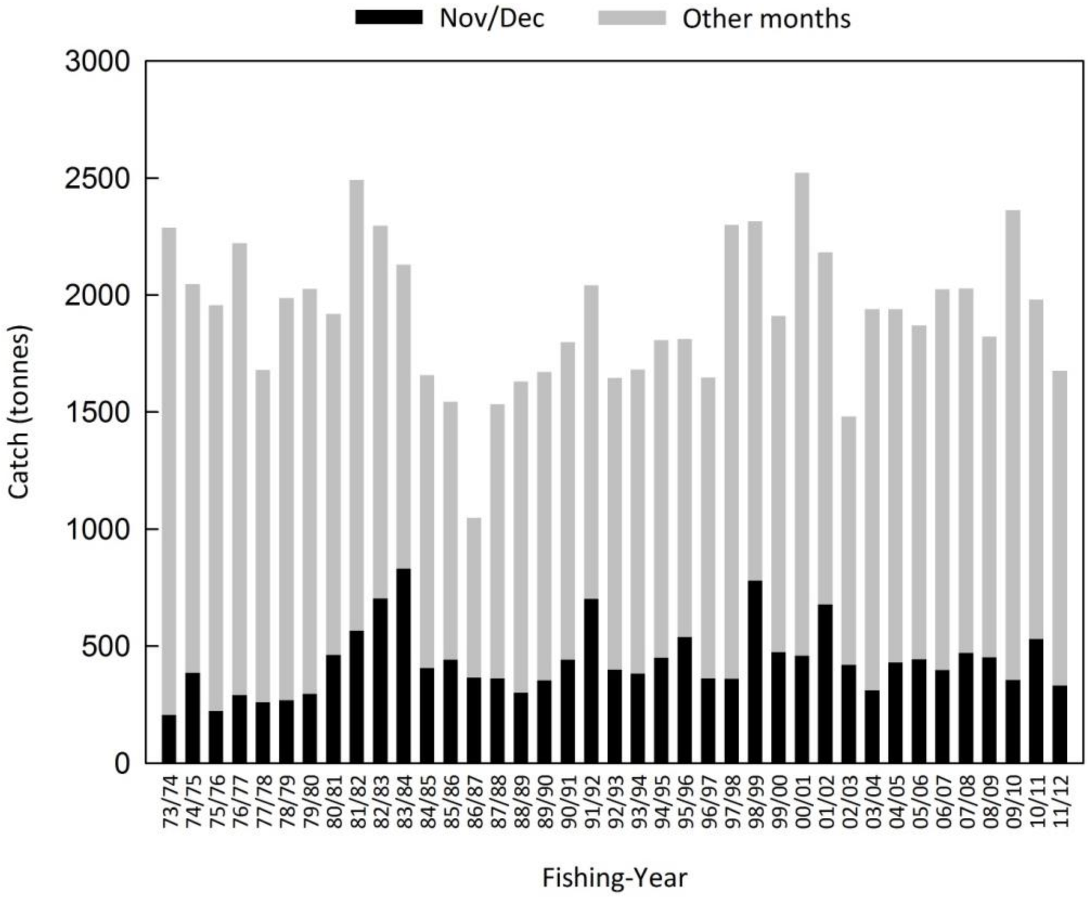


Figure 2.4 Catches from November and December relative to the total annual catch from 1973/74 to 2011/12 in Spencer Gulf.

2.3.5 Trends in daily effort among recent years

Despite considerable differences in the temporal distribution of nights fished throughout the fishing-year since 2005/06, the total number of nights fished each season has been very consistent with a mean of 50 nights and a range of 46-52 nights (Table 2.3).

The current management plan includes decision rules that aim to stabilise catch during the pre-Christmas period (Oct-Dec) based on the results of the November fishery-independent survey. While total pre-Christmas catch has ranged substantially during this period (333-532 t) the number of nights fished has been relatively stable with a mean of 15 and a range of 12-17. The distribution of nights fished post-Christmas was more variable due primarily to the timing of moon phases. For example, the moon phase in 2008/09 meant that a decision was made to begin fishing in February which led to the maximum number of nights fished between February and April surveys (17) and the minimum number of nights fished after the April survey (17). In most other fishing-years almost half of the annual effort was allocated to fishing periods after the April survey.

Table 2.3 The distribution of fishing nights throughout the fishing-year from 2005/06 to 2011/12.

	Nights during each calendar month								Nights between surveys			
Season	Oct	Nov	Dec	Feb	Mar	Apr	May	Jun	Nov to Feb	Feb to Apr	Post Apr	**Total**
2005/06		8	7		8	9	14	3	15	15	19	**49**
2006/07		9	8		7	10	11	6	17	10	24	**51**
2007/08		6	8		6	10	11	9	14	8	28	**50**
2008/09	1	12	4	2	10	7	15		17	17	17	**51**
2009/10		7	8		8	11	10	5	15	12	22	**49**
2010/11		6	6		6	9	12	7	12	8	26	**46**
2011/12	4	9	2		8	12	12	5	15	12	25	**52**
								Mean	*15*	*12*	*23*	***50***
								Min	*12*	*8*	*17*	***46***
								Max	*17*	*17*	*28*	***52***

2.3.6 Inter-annual trends in CPUE

Annual (nominal) CPUE has varied substantially since the inception of the fishery (Figure 2.5). Up to 1985/86, CPUE generally fluctuated between 40 and 70 kg/h, but a peak of 82.9 kg/h was recorded in 1973/74. The lowest CPUE, 35.2 kg/h, was recorded in 1986/87. CPUE increased during the late 1980s and the 1990s and first exceeded 100 kg/h in 1997/98. During 2011/12, CPUE was 91.4 kg/h which was the lowest recorded since 2004/05 (90.8 kg/h) and 66% of the peak CPUE recorded in 2009/10 (138.8 kg/h).

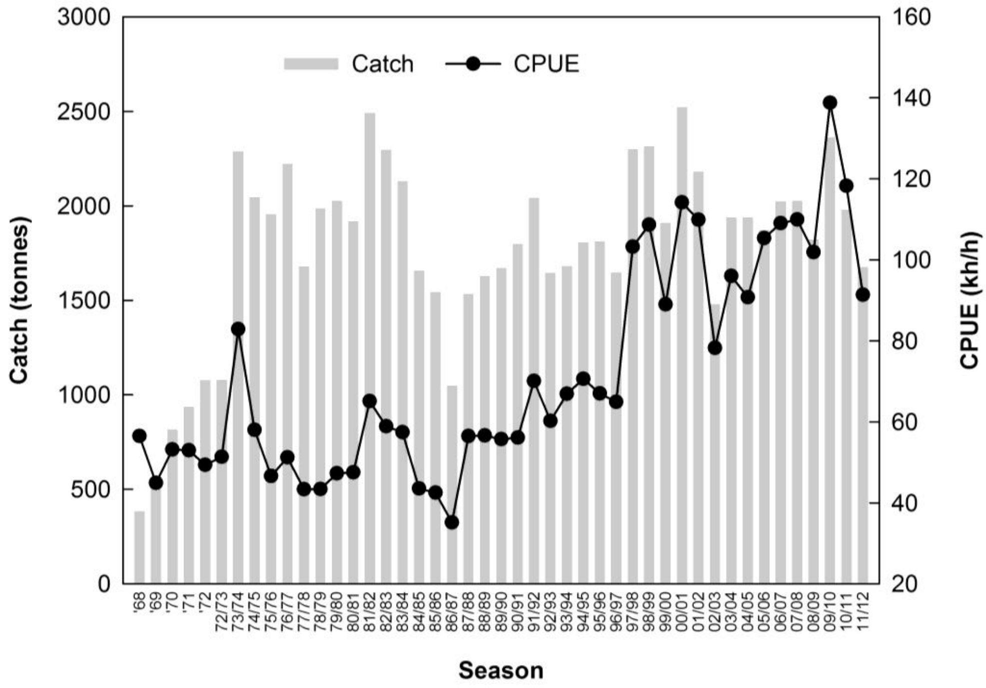


Figure 2.5 Annual catch and catch-per-unit-effort (CPUE) for Spencer Gulf from 1968 to 2011/12. Data for 1968–1972 are reported as calendar year. Data for 1972/73 are from January to October 1973. From 1973/74 data are reported in fishing-years.

2.3.7 Trends in CPUE among regions

Since 2003/04, CPUE has generally declined with latitude, being higher in the North, Shoalwater/Middlebank, Wallaroo and Main Gutter regions than regions further south (Figure 2.6). Regional differences in CPUE influence long-term CPUE trends for the fishery (Figure 2.5), as the distribution of effort and hence catch has changed over time. During 2011/12, CPUE was considerably lower than the previous 8-year mean in the North, Wallaroo, Western Gutter, Wardang and Thistle Island regions.

2.3.8 Inter-annual trends in prawn size grades

In 1978/79, small prawns comprised >40% of the catch compared to <7% in the six recent fishing-years (Figure 2.7). The proportion of medium prawns was similar in 1978/79 to all other fishing-years but the proportion of XL prawns in 1978/79 was approximately half. The distribution of the catch among size categories was similar in 1998/99 and 2002/03, however since then the proportion of XL prawns has been generally lower and the proportion of M prawns has been generally higher.

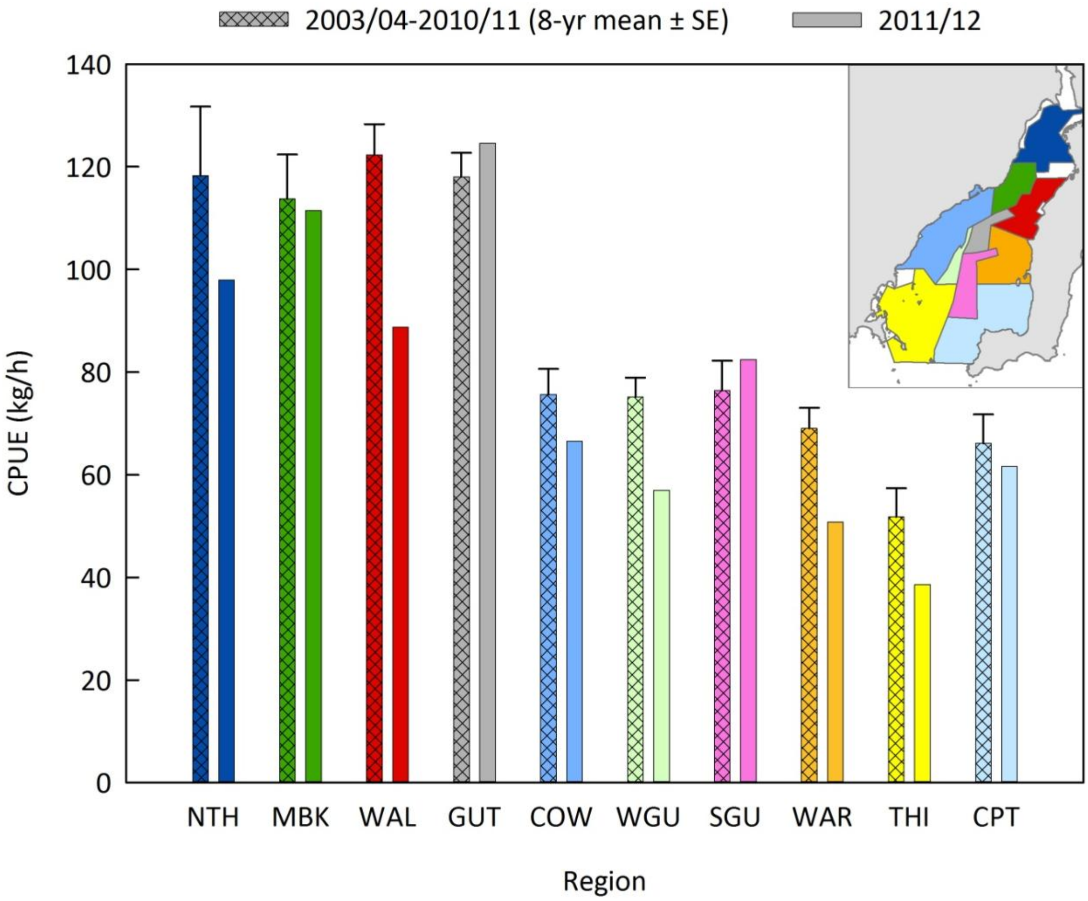


Figure 2.6 Mean (SE) annual catch-per-unit-effort (CPUE) for the 10 fishing regions within Spencer Gulf from 2003/04 to 2010/11 compared to 2011/12. Insert identifies colour coded regions.

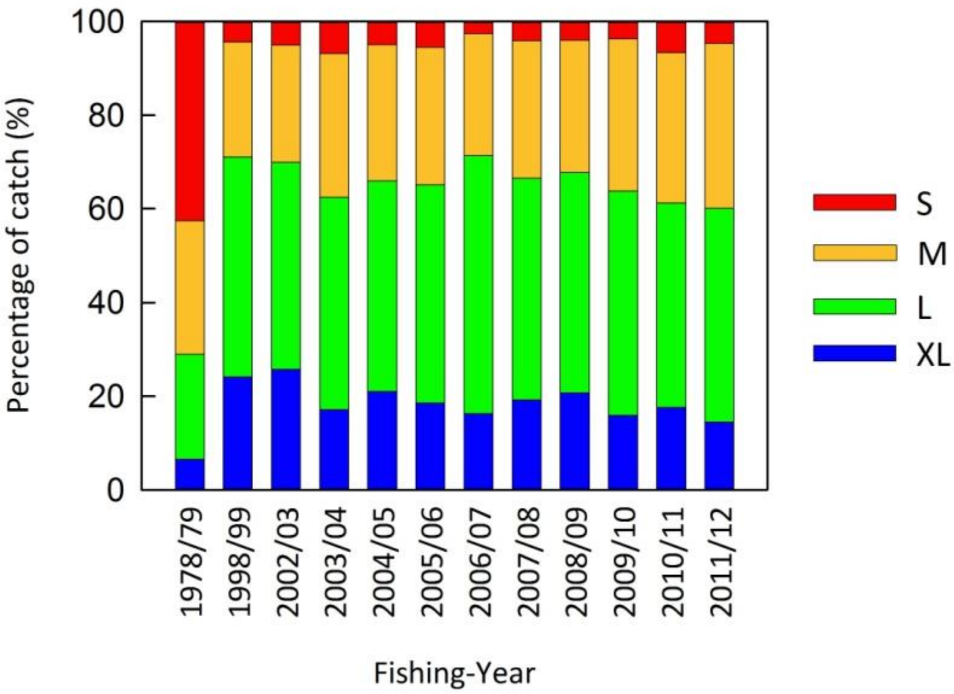


Figure 2.7 Size composition of prawns in the commercial catch in 1978/79, 1998/99 and 2002/03 to 2011/12.

2.3.9 Mean daily prawn size of the commercial catch

Prawns harvested in 2011/12 were a similar mean size (216 prawns/7 kg) to the long-term average size from the previous nine fishing-years (214 prawns/7 kg) (Table 2.4).

Target size criteria for fishing (as defined in the Management Plan) vary according to the status of the resource (determined from survey catch rates) and the time of the year. Most fishing periods during 2011/12 targeted prawns larger than 220 prawns/7 kg. Some periods allowed catches of smaller prawns up to 250 prawns/7 kg to be caught. Table 2.4 provides information on the number (and %) of vessel nights when prawns were caught at an average size smaller than 220, 250 and 280 prawns/7 kg. The proportion of nights fished when prawns smaller than 220 (37%), 250 (7%) and 280 prawns/7 kg (1%) were caught during 2011/12 was also similar to the long-term averages of 33%, 7% and 1%, respectively.

Table 2.4 Statistics associated with mean daily prawn size estimated from prawn grade data provided in commercial logbooks.

Year	Mean (p/7 kg)	Nights measured	Nights (%) >220 p/7 kg	Nights (%) >250 pp7kg	Nights (%) >280 p/7 kg
2002/03	206	1956	542 (28%)	133 (7%)	24 (1%)
2003/04	221	2088	919 (44%)	270 (13%)	66 (3%)
2004/05	214	2251	767 (34%)	125 (6%)	24 (1%)
2005/06	216	1903	624 (33%)	116 (6%)	16 (1%)
2006/07	209	1978	558 (28%)	73 (4%)	4 (0%)
2007/08	213	1938	702 (36%)	156 (8%)	12 (1%)
2008/09	211	1976	604 (31%)	103 (5%)	10 (1%)
2009/10	217	1902	687 (36%)	122 (6%)	18 (1%)
2010/11	221	1788	800 (45%)	185 (10%)	18 (1%)
2011/12	216	1990	745 (37%)	147 (7%)	12 (1%)

2.4 Discussion

Annual catch and effort information are available from the inception of the fishery in 1968 and daily logbook data are available since 1988. Historical data on commercial prawn size are available for 1978/79 and 1998/99. Since November 2002, daily prawn grade data have been reported in commercial logbooks.

During 2011/12, total catch (1,675 t) and pre-Christmas catch (333 t) were the lowest recorded since 2002/03 and 2003/04, respectively, despite higher levels of trawl effort compared to most recent fishing-years. Total commercial catch declined by ~30% since the high levels observed in 2009/10 (2,361 t). While it is unclear if this high catch alone precipitated the subsequent decline in catch, similar trends have been observed previously in the fishery following large annual catches. For example, the peak historic catch of 2,522 t harvested in 2000/01 was followed by catches of 2,182 and 1,479 t in the following two fishing-years.

It is also possible that environmental factors influenced commercial catch and CPUE in 2011/12, but again it is difficult to ascertain these effects. Fishers suggested that the usual movement of prawns from north to south during April and May were not occurring to the same extent as usual (Greg Palmer *pers. comm.*). This may explain the spatial distribution of the catch, with the Wallaroo region (556 t) having the lowest catch recorded since 1996/97.

The general increase in CPUE over time is influenced by factors including increases in fishing power, decisions to target larger prawns and changes in the seasonal distribution of the catch. Hence, CPUE does not accurately reflect prawn abundance over the entire history of the fishery. However, changes in CPUE over shorter time periods (e.g. between years) when variations in these factors are smaller, more reliably reflect changes in prawn biomass. Understanding these factors is essential for interpretation of nominal CPUE trends and conducting CPUE standardisations.

Trends in fishery-dependent data suggest that the SGPF continues to be harvested within sustainable limits. Firstly, since 1974/75 catches have ranged from ~1,500–2,500 t in all but one season (1986/87: 1,048 t). Secondly, the size of prawns harvested has been stable for a decade and is substantially larger than those harvested in 1978/79. Finally, where many other prawn fisheries have failed to manage increases in effective effort of the fleet, the SGPF has reduced total trawl hours to ~40% of the peak effort observed in 1978/79.

3. STOCK ASSESSMENT SURVEYS

3.1 Introduction

Fishery-independent, stock assessment surveys have been conducted since 1982 in Spencer Gulf. The survey design was altered almost a decade ago (since November 2004) to improve the consistency of spatial and temporal replication of survey shots. These data sources serve two important purposes: 1) to determine stock status of the SGPF; and 2) to inform management decisions (e.g. fishing strategy) that ensure sustainability of the resource. This chapter provides analyses and documents trends in relative biomass (derived from standardised catch data), prawn size, egg production and recruitment.

3.2 Methods

Stock assessment surveys, using industry vessels with scientific observers onboard, have been undertaken by SARDI Aquatic Sciences since February 1982. A summary of the number of survey trawl shots conducted within regions (see Figure 1.2) of Spencer Gulf is provided in Appendix 1.

Survey shots were done at semi-fixed sites. Each shot starts at a fixed Global Positioning System (GPS) position and then continues in a particular direction for a specified length of time (usually 30 minutes). The distance trawled depends on trawl speed (generally 3–5 knots), which is influenced by vessel power, tide and weather conditions. The accuracy of distance measurements and starting positions improved when GPS and computer technology were introduced into the fishery. The timing, location and number of surveyed shots have varied considerably over time (Appendix 1). Most surveys have been conducted in November, February and April. Due to the timing of moon phases, survey months have been occasionally offset (e.g. November surveys have been conducted in late October). For the purpose of statistical analyses, surveys conducted under these circumstances have been categorised as November, February or April. Some surveys have been conducted in June but these are ignored in analyses. Since 1982, a total of 347 different shots have been surveyed, with GPS information available for the start and finish positions of 306 of these.

Although the Management Plan (Dixon and Sloan 2007) specifies 209 pre-determined shots (Figure 3.1) are surveyed each November, February and April, the number of shots has since been modified twice. Firstly, in 2009, these shots were reduced to 207 for historic, location and survey logistic reasons, while still ensuring a spread of shots throughout the main fishing regions. Then in 2010, the number of survey shots conducted during November surveys only was further reduced to 182 shots by removing those from regions that produced consistently low catch rates at this time. This increased the efficiency and cost-effectiveness of November surveys without substantially affecting trends in relative biomass. February and April surveys currently remain unchanged. The main aim of all three surveys is to provide a measure of relative prawn biomass throughout the fishing-year as the primary biological measure of performance of the fishery. Additionally, data from November surveys provide information on egg production, and data from February surveys provide information on recruitment.

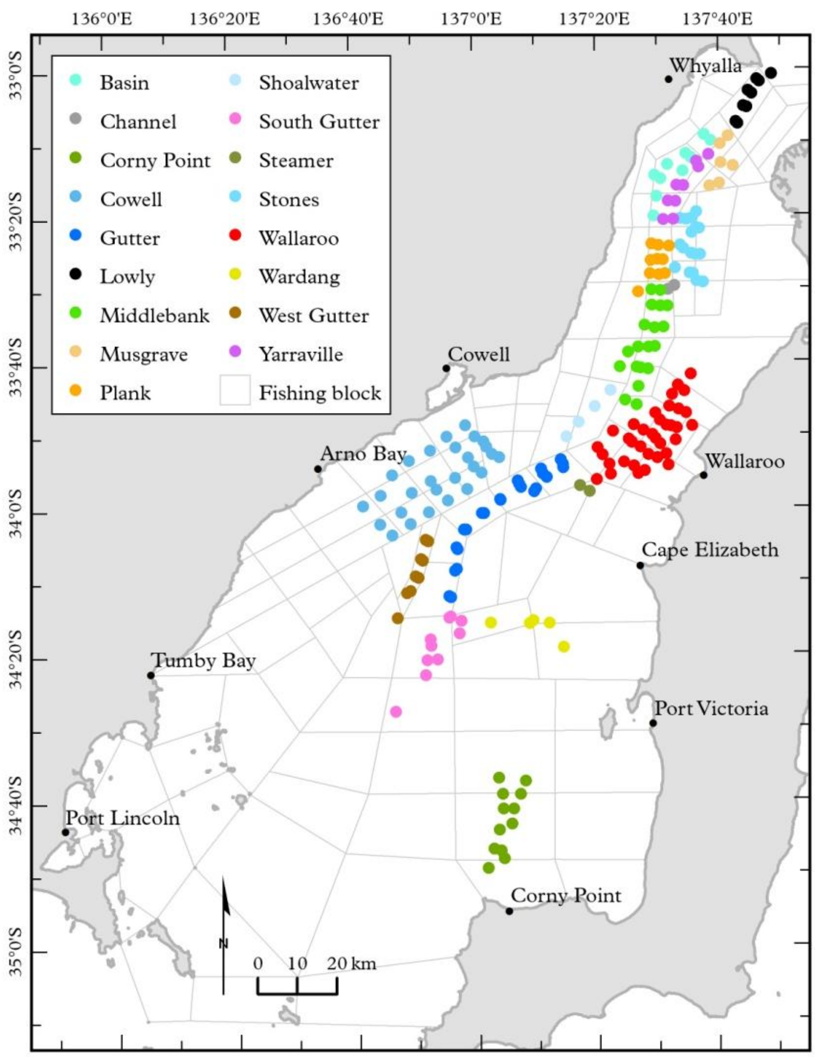


Figure 3.1 Map showing the regional distribution of the 209 shots surveyed throughout Spencer Gulf as a requirement of the Management Plan.

The data collected during surveys include total catch, trawl time, trawl distance, trawl direction and water temperature. A length frequency sample was also taken from the catch to provide sex-specific length, sex ratio and mean-prawn-weight data. During 1994, bucket counts were introduced for rapid estimation of mean prawn weight. GPS data for the start and end of each trawl shot have been collected from November 1998. Length-frequency data are not available for February 1998, April 2003, November 2003, February 2004 and April 2004. Only limited CPUE and prawn size data are available for November 2003, February 2004 and April 2004.

3.2.1 Standardised indices of relative biomass

To examine variability in survey catches (and derived catch rates as a measure of relative biomass) associated with factors other than abundance and to account for this variability when incorporating historic survey data into the assessment, we used a generalised linear model (GLM; Nelder and Wedderburn 1972, McCullagh and Nelder 1983). The explanatory variables considered in the model were survey, region, location, latitude, vessel, water temperature, tide direction, tide strength, moon luminosity and effort. A complete dataset for all of these external factors were only available for the 8-year period 2004/05 to 2011/12. A series of models were fitted to this dataset to obtain standardised catch (Maunder and Punt 2004). Firstly, an appropriate error distribution for the model was determined by fitting survey Catch ~ Season using four different distributional assumptions. These models were: a Gaussian (normal) GLM with a log link function fitted to survey catch, a Gaussian GLM with an identity link function fitted to log-transformed survey catch, a Gamma GLM with a log link function fitted to survey catch and a Gamma GLM with an identity link function fitted to log survey catch. Comparison of model residual and Q-Q plots identified the Gamma GLM with a log link function as fitting the observed data best.

The standardisation of survey catch was undertaken at three levels. The first model considered annual (fishing season) effects of total survey catch while the second and third models considered the interactions between season and survey, and season, survey and region, respectively. The models took the form:

$$\text{Catch} \sim \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n$$

where $X_{1...n}$ are the explanatory variables and $\beta_{1...n}$ are the estimated model coefficients.

Three seasonal surveys were examined: November, February and April. Three measures were used to quantify the position of survey shots: region (Figure 1.2), location (Figure 3.1) and latitude. Unique vessel identifiers were obtained from commercial logbook data. Daily water temperature for Spencer Gulf was derived from satellite data for each survey night obtained from the Physical Oceanography Distributed Active Archive Center (NASA 2012, Figure 3.2). Temperature data were smoothed with a moving average (MA = 7 days) to keep daily variation generally within ±0.2°C, which is considered to be more typical of the variability in bottom water temperature. Tide strength (m/h) at Whyalla was calculated from tide tables (Anon. 2010, 2011) as the sum of the absolute differences in tide heights between consecutive high and low water marks over a ~24 h period (from noon) relative to the actual hours elapsed, and tide direction was obtained from survey skipper logs as the direction relative to that in which the net is towed (i.e. against tide, AT; slack tide, ST; with tide, WT). The proportion of the moon illuminated (luminosity) at midnight for Guam (equivalent to AEST) was obtained for each survey night from the U.S. Naval Observatory (USNO 2012).

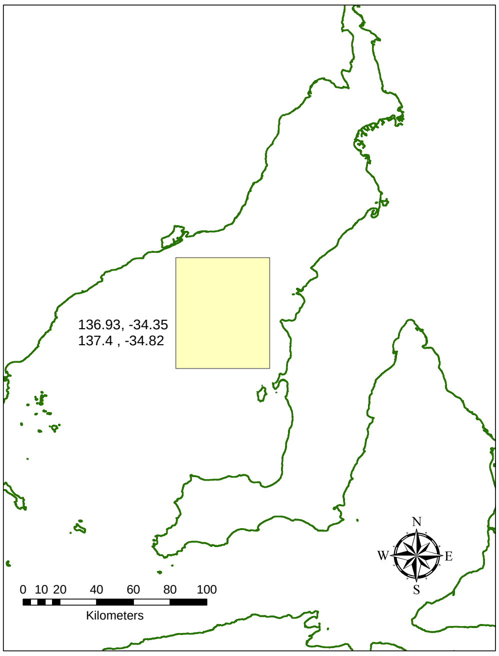


Figure 3.2 Area (shaded yellow) from which average SST was derived from satellite data from the Physical Oceanography Distributed Active Archive Center (NASA 2012).

A small constant (0.01) was added to catch data to include shots where catch was zero, as zeroes are not permitted under a log model. Latitude, water temperature, tide strength, moon luminosity and effort were included as continuous variables. The remaining variables (survey, region, location, vessel, tide direction) were included as categorical variables or factors.

Model selection was determined using the Bayesian Information Criteria (BIC; Burnham and Andersen 2002), with the model having the lowest BIC considered optimal. Models were fitted using a stepwise forward procedure, with terms added sequentially until the model was no longer statistically significant (Analysis of Deviance; $\alpha = 0.05$). Where the addition of a term reduced the BIC value by within two units, the model with the fewer terms was chosen as the optimal model. The position of survey shots should be represented by only a single term; thus, once region, location or latitude was included the other terms were excluded. Other than the interactions between season and survey, and season, survey and region, the only interaction term considered for the modelling of catch was that between survey (month) and temperature.

Standardised survey catch was determined by calculating the exponential of the estimated coefficients for the seasonal or interaction models, and then multiplying this factor by the base coefficient of the relative model (i.e. '2004/05' for the seasonal model, '2004/05_1' for the season-survey interaction model and '2004/05_1_COW' [Cowell] for the season-survey-region interaction model). The correlation coefficient was used as a measure of linear dependence between actual catch and model-predicted catch for each of the three models. Standardised catch rate (or CPUE) was calculated by dividing the standardised catch (kg) by the mean effort (h) at the level being examined.

Relative biomass (standardised) by size class

To examine the size structure of the survey population, a standardised measure of CPUE (derived from standardised catch) was separated into three prawn size classes: grade U10 and larger (referred to hereafter as large prawns), grades 10/15 and 16/20 (referred to hereafter mixed prawns), and grade 20+ and smaller (referred to hereafter as small prawns). The calculation of survey CPUE by size class was achieved by: 1) determining the abundance of prawns by sex in each size class from length frequency data (where prawns >45 mm CL are considered to be large, 35–45 mm are mixed, and <35 mm are small); 2) calculating the theoretical weight of prawns in each size class based on the sex-specific length-weight relationship

(Section 1.4.6); and 3) applying the fraction of the theoretical weight in each size class to the estimate of total mean survey CPUE.

3.2.2 Egg production

The egg production model utilises much of the current knowledge of the biology of *P. latisulcatus* (see Section 1.5). The model is underpinned by a range of assumptions including:

- the catchability of prawns was constant during the survey,
- female prawns spawned three times during the spawning period,
- spawning frequency does not vary with size,
- natural mortality was zero,
- the % of females within each grade does not vary during the spawning season,
- the size at maturity doesn't vary with time, and
- sex-specific length frequency data from surveys were representative of the population.

Data on the biology of prawns and on prawn grades obtained from commercial processors were used. Fertilisation success for each size grade was determined visually from figures presented by Courtney and Dredge (1988). The following steps describe the estimation of annual egg production totals:

1) The mean weight of prawns for each prawn grade was obtained from commercial processors;
2) Data from 1) were used to calculate the mean size (mm, CL) in each grade.
3) Data from 2) were used to calculate the mean number of eggs produced per female prawn for each prawn grade;
4) The proportion of mature female prawns (egg bearing) for each prawn grade was estimated from the logistic equation provided by Carrick (1996);
5) Spawning frequency was assumed to be 3 for all prawn grades;
6) Fertilisation success for each grade was determined (Courtney and Dredge 1988);
7) Mean (SE) catch weight per grade per shot was calculated directly from prawn grade weight data collected during November 2006;
8) Data from 7) and 1) were used to calculate the mean (SE) number of prawns captured per hour;
9) The % of females in each grade was calculated from length-frequency data;

10) Data from 8) and 9) were used to calculate the mean (SE) number of female prawns captured per hour;

11) Data from 3), 4), 5) and 10) were used to calculate the number of potential fertilised eggs per hour that captured females could have contributed to egg production prior to fishing.

3.2.3 Recruitment

The recruitment index was calculated as the square root transformation of the numbers of prawns (males <33 and females <35 mm CL) per nautical mile trawled from up to 39 stations in the north of the gulf during February surveys. Recruitment data were available for 21 February surveys conducted since 1982. Total recruit abundance throughout Spencer Gulf was examined for each survey period from 2004/05 to 2011/12 to identify trends in recruitment within and among years. A regional assessment of recruit abundance was also examined for each survey during this period.

3.3 Results

3.3.1 Standardised indices of relative biomass

Standardisation of catch

A strong linear dependence was found between actual catch and model-predicted catch for the three models (r^2 = 0.35-0.45). Despite the identification of several significant factors influencing the seasonal and interaction models (Tables 3.1, 3.2 and 3.3), the mean standardised catches were similar to mean nominal catches at the levels of the three models ('seasonal' and 'season_survey' models shown in Figure 3.3). The optimal seasonal model included location, survey (month), effort and tide direction (Table 3.1). The model coefficients indicate that survey catches were highest at locations in upper Spencer Gulf and generally increased between the three surveys (November through to April). Survey catches were also higher with the tide than against the tide or at slack tide.

The best-fitting season-survey and season-survey-region interaction models yielded similar coefficient estimates and included the same factors as those identified for the seasonal model (with the exception of location, which was not considered in the model that already included region as an interaction term).

These results are consistent with the standardisation of CPUE in the 2010/11 stock assessment report. Although this report presents the standardisation of catch data (with effort as candidate variable for the model) rather than CPUE, it can nevertheless be considered indicative of CPUE given the consistent duration of 30 min for most (75%) survey shots (CPUE = 2.08*Catch + 1.32 , r^2 = 0.96, P<0.001).

Relative biomass (standardised) by size class

For all surveys combined, mean total survey CPUE has been fairly consistent for the 8-year period from 2004/05-2011/12 at a grand mean of 5.4 lb/min, indicating a stable total biomass over this period (Figure 3.4). Relative to 2004/05, the total mean catch rate has increased by 6% (from 5.38 to 5.77 lb/min), which comprises reductions in relative biomass of 15% (0.48 to 0.42 lb/min) for large prawns and 2% (1.99 to 1.95 lb/min) for small prawns, and an increase in relative biomass of 14% (2.91 to 3.40 lb/min) for mixed prawns. The greatest rate of change in total biomass has occurred since 2008/09, where mean catch rate increased by 18% from 4.8 to 5.8 lb/min for the last two fishing years (2010/11 and 2011/12). This increase in total biomass over these 4 fishing years is attributed to slight but steady increases in relative biomass of large and mixed prawns.

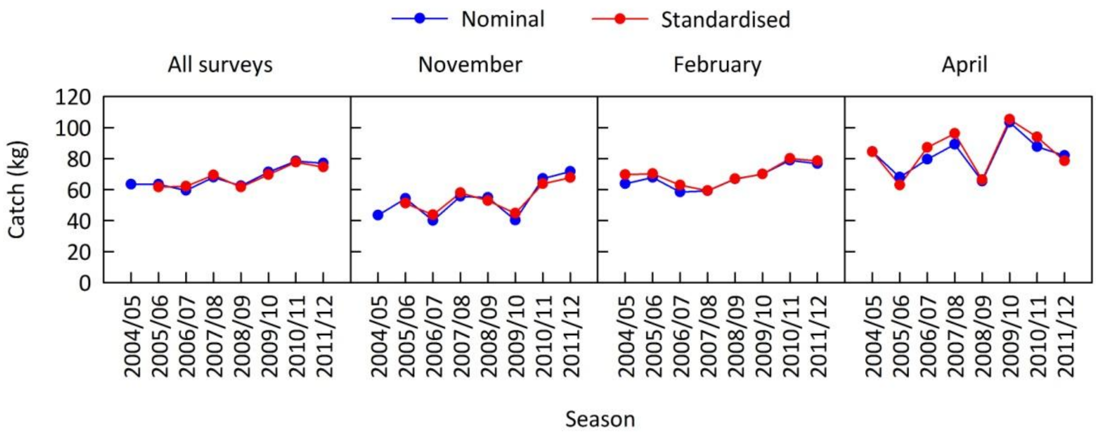


Figure 3.3. Nominal and standardised survey catch for November, February, April, and all surveys combined (annual).

Each of surveys are characterised by fluctuating catch rates of small and mixed prawns with no discernible trend in their relative biomass over the 8-year period, while catch rates for large prawns remained stable. Fluctuations of mean catch rates for small and mixed prawn were greatest during April surveys, ranging by 2.08 and

2.4 lb/min, respectively, and smallest during February surveys, where they ranged by 0.93 and 1.03 lb/min, respectively. Fluctuations of mean catch rates for large prawns were comparatively modest owing to the relatively low catch rate of this size class, ranging by up to 0.5-0.6 lb/min for all of the surveys.

3.3.2 Egg production

Mean egg production per hour trawled during the November survey of 2011/12 (578 million/hr) was less than the previous November survey (2010/11: 623 million/hr) but was above the previous seven-year average (mean 523 million/hr, range 310–770 million/hr, Figure 3.5).

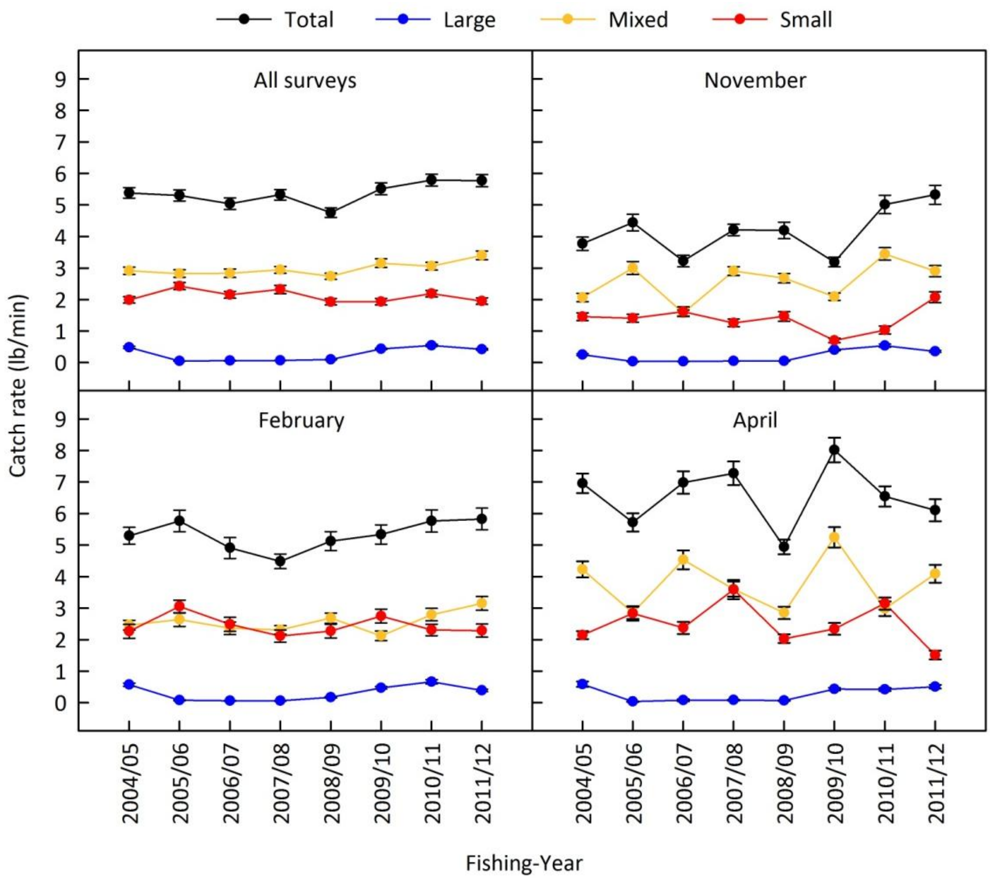


Figure 3.4. Mean total standardised catch rate and mean standardised catch rates of small (20+), mixed (10/20) and large (U10>) prawn grades, obtained from November, February, April and all surveys combined from 2004/05 to 2011/12.

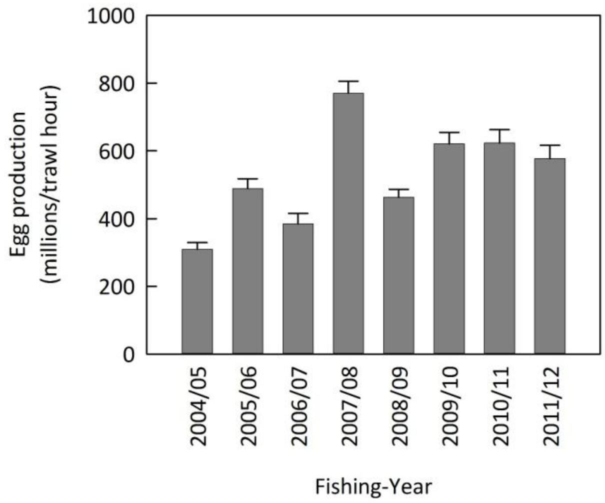


Figure 3.5 Total egg production for November surveys from 2004/05 to 2011/12.

Table 3.1. Generalised linear model (GLM) results modelling the annual effect of environmental and fishery variables on survey catch. Abbreviations: Res. dev., residual deviance; df, degrees of freedom, BIC, Bayesian information criterion; ΔBIC, difference in BIC between the candidate and best (*) model. The null model (Season only) is also shown.

Model	Formula	Res. dev.	df	AIC	BIC	ΔBIC	*p*-value
Null	Catch ~ Season	3801.5	4896	50827.7	50886.2	1786.0	-
1.3	Catch ~ Season + Location	2855.5	4880	49305.0	49467.4	367.3	<0.001
2.1	Catch ~ Season + Location + Survey	2690.7	4878	48990.7	49166.1	66.0	<0.001
3.6	Catch ~ Season + Location + Survey + log (Effort)	2665.3	4877	48942.2	49124.1	24.0	<0.001
4.3*	Catch ~ Season + Location + Survey + log (Effort) + Direction	2644.9	4875	48905.2	49100.1	0.0	<0.001
5.3	Catch ~ Season + Location + Survey + log (Effort) + Direction + Strength	2640.7	4874	48898.6	49100.1	-0.1	0.003

Table 3.2. Generalised linear model (GLM) results modelling the seasonal effect of environmental and fishery variables on survey catch. See Table 3.1 for definitions of abbreviations. The null model (Season_Survey only) is also shown.

Model	Formula	Res. dev.	df	AIC	BIC	ΔBIC	*p*-value
sNull	Catch ~ Season_Survey	3574.4	4880	50521.5	50683.9	1594.5	-
s1.2	Catch ~ Season_Survey + Location	2627.2	4864	48891.4	49157.8	68.3	<0.001
s2.6	Catch ~ Season_Survey + Location + log (Effort)	2602.7	4863	48843.3	49116.2	26.8	<0.001
s3.3*	Catch ~ Season_Survey + Location + log (Effort) + Direction	2581.4	4861	48803.6	49089.5	0.0	<0.001
s4.2	Catch ~ Season_Survey + Location + log (Effort) + Direction + Temperature	2578.2	4860	48799.1	49091.5	2.0	0.010

Table 3.3. Generalised linear model (GLM) results modelling the seasonal-regional effect of environmental and fishery variables on survey catch. See Table 3.1 for definitions of abbreviations. The null model (Season_Survey_Region only) is also shown.

Model	Formula	Res. dev.	df	AIC	BIC	ΔBIC	*p*-value
srNull	Catch ~ Season_Survey_Region	2308.2	4699	48534.6	49873.2	89.9	-
sr1.3	Catch ~ Season_Survey_Region + Direction	2283.2	4697	48481.0	49832.5	49.3	<0.001
sr2.5*	Catch ~ Season_Survey_Region + Direction + log (Effort)	2258.3	4696	48425.3	49783.3	0.0	<0.001
sr3.3	Catch ~ Season_Survey_Region + Direction + log (Effort) + Strength	2257.8	4695	48426.1	49790.6	7.3	0.254

3.3.3 Recruitment

The recruitment index ($\sqrt{\text{prawns/nm}}$) was lowest during 1999/00 (~30; Figure 3.6) and greatest during 2000/01 (~60). This two-fold difference in the transformed data is equivalent to a four-fold difference in the number of prawns per nautical mile. The recruitment index (mean) has been above the limit RP (35) for twelve consecutive years and for 22 of the 25 years since 1982. The recruitment index during 2011/12 (43.9) was similar to the previous 10-year average (43.0).

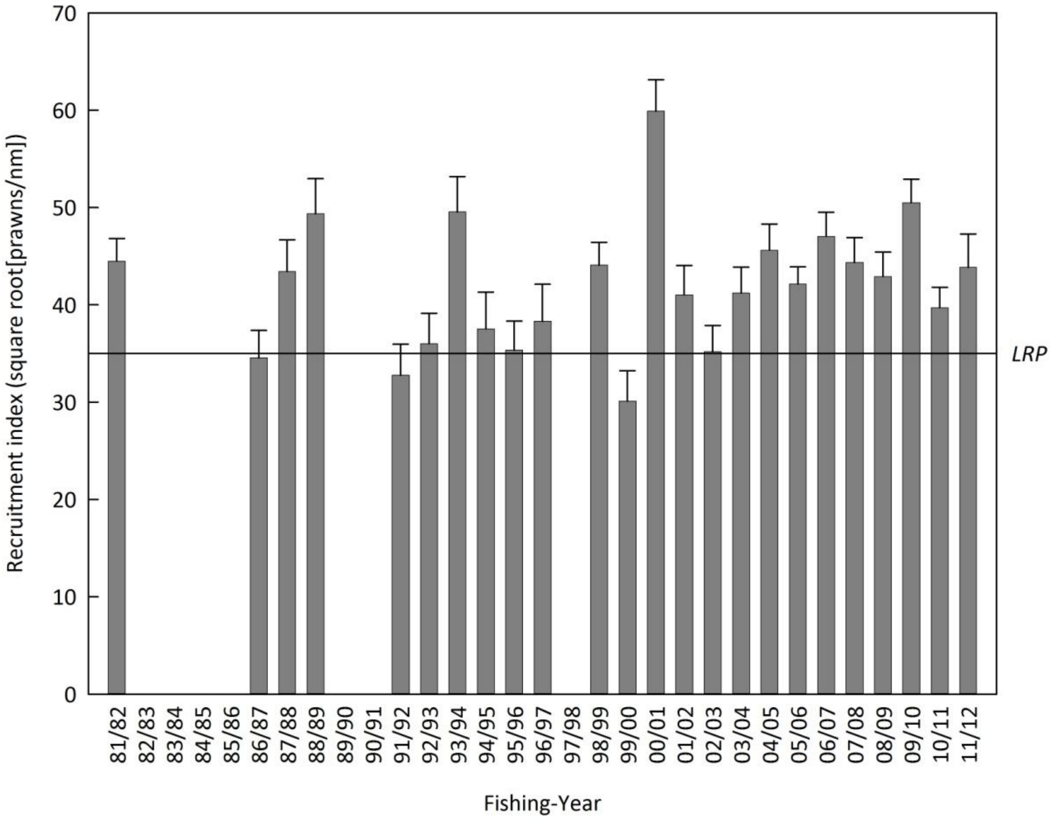


Figure 3.6 Mean (SE) recruitment index for up to 39 stations surveyed in February in the northern region of Spencer Gulf from 1981/82 to 2011/12. The horizontal line represents the limit reference point (LRP, 35/nm).

Mean recruit abundance across all survey sites was lowest in November during all years except 2011/12 when November recruitment was 1) twice as high as all previous years, and 2) higher than recruitment levels for April (Figure 3.7). While mean recruitment was generally much higher during February than April, the reverse was true in 2007/08 and 2010/11.

Regional assessment of recruit abundance indicated that recruitment was highest in the Northern and Middlebank/Shoalwater regions, particularly during February (Figure 3.8). Interestingly, recruit abundance increased substantially during April in the West Gutter and Main Gutter regions. There were very few recruits evident in the Wardang and Corny Point regions throughout the fishing-year. Recruit abundance during 2011/12 was generally similar to the previous 7-year mean in most regions during most months, with two notable exceptions. Firstly, November recruitment was substantially higher during 2011/12 in the Northern, Main Gutter and Cowell regions and secondly, recruitment in the Middlebank/Shoalwater region was substantially lower than previous years in February and April.

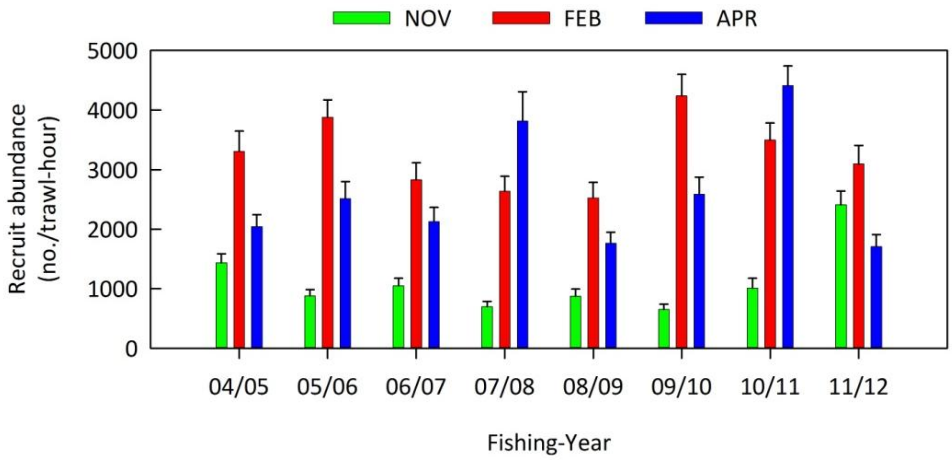


Figure 3.7 Mean (SE) recruit abundance throughout Spencer Gulf for surveys conducted in November, February and April from 2004/05 to 2011/12.

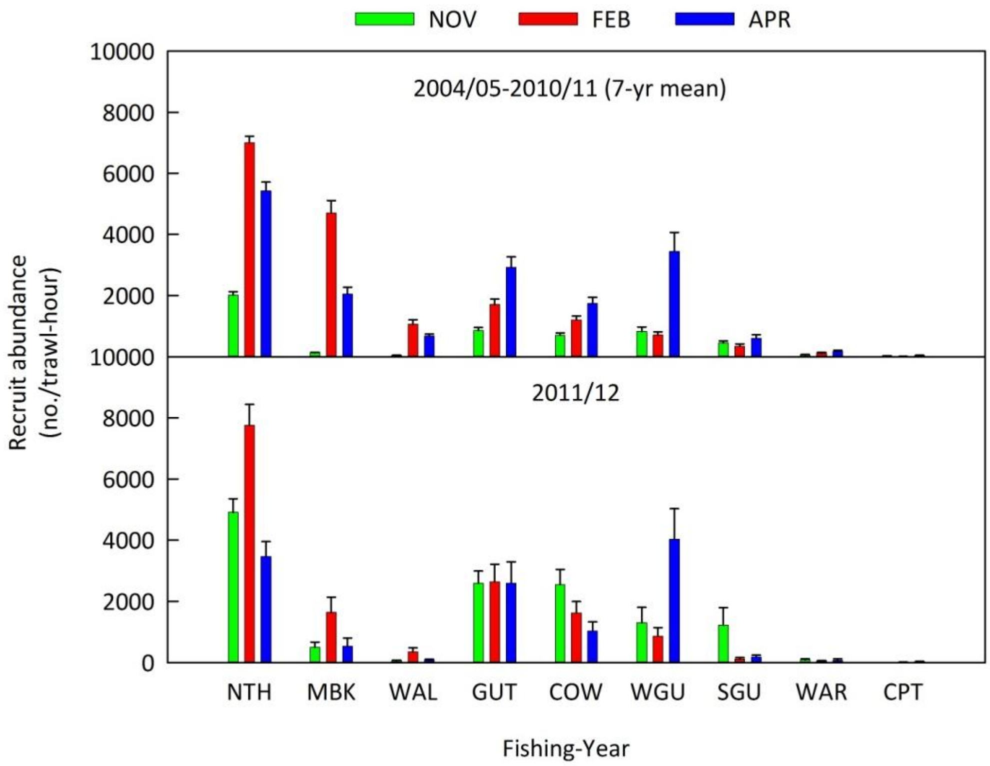


Figure 3.8 Mean (SE) recruit abundance from 2004/05 to 2010/11 and for 2011/12 for regions of Spencer Gulf for surveys conducted in November, February and April.

3.4 Discussion

Fishery-independent surveys in Spencer Gulf have been conducted since 1982, most frequently during the months of November, February and April. These data have provided an excellent basis for stock assessment of the SGPF and for the development of monthly fishing strategies. The primary focus of surveys prior to 2004/05 was for the development of monthly fishing strategies and as a consequence the location of selected shots for any given survey was variable. Since 2006/07, the locations of survey shots have been fixed to enable more robust comparisons of catch rate (index of relative biomass) and prawn size among years and survey months.

This report provides the first update of the standardised measure of biomass for the fishery. The updated model presents standardised catch with effort as a covariate rather than survey CPUE. The differences between standardised and nominal estimates were minimal for both seasonal and annual measures, despite the analysis identifying several significant factors that affect standardised survey catch. This results from the consistent spatial and temporal survey design that minimises variability in these effects between years since 2004/05. While nominal measures are clearly adequate for assessment since 2004/05, standardisation approaches may significantly improve estimates of relative biomass when data from surveys conducted prior to 2004/05 are included in the assessment.

Although there are statistical reasons to use standardised survey catch as the response variable (with effort as a candidate predictor variable) rather than standardised survey CPUE (see Dixon *et al.* 2012), there are several practical reasons why CPUE should be the preferred measure for future assessments. Firstly, there are negligible differences among model outputs for each response variable. Secondly, survey CPUE is a relative measure and is therefore the most sensible proxy for relative biomass. Finally, the reason tow duration was a significant factor in the model was due to the logistic decision to shorten shots with very high catch rates of small prawns to 15 rather than 30 minutes. It is reasonable to assume that tow duration has no effect on survey CPUE in our model because less than 1% of survey shots conducted were <20 minutes duration.

The most important factor for the annual and seasonal models was location, with higher catch rates in the northern parts of the gulf. For the annual model, survey month was the second most important factor, with catch rates increasing each survey from November to April. Tide direction was a significant factor, with higher catch rates when survey shots were conducted with the tide than either during slack or against the tide.

Splitting catch rate into size classes demonstrated considerable stability in the size structure and biomass of the population over the last seven fishing years. This stability in the annual measure was apparent despite substantial variation in biomass between years for the mixed and small prawn categories in November and April. Overall, there were no discernable trends in size structure of the population at any scale assessed.

Long-term assessment of recruitment is determined from 39 shots that have been regularly surveyed in February since 1982. The decision to stabilise pre-Christmas harvest has seen a 25% increase in mean recruitment in recent years compared to the historic average, as well as a reduction in recruitment variability. This has been achieved with no reduction in the average pre-Christmas catch for the same time period.

Analyses of recruit abundance from shots surveyed consistently throughout Spencer Gulf since 2004/05 demonstrate considerable spatial and temporal variability in the patterns of abundance. While peak recruitment was observed during February in most years, it occurred in April during 2008 and 2011. Recruitment was generally low in November with the exception of 2011/12 when recruitment was twice as high as any previous November. During February, 70% of recruits were observed in the North and Middlebank/Shoalwater regions with increasing abundances of recruits observed in the Gutter and Western Gutter regions during April. This spatial and temporal variability in recruit abundance suggest that a more sophisticated performance measure of recruitment may be required.

A simple egg production model was developed for the fishery in 2007. The FRDC Project (2008/011) will provide an improved understanding of reproductive biology and of larval biology and transport in Spencer Gulf. Until these results are obtained, annual comparisons of egg production from the current model should be interpreted cautiously.

Fishery-independent data on survey catch and CPUE by size category, recruitment and egg production suggest that the fishery is currently being harvested in a sustainable manner. Further, standardisations of survey data suggest that the use of nominal survey CPUE is an adequate measure of relative biomass for determining monthly fishing strategies. While nominal survey CPUE could also be used for determining stock status, standardised measures are preferred because they will be used in future bio-economic modelling to determine measures of absolute biomass. Analyses of recruitment data collected consistently over the last eight fishing-years suggest that peak recruitment is spatially and temporally variable. Consequently, the revised Management Plan should consider altering the PI for recruitment which is currently limited to a group of shots located in the north of the gulf surveyed during February.

4. FISHING STRATEGY ASSESSMENT

4.1 Introduction

Monthly fishing strategies for the SGPF have been a key factor in its success because they aim to maximise economic yield in an ecologically sustainable manner by limiting effort spatially and temporally. During each fishing period, areas of the gulf are opened to fishing by assessing data gathered during stock assessment or spot surveys against the decision rules in the Management Plan (Dixon and Sloan 2007). During fishing, the "committee-at-sea" monitor the catch to determine if target-sized prawns are being captured. Based on historic knowledge and these "real-time management" data, the area fished is regularly reduced in size throughout each fishing period. This section of the report assesses the effectiveness of the real time management process by examining the size of prawns captured at fine temporal and spatial scales against the application of decision rules as outlined in the current Management Plan.

Monthly fishing strategies for the SGPF are developed under three broad categories as defined in the Management Plan; conservative, standard or increasing. These categories are referred to as the 'nature of the strategy' and aim to reflect the current status of the resource to dictate how much can be harvested sustainably. For example, conservative strategies suggest that the biomass is relatively low and thus aim to promote low levels of catch that will restore the biomass to historic averages.

These categories are determined from stock assessment survey data following the decision rules in the Management Plan. Fishing periods in November and December are primarily restricted by total catch limits, whereas fishing periods from February to June are restricted by target prawn size. Once the nature of the strategy has been determined from a stock assessment survey, the decision rules remain in place until the next stock assessment survey is completed.

4.2 Methods

Fishery-independent, stock assessment surveys were conducted during October 2011, February 2012 and April 2012. The mean catch rate from surveys was assessed against the criteria of the Management Plan to determine the nature of the strategy and primary decision rule (see Table 4.1).

Table 4.1. Stock assessment survey catch rate criteria in the Management Plan. These measures define the nature of the strategy.

Measure	Survey	Lower	Upper
Mean survey catch rate for 20+ grade prawns	Nov	10	
	Feb	50	
	Apr	40	
Mean survey total catch rate for all prawns	Nov	95	135
	Feb	120	160
	Apr	160	200

Total catch and mean harvested size were assessed for each fishing year at a fine spatial scale (fishing block) and temporal scale (fishing period) from commercial logbook data. Fishing periods were defined as consecutive days fishing separated by the end of the lunar period or the conduct of a survey. Seven fishing periods were assessed during 2011/12 (Table 4.3). Total catch and mean harvested size were summarised for each fishing period and assessed against the relevant criteria for minimum catch per vessel night (Table 4.2) and target harvested size (see Tables 4.3 and 4.4). Detailed maps for each survey and fishing period are provided in Appendix 1.

Table 4.2 At-sea decision rules for the SGPF for minimum catch per night.

Fishing Period	Nov & Dec	Mar & Apr	May & June
Minimum catch (kg/vessel night)	350	400	400

4.3 Results

Three surveys were conducted during 2011/12 (Table 4.2). The limit reference for the 20+ grade was achieved during all surveys, thus the nature of each strategy was dependent upon total catch rate in each instance. Increasing strategies resulted from surveys conducted during October 2011 and February 2012. A standard strategy resulted from the survey conducted during April 2012.

Table 4.3. Stock assessment survey results and the nature of strategies for the SGPF during 2011/12. Limit ref. refers to the lower limit for the mean 20+ prawn grade weight. Range refers to the lower and upper limits for mean total catch rate. These measures define the nature of the strategy.

Fishing year	Survey	20+ grade (kg/h)		Total (kg/h)		Nature of strategy	Primary decision rule
		Limit ref.	Result	Range	Result		
2011/12	Oct	10	71	95–135	160	Increasing	<600 t
	Feb	50	67	120–160	171	Increasing	<240 prawns/7 kg
	Apr	40	55	160–200	193	Standard	<240 prawns/7 kg

During 2011/12, 276 blocks were fished during seven fishing periods (Table 4.3). Prawns that did not meet target size criteria were harvested in 9 (3%) of these blocks after the April stock assessment survey (fishing periods 5, 6 and 7). The total catch from these blocks was 68 t which represented 4% of the annual catch. Of the 52 nights fished throughout the fishing-year, target size criteria were not met on 2 nights (4%) (one each in fishing periods 3 and 7), while minimum catch criteria were not met on 8 nights (15%).

Table 4.4. Statistics of fishing performance regarding catch and prawn size criteria as assessed against the Management Plan for seven fishing periods in 2011/12. *Blocks and total catch outside of size criteria do not include confidential catches. Grey borders indicate the timing of the three stock assessment surveys in relation to the fishing periods.

Fishing year	Fishing period	Target size (pr/7 kg)	Blocks fished	Blocks outside size criteria*	Total catch (t)	Total catch outside of size criteria (t)*	Nights fished	Nights below size criteria	Nights below catch criteria
2011/12	1 (Oct-Nov)	<250	20	0	175	0	6	0	1
	2 (Nov-Dec)	<250	31	0	158	0	11	0	3
	3 (Mar)	<240	42	0	308	0	6	0	0
	4 (Apr)	<240	34	0	158	0	4	1	0
	5 (Apr)	<240	48	3	418	18	8	0	0
	6 (May)	<240	58	2	365	14	12	0	2
	7 (June)	<240	43	4	93	35	5	1	2
		Sub-total	**276**	**9**	**1675**	**68**	**52**	**2 (4%)**	**8 (15%)**

5. PERFORMANCE INDICATORS

In this section, performance of the fishery is assessed against the performance indicators (PIs) identified in the Management Plan. The Plan provides a set of key PIs (Table 5.1) that, if breached, initiate a management response. That response includes a comprehensive assessment of additional performance measures (Table 5.2).

Table 5.1 Summary of key performance indicators for the 2009/10, 2010/11 and 2011/12 fishing-years of the SGPF. The figure highlighted in red indicate that the performance measure did not meet the limit RP.

PI	Limit RP	'09/'10	'10/'11	'11/'12
Recruitment index	<35	50.5	39.7	43.9
Total commercial catch (t)	<1800	2,361	1,979	1,675
Mean commercial CPUE (kg/h)	<80	139	118	91
% vessel nights with mean size >280 prawns/7 kg	>2%	1.0%	1.0%	0.6%
Fishery independent surveys	3 surveys completed	Yes	Yes	Yes
Indices of future and current biomass	Neither index is below threshold levels in 2 consecutive surveys	✓	✓	✓
Committee comply with harvest strategy decision rules	Committee develops all harvest strategies based on results of surveys and in accord with decision rules	✓	✓	✓

5.1 Key performance indicators

Recruitment indices were calculated as the square root transformation of the numbers of prawns (males <33 and females <35 mm CL) per nautical mile trawled (after Carrick 2003). As GPS data were unreliably reported on some occasions during surveys, a mean trawl distance of 1.593 nm per 30-minute trawl shot was used to convert to distance measures (calculated from reliable survey GPS data). The recruitment index of 43.9 during 2011/12 was above the limit RP.

Total commercial catch in 2011/12 (1,675 t) was below the limit RP for the fishery, thus the PI for total commercial catch was breached, whereas mean commercial CPUE in 2011/12 (91 kg/h) was above the limit RP for the fishery.

The mean size of prawns harvested for each vessel night was calculated from commercial logbook prawn grade data. During 2011/12, prawns with an average size smaller than 280 prawns/7 kg were harvested on 12 of 1990 (0.6%) vessel nights when prawn grade data were reported. This was above the limit RP for the fishery.

Three fishery independent surveys were conducted during 2011/12. Indices of future biomass were above the limit RP for all three stock assessment surveys. Increasing strategies resulted from surveys conducted during November and February 2011/12. A standard strategy resulted from the survey conducted during April 2011/12. As there were no conservative strategies for this period, this PI was met successfully. All fishing strategies were established and managed within the decision rules of the harvest strategy.

5.2 Additional performance measures

The Management Plan provides a set of additional performance measures that are critically assessed if a key PI is not met (Table 5.2). One key PI was not met during 2011/12 (total commercial catch). In accordance with the Management Plan, triggering additional performance measures does not evoke a management response.

Table 5.2 Summary of additional performance measures for the 2009/10, 2010/11 and 2011/12 fishing-years of the SGPF. The figures highlighted in red indicate that the performance measure did not meet the Limit RP.

Performance Measure	Limit RP	2009/10	2010/11	2011/12
Recruit index November survey all shots	>12	**10.1**	12.1	20.9
Recruit index February survey all shots	>19	27.9	26.6	22.9
Recruit index April survey all shots	>15	21.2	29.5	15.6
Egg production (eggs*10^6/ hr trawled)	>500	621	623	578
% of 20+ in the catch – Nov & Dec	<12%	3.9	3.9	6.3
% of 20+ in the catch – March to June	<7%	3.4	7.0	3.8
% of 16–20 in the catch – Nov & Dec	25–35%	20.7	29.6	31.4
% of 16–20 in the catch – March to June	<30%	**32.4**	**30.2**	**32.9**

During 2011/12, recruitment indices were above the limit RP for all three stock assessment surveys, and the egg production estimate of 578 eggs*10^6/ hr trawled was above the limit RP for the November survey.

The proportion of 16–20 grade prawns from March to June was outside of the reference range in 2011/12. All other measures of prawn size were within acceptable reference ranges.

5.9 Discussion

Six of the seven key PIs were achieved or were above the limit RP during 2011/12. Total commercial catch was the only PI to be breached.

The primary PIs do not relate to traditional measures of stock status but rather most reflect adherence to harvest strategy decision rules or are measures of fishery (economic) performance. For example, triggering the total commercial catch PI does not suggest that this was an unsustainable catch rather it suggests that it was likely to be a year of low economic returns. This was raised as an issue by assessors for the Marine Stewardship Council (MSC). A more appropriate framework could be to have a primary PI(s) to assess annual “stock status” by explicitly defining relative or absolute biomass and determining appropriate target and limit RPs.

The PI for “Committee comply with harvest strategy decision rules” cannot be objectively assessed as there is currently no quantitative measures by which to assess monthly fishing strategy development or management by the Committee-At-Sea. Whilst appropriate assessment of fishing strategy development requires scrutiny of the data from survey shots included in fishing strategies, assessment of management at sea can be achieved by determining whether decision rules were met, particularly regarding prawn size. Analyses in this report provide a useful tool for such measures, with prawn size measured as a daily average for the fleet, and for each fishing block for each harvest period. Although size criteria were not always met during 2011/12, technically the RP was not triggered.

As discussed in previous reports (e.g. Dixon *et al.* 2012), the egg production model is not fully developed and outputs should be interpreted with caution. The model will be substantially augmented with the completion of FRDC project 2008/011. Also, the limit RP for egg production is determined as a fixed value, when a more appropriate approach may be to link the limit RP to a reference year (for example 2004/05) to ensure that the assessment is relevant to a modified egg production model in the future.

There is a need to collect information on the fishing power of the fleet. These data are critical for interpreting changes in commercial CPUE and survey catch rate that underpin the PI for “commercial CPUE” and “indices of current and future biomass”.

6. DISCUSSION

6.1 Stock Status and uncertainty

This report provides detailed analyses from several sources of reliable data that represent a robust assessment of the resource upon which the SGPF is based. As indicated in other recent stock assessment reports (Dixon *et al.* 2005a, 2007, 2008, 2009, 2010, 2012), there are several lines of evidence that suggest the SGPF is being fished within sustainable limits: annual catch has exceeded 1400 t since 1986/87; effort has reduced to 40% of the 1978/79 peak; and mean harvested prawn size has been consistently larger in recent years than in 1978/79. On balance, these lines of evidence suggest that the fishery is likely to have been exploited at an appropriate level. This conclusion was also reached in the recent Marine Stewardship Council (MSC) assessment of the fishery (Banks *et al.* 2011).

This long-term sustainability can be largely attributed to the effectiveness of fishery-independent surveys conducted since 1982 that have established an understanding of the patterns of prawn distribution and abundance to enable the development of monthly fishing strategies that ensure biological sustainability. By continually altering monthly fishing strategies based on knowledge obtained from regular surveys, commercial catches have ebbed and flowed with apparent levels of relative biomass. While this approach has likely maintained the biomass at a sustainable level, it has also resulted in substantial fluctuations in catch among some years. For example, total catch for 2011/12 was 30% lower than 2009/10 despite stable estimates of relative biomass for the last eight years. Although it is difficult to ascertain the reasons for the recent decline, it is notable that similar trends (two-year declines) have been observed on previous occasions when very high catches have been taken in one year. While the fishery has a proud history of responsive, real-time management, a harvest strategy that reduces fluctuations in catch among years should provide greater certainty and stability for industry with potential economic benefits as well.

The standardisation of survey CPUE in the previous report (Dixon *et al.* 2012) and survey catch for this report, both indicate a high degree of similarity among standardised and nominal estimates, which reflects the robust spatial and temporal replication of the survey design in recent years. Although there are statistical reasons to use standardised catch, survey CPUE is a more sensible measure for performance assessment given the consistency of survey tow duration. The similarity between nominal and standardised measures suggest that nominal survey CPUE is an appropriate measure for developing monthly fishing strategies and while it could also be used for determining stock status, standardised measures are preferred and they will be used to estimate absolute biomass in future modelling. Finally, although surveys conducted prior to 2004/05 were highly variable in their spatial extent, the significant differences in catch rates among locations identified in the model can be used to improve model fits when incorporating historical survey data (1981/82 to 2004/05) into the assessment.

6.2 Management Plan and harvest strategy

A new Management Plan is being developed for the SGPF, which will include a revision of the harvest strategy in the existing plan (Dixon and Sloan 2007). While fishery-independent surveys should continue to provide an excellent platform to underpin the new harvest strategy, some modifications to the current approach are required. In particular, the original harvest strategy does not conform to conventional harvest strategy structures. However, most of these limitations can be addressed by adopting conventional terminology (see Dixon *et al.* 2012, Section 6.3) and the development of appropriate performance indicators (PIs) and reference points (RPs).

Australian harvest strategies are usually underpinned by an annual assessment of stock status, with associated management actions that aim to ensure that fishing effort for the upcoming year is maintained at levels that will achieve the maximum economic or sustainable yield (DAFF 2007). The existing harvest strategy for the SGPF does not aim to control catch or effort levels on an annual scale. Instead, stock status is assessed on three occasions each year based on fishery-independent survey results. These data are used to inform monthly fishing strategies for the subsequent fishing period. The fishery is then managed at a daily scale using real time management (RTM) by the Committee-At-Sea.

A better approach may be to have clearly defined management of the fishery at three temporal scales: 1) annual harvest strategy; 2) monthly fishing strategies, and; 3) daily management at sea. Fishery-independent survey results could be used to determine annual stock status, from which an annual harvest strategy can be determined. Subsequent survey results could then be used to adjust monthly fishing strategies, within the bounds of the annual harvest 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 6.1 provides a description of how annual stock status and subsequent surveys can be used to inform fishing strategies.

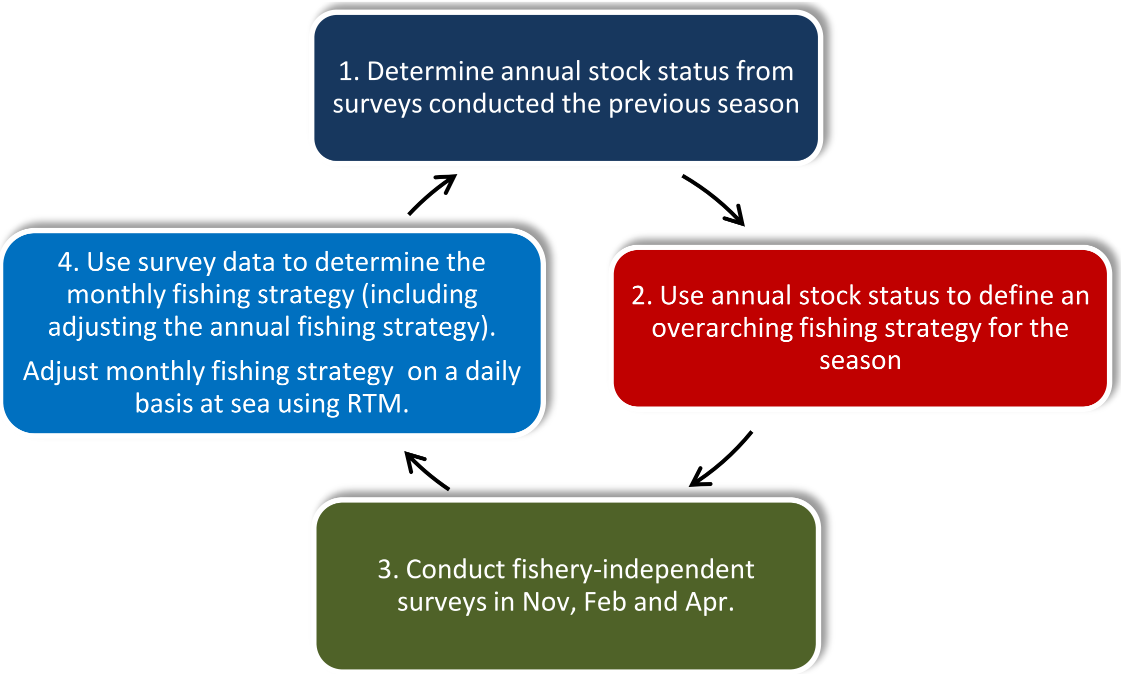


Figure 6.1 The harvest strategy cycle.

Biomass as a key biological performance indicator for assessing stock status

The PI for survey catch rate (SCR) is used as a measure of relative biomass in the existing harvest strategy, however there are limitations to its current application. Firstly, the RPs are not defined as traditional measures. Secondly, the current harvest strategy lacks a threshold RP, below which the biomass is considered at an unacceptable risk of recruitment overfishing (i.e. where cessation of fishing is required). Also, the current measures refer to nominal and not standardised catch rates. Finally and most importantly, they are not explicitly linked to an annual assessment of stock status.

PIRSA Fisheries and Aquaculture are in the process of implementing definitions of stock status for South Australia's fisheries (A. Jones pers. comm.) following a similar format to those used for the national status report (Flood *et al.* 2012). For the SGPF, stock status could be determined in three categories defined by limit and threshold

RPs (Figure 6.2). Levels of biomass above the limit RP could be classified as "sustainably fished", levels of biomass between the limit and threshold RP classified as "transitional" and levels of biomass below the threshold RP defined as "overfished".

The primary PI for annual stock status could be a measure of adult (i.e. spawning) biomass. The CRC funded project 2011/750 "Bio-economic model for SA prawn trawl fisheries" is due to be completed in 2014 and will provide the first model-derived estimates of biomass for the fishery. Commonwealth harvest strategies based on modelled biomass estimates use a default threshold RP (termed B_{LIM}) of $B_{20\%}$ (20% of virgin biomass) based on studies of fisheries worldwide (Myers *et al.* 1994). Similarly, the default setting for a limit RP is maximum sustainable yield (B_{MSY}). These measures may provide appropriate RPs to define stock status once the bio-economic model is complete.

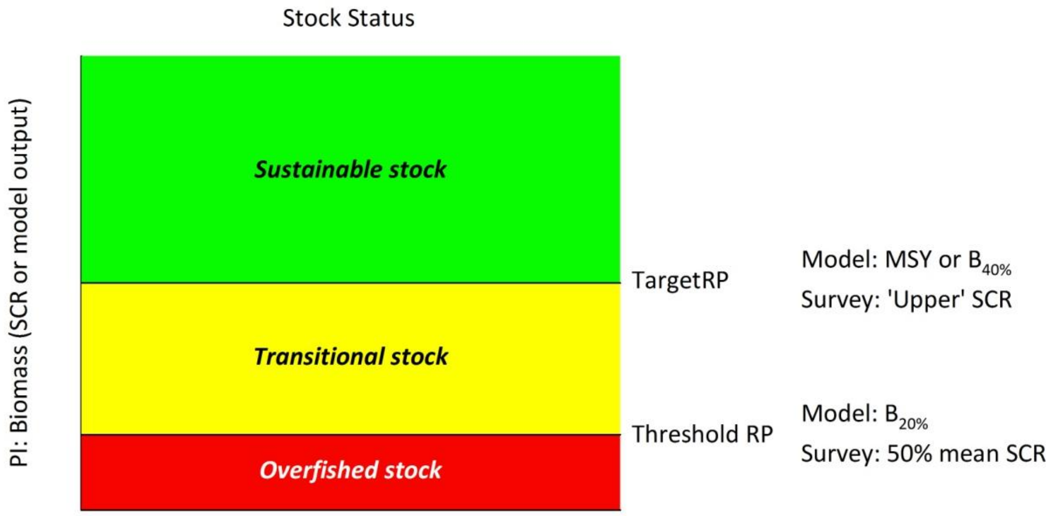


Figure 6.2 Assessment of stock status using biomass as a key biological PI, with RPs based on model-derived outputs and/or stock assessment survey results.

In the meantime, a suitable proxy could be a measure of relative adult biomass derived from the three annual fishery-independent surveys (e.g. mean SCR of all three surveys combined). In the MSC assessment of the fishery, Banks *et al.* (2011, page 22) suggest that the SGPF has generally been fished at biomasses at or above B_{MSY} throughout its history. Smith *et al.* (2011) suggest that B_{LIM} is approximately half that of B_{MSY} for low-trophic level species such as prawns. Following this logic, a suitable proxy for the threshold RP could be 50% of the mean adult SCR. It should be noted that this is a conservative proxy under the reasonable assumption that the fishery has on average been fished above B_{MSY}. This conservatism is required for such proxy measures in Commonwealth harvest strategies (DAFF 2007) and should be considered here. While it is more difficult to determine a SCR proxy for the limit RP, the measure should consider the range of mean SCR estimates obtained over the past eight years when the survey design has aimed to provide robust estimates of relative biomass for the fishery.

Annual and monthly fishing strategies

There are two primary limitations of the current harvest strategy with regard to controlling exploitation on an annual and monthly basis. Firstly, the strategy aims to control catch and effort between surveys only and thus does not reflect an annual strategy. Secondly, the decision rules that guide the development of monthly strategies do not always reflect the current practices of the fishery, particularly regarding target size.

The assessment of annual stock status should provide guidance for an overarching, annual harvest strategy for the fishery. The objective of the annual harvest strategy is to define bounds of acceptable annual levels of catch and or effort for each level of stock status. The annual strategy should: prevent fishing when the status is overfished; reduce catch or effort when the status is transitional; and maintain normal practices when the status is sustainable.

While the current strategy only controls effort and or catch on a monthly basis, this adaptive approach is a critical element of the fishery's success that should be maintained. Monthly strategies are currently defined by 1) limiting total catch during the pre-Christmas period, 2) restricting the area fished (and therefore total catch) using target size rules for the remainder of the season and 3) ensuring a minimum catch per night is achieved. The rules controlling pre-Christmas harvest and minimum catch per night have been generally well adhered to. However, controlling effort using only target size has been problematic on several occasions in recent years (Dixon *et al.* 2012), particularly when a "conservative" strategy needed to be implemented.

On these occasions a range of alternative effort controls (and combinations thereof) were suggested by industry to demonstrate conservative monthly strategies. These included a reduction in the nights fished for that month, shorter duration of nights fished, reducing the relative area fished, increasing the target size, and increasing the minimum catch per night. Individually or in combination, modifying these rules aimed to demonstrate a reduction in the total effort or area fished for a monthly fishing strategy. The challenge when developing the new harvest strategy will be to ensure that decision rules are appropriate to ensure conservative fishing at both the monthly and annual scale when required.

6.3 Future research needs

The MSC assessment process provided a series of additional recommendations for future research of the fishery including the standardisation of commercial CPUE data and the testing of the design and interpretability of the stock assessment surveys. The standardisation of commercial CPUE will be undertaken as part of the development of a bio-economic model. The model will also provide a platform to examine the effects of altering the survey design on the assessment process.

Another research priority for the SGPF is an ability to determine changes in fishing power (efficiency) of the fleet. These changes can result from improvements in gear technology (vessel speed, heavier ground chains, larger or more effective otterboards etc.) or changes in fisher behaviour (increasing experience, increased knowledge through surveys, vessels sharing knowledge as “teams”). An assessment of vessel power may also be undertaken as part of the bio-economic modelling project.

7. REFERENCES

Anon (2003) Ecological assessment of the South Australian Spencer Gulf Prawn Fishery, Gulf St Vincent Prawn Fishery and West Coast Prawn Fishery. South Australian fisheries management series, Primary Industries and Resources of South Australia.

Anon (2007a) Annual status report 2007 – East Coast Trawl Fishery. Queensland Government. Department of Primary Industries and Fisheries.

Anon (2007b) Commonwealth Fisheries Harvest Strategy Policy and Guidelines. Department of Agriculture, Fisheries and Forestry.

Anon (2008a) Annual status report 2008—River and Inshore (Beam) Trawl Fishery. Queensland Government. Department of Primary Industries and Fisheries.

Arnstein D.R. and Beard T.W. (1975) Induced maturation of the prawn, *Penaeus orientalis* Kishinouye in the laboratory by means of eyestalk removal. Aquaculture 5: 411–412.

Banks, R., Stokes, K., and Dews, G. (2011) MSC Assessment Report for Spencer Gulf Prawn *(Penaeus (Melicertus) latisulcatus)* Fishery. Final Report, Version 4 for the Marine Stewardship Council. Ref: 82110 v4.

Benzie J.A.H., Frusher S.D., Kenway M. and Trott L. (1995) Utility of streamer tags to assess survival and growth of juvenile tiger prawns (*Penaeus monodon*) in aquaculture environments. Aquaculture 136(1–2): 57–69.

Bryars S. (2003) An inventory of important coastal fisheries habitats in South Australia. Fish Habitat Program, Primary Industries and Resources South Australia.

Bryars, S.R., Havenhand, J.N., (2006). Effects of constant and varying temperatures on the development of blue swimmer crab (Portunus pelagicus) larvae: laboratory observations and field predictions for temperate coastal waters. J. Exp. Mar. Biol. Ecol. 329, 218-229.

Carrick, N.A. (1982) Spencer gulf prawn fishery – surveys increase our knowledge. SAFIC vol 6(1) pp 3-32.

Carrick, N.A. (1996) Key factors which affect prawn recruitment and implications to harvesting prawn stocks. Final report FRDC 91/3.

Carrick, N.A. (2003) Spencer Gulf Prawn (*Melicertus latisulcatus*) Fishery. Fishery Assessment report to PIRSA. SARDI Aquatic Sciences RD03/0079-2.

Carrick, N.A. and Mc Shane, P. (1998) Spencer Gulf and West Coast Prawns. South Australian Fisheries Assessment Series 98/8.

Carrick, N.A. and Williams, H. (2000) Spencer Gulf and West Coast Prawns. Fishery Assessment Report to PIRSA. South Australian Fisheries Assessment Series 00/08.

Carrick, N.A. and Williams, H. (2001) Spencer Gulf and West Coast Prawn. Fishery Assessment Report to PIRSA. South Australian Fisheries Assessment Series 01/08.

Courtney A.J. and Dredge M.C.L. (1988) Female reproductive biology and spawning periodicity of two species of king prawns, *Penaeus longistylus* Kubo and *Penaeus latisulcatus* Kishinouye, from Queensland's east coast fishery. Aust. J. Mar. Freshwater Res. 39: 729–741.

Courtney A.J., Cosgrove M.G. and Die D.J. (2001) Population dynamics of Scyllarid lobsters of the genus *Thenus* spp. on the Queensland (Australia) east coast. I. Assessing the effects of tagging. Fish. Res. 53: 251–261.

Courtney A.J., Montgomery S.S., Die D.J., Andrew N.L., Cosgrove M.G. and Blount C. (1995) Maturation in the female eastern king prawn *Penaeus plebejus* from coastal waters of eastern Australia, and consideration for quantifying egg production in penaeid prawns. Mar. Biol. 122(4): 547–556.

Crookes, J.A. and Soulé, M.E. (1999) Lag times in the population explosions of invasive species: Causes and implications. In. Sandlund O.T., Schei P.J. & Viken Á. (eds). Invasive species and biodiversity management. (Kluwer Academic Publishers. Netherlands).

DAFF (2007). Commonwealth Fisheries harvest strategy: policy and guidelines. Australian Government Department of Agriculture, Fisheries and Forestry, Canberra, Australia, 55 pp.

Dixon C.D. and Roberts S.D. (2006) West Coast Prawn (*Melicertus latisulcatus*) Fishery. Fishery Assessment report to PIRSA Fisheries. SARDI Aquatic Sciences Publication no. RD03/0076–4, SARDI Research Report Series No 122.

Dixon C.D., Roberts S.D. and Ward T.M (2005a) Spencer Gulf Prawn (*Melicertus latisulcatus*) Fishery. Fishery Assessment report to PIRSA. SARDI Aquatic Sciences RD03/0079–3.

Dixon C.D., Roberts S.D. and Hooper, G.E. (2007) Spencer Gulf Prawn (*Melicertus latisulcatus*) Fishery. Fishery Assessment report to PIRSA. SARDI Aquatic Sciences RD03/0079–4.

Dixon C.D., and Hooper, G.E. (2008) Spencer Gulf Prawn (*Melicertus latisulcatus*) Fishery 2006/07. Fishery Assessment report to PIRSA. SARDI Aquatic Sciences RD03/0070–2. SARDI Research Report Series No. 322.

Dixon C.D., Hooper, G.E. and Roberts, S.D. (2009) Spencer Gulf Prawn Penaeus (Melicertus) latisulcatus Fishery 2007/08. Fishery Assessment Report to PIRSA Fisheries. SARDI Aquatic Sciences, Adelaide. SARDI Publication No. F2007/000770-3. SARDI Research Report Series No. 387.

Dixon, C.D., Hooper, G.E. and Roberts, S.D (2010). Spencer Gulf Prawn *Penaeus (Melicertus) latisulcatus* Fishery 2008/09. Fishery Assessment Report to PIRSA Fisheries. SARDI Aquatic Sciences, Adelaide. SARDI Publication No. F2007/000770-4. SARDI Research Report Series No. 511. 114pp.

Dixon, C. D., Hooper, G.E., and Burch, P. (2012). Spencer Gulf Prawn Penaeus *(Melicertus) latisulcatus* Fishery 2010/11. Fishery Assessment Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007/000770-5. SARDI Research Report Series No. 603. 118pp.

Dixon C.D., Roberts S.D., Hooper, G.E., Steer M.A. and Ward T.M (2006) Gulf St Vincent Prawn (*Melicertus latisulcatus*) Fishery. Fishery Assessment report to PIRSA. SARDI Aquatic Sciences RD03/0063-4. SARDI Report Series No 159.

Dixon C.D. and Sloan S. (2007) Management Plan for the South Australian Spencer Gulf Prawn Fishery. The South Australian Fisheries Management Series. Paper No. 54.

Edyvane K. (1999) Coastal and marine wetlands in Gulf St Vincent, South Australia: understanding their loss and degradation. Wetlands Ecol. Manag. 7: 83–104.

Evans, S. K. (2010) Northern Prawn Fishery Data Summary 2009. NPF Industry Pty Ltd, Australia.

Fernandes M.B., Wiltshire K.H. and Deveney, M.R. (submitted for publication) Macroalgae (*Caulerpa taxifolia*) and seagrasses (*Zostera muelleri*) as benthic ecosystem engineers and their effects on sediment biogeochemistry. Estuarine, Coastal and Shelf Science.

Flegel T. (2007) The right to refuse revision in the genus Penaeus. Aquaculture 264: 2-8.

Flood, M, Stobutzki, I, Andrews, J, Begg, G, Fletcher, W, Gardner, C, Kemp, J, Moore, A, O'Brien, A, Quinn, R, Roach, J, Rowling, K, Sainsbury, K, Saunders, T, Ward, T & Winning, M (eds) 2012, Status of key Australian fish stocks reports 2012, Fisheries Research and Development Corporation, Canberra.

Franco, A.R., Ferreira, J.G., Nobre, A.M., (2006). Development of a growth model for penaeid shrimp. Aquaculture 259, 268-277.

Grey, D.L., Dall, W. and Baker, A. (1983) "A guide to the Australian penaeid Prawns". Department of Primary Production, Northern Territory, Australia.

Harvell D., Aronson R., Baron N., Connell J., Dobson A., Ellner S., Gerber L., Kim K., Kuris A., McCallum H., Lafferty K., McKay B., Porter J., Pascual M., Smith G., Sutherland K., and Ward J. (2004) The rising tide of ocean diseases: unsolved problems and research priorities. Front. Ecol. Environ. 2(7): 375–382.

Harvell C.D., Kim K., Burkholder J. M., Colwell R. R., Epstein P. R., Grimes D. J., Hofmann E.E. and Lipp E. K. (1999) Emerging Marine Diseases--Climate Links and Anthropogenic Factors. Science Magazine 285(5433,3):1505–1510.

Harvell C.D., Mitchell C.E., Ward J.R., Altizer S., Dobson A., Ostfeld R.S. and Samuel M.D. (2002) Climate warming and disease risks for terrestrial and marine biota. Science 296: 2158-2162.

Hudinaga, M. (1942). Reproduction, development and rearing of *Penaeus japonicus* Bate. Jap. J. Zool. 10: 305-393.

Ignacio Vilchis L., Tegner M.J., Moore J.D., Friedman C.S., Riser K.L., Robbins T.T. and Dayton P.K. (2005) Ocean warming effects on growth, preproduction and survivorship of southern California abalone. Ecological Applications, 15(2): 469–480.

Jackson, C.J., Burford, M.A., (2003). The effects of temperature and salinity on growth and survival of larval shrimp Penaeus semisulcatus (Decapoda: Penaeoidea). J. Crust. Biol. 23(4), 819-826.

James, C.E., Dixon, C.D., Fowler, A.J., Linnane, A., Luick, J.L., McClatchie, S., McGarvey, R., Middleton, R.F., Steer, M.A. and Wu, Y. (2010) Effects of environmental variability on recruitment to South Australian fisheries: a preliminary investigation. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2009/000403-1. SARDI Research Report Series No. 438. FRDC Project No. 2006/046.

Kangas M. (1999) Postlarval and juvenile western king prawns *Penaeus latisulcatus* Kishinouye studies in Gulf St Vincent, South Australia with reference to the commercial fishery. PhD thesis, University of Adelaide.

Kangas M. and Jackson B. (1997) Gulf St Vincent Prawn Fishery. South Australian Fisheries Assessment Series 99/05.

Kangas M. and Jackson B. (1998) Sampling juvenile *Penaeus latisulcatus* Kishinouye with a water-jet net compared with a beam-trawl: spatial and temporal variation and nursery area in Gulf St Vincent, South Australia. Mar. Freshwater Res. 49: 517-523.

Kangas M., Sporer E. and Brown S. (2008) Prawn Managed Reports. In: State of the Fisheries Report 2007/08, eds W.J. Fletcher and K. Santoro, Department of Fisheries, Western Australia.

King M.G. (1977) The biology of the western king prawn *Penaeus latisulcatus* Kishinouye and aspects of the fishery in South Australia. MSc Thesis, University of Adelaide.

Knight M. and Tsolos A. (2012) South Australian Wild Fisheries Information and Statistics report 2010/11. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 57p. SARDI Publication No F2008/000804-4 SARDI Research Report Series No.612.

Lee S.Y. (2004) Relationship between mangrove abundance and tropical prawn production: a re-evaluation. Mar. Biol. 145:943–949.

Lightner D.V., Redman R.M., Nunan L.N., Mohney L.L., Mari J.L. and Poulos B.T. (1997) Occurrence of WSSV, YHV and TSV in Texas shrimp farms in 1995: possible mechanisms for introduction. World Aquaculture 97 Book of abstracts. World Aquaculture Society Baton Rouge, LA. p 288.

Linnane A., Ward, T.M., McGarvey R., Xiao, Y. and Feenstra J. (2005). Northern Zone Rock Lobster (*Jasus edwardsii*) Fishery 2003/04. South Australian Research and Development Institute, Publication No. RD03/0142–2.

Lober, M., Zeng, C., (2009). Effect of microalgae concentration on larval survival, development and growth of an Australian strain of giant freshwater prawn Macrobrachium rosenbergii. Aquaculture 289, 95-100.

MacDonald, N. (1998) Management plan for the Spencer Gulf and West Coast prawn fisheries. Internal document, Primary Industries and Resources, South Australia.

Menz A. and Blake B.F. (1980) Experiments on the growth of *Penaeus vannamei* Boone. J. Exp. Mar. Biol. Ecol. 48: 99–111.

Myers, R.A., Rosenberg, A.A., Mace, P.M., Barrowman, N and Restrepo, V.R. (1994) In search of thresholds for recruitment overfishing. ICES J. Mar. Sci. 51:191-205.

Nash G., Anderson I.G. and Shariff M. (1988) Pathological changes in the tiger prawn, *Penaeus monodon* Fabricus, associated with culture in brackishwater ponds developed from potentially acid sulphate soils. J. Fish Dis. 11: 113–123.

Nunes R. and Lennon G. (1986) Physical property distributions and seasonal trends in Spencer Gulf, South Australia: an inverse estuary. Aust. J. Mar. Freshwater Res. 37: 39–53.

Pedersen, O.P., Aschan, M., Rasmussen, T., Tande, K.S., Slagstad, D., (2003). Larval dispersal and mother populations of Pandalus borealis investigated by a Lagrangian particle-tracking model. Fish. Res. 65, 173-190.

Penn J.W. (1975) Tagging experiments with the western king prawn Penaeus *latisulcatus* Kishinouye. I. Survival, growth, and reproduction of tagged prawns. Aust. J. Mar. Freshwater Res. 26(2): 197–211.

Penn J.W. (1976) Tagging experiments with the western king prawn *Penaeus latisulcatus* Kishinouye. II. Estimation of population parameters. Aust. J. Mar. Freshwater Res. 27: 239–250.

Penn, J.W. (1980) Spawning and fecundity of the western king prawn, Penaeus latisulcatus Kishinouye, in Western Australian waters. Aust. J. Mar. Freshwater Res. 31: 21-35.

Penn, J.W., Hall, N.G. and Caputi, N. (1988) Resource assessment and management perspectives of the Penaeid prawn fisheries of Western Australia. In: J. Caddy (Ed) The scientific basis of Shellfish Management. John Wiley and Sons, New York.

Perez Farfante I. and Kensley B. (1997) Penaeoid and Sergestoid shrimps and prawns of the world. Keys and diagnoses for the families and genera. Mem. Mus. Nat. Hist. Nat. 175: 1–233.

Portner H.O. and Knust R. (2007) Climate change affects marine fishes through the oxygen limitation of thermal tolerance. Science 315: 95-97.

Potter, I.C., Manning, R.J.G. and Loneragan, N.R. (1991) Size, movements, distribution and gonadal stage of the western king prawn (*Penaeus latisulcatus*) in a temperate estuary and local marine waters. J. Zool., Lond. 223: 419-445.

Preston, N., (1985). The combined effects of temperature and salinity on hatching success and the survival, growth and development of the larval stages of *Metapenaeus bennettae* (Racek and Dall). J. Exp. Mar. Biol. Ecol. 85, 57-74.

Primavera, J.H. and Lebata, M.J.H.L. (2000) Size and diel differences in activity patterns of *Metapenaeus ensis*, *Penaeus latisulcatus* and *P. merguiensis*. Mar. Fresh. Behav. Physiol. 33: 173-185.

Queiroga, H., Cruz, T., dos Santos, S., Dubert, J., Gonzalez-Gordillo, J.I., Paula, J., Peliz, A., Santos, A.M.P. (2007). Oceanographic and behavioural processes affecting invertebrate larval dispersal and supply in the western Iberia upwelling ecosystem. Prog. Oceanogr. 74, 174-191.

Rasheed, M.A. and Bull, C.M. (1992) Behaviour of the Western king prawn, *Penaeus latisulcatus* Kishinouye: Effect of food dispersion and crowding. Aust. J. Mar. Freshwater Res. 43: 745-752.

Roberts, S.D., Deveney, M., Sierp, M., (2010). Biosecurity and disease status of prawn nurseries in South Australia. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI publication number F2010/000593-1. SARDI research report series No. 449. 35p.

Roberts, S.D., Dixon, C.D., Andreacchio, L. (2012). Temperature dependent larval duration and survival of the western king prawn, *Penaeus (Melicertus) latisulcatus* Kishinouye, from Spencer Gulf, South Australia. J. Exp. Mar. Biol. Ecol. 411, 14-22.

Roberts, S.D, Dixon C.D. and Ward T.M. (2005) Assessment of juvenile prawn (*Melicertus latisulcatus*) surveys in Spencer Gulf, South Australia. Report to PIRSA Fisheries. SARDI Aquatic Sciences RD04/0211–2, SARDI Research Report Series No 95.

Sang H.M. and Fotedar R. (2004) Growth, survival, haemolymph osmolality and organosomatic indices of the western king prawn (*Penaeus latisulcatus* Kishinouye, 1896) reared at different salinities. Aquaculture 234: 601–614.

Scandol J., Rowling K. and Graham K. (2008) Status of Fisheries Resources in NSW 2006/07, NSW Department of Primary Industries, Cronulla.

Shokita, S. (1984) Larval development of *Penaeus* (*Melicertus*) *latisulcatus* Kishinouye (Decapoda, Natandtia, Penaeidae) reared in the laboratory. Galaxea 3: 37-55.

Sluczanowski, P. (1980) The modelling and optimal control of the Spencer Gulf Prawn Fishery. PhD thesis, Imperial College, London, 1-237.

Smith A.D., Brown C.J., Bulman C.M., Fulton E.A., Johnson P., Kaplan I.C., Lozano-Montes H., Mackinson S., Marzloff M., Shannon L.J., Shin Y.J., and Tam J. Impacts of fishing low-trophic level species on marine ecosystems. Science. 333(6046):1147-50.

South Australian Coast Protection Board (2003) Coastline: a strategy for implementing CPB policies on coastal acid sulphate soils in South Australia. Department for Environment and Heritage, Report No. 33, January 2003.

Svane I. (2003) Gulf St Vincent Prawn Fishery (*Melicertus latisulcatus*). Fishery assessment report to PIRSA for the Prawn FMC, October 2003. SARDI Aquatic Sciences RD03/0063-2.

Svane I. and Roberts S.D. (2005) Gulf St Vincent Prawn Fishery (*Melicertus latisulcatus*). Fishery assessment report to PIRSA. SARDI Aquatic Sciences RD03/0063–3.

Tanner, J.E. and Deakin, S. (2001) Active habitat selection for sand by juvenile western king prawns, *Melicertus latisulcatus* (Kishinouye). J. Exp. Mar. Biol. Ecol. 261: 199-209.

Vijayan K.K., Balasubramanian C.P., Jithendran K.P., Alavandi S.V. and Santiago T.C. (2003) Histopathology of Y-organ in Indian white shrimp *Fenneropenaeus indicus*, experimentally infected with white spot syndrome virus. Aquaculture 221: 97–106.

Wallis D., Cocking L., Turnbull C., Zunic Y. and Fava S. (2009) Torres Strait Prawn Fishery Handbook 2009, Australian Fisheries Management Authority. Canberra, Australia.

Wallner B. (1985) An assessment of the South Australian West Coast western king prawn (*Penaeus latisulcatus*) fishery. Department of Fisheries, South Australia.

Wu, J. (1990). Environmental factors affecting the survival and growth of western king prawns, *Penaeus latisulcatus*, under aquaculture conditions in Spencer Gulf, South Australia. Masters Thesis, University of Adelaide.

Xiao Y. and McShane P. (2000) Estimation of instantaneous rates of fishing and natural mortalities from mark-recapture data on the western king prawn *Penaeus latisulcatus* in the Gulf St Vincent, Australia, by conditional likelihood. Trans. Am. Fish. Soc. 129: 1005-1017.

Electronic references

NASA (2012). *Physical Oceanography Distributed Active Archive Center*. Retrieved 26 October 2012 from http://poet.jpl.nasa.gov/.

USNO (2012). *Fraction of the Moon Illuminated*. Retrieved 26 October 2012 from http://aa.usno.navy.mil/data/docs/MoonFraction.php.

8. APPENDIX 1

Table 8.1. Number of stock assessment survey shots done in fishing regions of Spencer Gulf from February 1982 to June.

Year	Month	NTH	MBK	COW	GUT	SGU	WAL	WGU	CPT	WAR	Total
1982	Feb	52	3								55
	Mar	52	3	36							91
	Apr	53	6								59
	Nov	13									13
1983	Jun	53	6	38							97
	Oct			36	24						60
	Nov			34							34
1984	Oct	56	6								62
1985	Jun	66	15	39							120
	Oct				27						27
1986	Apr	74	15								89
	Jun	74	14	42							130
	Oct	70	15		18						103
1987	Feb	74	15	40	27	3	18				177
	Jun	75	15	36	27	3					156
	Oct	76	15		27	3	18				139
1988	Feb	77	15	42	27	3	11				175
	Jun	68	15	38							121
	Nov	75	15	32	27		16				165
1989	Feb	75	15	42	27		16				175
	Apr	37	16	17							70
	Jun	59	1	21							81
1990	Jun	68	17								85
1992	Feb	65	16	46	27	3	20				177
1993	Feb	73	16	34	27		20				170
	Apr	3	15								18
	May	19									19
	Jun	68	9								77
1994	Feb	58	12	40	27	3	17				157
	Apr	68	20	30	11		24	4			157
	Jun	82	4	36	16	1					139
	Nov	94	17	35	22		18	4			190
1995	Feb	68	15	36	23		18				160
	Apr	82	18	36	10		3				149
	May	80	7	36							123
	Nov	80	6	37	12		11				146
1996	Feb	75	16				2				93
	Apr	76	18				9				103
	Jun	74	9	52	30						165
	Nov	61	9	50	28		16				164
1997	Feb	69	13	49	26	2	21	10	6		196
	Nov	69	12	48	25	6	21	10	3		194
1998	Feb	74	15	61	29	5	22	10	6		222
	Apr	74	18				22				114
	Nov	78	12	52	25	1	21	10			199
1999	Feb	86	16	41	27	2	22	8	6		208
	Nov	77	16	44	25	4	23	10	6		205
2000	Feb	76	15	11	27	4	22				155
	Oct	62	16	24	27	2	27				158
2001	Feb	76	16	36	30	8	27	10	12		215
	Apr	80	18		7		32				137
	Nov	82	19	35	29	6	38	10			219
2002	Feb	82	17	5	25	2	43				174
	Apr	71	21		7		31				130
	Nov	82	17	36	30	9	43	10	12	6	245
2003	Mar	80	18	36	30	8	42	10	12	7	243
	Apr	77	21				40				138
	Nov	82	16	36	29	6	31	9			209

(*continued*)

Year	Month	NTH	MBK	COW	GUT	SGU	WAL	WGU	CPT	WAR	Total
2004	Feb	81	21	36	27	10	40	2	12	8	237
	Apr	80	22	28	13		40				183
	Nov	78	22	38	23	1	29	10			201
2005	Feb	78	22	42	24	7	29	9	12		223
	Apr	78	22	22	19	5	41	3			190
	Nov	78	22	39	24	1	29	10			203
2006	Feb	78	23	39	26	10	29	10	12		227
	Apr	81	22	22	20	4	36	3		2	190
	Nov	64	21	25	22	8	40	9	12	5	206
2007	Feb	63	21	27	22	8	40	9	12	5	207
	Apr	64	22	27	22	8	40	9	12	5	209
	Nov	64	22	27	22	8	40	9	12	5	209
2008	Feb	63	22	27	21	8	40	9	12	5	207
	Apr	63	22	27	21	8	40	9	12	5	207
	Nov	62	22	25	22	8	38	9	12	5	203
2009	Feb	63	22	27	22	8	40	9	12	5	208
	Apr	63	22	27	22	8	40	9	12	5	208
	Nov	63	22	27	22	8	40	9	12	5	208
2010	Feb	62	22	27	22	8	40	9	12	5	207
	Apr	62	22	27	22	8	41	9	12	5	208
	Nov	62	22	18	22	8	40	5		5	182
2011	Feb	62	22	27	22	9	40	9	12	5	208
	Apr	62	22	20	22	8	40	4	12	5	195
	Nov	62	22	18	22	8	40	5		5	182
2012	Feb	61	22	27	22	8	40	9	12	5	206
	Apr	62	22	27	22	8	40	9	12	5	207

The following figures in this Appendix inform Section 4, “Harvest Strategy Assessment”. Two types of figures are presented; one type presents survey data on catch rate and mean size prior to commercial fishing, and the second presents commercial catch and mean size data by fishing block, for each harvest period. Both figures contain the initial harvest strategy closure lines adopted during the subsequent harvest period. Presentation of these data in this manner allows 1) visual assessment of survey data included in the harvest strategy, 2) assessment of the commercial catch with regard to the decision rules of the Management Plan at various spatial and temporal scales, and 3) assessment of how well the survey data reflect the resultant commercial catch.

Fishery-independent “stock assessment” surveys were conducted during October 2011, February 2012 and April 2012. Fishery-dependent “spot” surveys were conducted during November 2011, March 2012, April 2012, May 2012 and June 2012. Data on catch rate and mean size are presented for each survey site. Start and end dates and the number of nights surveyed are provided. Commercial catch and mean size were determined from commercial logbooks (see Section 2). Data from fishing blocks with catches from <5 fishers for that harvest period are displayed as confidential. The start and end dates, numbers of night's fished and total catch for each harvest period are provided.

Results are discussed in terms of the regions defined in Figure 1.2. Catch rates <4 lb/min are referred to as "low", 4–10 lb/min as "medium", and >10 lb/min as "high". Size categories reflect the target size criteria for that harvest period based on the nature of the harvest strategy i.e. conservative, standard or increasing. Commercial catches are reported in ranges that vary with respect to the total catch for that period, with the upper range of each "high" category reflecting the highest catch per block. Within each map showing commercial catch and mean size by harvest period are daily catch (t) and mean size (prawns/7 kg) graphs. Both of these output controls are used by the "Committee at-sea" to assess the commercial catch on a nightly basis against the "at-sea decision rules" in the Management Plan (Table 8.1).

Table 8.2 At-sea decision rules for the SGPF.

Harvest Period	Nov & Dec	Mar & Apr	May & June
Minimum catch (kg/vessel night)	350	400	400
Minimum mean size (prawns/7kg)	250	240	240

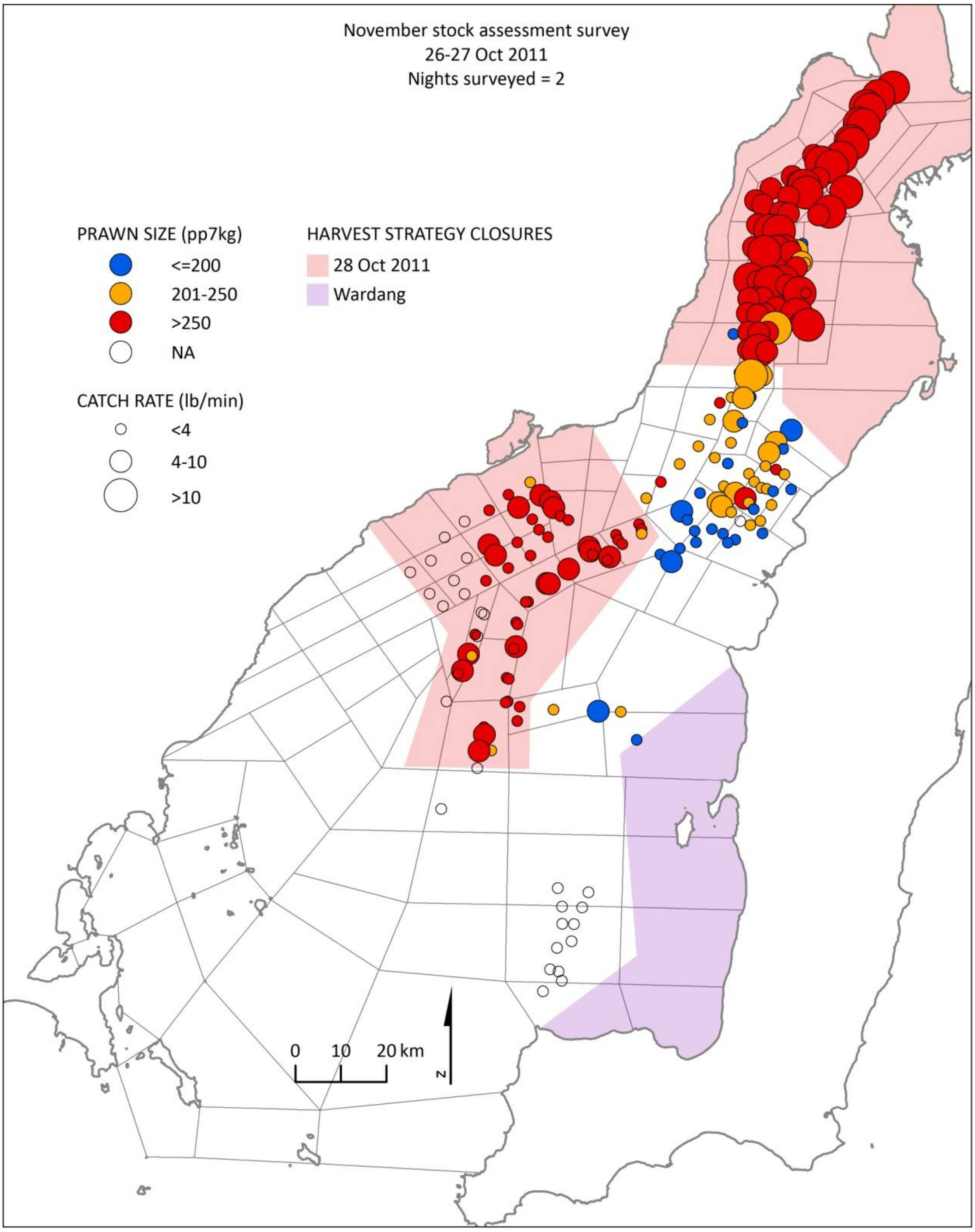


Figure 8.1 Catch rate and mean size during the November 2011 stock assessment survey, prior to harvest period 1. Shading indicates areas subsequently closed to fishing.

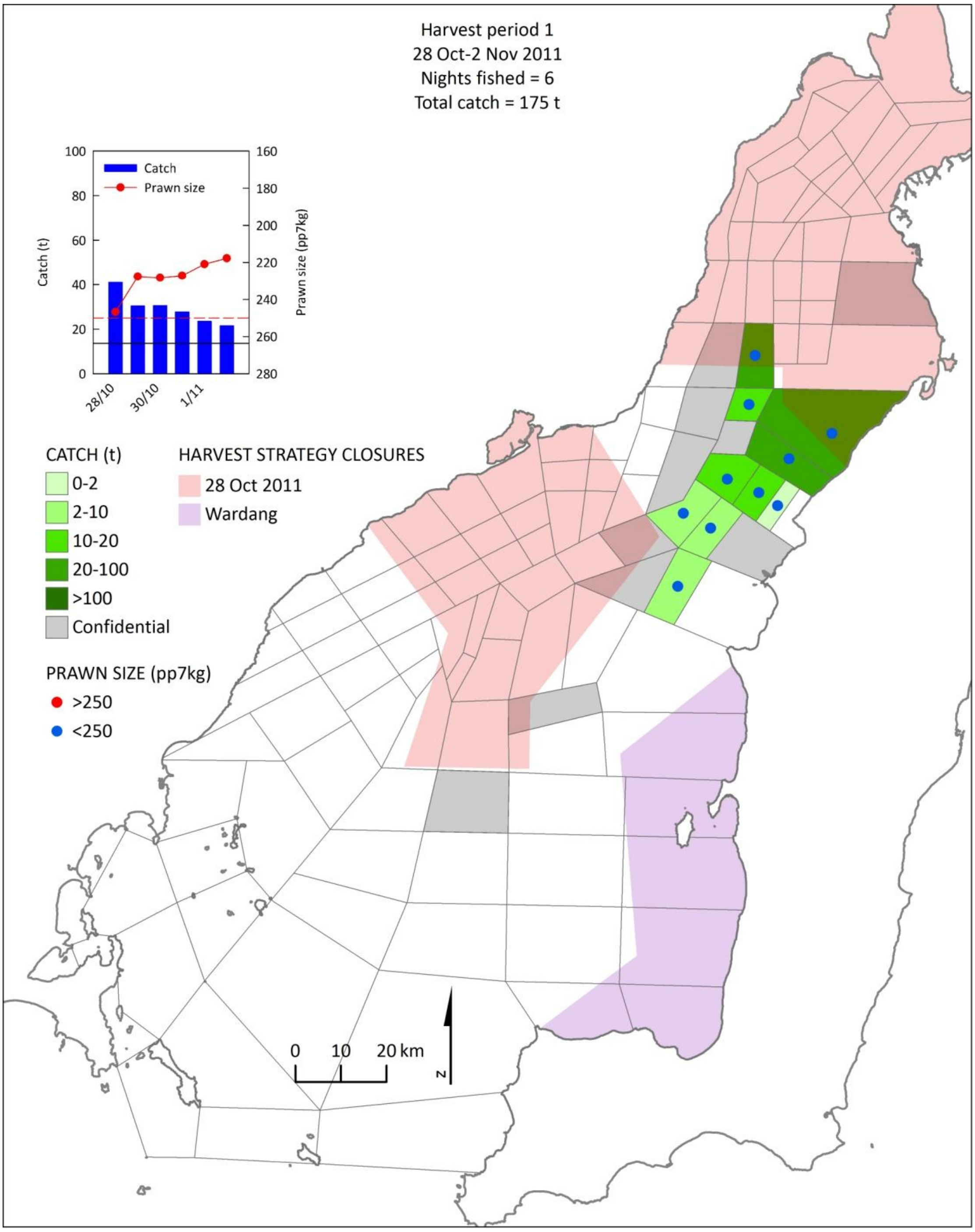


Figure 8.2 Commercial catch and mean size from blocks fished during harvest period 1, 2011/12. Shading indicates harvest strategy closures implemented on 28 October 2011. Inset graph displays daily total catch (blue bars), daily mean prawn size (red line), and at-sea decision rules for daily total catch (black horizontal line) and mean daily prawn size (red dashed line).

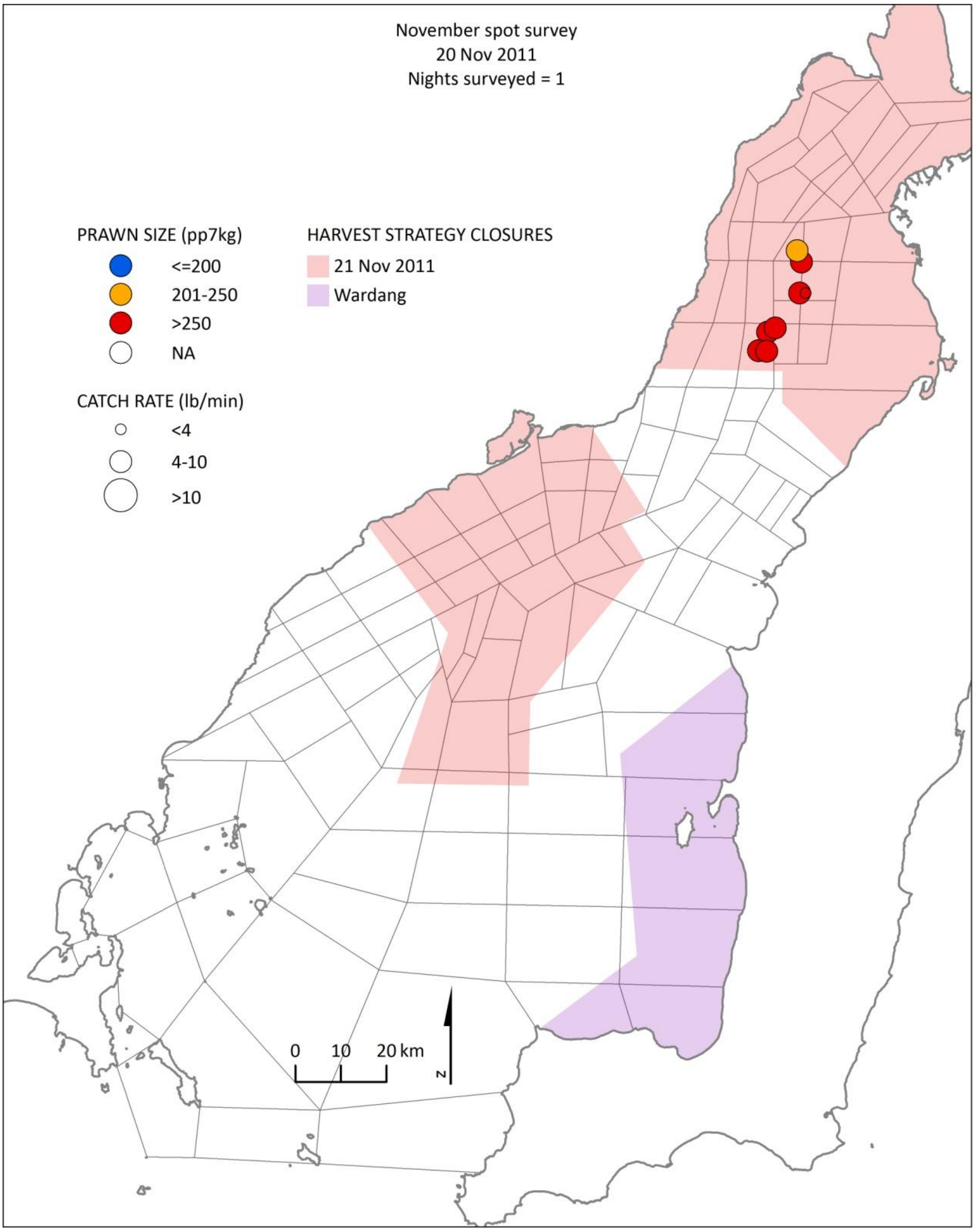


Figure 8.3 Catch rate and mean size during the November 2011 spot survey, prior to harvest period 2. Shading indicates areas subsequently closed to fishing.

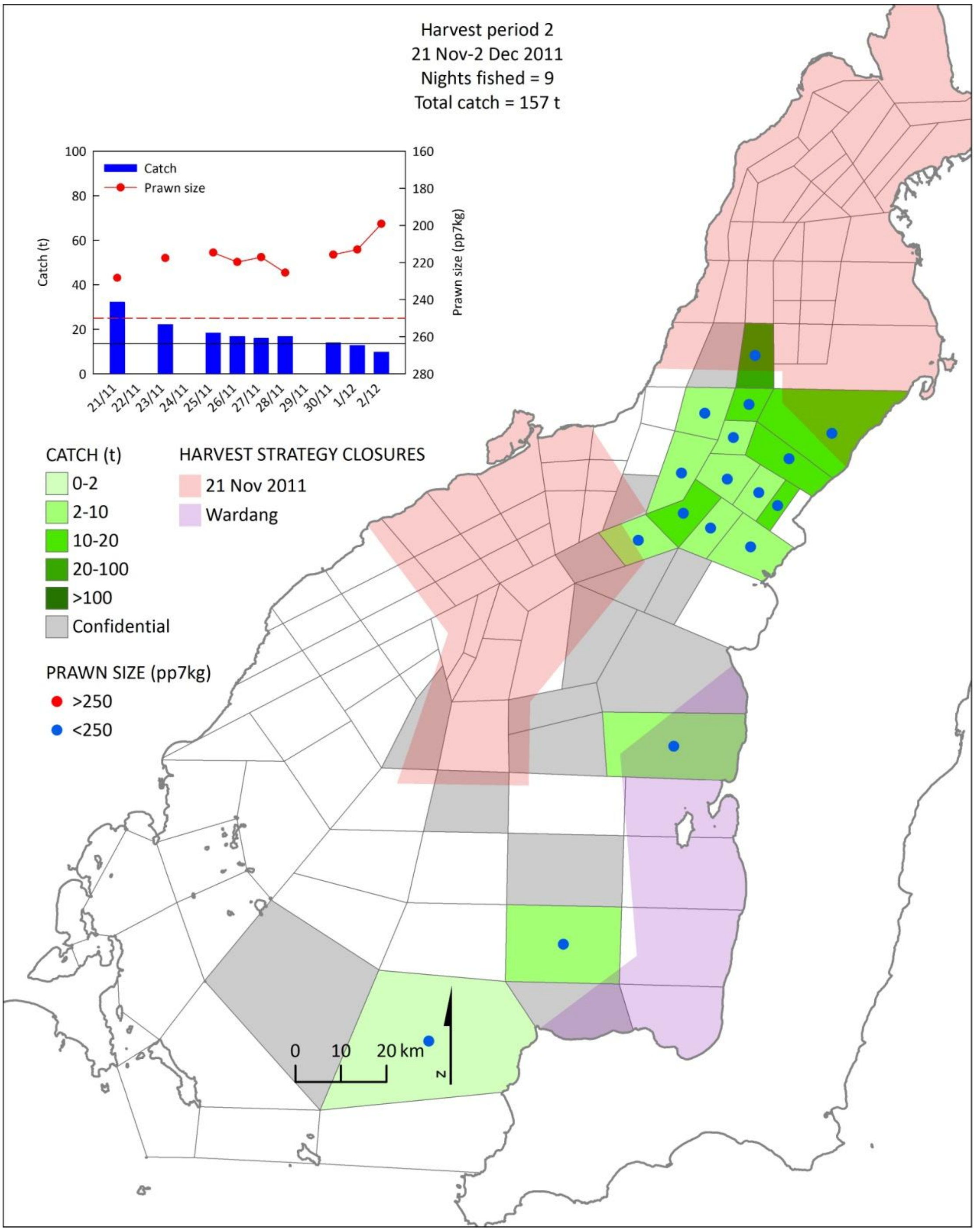


Figure 8.4 Commercial catch and mean size from blocks fished during harvest period 2, 2011/12. Shading indicates harvest strategy closures implemented on 21 November 2011. Inset graph displays daily total catch (blue bars), daily mean prawn size (red line), and at-sea decision rules for daily total catch (black horizontal line) and mean daily prawn size (red dashed line).

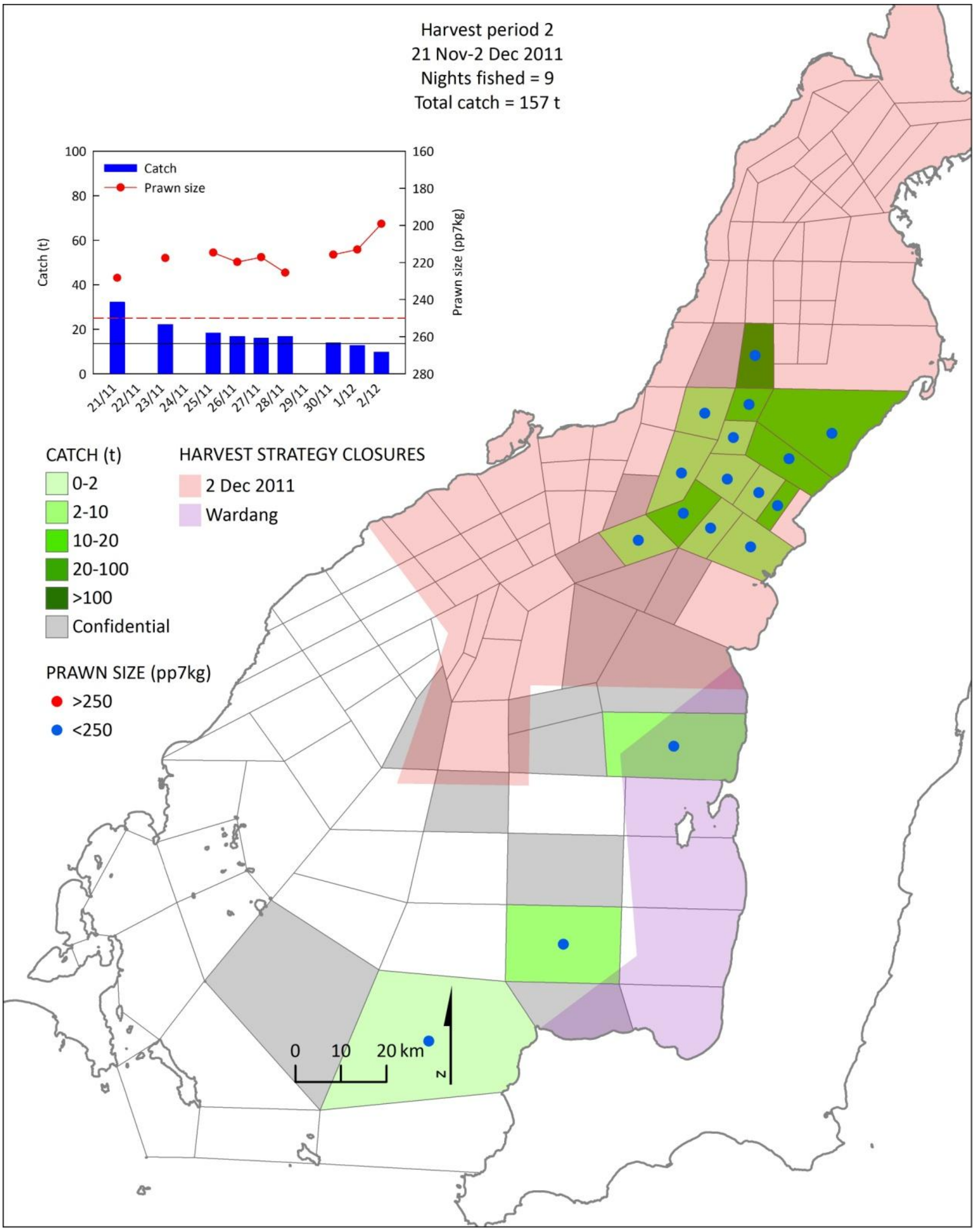


Figure 8.5 Commercial catch and mean size from blocks fished during harvest period 2, 2011/12. Shading indicates harvest strategy closures implemented on 2 December 2011. Inset graph displays daily total catch (blue bars), daily mean prawn size (red line), and at-sea decision rules for daily total catch (black horizontal line) and mean daily prawn size (red dashed line).

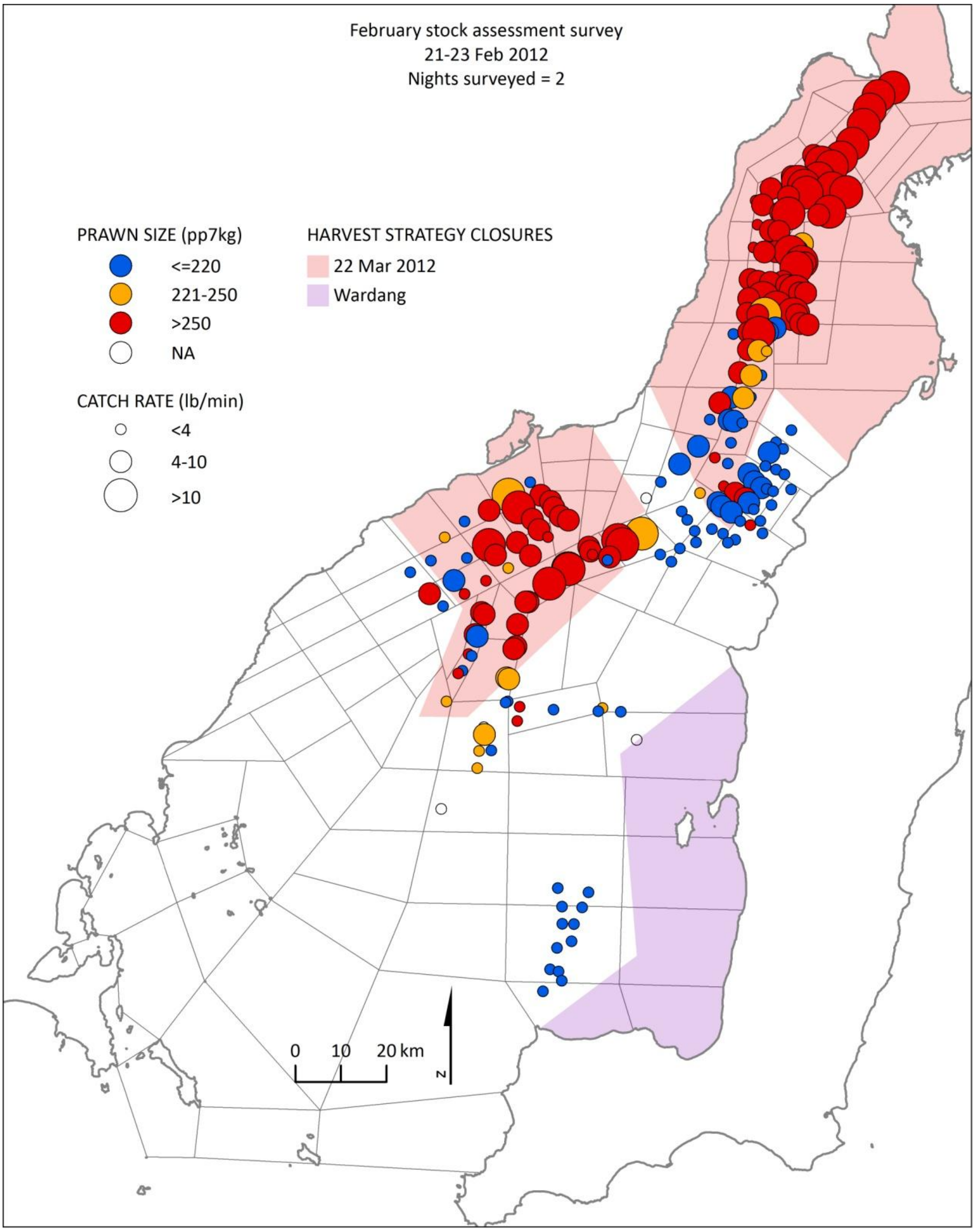


Figure 8.6 Catch rate and mean size during the February 2012 stock assessment survey, prior to harvest period 3. Shading indicates areas subsequently closed to fishing.

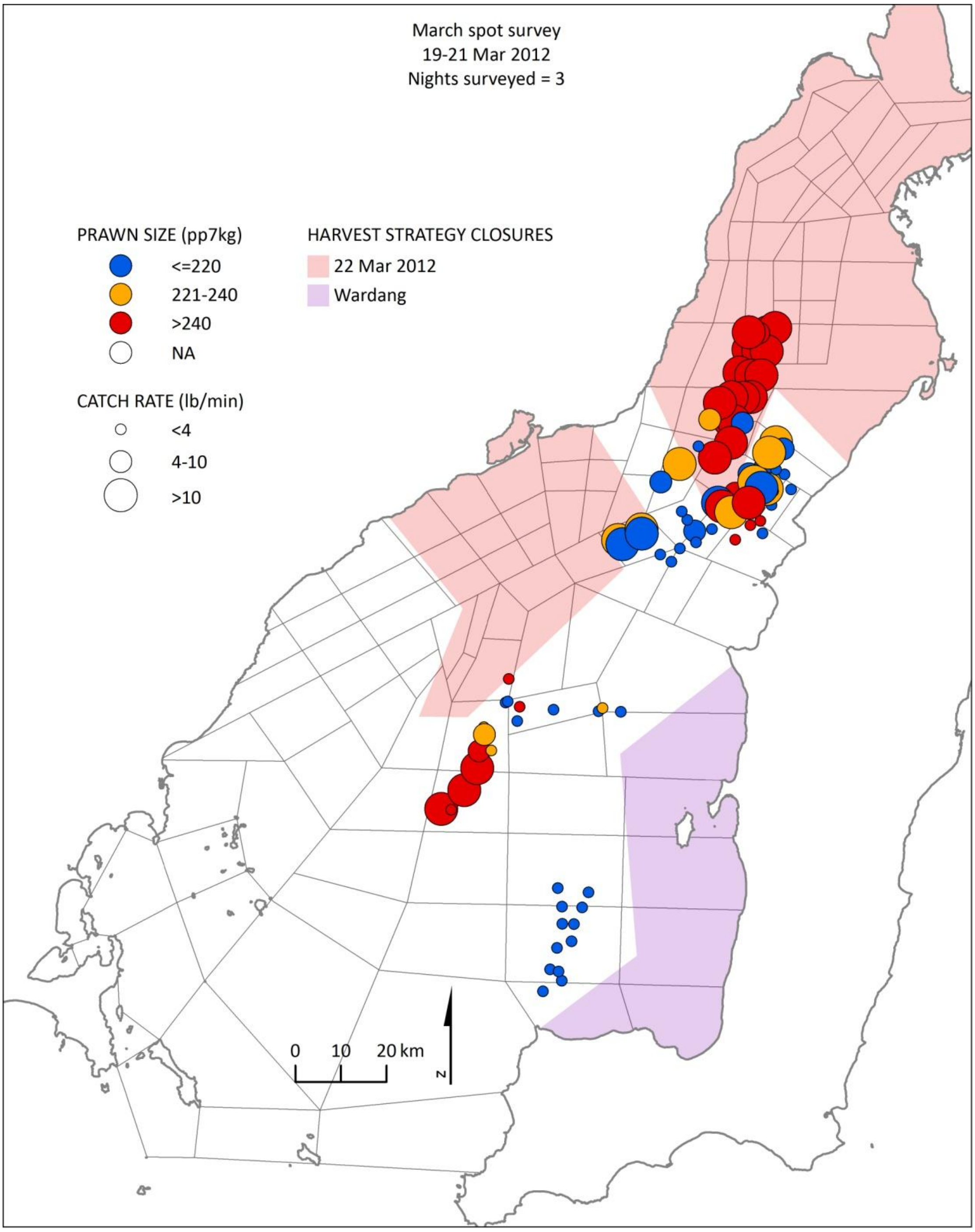


Figure 8.7 Catch rate and mean size during the March 2012 spot survey, prior to harvest period 3. Shading indicates areas subsequently closed to fishing.

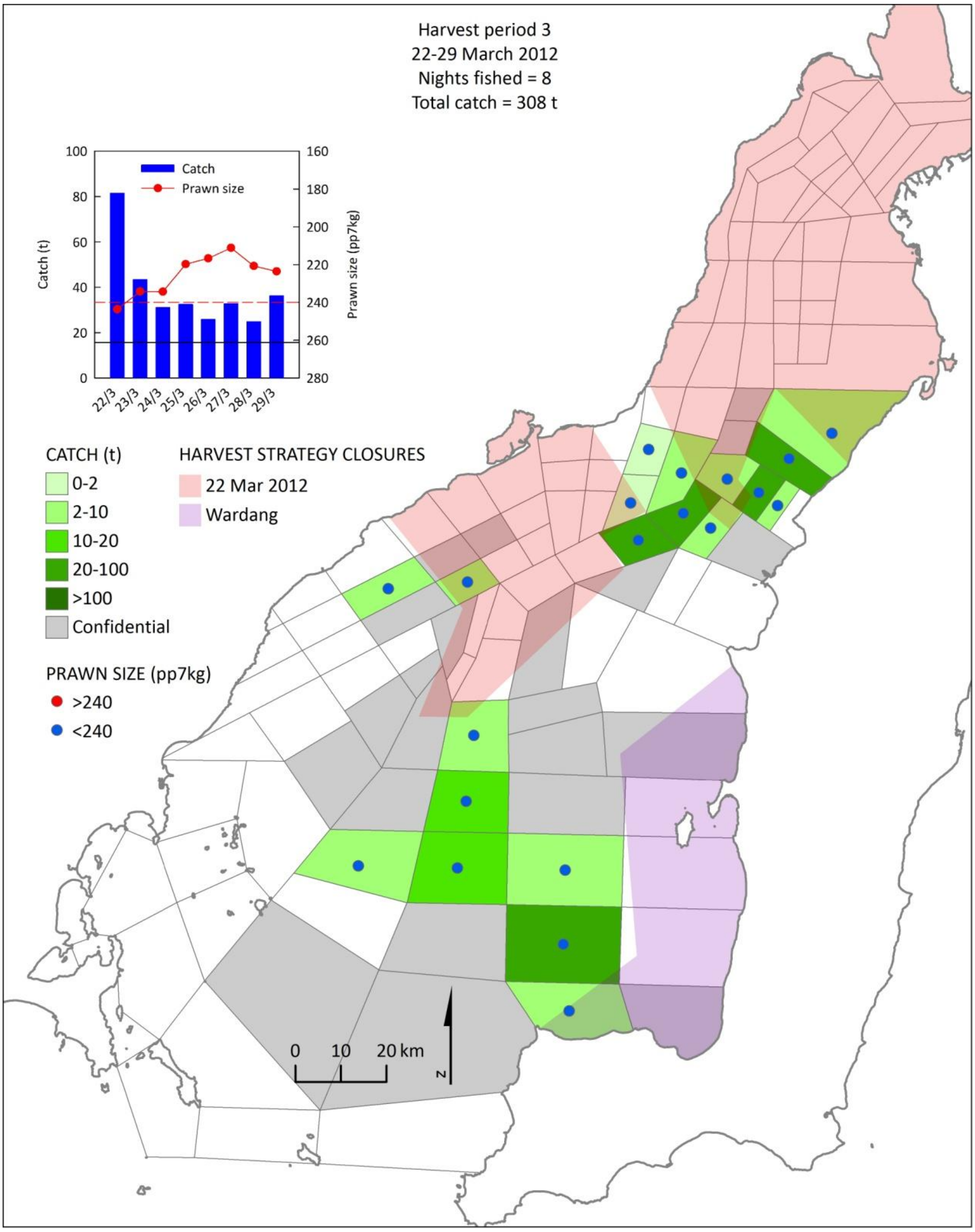


Figure 8.8 Commercial catch and mean size from blocks fished during harvest period 3, 2011/12. Shading indicates harvest strategy closures implemented on 22 March 2012. Inset graph displays daily total catch (blue bars), daily mean prawn size (red line), and at-sea decision rules for daily total catch (black horizontal line) and mean daily prawn size (red dashed line).

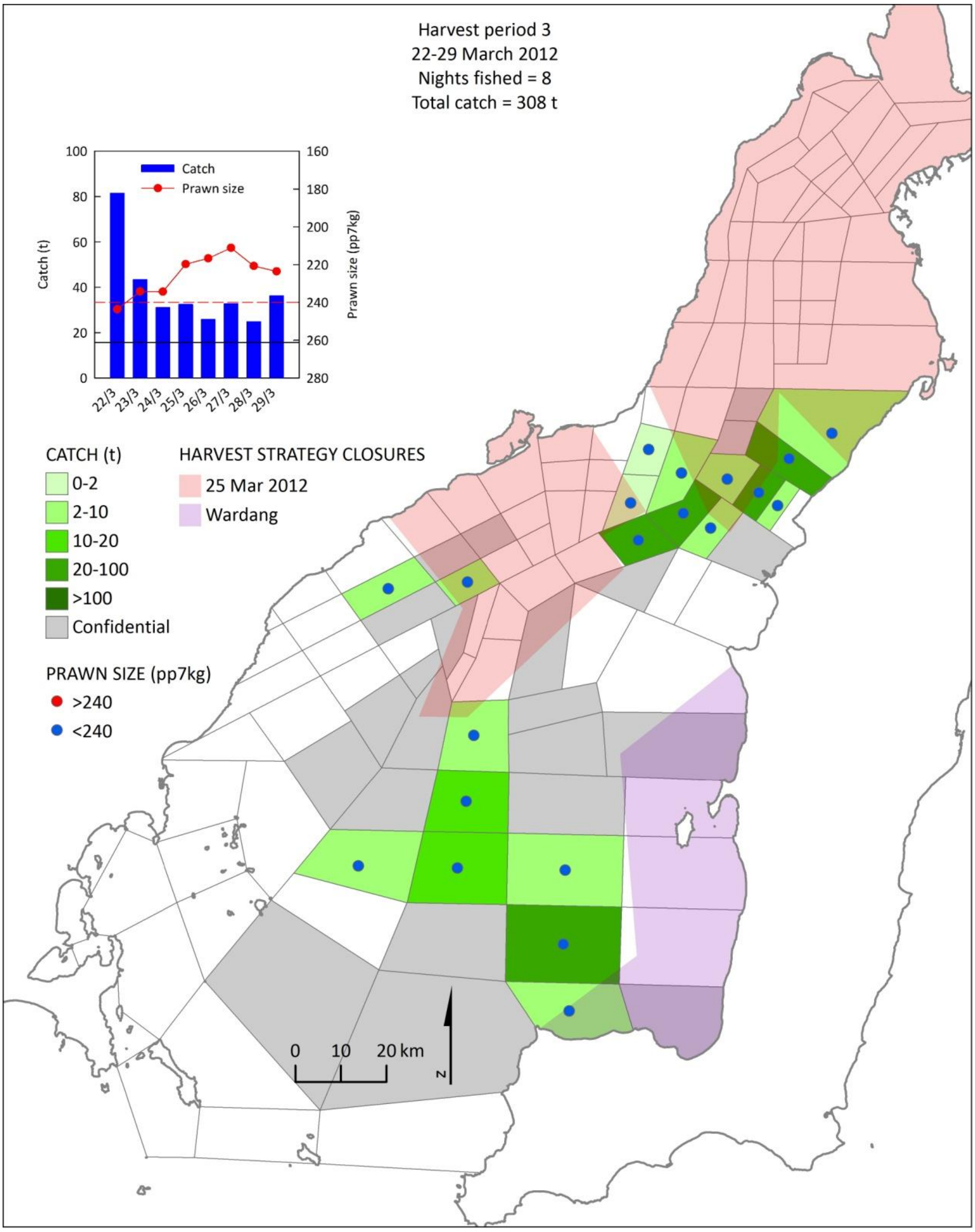


Figure 8.9 Commercial catch and mean size from blocks fished during harvest period 3, 2011/12. Shading indicates harvest strategy closures implemented on 25 March 2012. Inset graph displays daily total catch (blue bars), daily mean prawn size (red line), and at-sea decision rules for daily total catch (black horizontal line) and mean daily prawn size (red dashed line).

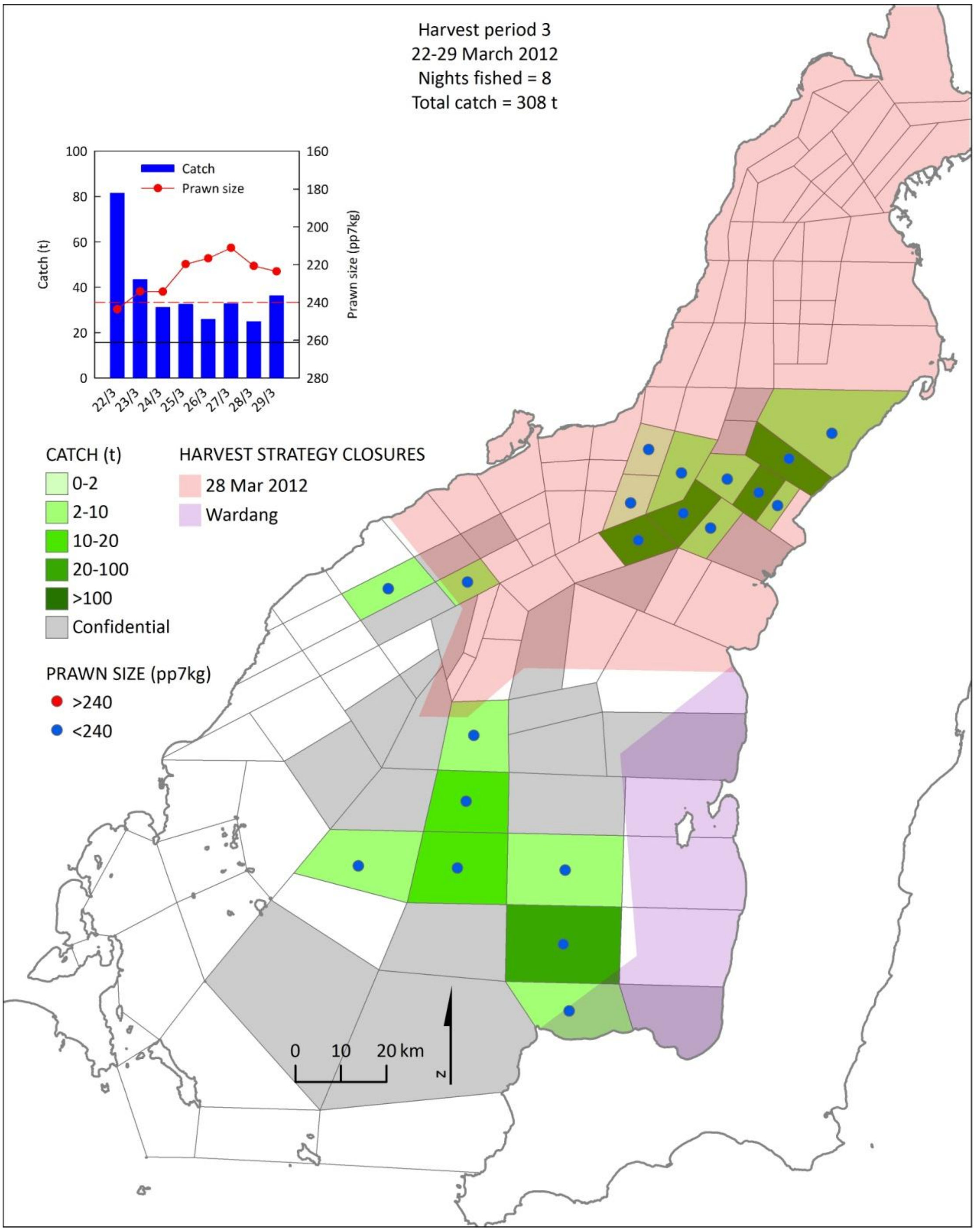


Figure 8.10 Commercial catch and mean size from blocks fished during harvest period 3, 2011/12. Shading indicates harvest strategy closures implemented on 28 March 2012. Inset graph displays daily total catch (blue bars), daily mean prawn size (red line), and at-sea decision rules for daily total catch (black horizontal line) and mean daily prawn size (red dashed line).

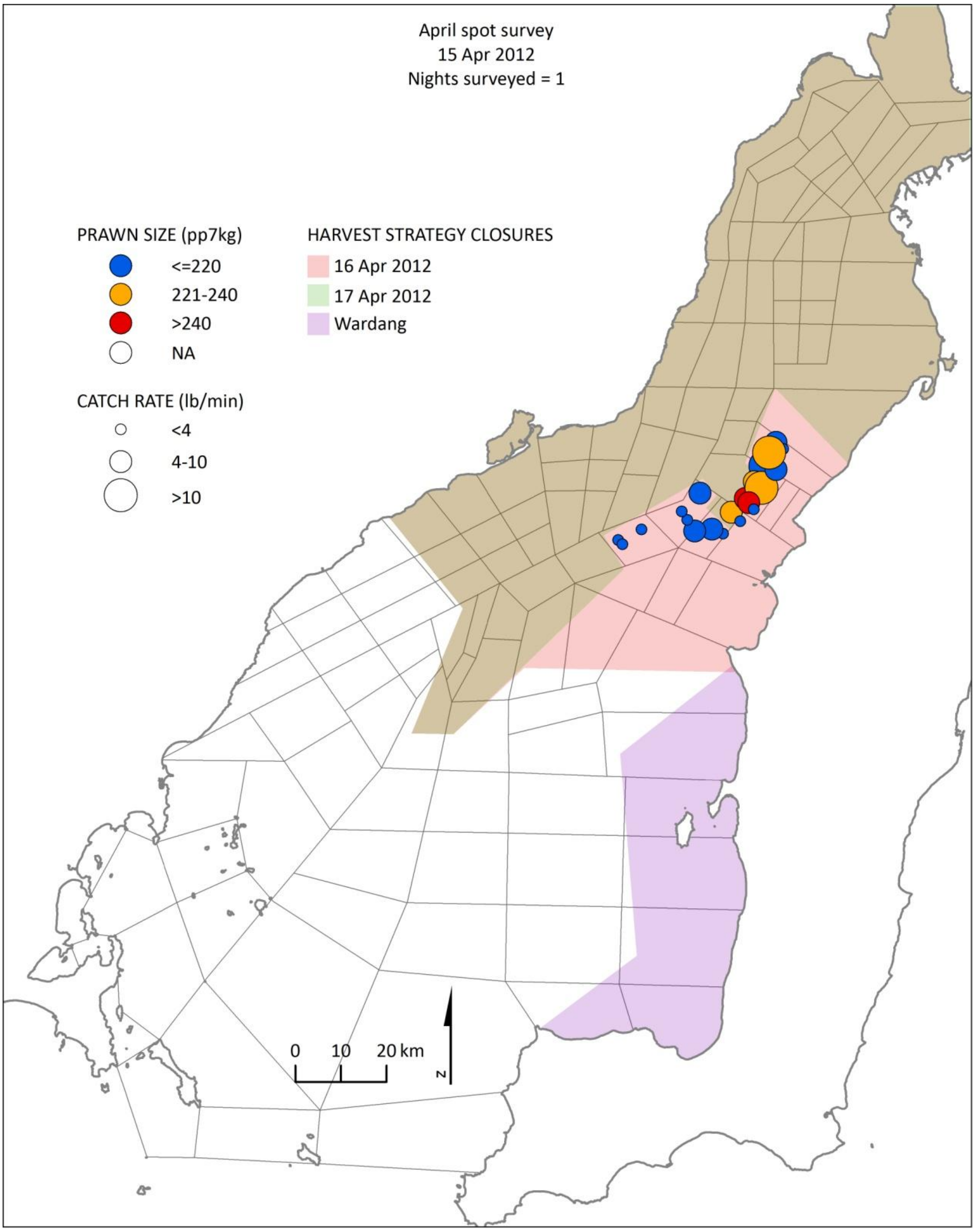


Figure 8.11 Catch rate and mean size during the April 2012 spot survey, prior to harvest period 4. Shading indicates areas subsequently closed to fishing.

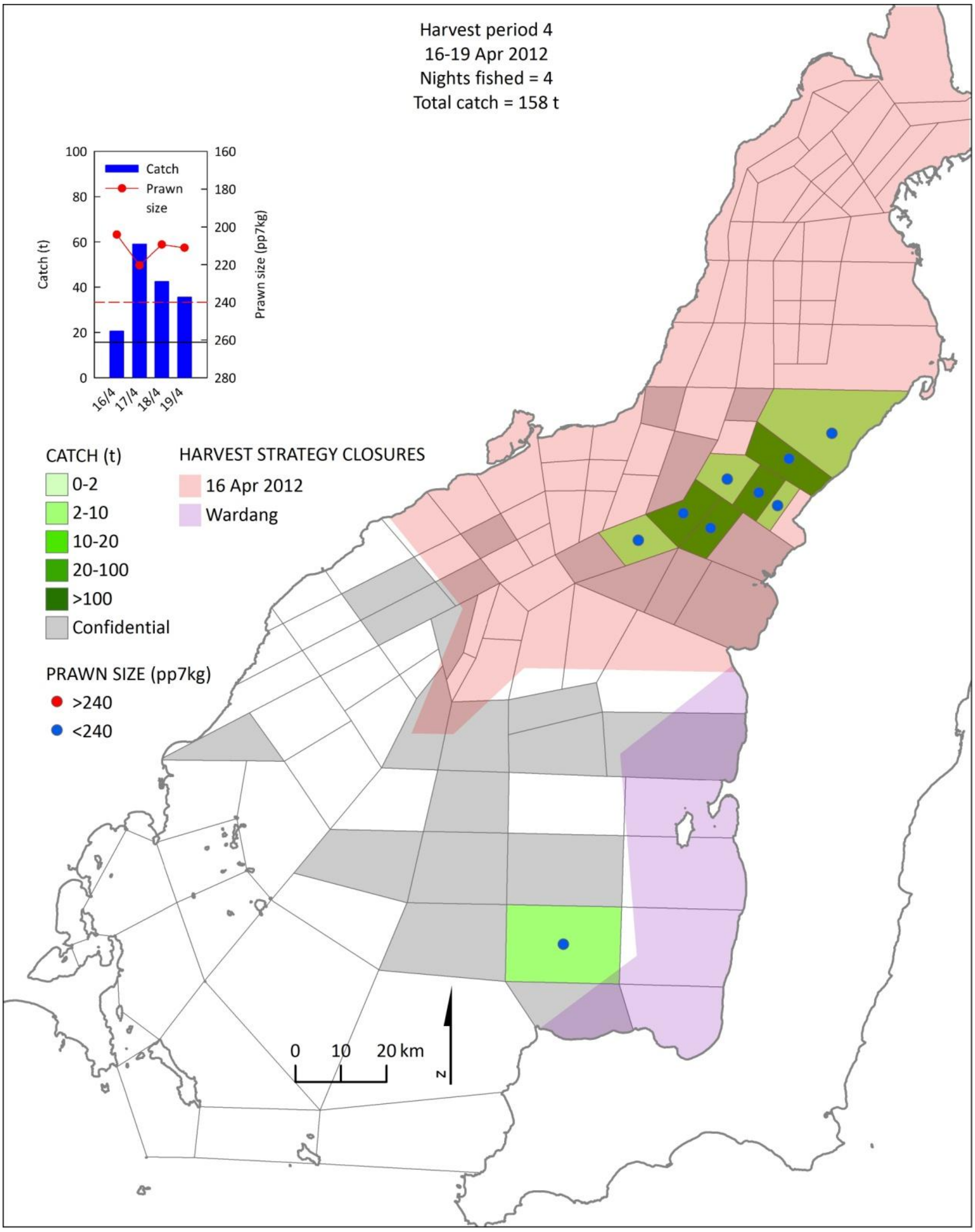


Figure 8.12 Commercial catch and mean size from blocks fished during harvest period 4, 2011/12. Shading indicates harvest strategy closures implemented on 16 April 2012. Inset graph displays daily total catch (blue bars), daily mean prawn size (red line), and at-sea decision rules for daily total catch (black horizontal line) and mean daily prawn size (red dashed line).

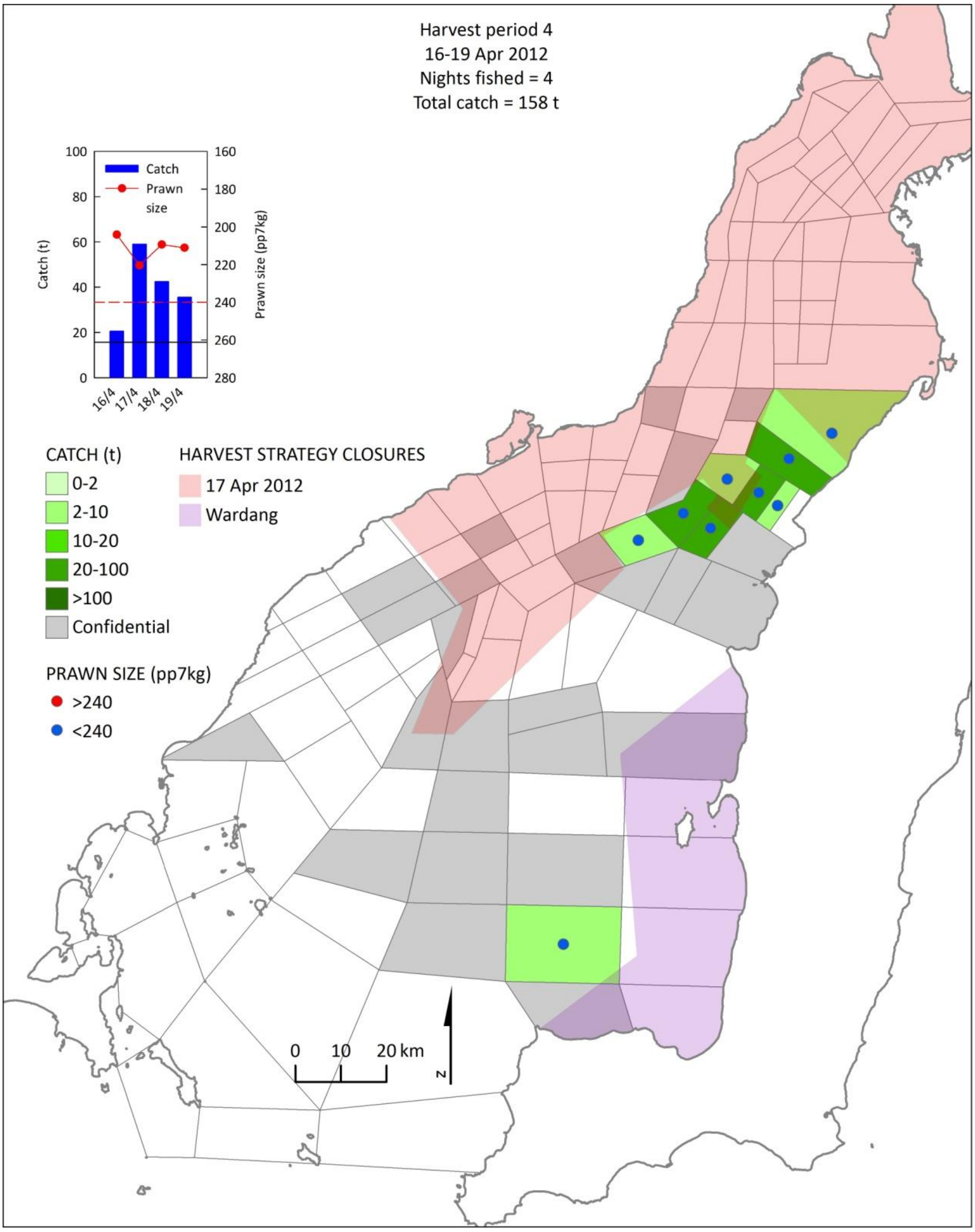


Figure 8.13 Commercial catch and mean size from blocks fished during harvest period 4, 2011/12. Shading indicates harvest strategy closures implemented on 17 April 2012. Inset graph displays daily total catch (blue bars), daily mean prawn size (red line), and at-sea decision rules for daily total catch (black horizontal line) and mean daily prawn size (red dashed line).

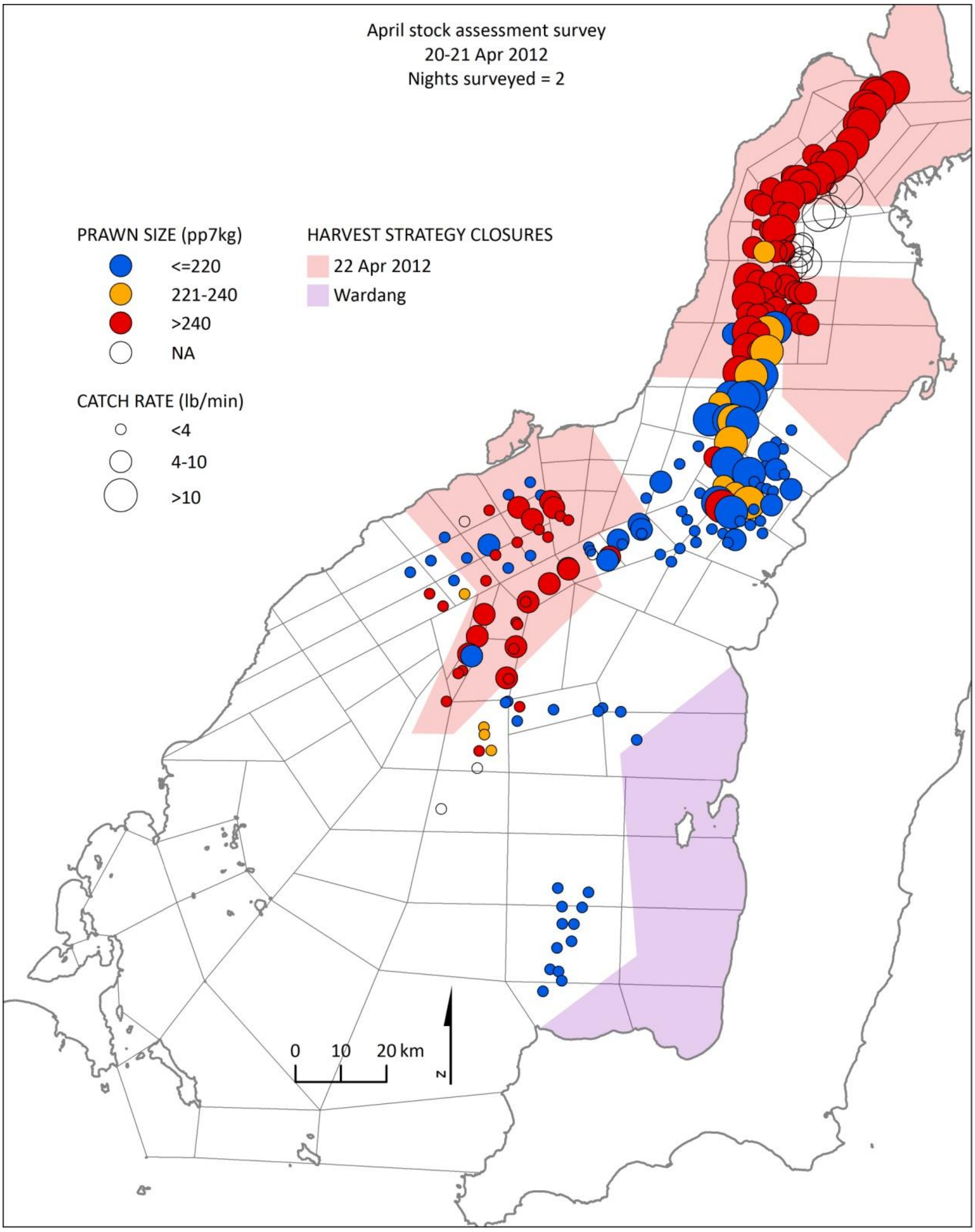


Figure 8.14 Catch rate and mean size during the April 2012 stock assessment survey, prior to harvest period 5. Shading indicates areas subsequently closed to fishing.

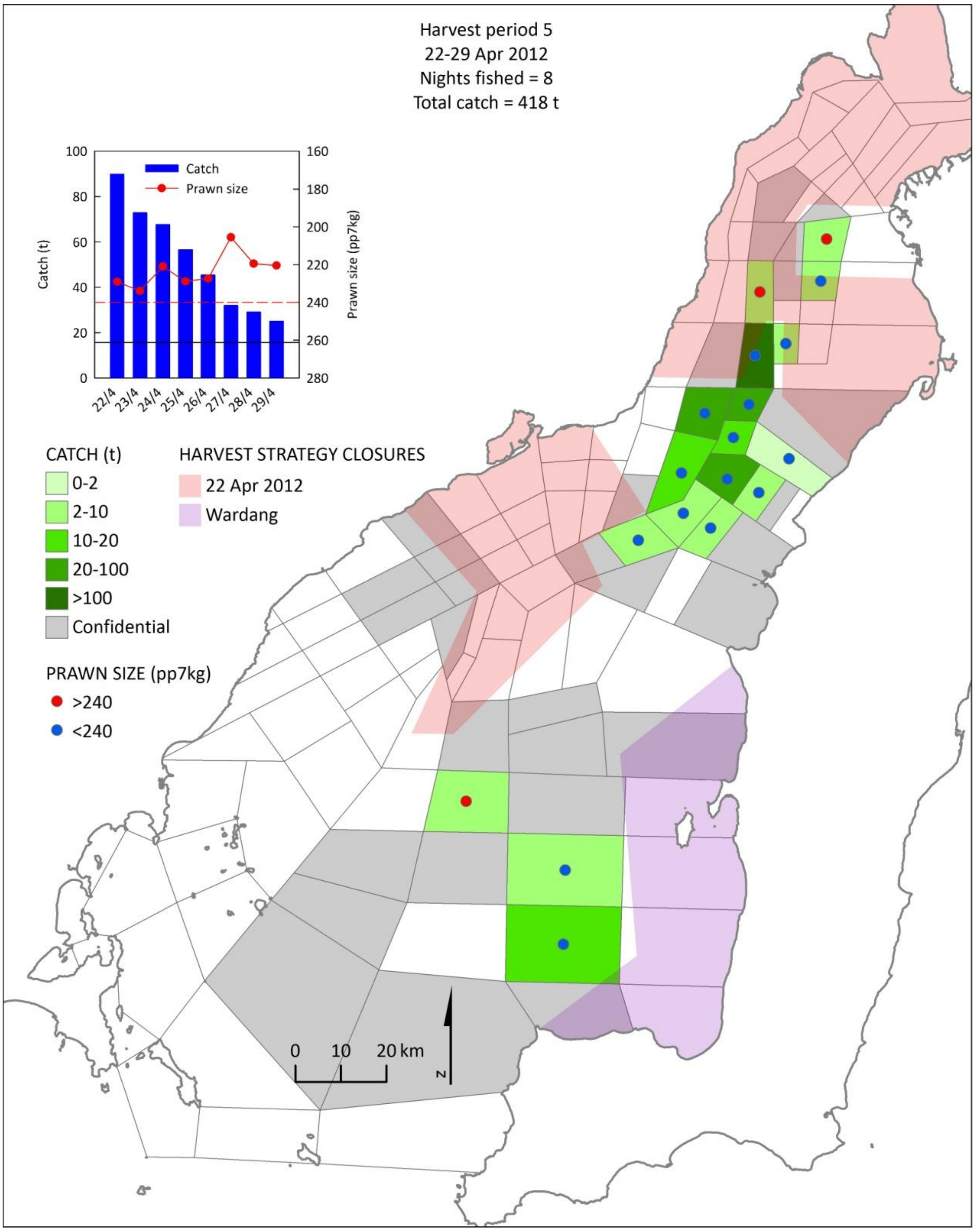


Figure 8.15 Commercial catch and mean size from blocks fished during harvest period 5, 2011/12. Shading indicates harvest strategy closures implemented on 22 April 2012. Inset graph displays daily total catch (blue bars), daily mean prawn size (red line), and at-sea decision rules for daily total catch (black horizontal line) and mean daily prawn size (red dashed line).

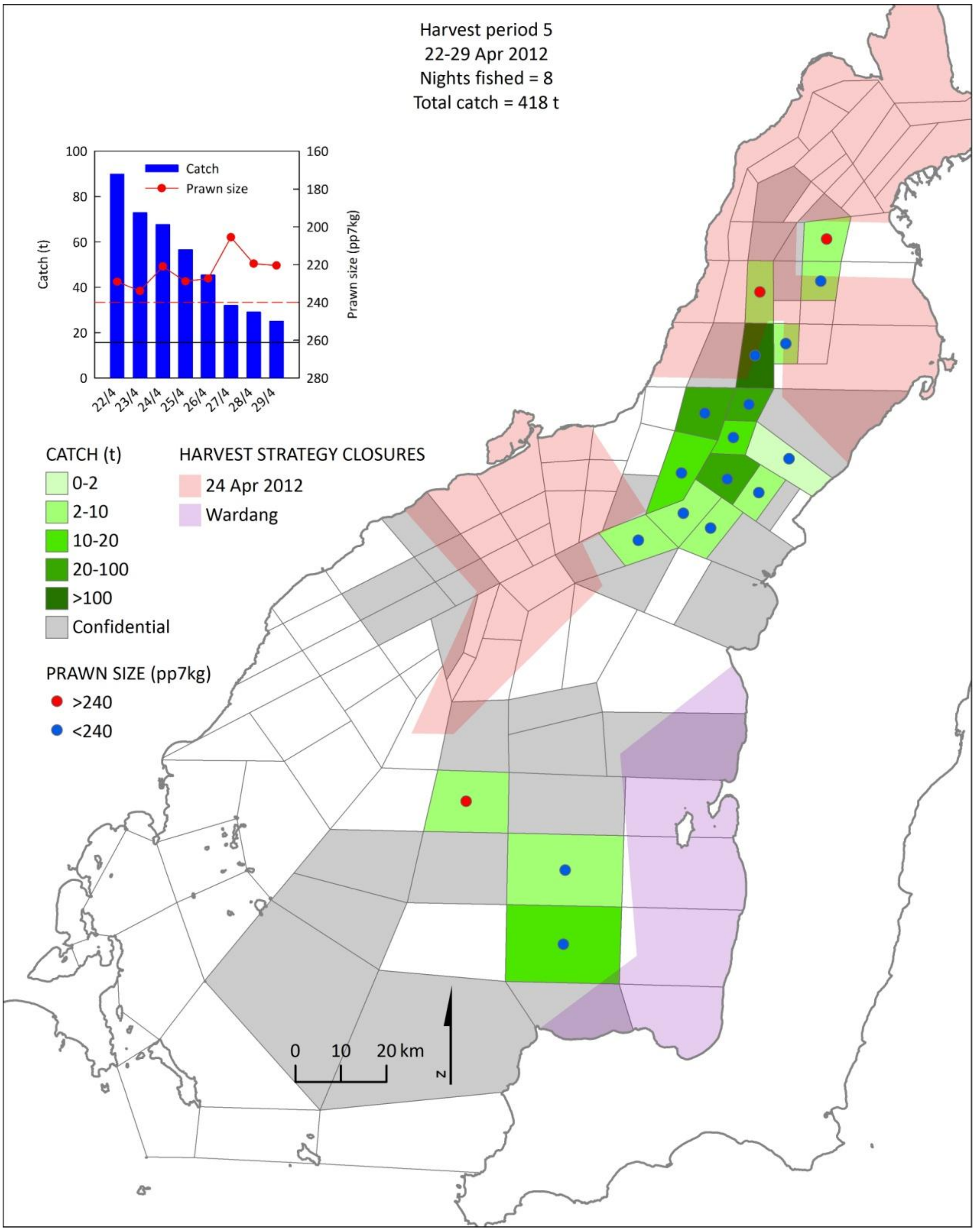


Figure 8.16 Commercial catch and mean size from blocks fished during harvest period 5, 2011/12. Shading indicates harvest strategy closures implemented on 24 April 2012. Inset graph displays daily total catch (blue bars), daily mean prawn size (red line), and at-sea decision rules for daily total catch (black horizontal line) and mean daily prawn size (red dashed line).

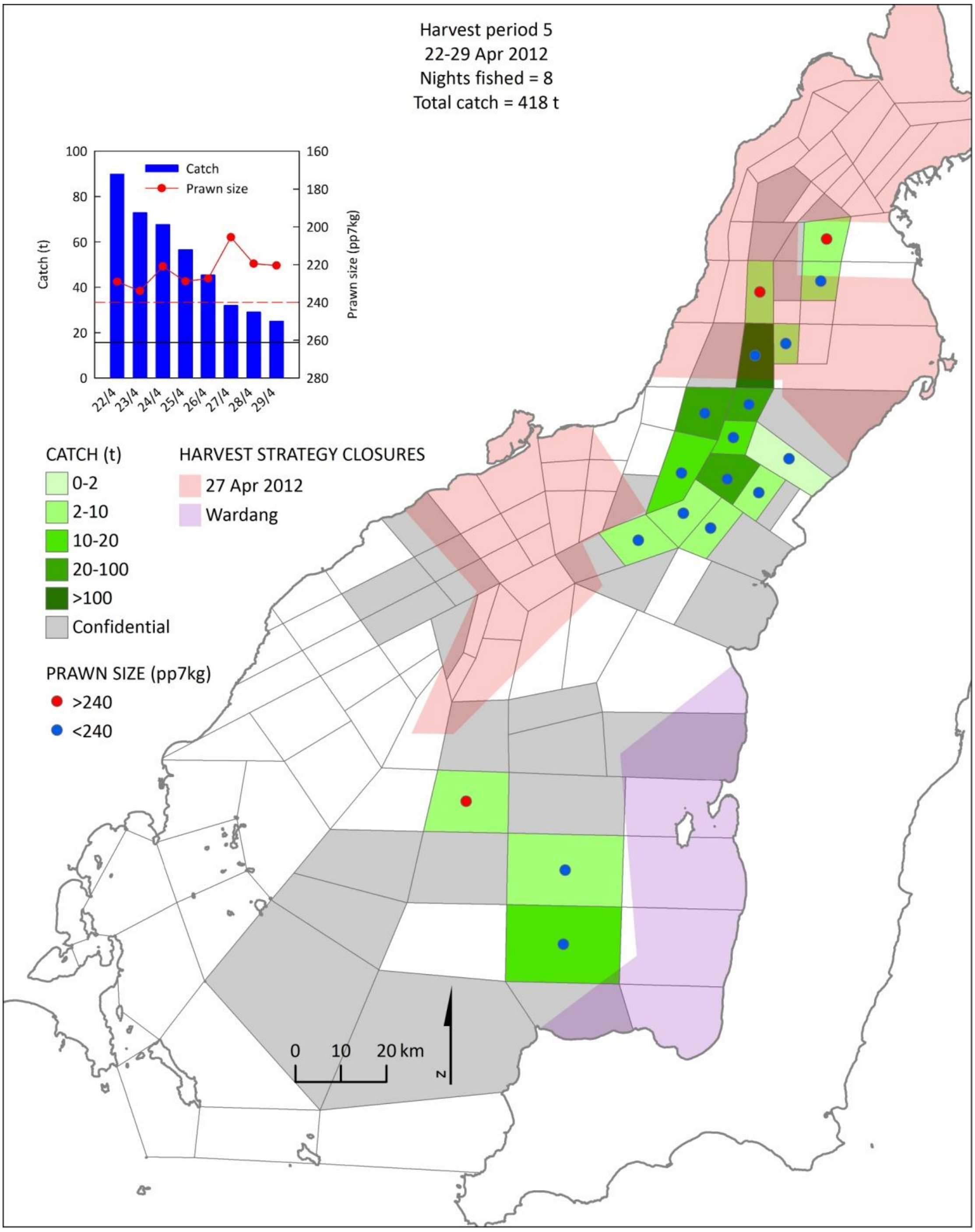


Figure 8.17 Commercial catch and mean size from blocks fished during harvest period 5, 2011/12. Shading indicates harvest strategy closures implemented on 27 April 2012. Inset graph displays daily total catch (blue bars), daily mean prawn size (red line), and at-sea decision rules for daily total catch (black horizontal line) and mean daily prawn size (red dashed line).

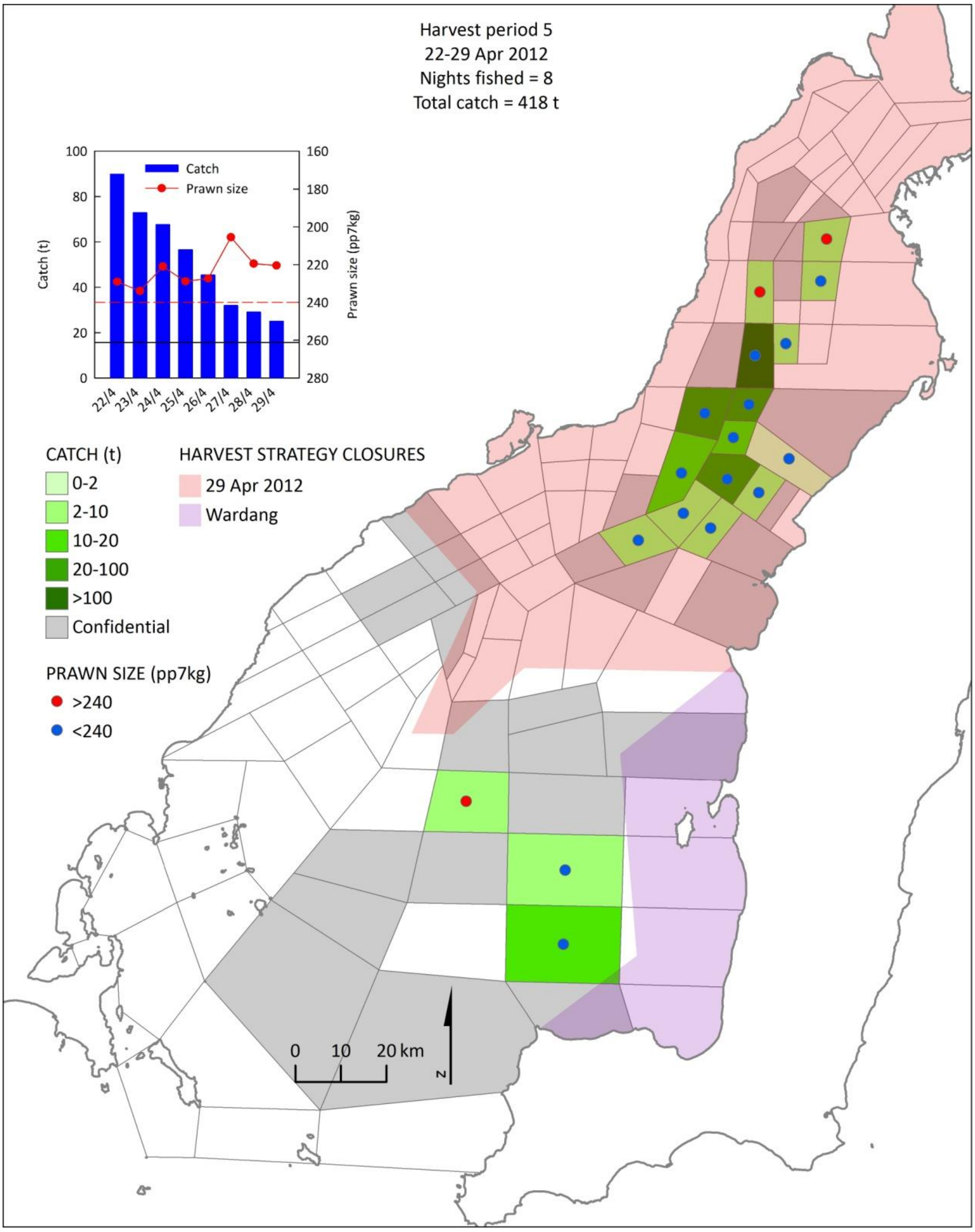


Figure 8.18 Commercial catch and mean size from blocks fished during harvest period 5, 2011/12. Shading indicates harvest strategy closures implemented on 29 April 2012. Inset graph displays daily total catch (blue bars), daily mean prawn size (red line), and at-sea decision rules for daily total catch (black horizontal line) and mean daily prawn size (red dashed line).

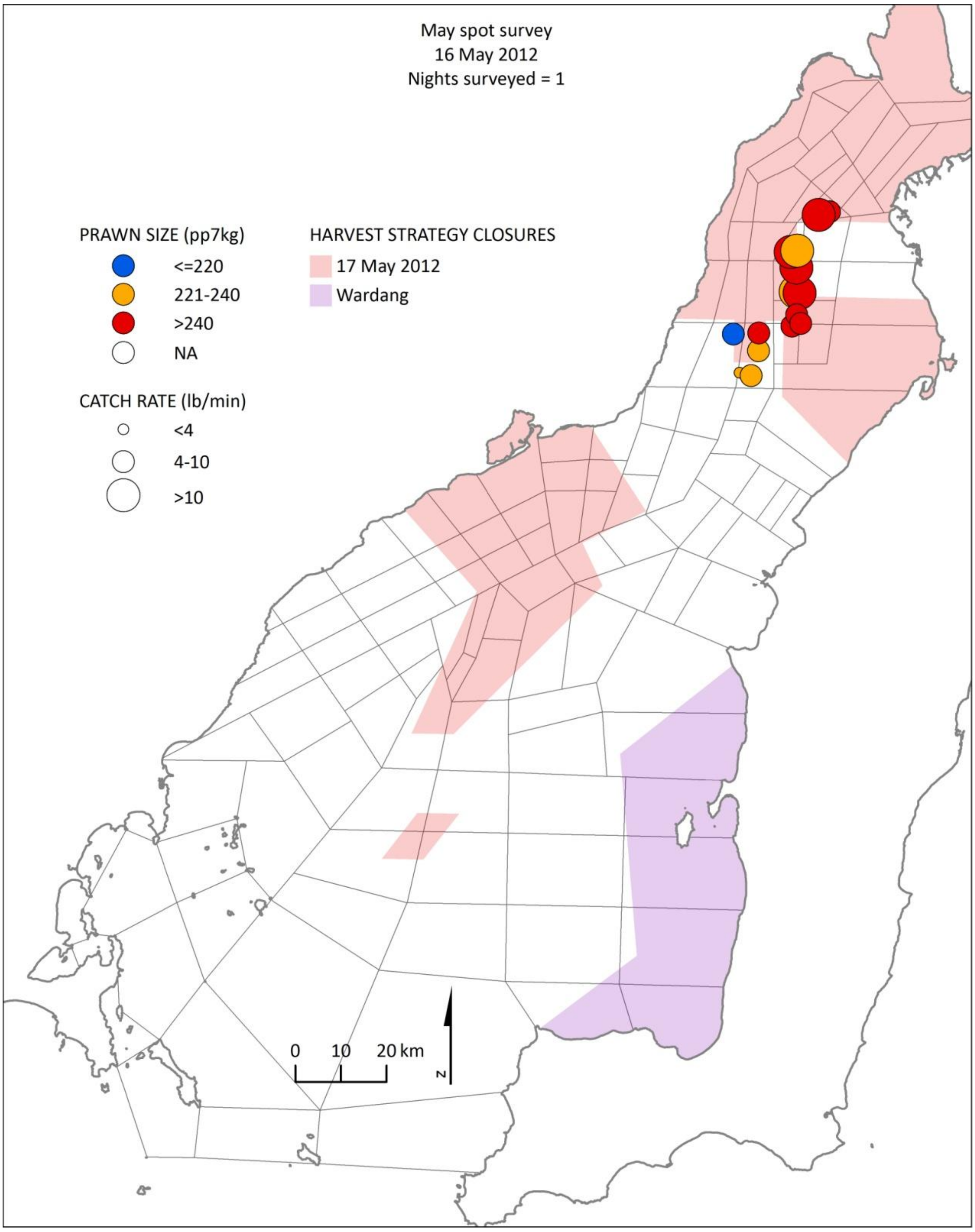


Figure 8.19 Catch rate and mean size during the May 2012 spot survey, prior to harvest period 6. Shading indicates areas subsequently closed to fishing.

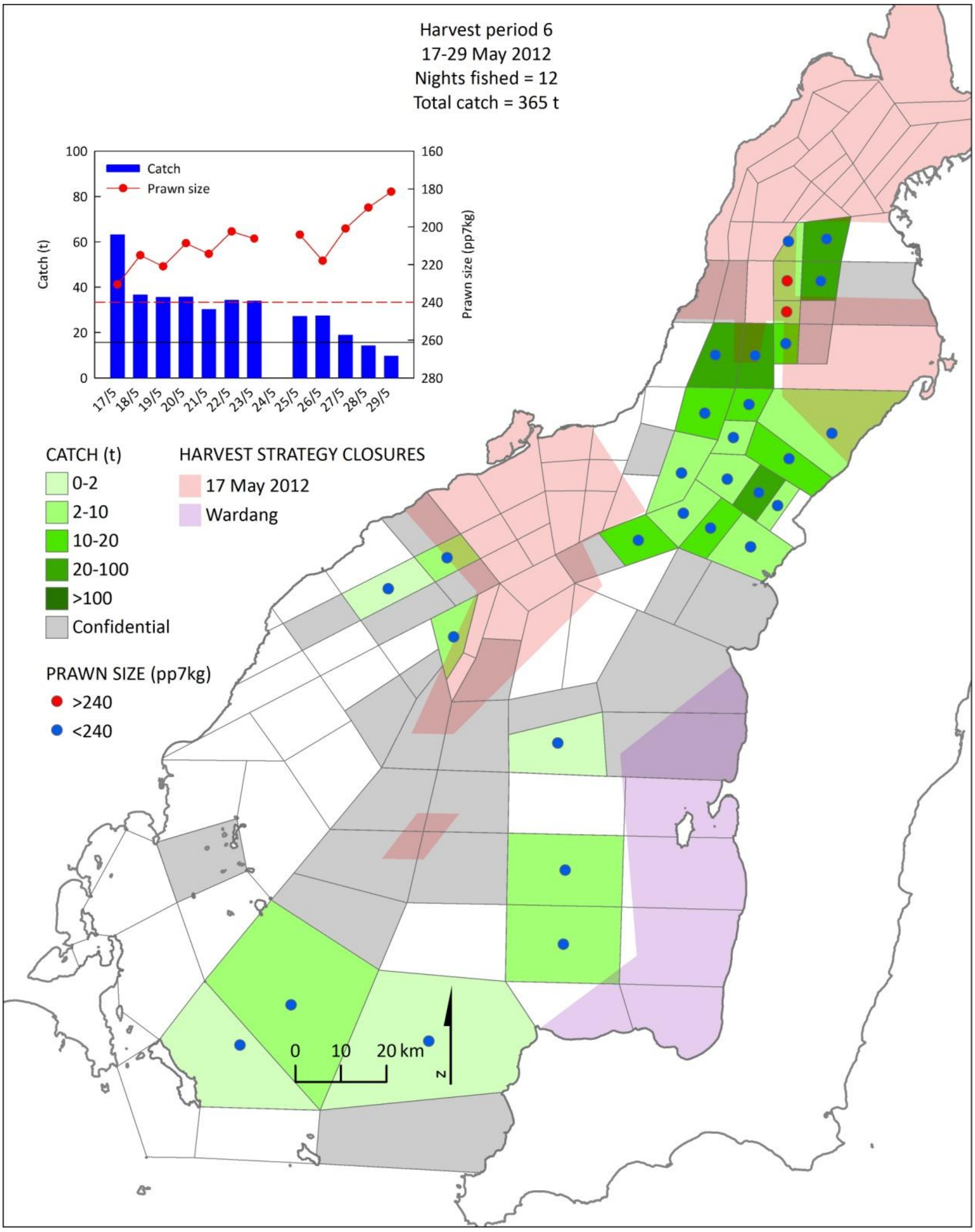


Figure 8.20 Commercial catch and mean size from blocks fished during harvest period 6, 2011/12. Shading indicates harvest strategy closures implemented on 17 May 2012. Inset graph displays daily total catch (blue bars), daily mean prawn size (red line), and at-sea decision rules for daily total catch (black horizontal line) and mean daily prawn size (red dashed line).

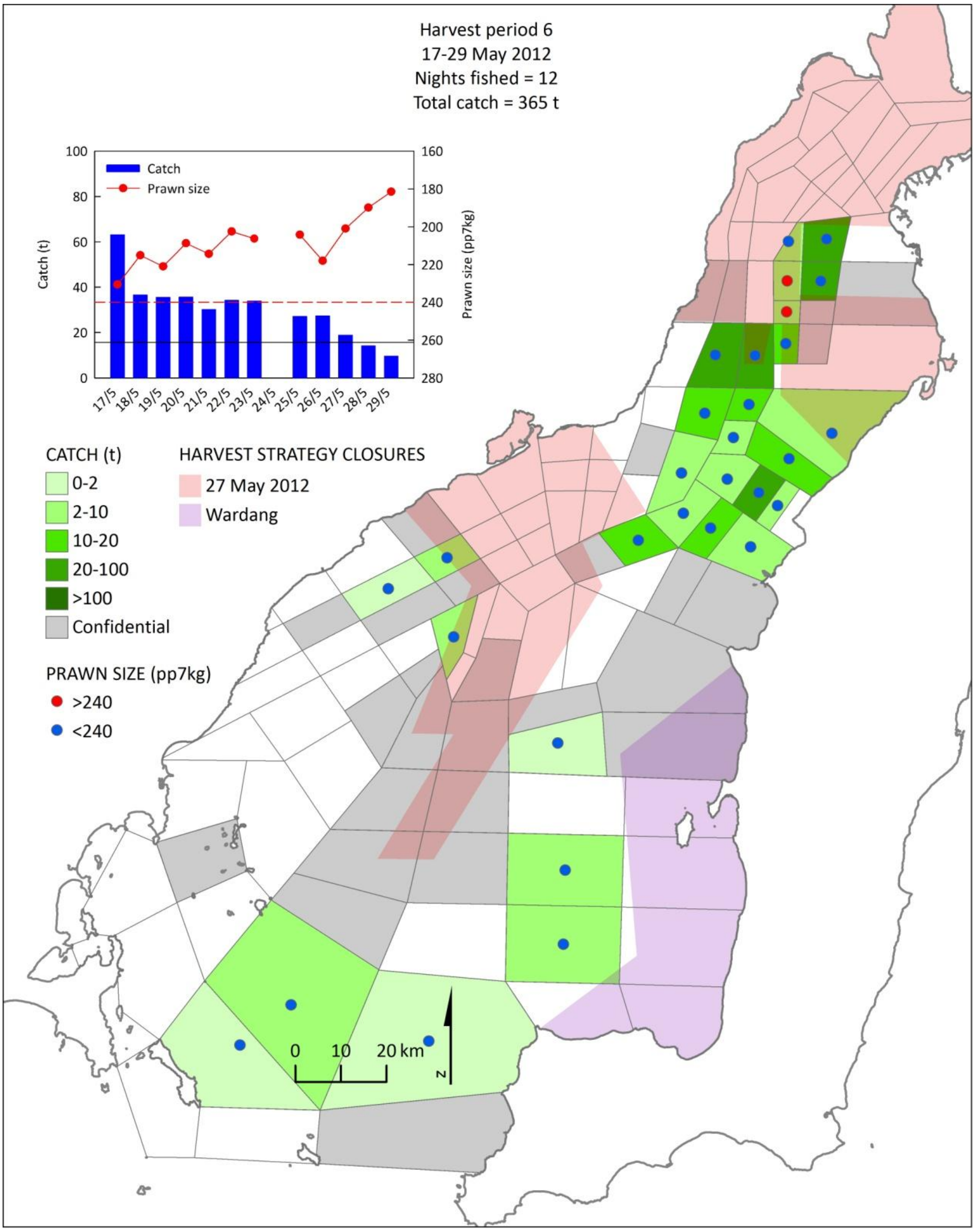


Figure 8.21 Commercial catch and mean size from blocks fished during harvest period 6, 2011/12. Shading indicates harvest strategy closures implemented on 27 May 2012. Inset graph displays daily total catch (blue bars), daily mean prawn size (red line), and at-sea decision rules for daily total catch (black horizontal line) and mean daily prawn size (red dashed line).

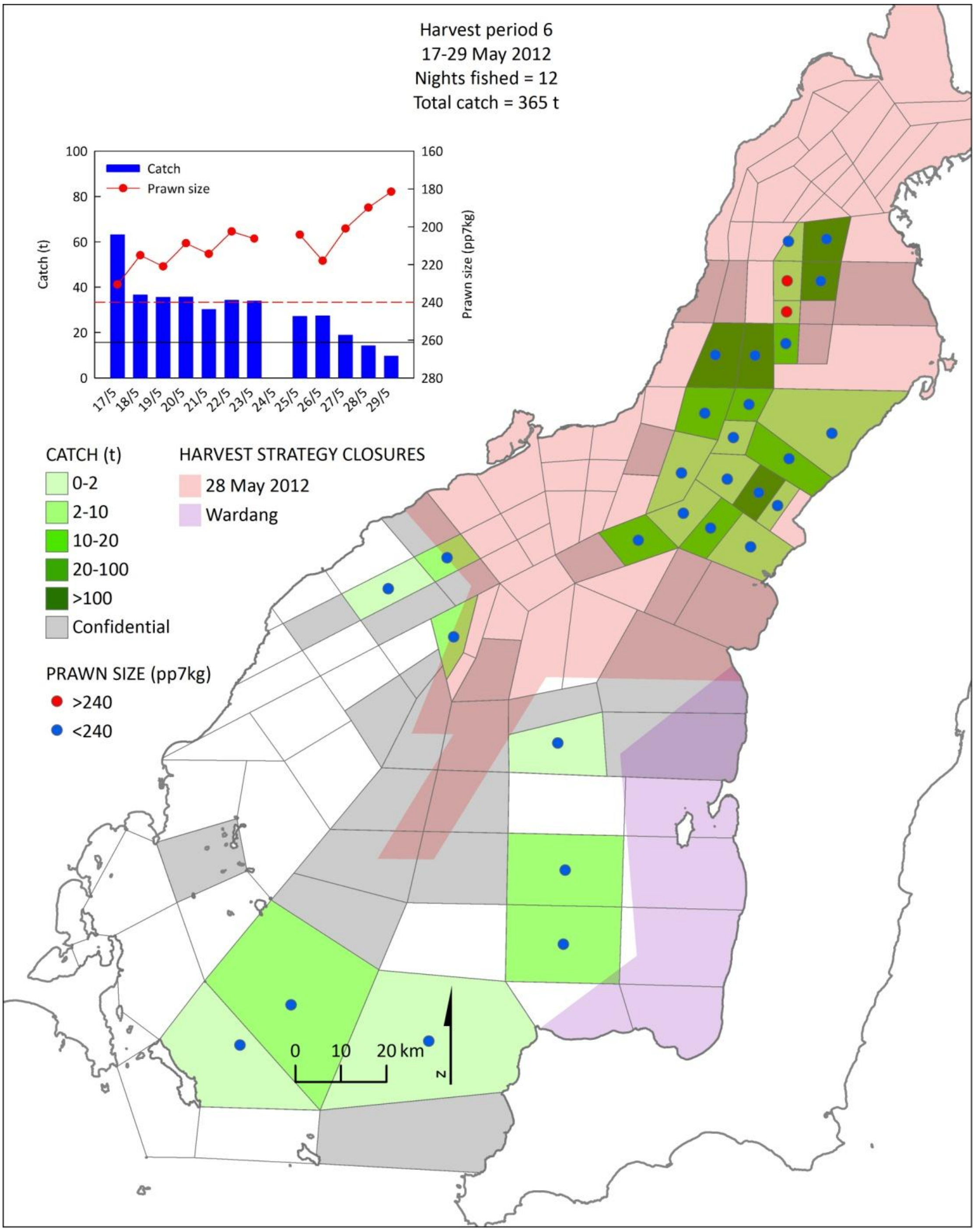


Figure 8.22 Commercial catch and mean size from blocks fished during harvest period 6, 2011/12. Shading indicates harvest strategy closures implemented on 28 May 2012. Inset graph displays daily total catch (blue bars), daily mean prawn size (red line), and at-sea decision rules for daily total catch (black horizontal line) and mean daily prawn size (red dashed line).

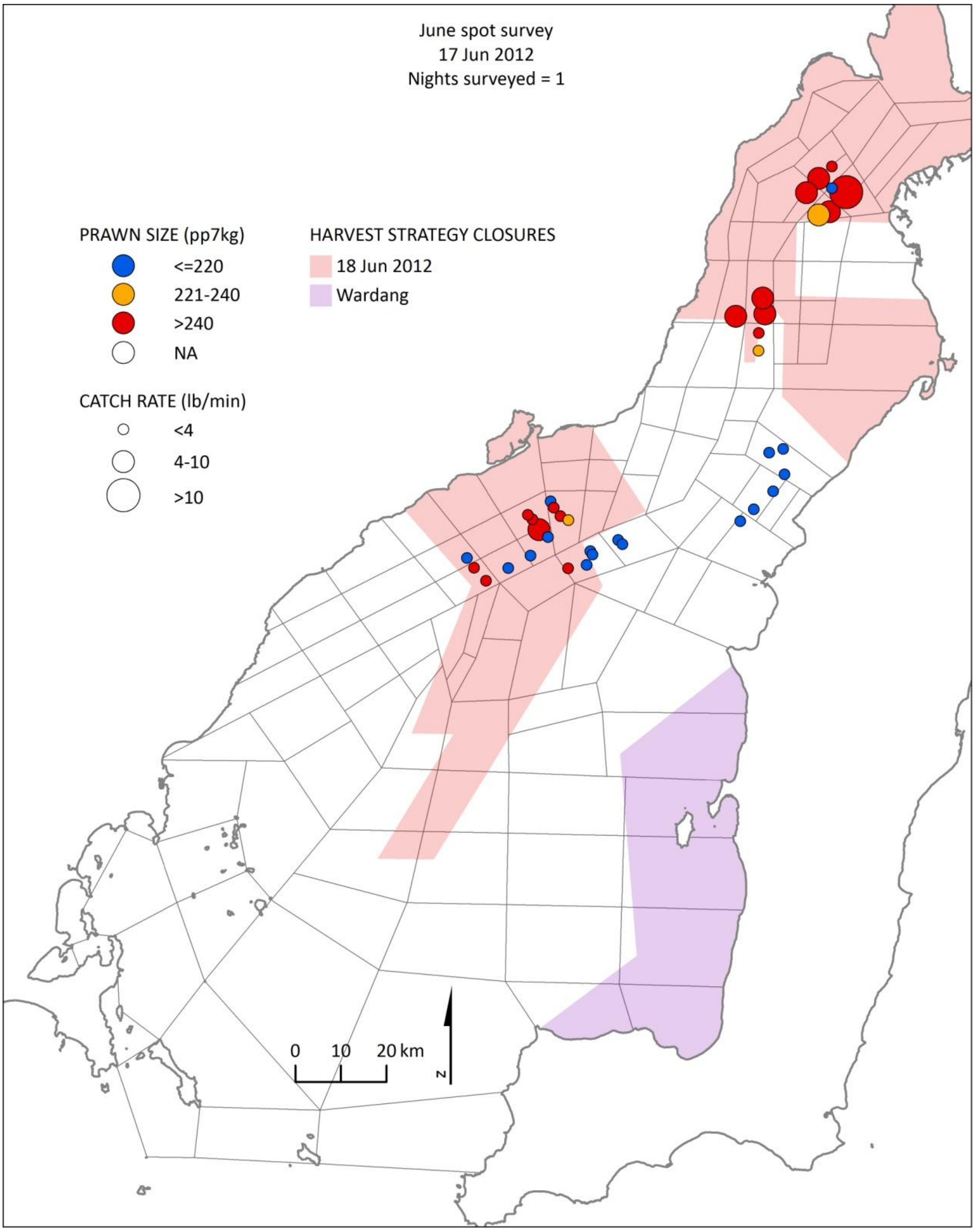


Figure 8.23 Catch rate and mean size during the June 2012 spot survey, prior to harvest period 7. Shading indicates areas subsequently closed to fishing.

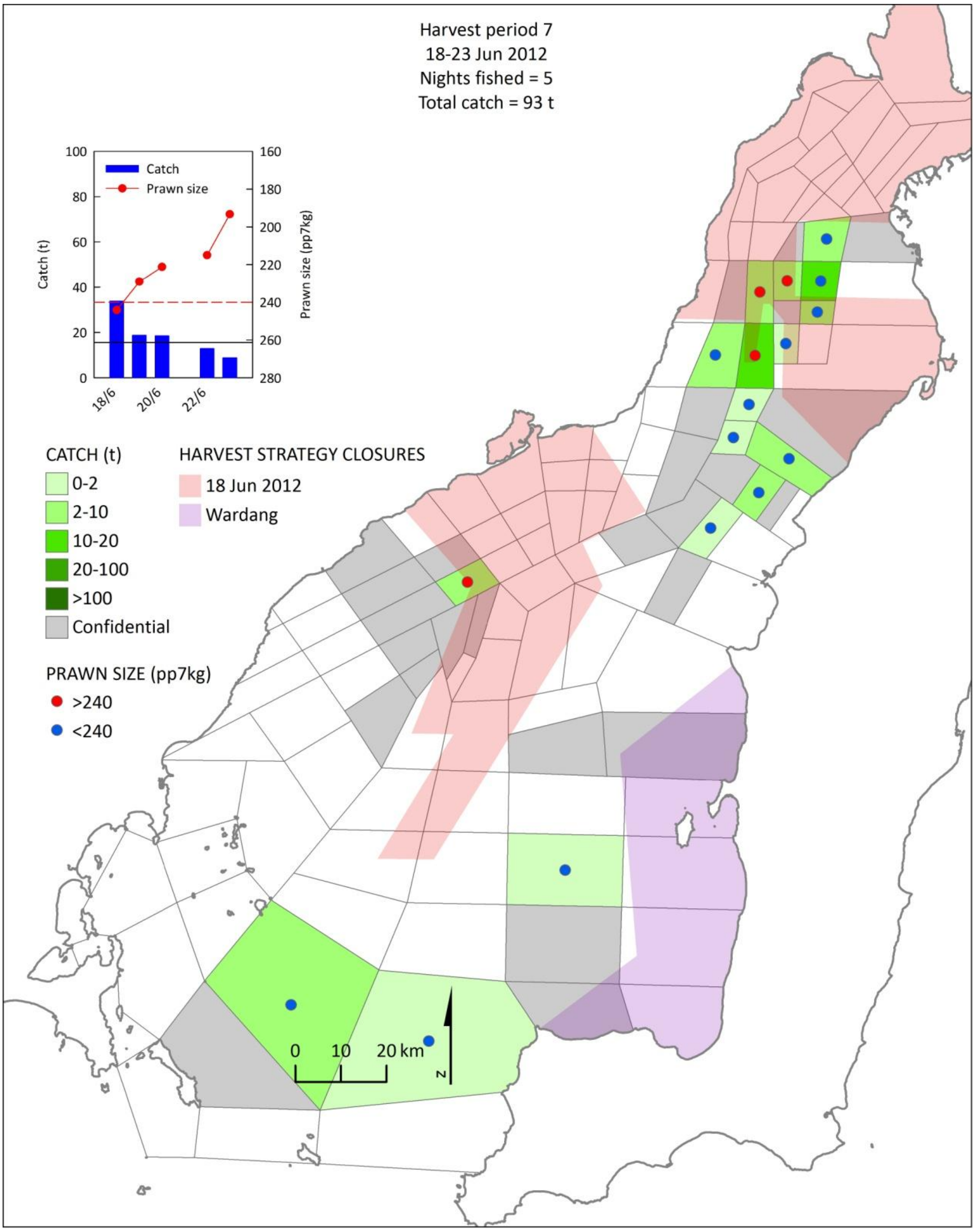


Figure 8.24 Commercial catch and mean size from blocks fished during harvest period 6, 2011/12. Shading indicates harvest strategy closures implemented on 18 June 2012. Inset graph displays daily total catch (blue bars), daily mean prawn size (red line), and at-sea decision rules for daily total catch (black horizontal line) and mean daily prawn size (red dashed line).

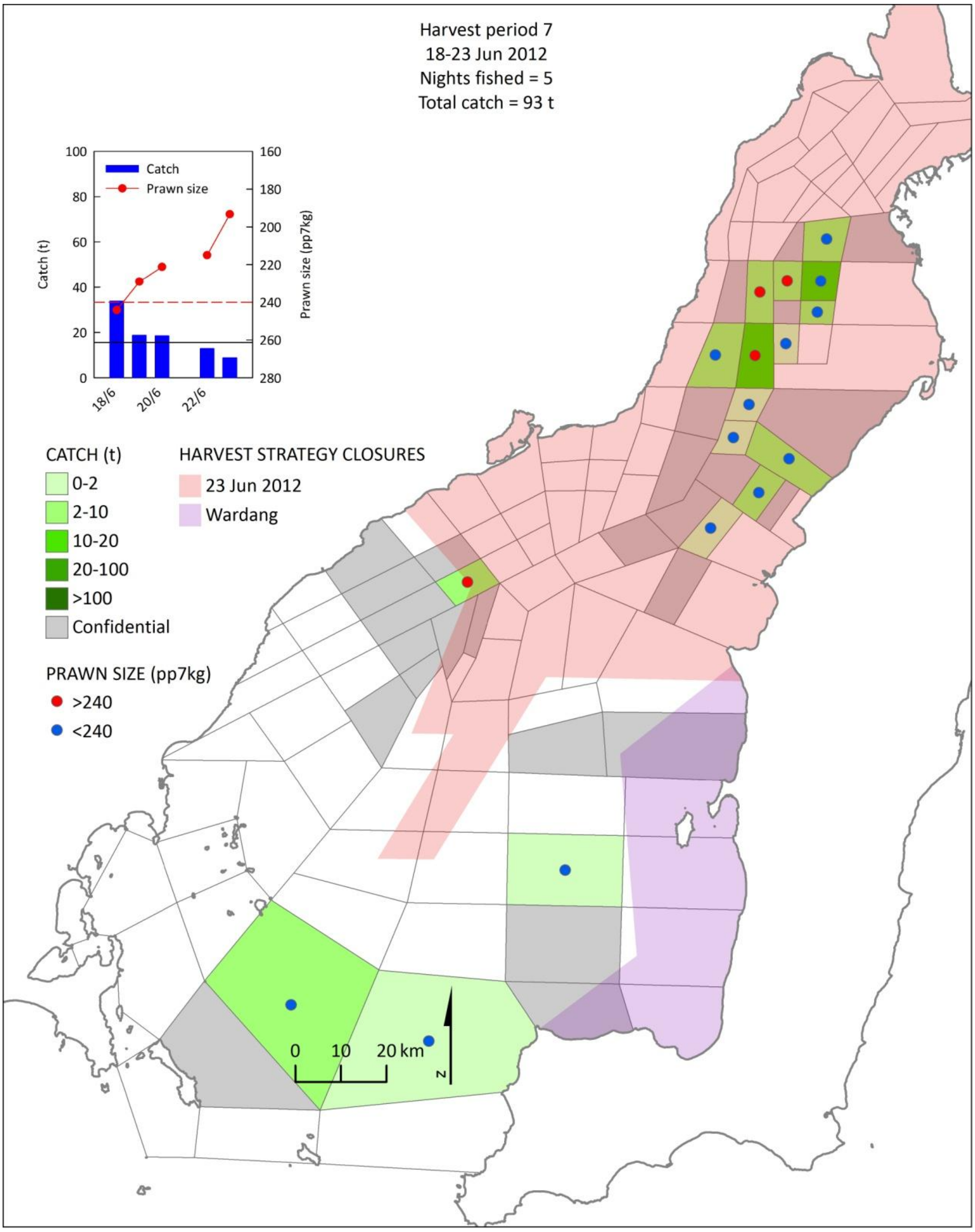


Figure 8.25 Commercial catch and mean size from blocks fished during harvest period 6, 2011/12. Shading indicates harvest strategy closures implemented on 23 June 2012. Inset graph displays daily total catch (blue bars), daily mean prawn size (red line), and at-sea decision rules for daily total catch (black horizontal line) and mean daily prawn size (red dashed line).