

Wild Fisheries



Spencer Gulf Prawn *Penaeus (Melicertus) latisulcatus* Fishery 2010/11



C.D. Dixon, G.E. Hooper and P. Burch

SARDI Publication No. F2007/000770-5
SARDI Research Report Series No. 603

SARDI Aquatic Sciences
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March 2012



Government
of South Australia

Fishery Assessment Report to PIRSA Fisheries and Aquaculture

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This report may be cited as:

Dixon, C. D., Hooper, G.E., 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.

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Printed in Adelaide: March 2012

SARDI Publication No. F2007/000770-5

SARDI Research Report Series No. 603

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Date: 15 March 2012

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

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ACKNOWLEDGEMENTS

Funds for this research were provided by PIRSA Fisheries & Aquaculture, obtained through licence fees. 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 Jenny Kranz. The catch and effort data were provided by Annie Vainickis of the Fisheries Statistics Unit (FSU) at SARDI Aquatic Sciences. The report was reviewed by Dr Stephen Mayfield and Dr Tony Fowler of SARDI Aquatic Sciences. Dr Craig Noell 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

1. This report updates the fishery assessment report for 2008/09 and analyses data from the 2009/10 and 2010/11 fishing years 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 current biological performance indicators for the fishery, and (4) identify future research priorities.
2. 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 <37% of this level. Increases in commercial CPUE during this period reflect increases in fishing power.
3. Commercial catches in 2009/10 and 2010/11 were 2,361 and 1,979 t, respectively, the former being the third highest catch recorded for the fishery. Commercial CPUE during 2009/10 (139 kg/h) was 36% higher than the previous fishing year (102 kg/h) and 22% higher than the historical peak (114 kg/h, 2000/01). While CPUE reduced to 118 kg/h in 2010/11 it remained historically high. The sharp increase in CPUE partly reflects an industry decision to stop trawling close to dusk and dawn when catch rates are lower.
4. Trends in relative biomass (survey CPUE) have been stable over the last eight fishing-years. Standardisation of survey CPUE had a minor effect on trends in nominal CPUE despite the identification of several statistically significant external factors that affect CPUE. The similarity among measures was due to the consistent spatial and temporal design of surveys and suggests that the current nominal measures of survey CPUE are appropriate for harvest strategy development and performance assessment.
5. The mean size of prawns harvested during 2010/11 was the smallest observed since 2002/03. While much of the catch was harvested outside of the size criteria in the Management Plan, in most instances this was an agreed decision among industry and Government and reflects a need to review the decision rules of the harvest strategy in the Management Plan.

6. Each of the seven primary Performance Indicators (PIs) were achieved during 2009/10 and 2010/11. Of the eight secondary PIs, the November recruitment index triggered in 2009/10 and the % of 16/20 grade prawns harvested from March to June triggered in both years.
7. 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. The development of a bio-economic model, due to begin in mid 2012, provides opportunity to develop a stronger focus on economic objectives for the fishery.

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 SARDI Aquatic Sciences’ ongoing assessment programs for South Australian Prawn Fisheries. The aims of the Fishery Assessment Report are to: (i) synthesise information for the Spencer Gulf Prawn Fishery; (ii) assess the current status of the resource and consider the uncertainty associated with the assessment; (iii) comment on the current biological Performance Indicators and Reference Points; and (iv) identify future research needs for the fishery.

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. 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 Spencer Gulf Prawn Fishery’s success.

This report is the first to examine the factors that affect survey catch rates, with a standardisation of survey CPUE 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 that is planned to begin in mid 2012 from funding obtained through the CRC with an aim to examine 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) latissulcatus* fisheries in South Australia: Spencer Gulf, Gulf St. Vincent (GSV) and the West Coast (Figure 1.1). The Spencer Gulf Prawn Fishery 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 34° 35.4'S, Longitude 136° 36.0'E) on Eyre Peninsula and Cape Spencer (Latitude 34° 9.6'S, Longitude 135° 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).

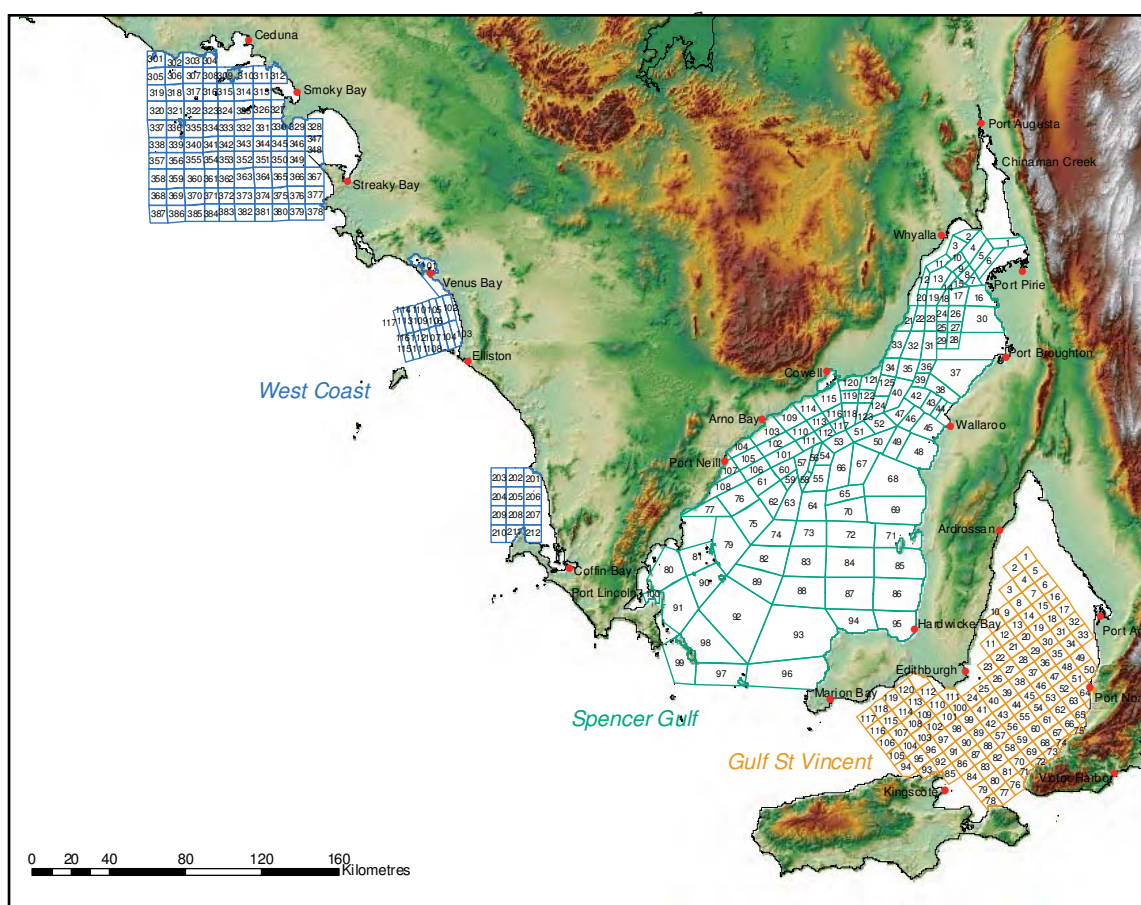


Figure 1.1 Location of South Australia's three commercial prawn fisheries.

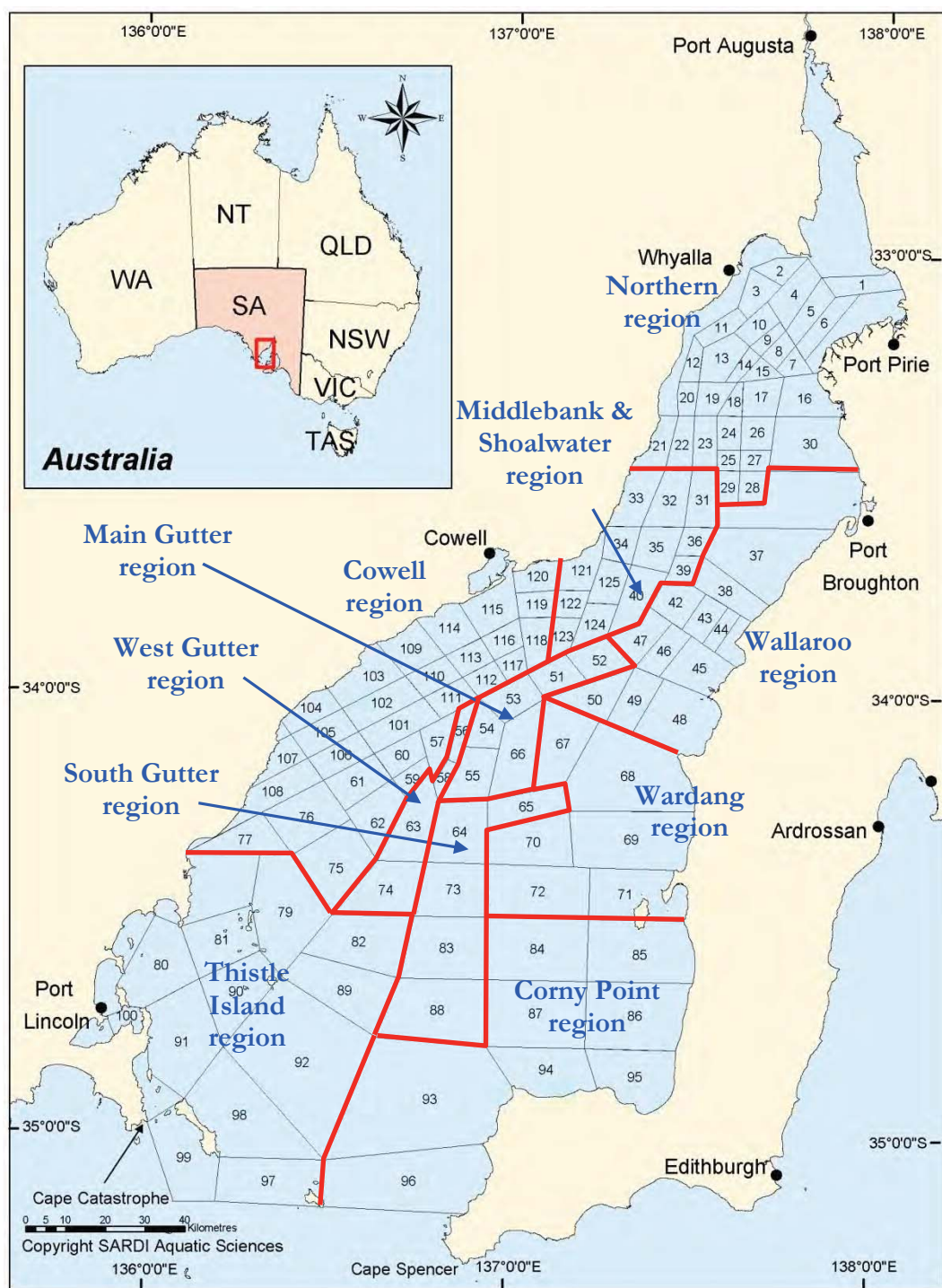


Figure 1.2 Fishing blocks (numbers) and reporting regions of the Spencer Gulf Prawn Fishery.

1.2.2 Spencer Gulf environment

Spencer Gulf is a shallow embayment <40 m deep in northern areas and up to 60 m deep in southern areas (Figure 1.5). Sediments are predominately sand and mud, and seagrass habitats are common at depths <10 metres. 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 & Lennon 1986).

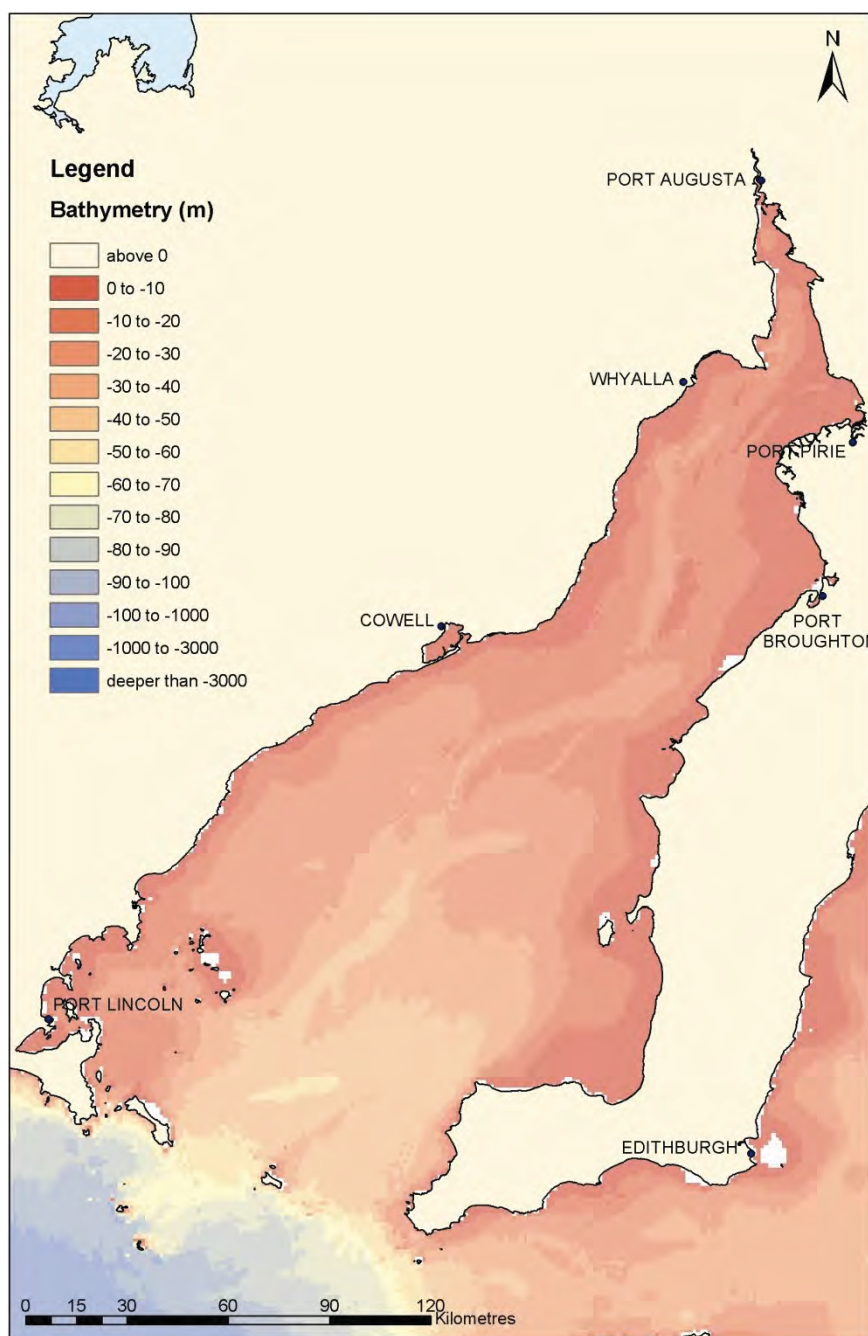


Figure 1.3 The bathymetry of Spencer Gulf

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 & 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).

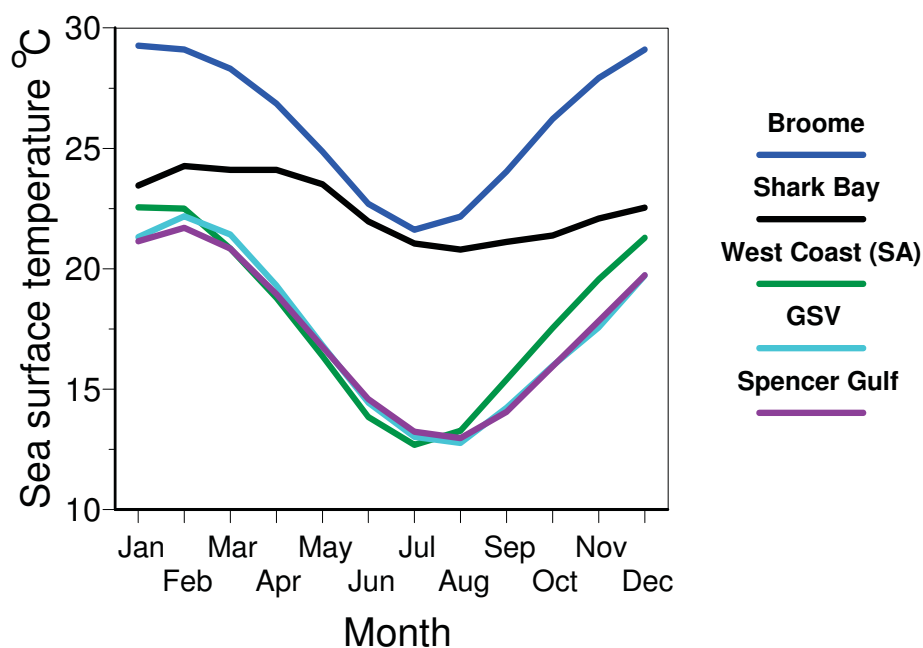


Figure 1.4 Comparison of mean monthly sea surface temperature (SST, °C) for the Australian prawn fisheries that target *P. latisulcatus*. Figure reproduced from Carrick 2003.

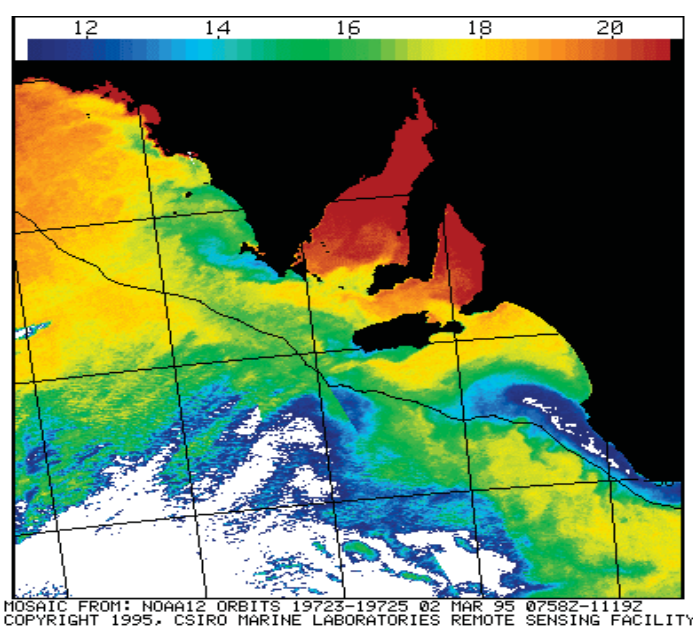


Figure 1.5 Sea-surface temperatures over the continental shelf of South Australia during late summer/early autumn, 1995. A colour-coded key in degree Celsius is situated at the top of the map. Figure from Linnane et al. (2005), sourced from CSIRO.

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 GSV 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 Area's (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
GSV	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).

The extent of available juvenile habitat appears to correlate well with production from each fishery (Table 1.1), particularly with respect to mangrove habitat (Table 1.1). Of note, the importance of mangrove habitat for prawn recruitment has long been debated (see Lee 2004).

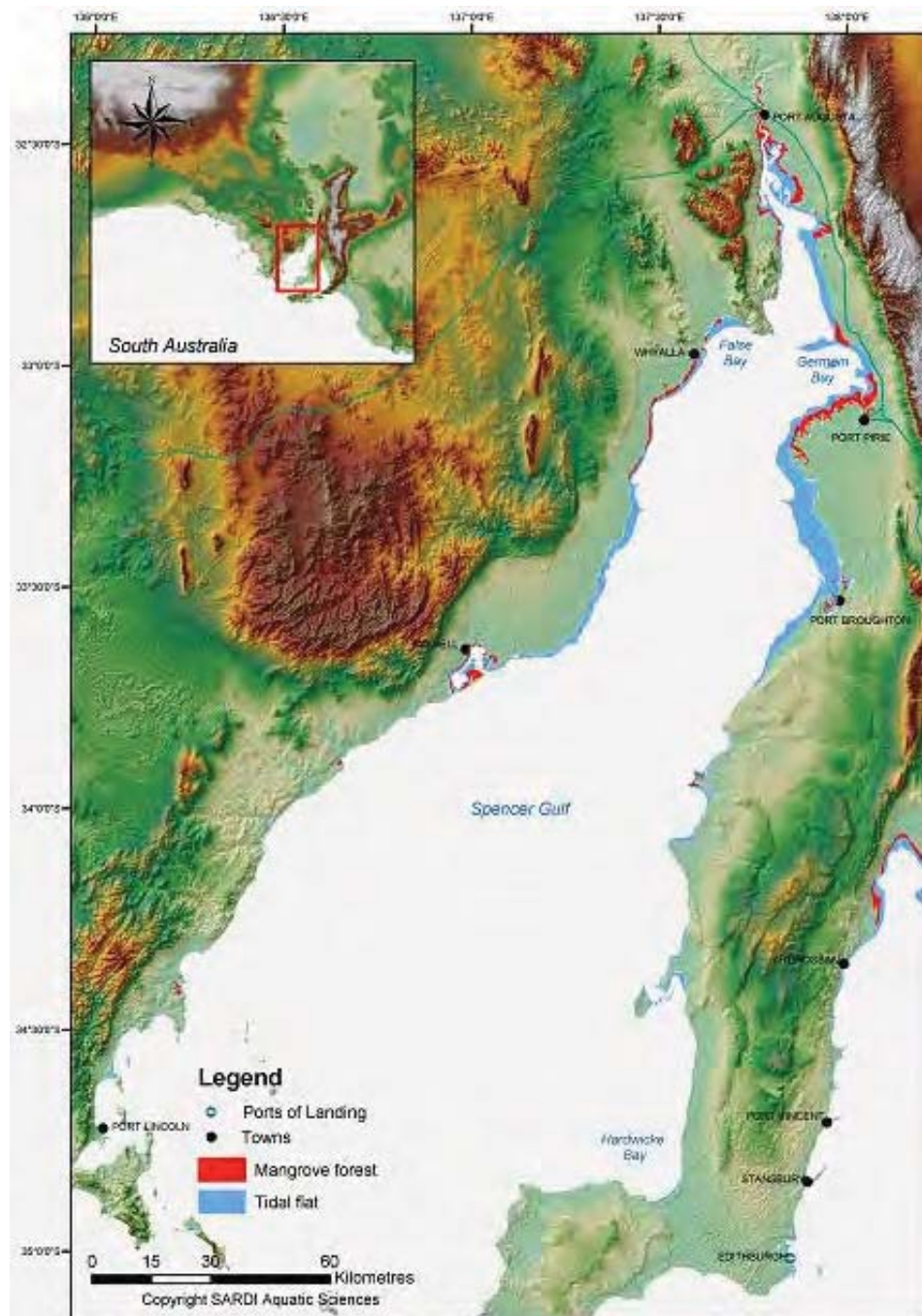


Figure 1.6 Important juvenile nursery habitat, mangrove forest and tidal flats, around coastal Spencer Gulf. Reproduced from Bryars (2003).

1.2.4 Commercial fishery

The Spencer Gulf Prawn Fishery 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 were 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.

Currently, the Spencer Gulf Prawn Fishery (\$29.5M in 2008/09) is the third most valuable prawn fishery in Australia 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 Spencer Gulf Prawn fishery is ranked second (39 licences, \$0.76M per licence) behind the Northern Prawn Fishery (52 licences, \$1.20M / licence). The Queensland East Coast Prawn Fishery has 498 licence holders (\$0.18M / 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 Spencer Gulf Prawn Fishery 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.

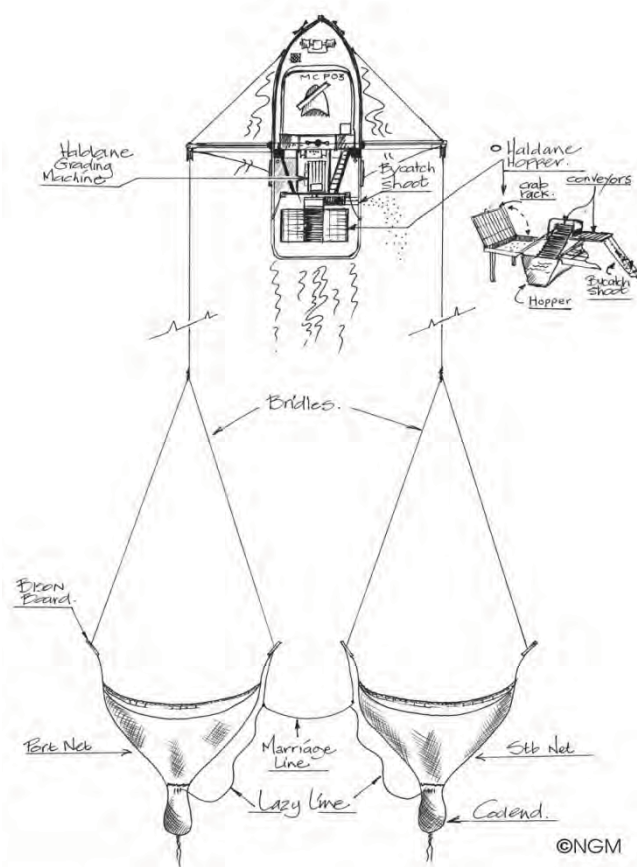


Figure 1.7 Double rig trawl gear and location of hopper sorting and prawn grading systems used in the Spencer Gulf Prawn Fishery. Figure from Carrick (2003).

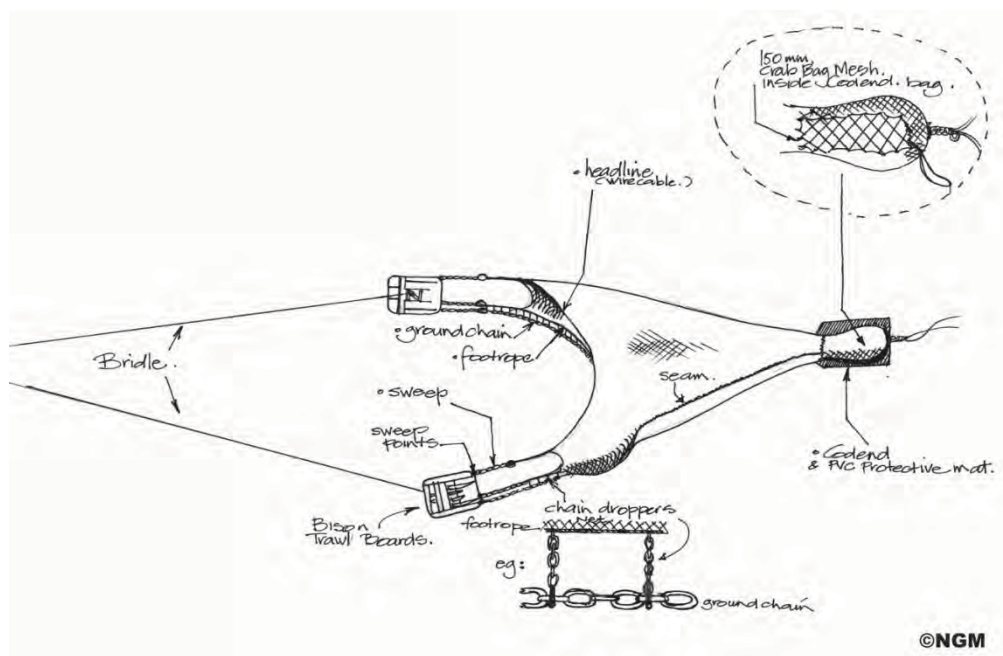


Figure 1.8 Trawl net configuration showing trawl boards, head rope, ground chain and cod end with crab bag. Figure from Carrick (2003).

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 \$ (million)	Licences	Prawn species harvested
South Australia					
Spencer Gulf ¹	2009/10	2361 (100%)	27.4	39	Western king
GSV ¹	2009/10	224(100%)	2.57	10	Western king
West Coast ¹	2009/10	84 (100%)	1.12	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 & Tsohos (2011); 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 Spencer Gulf Prawn Fishery is managed by Primary Industries and Resources 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 Spencer Gulf Prawn 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 FMC's, and establishment of a Fisheries Council. 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 Spencer Gulf Prawn Fishery since its inception in the late 1960's, with key milestones presented in Table 1.3.

Table 1.3 Major management milestones for the Spencer Gulf Prawn Fishery

Date	Management milestone
1968	Licence limitation. Trawling prohibited in waters of <10 metres. Commercial recording of catch and effort introduced
1969	Prawn Resources Regulations 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 <i>Fisheries (Management Committees) Regulations 1995</i> are introduced
1998	1 st Management Plan implemented
2007	Management Plan reviewed and updated

1.3.2 Current management arrangements

The Spencer Gulf Prawn Fishery is a limited entry fishery with 39 licensed operators. Trawling activities are banned during daylight hours and must be conducted in waters >10m 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	<i>Penaeus (Melicertus) latisulcatus</i>
Permitted by-product species harvested	<i>Ibacus</i> spp., <i>Sepioteuthis australis</i>
Limited entry	Yes
Number of licences	39
Corporate ownership of licences	Yes
Licence transferability	Yes
Minimum depth trawled	10 metres
Method of capture	Demersal Otter Trawl
Trawl net configuration	Single or double
Maximum total headline length	29.26 metres
Minimum mesh size	4.5 cm
Maximum length of vessel	22 metres
Maximum engine capacity	272 kW
Catch and effort data	Daily logbook submitted monthly
Catch and disposal records	Daily CDR records
Recreational fishery	Depth >10 metres, 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 Spencer Gulf Prawn Fishery 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 Spencer Gulf Prawn Fishery was documented (Dixon & 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 Spencer Gulf Prawn Fishery 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 spatial and temporal closures. The aim of such closures is for the fleet to target areas of 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 Management 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 Management Plan.

Table 1.5 Biological and management Performance Indicators and Limit Reference Points for the Spencer Gulf Fishery.

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 >280prawns/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

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.

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 Spencer Gulf Fishery.

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 & Deakin 2001). Both juvenile and adult prawns show a strong diel behavioural pattern of daytime burial and nocturnal activity (Rasheed & Bull 1992; Primavera & Leбата 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 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 & 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 Spencer Gulf Prawn Fishery 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 & 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.* in press).

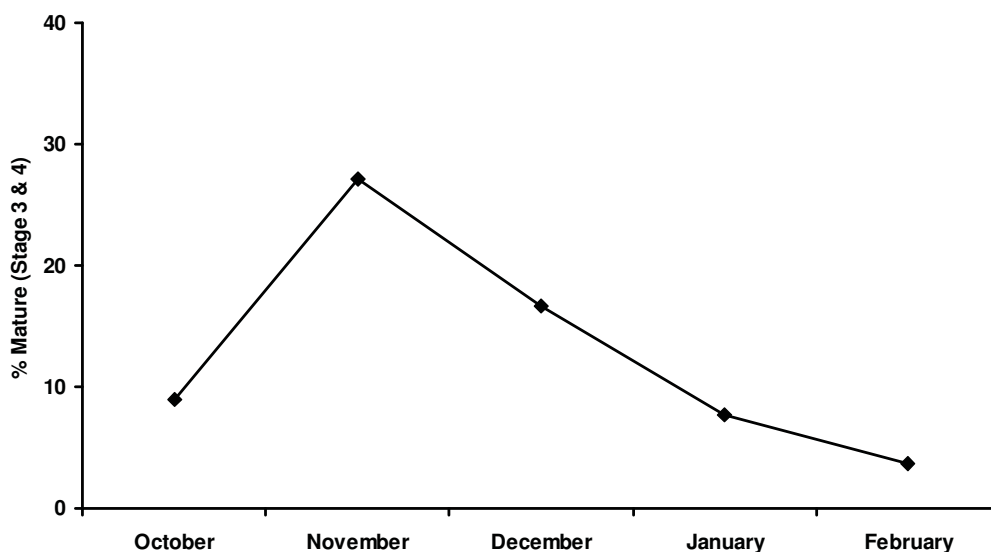


Figure 1.9 Female prawn reproductive maturation based on the percentage of ripe (Stage 3 & 4) prawns collected from northern Spencer Gulf during the summer of 2008/09 (SARDI unpublished data as part of N. Hackett PhD).

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 West 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 GSV (Svane 2003; Svane & 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 fertilization 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 GSV (Kangas unpublished, cited in Carrick 2003), Shark Bay (Penn 1980) and the North East Coast of Queensland (Courtney and Dredge 1988). In all three fisheries, fecundity increases exponentially with carapace length, however this is more pronounced in the cooler waters of GSV (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 & Dredge 1988; Carrick 1996).

Table 1.7 Fecundity relationships for *P. latisulcatus* in Gulf St. Vincent, Western Australia and Queensland. Fecundity = $a \times \text{carapace length}^b$

Location	<i>a</i>	<i>b</i>
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.

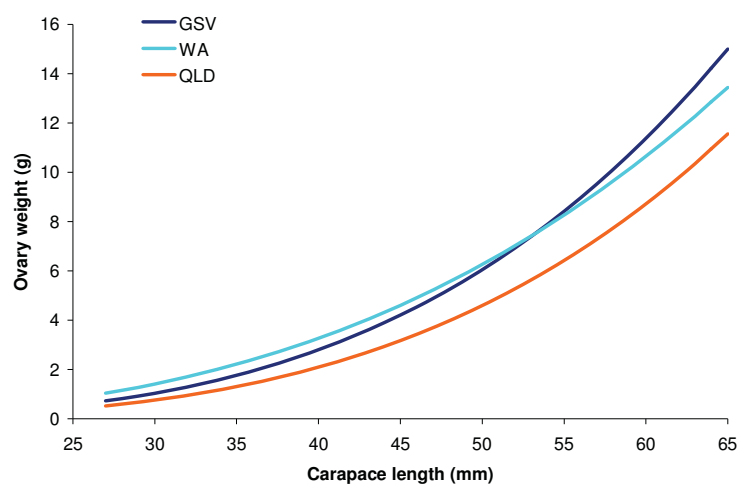


Figure 1.10 The relationship between fecundity (ovary weight) and carapace length (CL) for *P. latisulcatus* in GSV, Western Australia and Queensland.

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 & Dredge 1988); females generally lose spermatophores with the exuviae 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).

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 & 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 & 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 *F. 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).

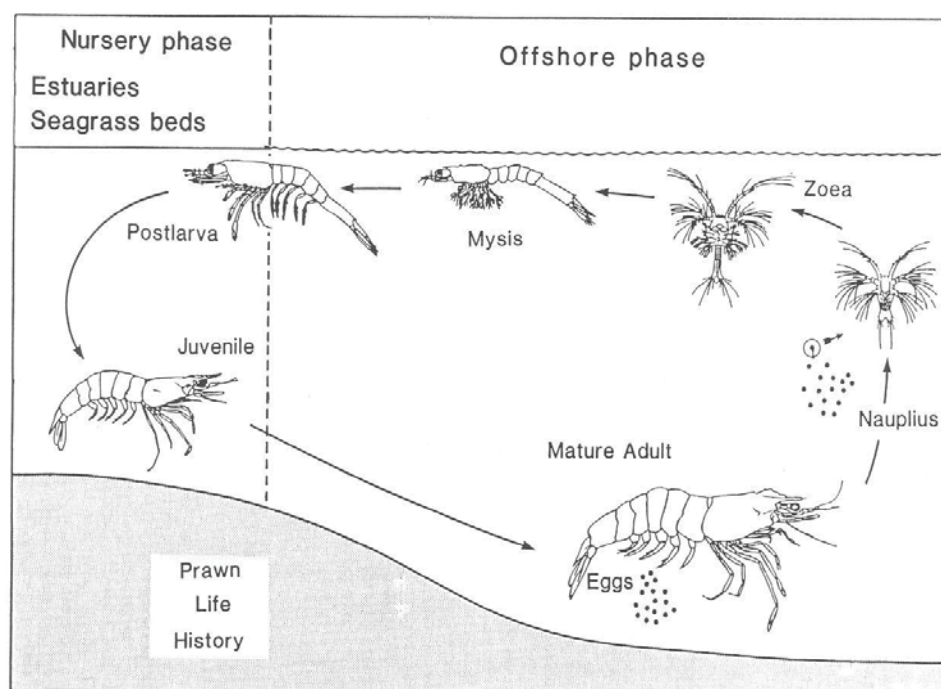
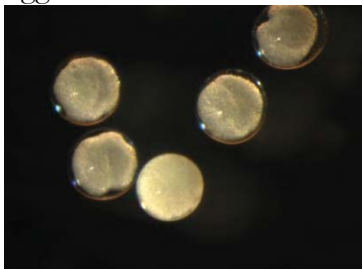


Figure 1.11 Life cycle of *P. latisulcatus* (King unpublished thesis).

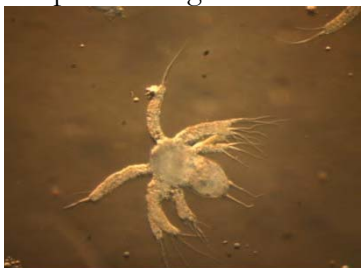
Prawn larvae undergo metamorphosis through four main stages: nauplii, zoea, mysis and post-larvae (Figure 1.12). Stage specific sizes (body length) are approximately: egg ~300µm (diameter), nauplii >350µm, zoea >0.9mm, mysis >2.0mm and post-larvae >6.0mm (Shokita, 1984; Roberts *et al.* submitted). Key parameters that affect larval development and survival are generally considered to be: temperature, salinity and food availability (Preston, 1985; Jackson & Burford 2003; Bryars & Havenhand 2006; Lober & 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.* submitted). As part of the FRDC project 2008/011 “Prawn and crab harvest optimisation: a biophysical management tool”, Roberts *et al.* (in press) 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.* (submitted) 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.

Eggs



Nauplii sub-stage 1



Nauplii sub-stage 2



Nauplii sub-stage 3



Protozoa sub-stage 1



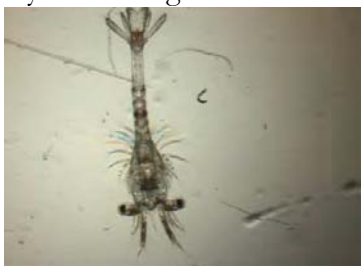
Protozoa sub-stage 2



Protozoa 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).

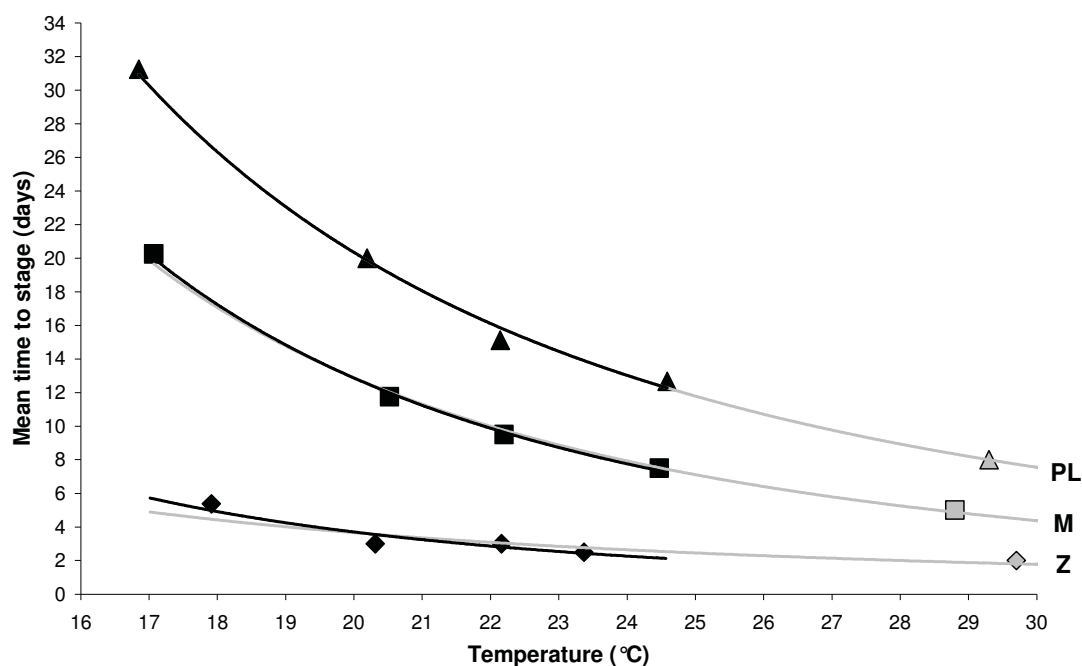


Figure 1.13: Mean time (days) to reach zoea (Z), mysis (M) and post-larvae (PL, total duration) stages from hatching at constant temperatures. Black data points and black fitted power curves indicate data from this study, while grey indicates data for higher temperatures sourced from Shokita (1984),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

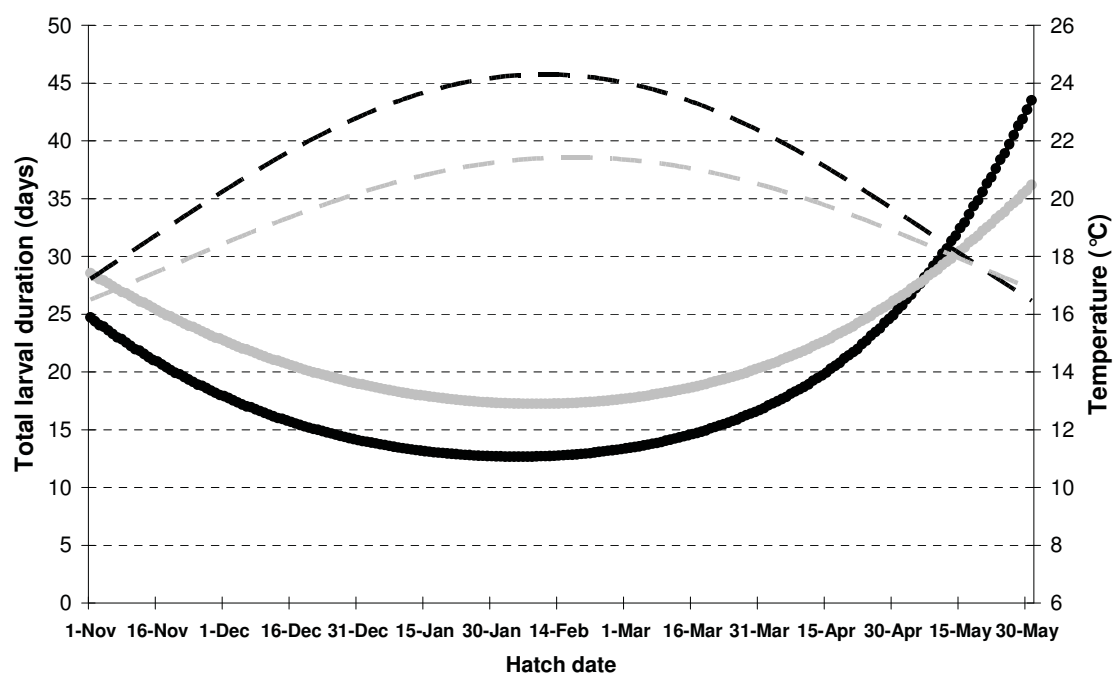


Figure 1.14: Predicted larval developmental duration (full lines) for *P. latissulcatus* in north (dark lines) and south (light lines) Spencer Gulf waters under seasonally average water temperature (hatched lines) conditions (Roberts et al. submitted).

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 (ie. vertical migration), and hydro-meteorological dynamics such as wind-driven and tidal currents (Scheltema 1986; Rothlisberg 1988; Rothlisberg et al, 1995; Garrison, 1999; Forward & Tankersley, 2001; Queiroga et al, 2007; Webley & Connolly, 2007; López-Duarte & Tankersley, 2009; Roberts *et al.*, submitted). 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.

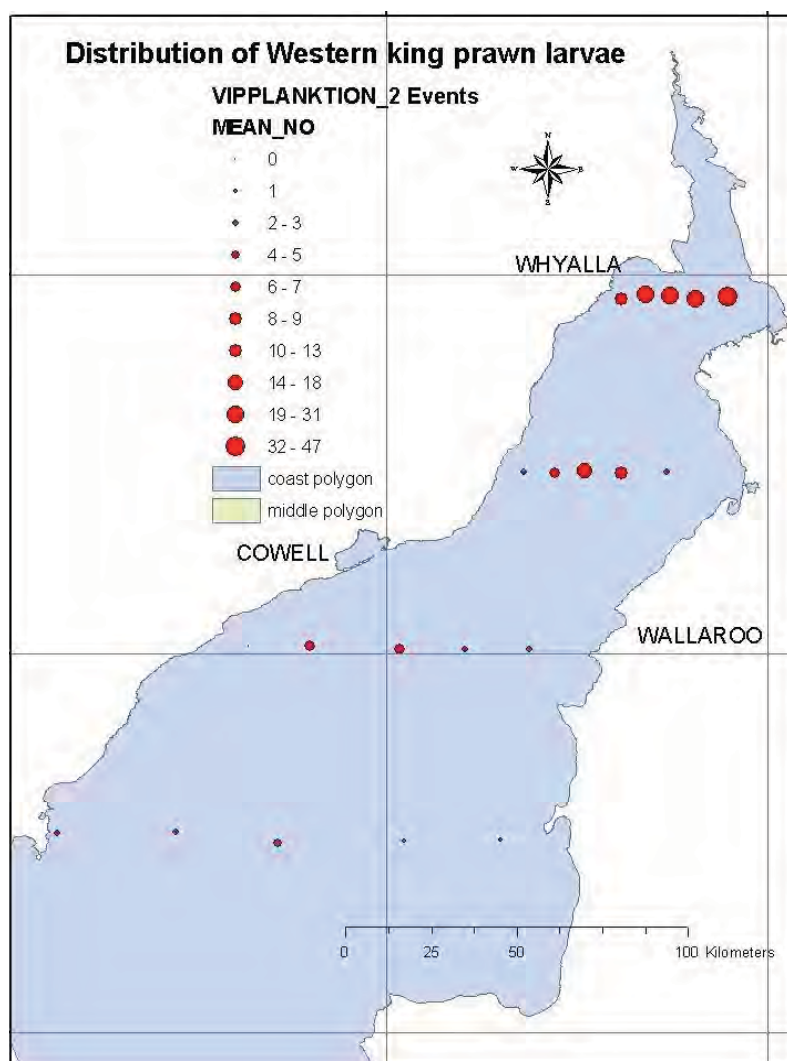


Figure 1.15 Mean larval density ($\sqrt{\text{no.}/100 \text{ m}^3}$) in Spencer Gulf during 1993 and 1994 (Carrick 2003).

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.

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 & 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 >150,000 prawns were individually tagged with streamer tags in Spencer Gulf. The carapace length 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 $L(t) = L_{\infty} (1 - e^{-r(t-t_0)})$, 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 GSV and the West Coast Fishery in Table 1.9 and Figure 1.16. Kangas & Jackson (1997) estimated growth rates from 464 tag-recaptures in GSV while in the West Coast Prawn Fishery growth was estimated from 510 tag-recaptures as well as from length-frequency cohort analyses (Wallner 1985).

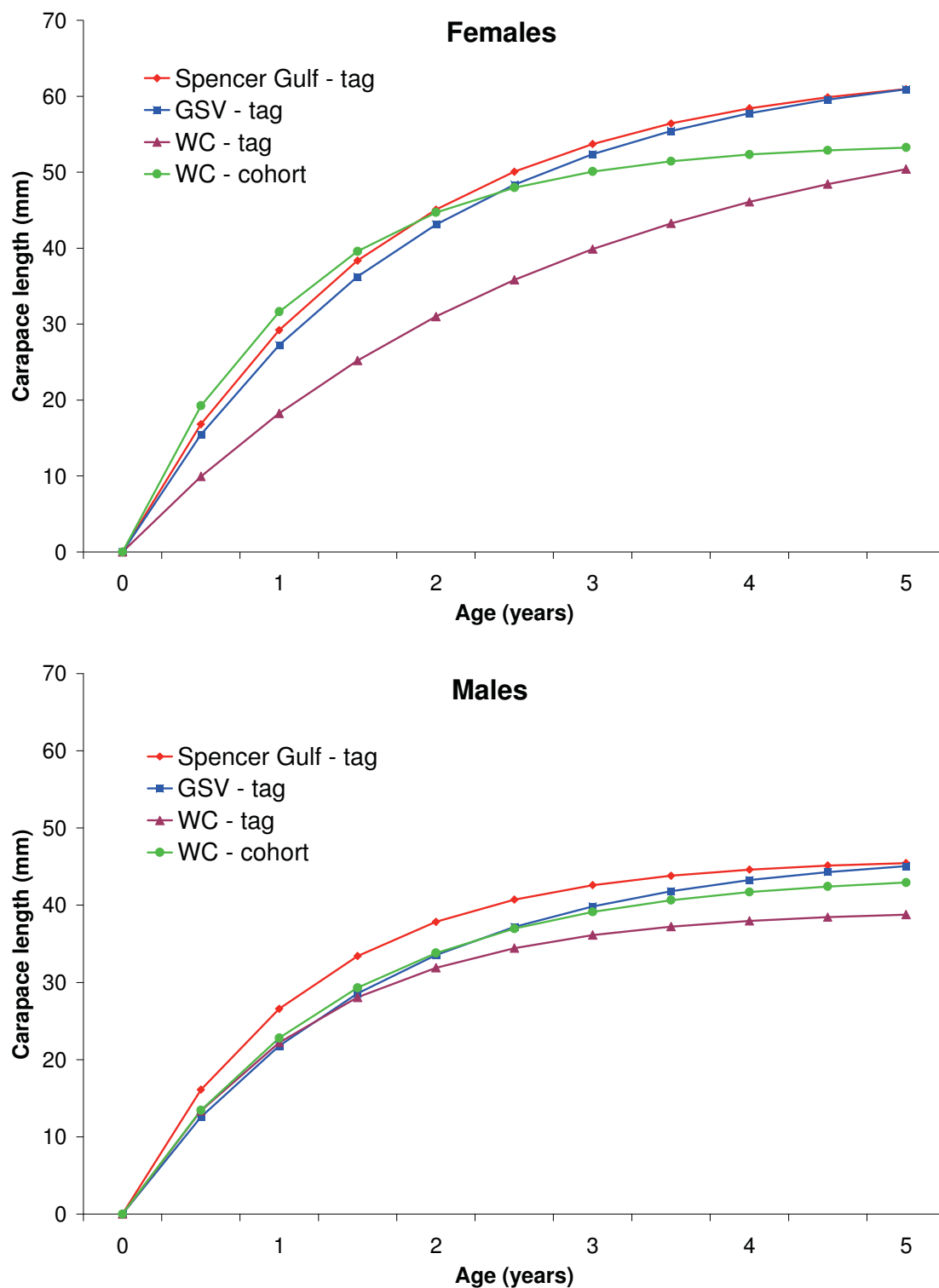


Figure 1.16 Sex-specific growth curves for *P. latissulcatus* estimated from tag-recapture and cohort analysis in the West Coast (Wallner 1985) and from tag-recapture in Spencer Gulf (Carrick 2003) and Gulf St Vincent (Kangas & Jackson 1997).

Seasonal growth and differences between genders were evident in each fishery. Prawns in Spencer Gulf attained a similar size to GSV prawns, although a slower growth rate was evident for male prawns in GSV (Figure 1.16). Also, prawns in both gulfs attain a greater size and growth rate than their West Coast counterparts. Whilst this may be an artefact of the uncertainty associated with West Coast prawn growth estimates (see Dixon & 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.

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 & 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
GSV	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 = $a \times \text{carapace length}^b$ " 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 GSV ($a = 0.00066$, $b = 2.91$, $N = 325$). 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).

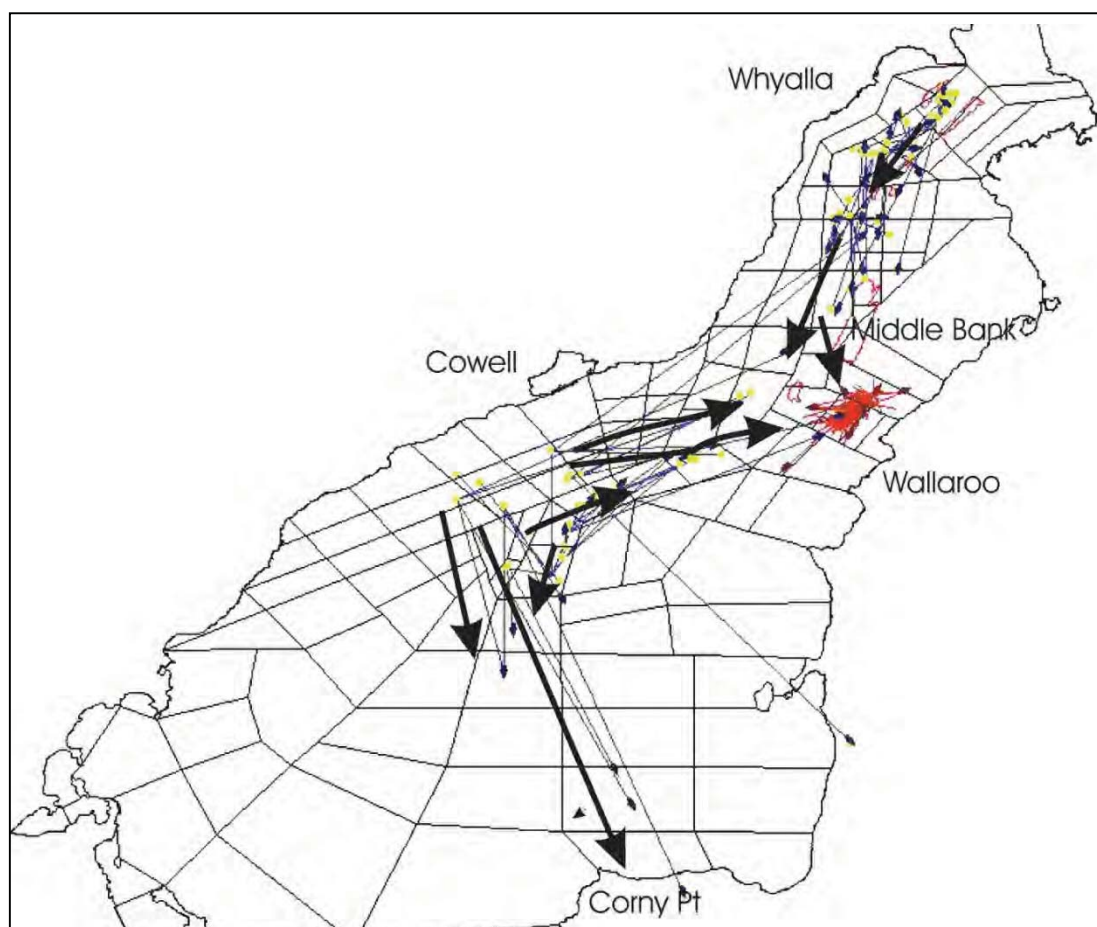


Figure 1.17 Generalised movement patterns of tagged *P. latisulcatus* in Spencer Gulf (Carrick 2003).

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 & 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).

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 GSV (0.003.day⁻¹; Kangas & 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 & 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 naïve 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 (ie. 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 GSV, anecdotal evidence suggests that juvenile prawn abundances at Barker Inlet have significantly declined since the early 1970's, 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 GSV, 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 address 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 Spencer Gulf Prawn Fishery was completed in 1998 (Carrick and McShane 1998). Subsequent stock assessments in 2000 and 2001 were the first to consider the biological PI's 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 Management 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.

1.6 Current Research and Monitoring Program

The current research program conducted by SARDI Aquatic Sciences in support of the Spencer Gulf Prawn Fishery 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 harvest strategies and 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 Spencer Gulf Prawn Fishery, including assessment of the fishery against the PIs defined in the Management 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 to 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 Spencer Gulf Prawn Fishery 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 fertilization 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 (ie. 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 strongly 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. Funding has been from the Seafood CRC for the development of such a model for the Spencer Gulf and Gulf St Vincent fisheries. The project has received preliminary approval and if funded, is planned to begin in mid 2012.

2. FISHERY STATISTICS

2.1 Introduction

Fishery-dependent catch and effort 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 2010/11. 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. does not include 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 SAFIC annual reports (1973 to 1988); data from 1988/89 to 2010/11 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 “harvest periods” of varying length between the last and first quarter of the moon (maximum length 18 days). Monthly trends disregard harvest 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 2010/11. 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 onward, 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 2009/10 and 2010/11 targeted prawns larger than 220 prawns/7kg. 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

Total catches in 2009/10 and 2010/11 were 2,361 and 1,979 t, respectively, the former being the third highest catch recorded for the fishery (Figure 2.1). In the eight fishing years since the low catch of 2002/03 (1,479 t), annual catch has averaged 1,995 t, which is 86 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 (LR): $r^2 = 0.92$, $df = 31$, $P < 0.01$). During 2009/10 and 2010/11, trawl effort declined to 17,012 and 16,738 h, respectively, the latter being <37% of peak trawl effort.

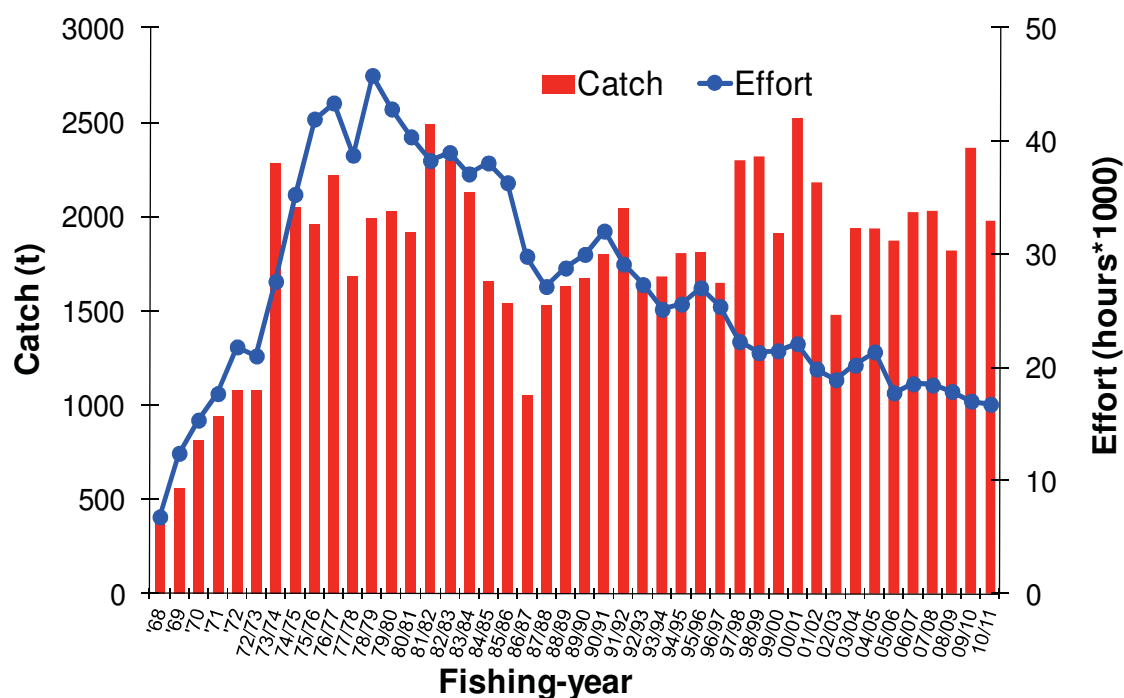


Figure 2.1 Total catch (t) and effort (hrs) for Spencer Gulf from 1968 to 2010/11. Data for 1968–1972 are reported as calendar year. Data for 1972/73 are from January to October 1973. From 1973/74 data are reported in fishing years.

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 Northern region peaked at 933 t in 1991/92 but has not exceeded 250 t over the last 13 fishing years. Peak catches in the Northern region coincided with the lowest annual catch from the Wallaroo region (206 t). During the past ten fishing years, the Wallaroo, Middlebank/ Shoalwater and Main Gutter regions have produced consistent annual catches, averaging 961, 483 and 156 t, respectively. Other regions have produced variable annual catches. During 2009/10 and 201/11, most of the catch was harvested from the Wallaroo (1,202 and 988 t), Middlebank/ Shoalwater (641 and 518 t), Main Gutter (130 and 130 t), Corny Point (120 and 122 t) and Northern (40 and 135 t) regions, with smaller catches obtained from the South Gutter (88 and 36 t), Cowell (80 and 17 t), Wardang (47 and 20 t), Thistle Island (9 and 11 t), and West Gutter (4 and 2 t) regions.

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 2009/10, a very high monthly catch was recorded in April (835 t).

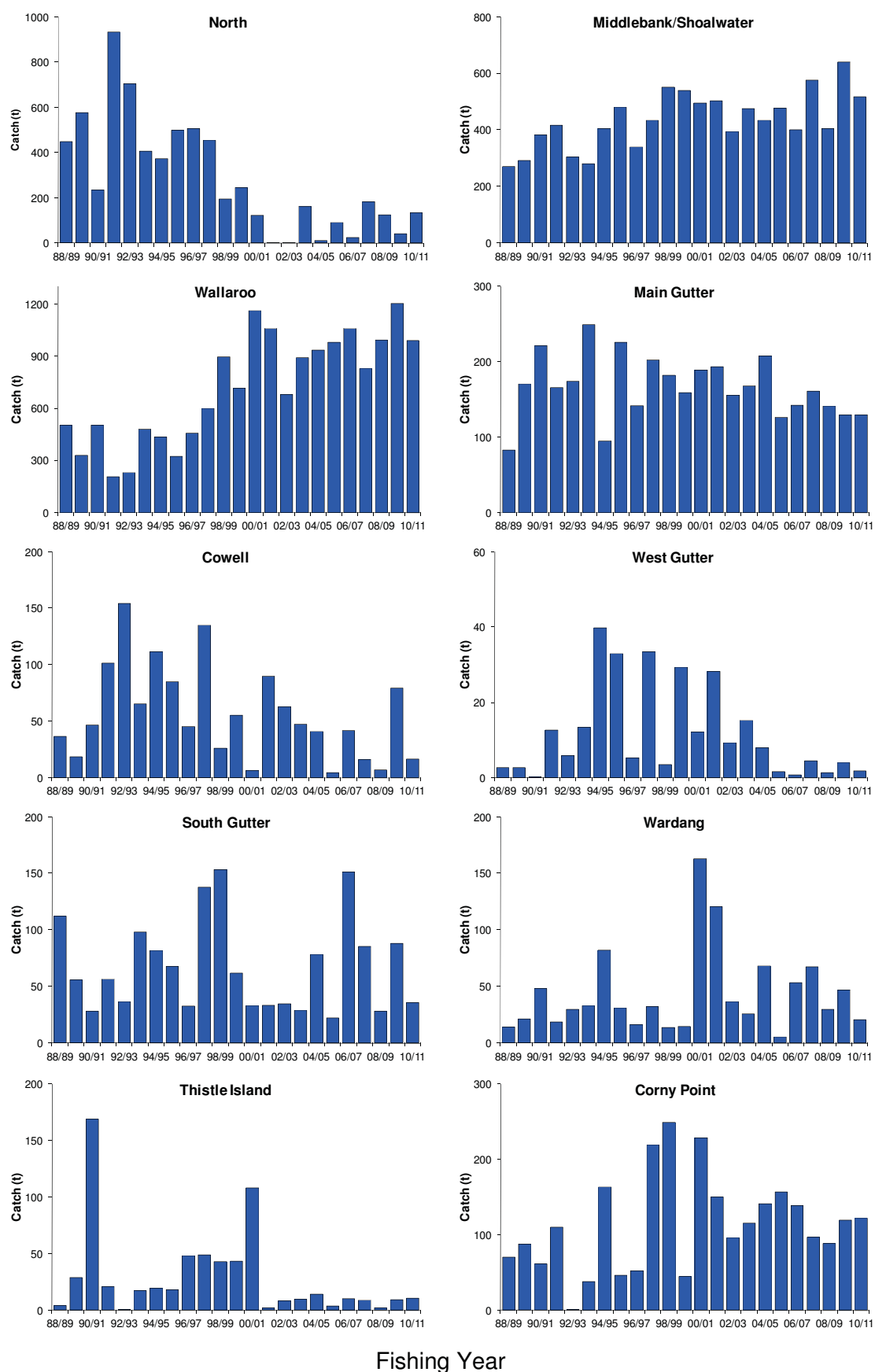


Figure 2.2 Average annual catches from regions of Spencer Gulf from 1988/89 to 2010/11. Note change in Y-axis scales among graphs.

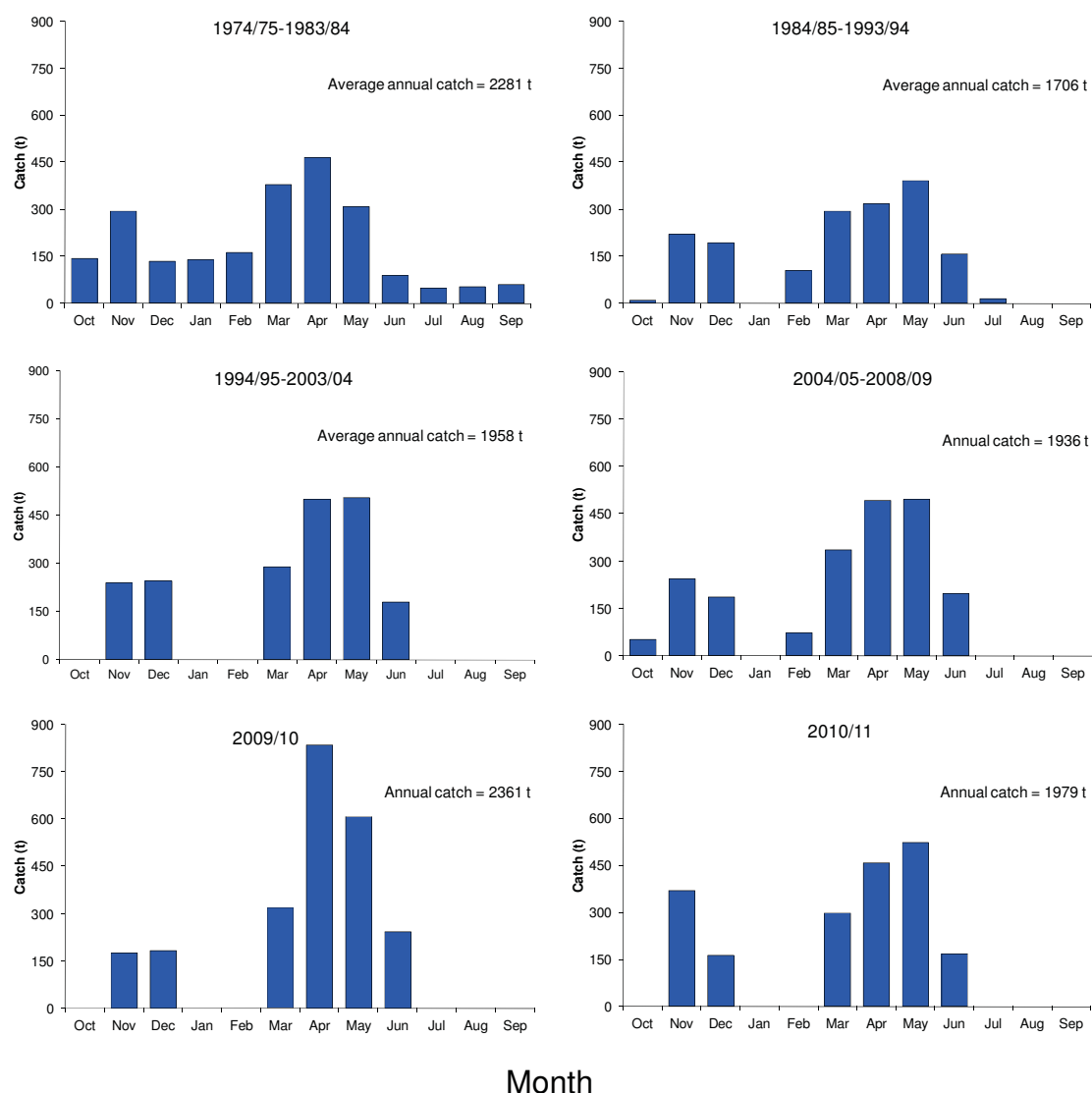


Figure 2.3 Average monthly catches from Spencer Gulf for 10-year periods from 1974/75 to 2003/04, the 5-year period from 2004/05 to 2008/09 and for the fishing-years 2009/10 and 2010/11.

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 for the established fishery 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 in order to maintain high levels of annual recruitment. Pre-Christmas catches during 2009/10 and 2010/11 were 358 and 532 t, respectively, with the latter being the highest pre-Christmas catch harvested since 2001/02.

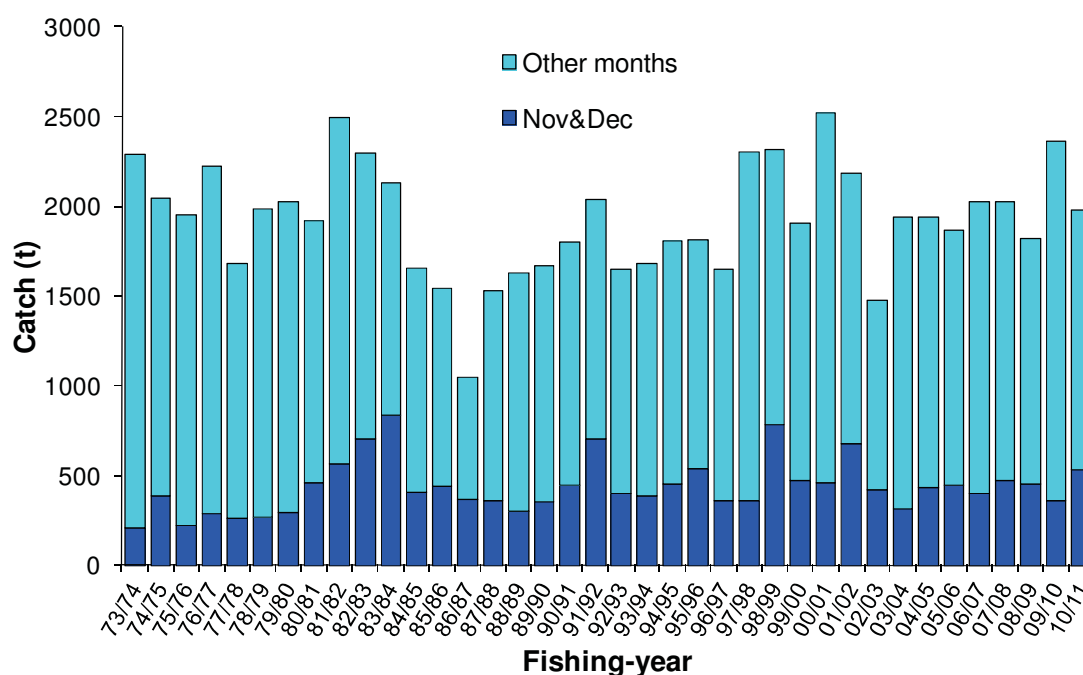


Figure 2.4 Catches from November and December relative to the total annual catch from 1973/74 to 2010/11 in Spencer Gulf.

2.3.5 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 throughout the 90s and first exceeded 100 kg/h in 1997/98. During 2009/10 (138.8 kg/h) and 2010/11 (118.2 kg/h), CPUE was the highest and second highest recorded, respectively.

The general historical increase in CPUE over time probably reflects increases in the fishing power of the fleet. Decisions to target larger prawns and to reduce fishing hours are also likely to affect CPUE. 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 fishing power are smaller, more reliably reflect changes in prawn biomass. Understanding the many different factors that affect fishing power is essential for interpretation of nominal CPUE trends.

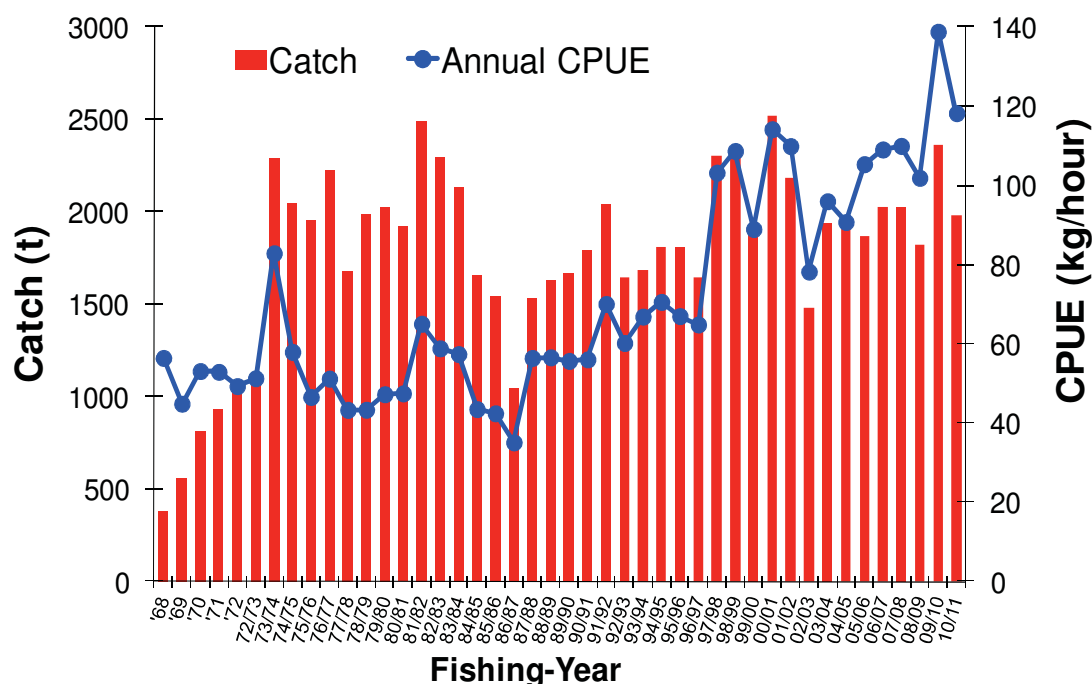


Figure 2.5 Annual catch and catch-per-unit-effort (CPUE) for Spencer Gulf from 1968 to 2010/11. Data for 1968–1972 are reported as calendar year. Data for 1972/73 are from January to October 1973. From 1973/74 data are reported in fishing years.

2.3.6 Trends in CPUE among regions

Since 2005/06, CPUE has generally declined with latitude, being higher in the Northern, 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.

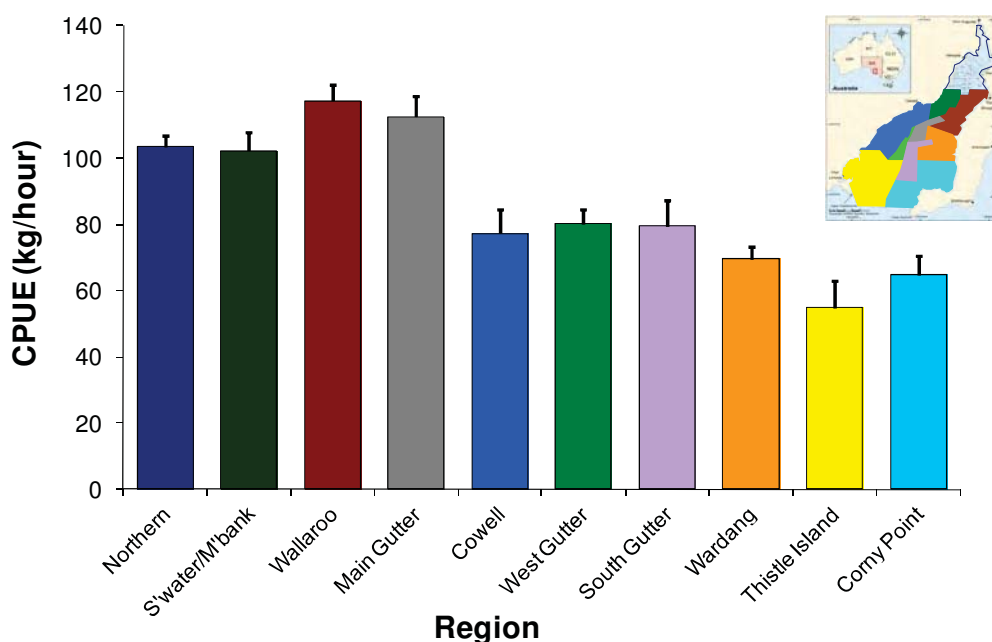


Figure 2.6 Mean (SE) annual catch-per-unit-effort (CPUE) for the 10 fishing regions within Spencer Gulf from 2005/06 to 2010/11. Insert identifies colour coded regions.

2.3.7 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.

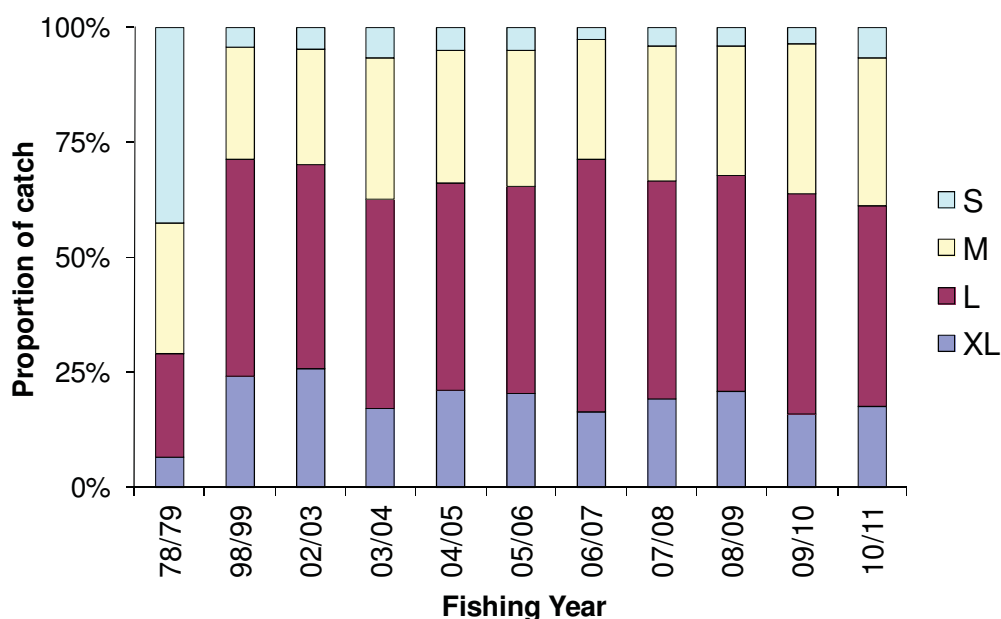


Figure 2.7 Size compositions of prawns in the commercial catch in 1978/79, 1998/99 and 2002/03 to 2010/11.

2.3.8 Trends within years in prawn size grades

Although the size composition of prawns varied among months in all fishing years, a high proportion of the catch (range 53-81%, mean 71%) was comprised of L and M sized prawns in all months (Figure 2.8). The proportion of XL sized prawns in the catch was generally highest during March and lowest during May. Few other consistent seasonal trends were observed among years for other size classes.

During 2009/10 and 2010/11, the proportion of XL prawns in the catch was lower and the proportion of M prawns in the catch was generally higher than most previous years. While the proportion of S prawns was generally low in 2009/10, the proportion of S prawns was very high (10%) in March 2010/11 and remained high (5-7%) from April to June. The proportion of SB prawns was within the range of previous years, except for December 2010/11 where the proportion of SB was very high (13%). The reason for the increase in SB catch during this month is unknown.

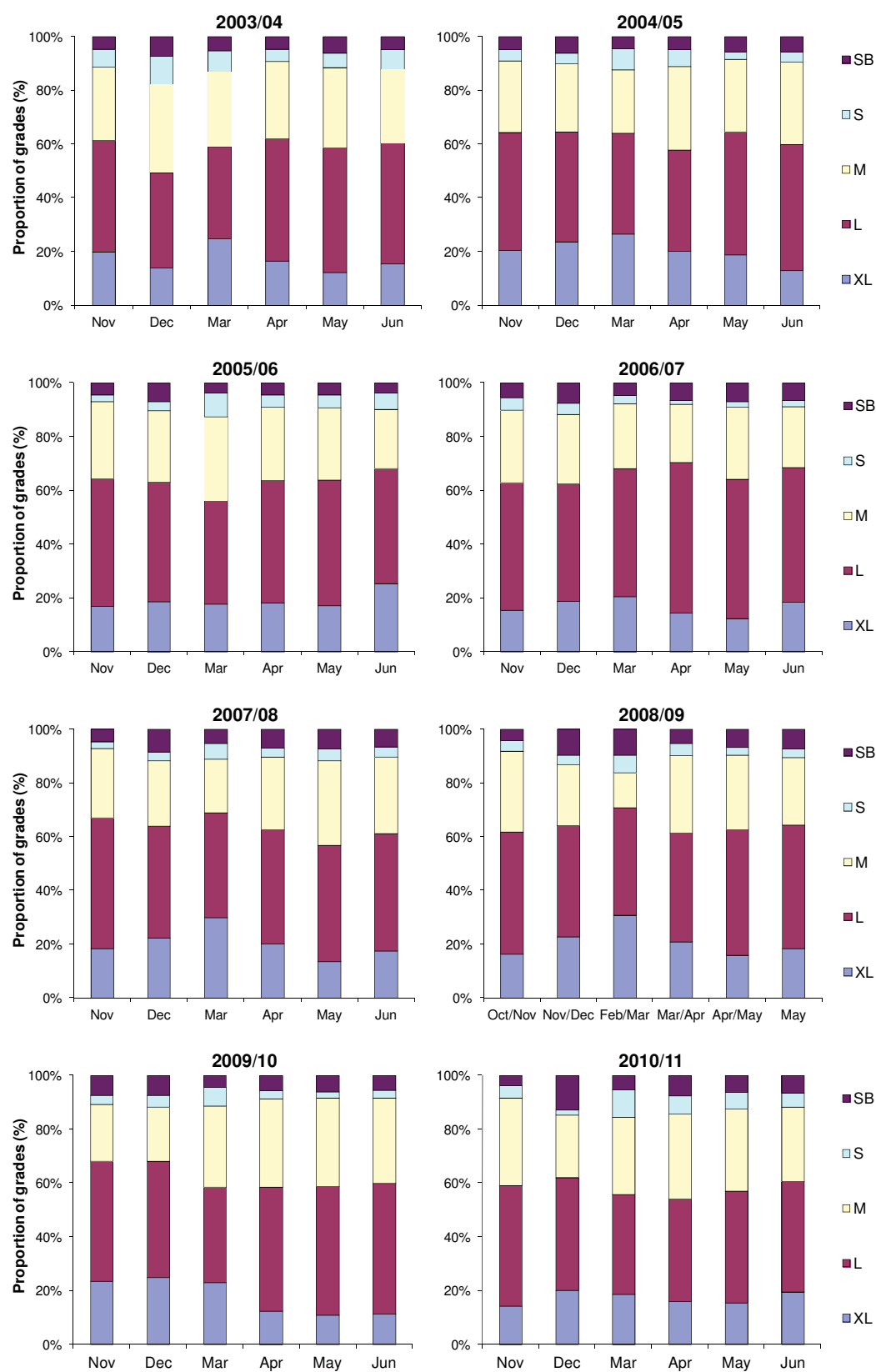


Figure 2.8 Size composition of the commercial catch during each month fished in Spencer Gulf from 2003/04 to 2010/11.

2.3.9 Mean daily prawn size of the commercial catch

Prawns harvested in 2009/10 and 2010/11 were smaller than those captured in the previous five fishing years, with mean prawn size in 2010/11 (221 prawns/7 kg) being the equal smallest recorded (same as 2002/03; Table 2.3). The fewer nights when prawns were measured reflected reductions in the nights fished.

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 2009/10 and 2010/11 targeted prawns larger than 220 prawns/7kg. Some periods allowed catches of smaller prawns up to 250 prawns/7 kg to be caught. Table 2.3 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 prawns/7 kg were caught was higher during 2010/11 (45%) than any previous year (Table 2.3). Proportions of nights when the catch was smaller than 250 prawns/7 kg was also high during 2010/11 (10%) and was the second highest recorded (13% in 2003/04). The number and proportion of nights when very small prawns (>280 prawns/7 kg) remained low during 2009/10 and 2010/11.

Table 2.3 Statistics associated with mean daily prawn size estimated from prawn grade data provided in commercial logbooks.

Year	Mean (pp7kg)	Nights measured	Nights (%) >220 pp7kg	Nights (%) >250 pp7kg	Nights (%) >280 pp7kg
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%)

2.4 Discussion

Annual catch and effort information are available for the entire period since the inception of the fishery in 1968 and validated 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.

Total catches during 2009/10 and 2010/11 were 2361 and 1979 t, respectively, the former being the third highest annual catch for the fishery. Interestingly, the high catch in 2009/10 was attained despite a relatively low pre-Christmas harvest (358 t). Total effort continued to decline and in 2010/11 was lowest recorded in the post-expansion phase of the fishery (i.e. since 1973/74). Currently, trawl hours are less than 37% of the peak effort in 1978/79.

The reduction in nominal effort, in the context of a stable catch history, represents substantial increases in the efficiency of prawn fishing. Whilst some of this efficiency may have been achieved with increased knowledge of the fishery, it is most likely that these increases arise predominately from changes in vessel power. As a result, commercial CPUE has increased substantially over time. During 2009/10 and 2010/11, CPUE was the highest observed in the fishery's history. One factor that has increased CPUE in the last two years was a decision to reduce the length of fishing nights following an analysis that demonstrated reduced CPUE associated with sunset and sunrise trawl shots (Dixon *et al.* 2010). While this analysis provided useful information for commercial fishing, they also demonstrate the limitations of interpretation of nominal CPUE data. While standardisation of CPUE data may improve the reliability of using commercial CPUE in the assessment, commercial CPUE would have limited weighting in stock assessment compared to independent survey data.

The reduction in fishing effort in the Northern region in the last ten years reflects the management decision to target larger and more valuable prawns, which generally occur further south. Historical grade data demonstrate this through a large shift in the size structure of recent catches compared to that obtained in 1978//79. The shift in size and regional distribution of the catch is an important factor in the long-term sustainability of the fishery.

While the size distribution of the catch has been stable from 2003/04 to 2010/11, in comparison to catches in 1998/99 and 2002/03, the proportion of large prawns was lower and the proportion of medium prawns was higher in each of the last eight years. Although these subtle differences in size structure are not of biological importance, they are of economic importance to the fishery.

Data on mean daily prawn size determined from commercial logbooks indicate that during 2010/11 prawns were harvested at the smallest mean size since 2002/03. While the number of nights that very small prawns (>280 per 7 kg) were harvested remained low (1%), small prawns (>220 per 7 kg) were harvested more regularly throughout 2010/11. Again, these differences in harvested prawn size are not of biological significance.

Trends in fishery-dependent data suggest that the Spencer Gulf Prawn Fishery is being harvested within sustainable limits. Firstly, catches have been relatively stable throughout the fishery's history. Secondly, effort has reduced to <37% of peak effort. And finally, the size of prawns harvested in recent years is substantially larger than those harvested 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 from November 2004 to improve the consistency of spatial and temporal replication of survey shots. These data are the primary information source for assessment and management of the SGPF. This chapter provides analyses that document trends in relative biomass (standardised catch rate), 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 Table 3.1.

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 (Table 3.1). 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 (Figure 3.1).

The Management Plan indicates that 209 shots (Figure 3.1) are surveyed each November, February and April. These shots were selected because of their history, location (ensuring a spread of shots throughout the main fishing regions) and survey logistics. During 2010, the number of survey shots conducted during November surveys was reduced to 182 by removing shots 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 primary aim of all three surveys is to provide snapshots of relative prawn biomass throughout the fishing-year to ensure that future harvest levels are sustainable. Additionally, data from November surveys provide information on egg production, and data from February surveys provide information on recruitment.

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 catch rate and prawn size data are available for November 2003, February 2004 and April 2004.

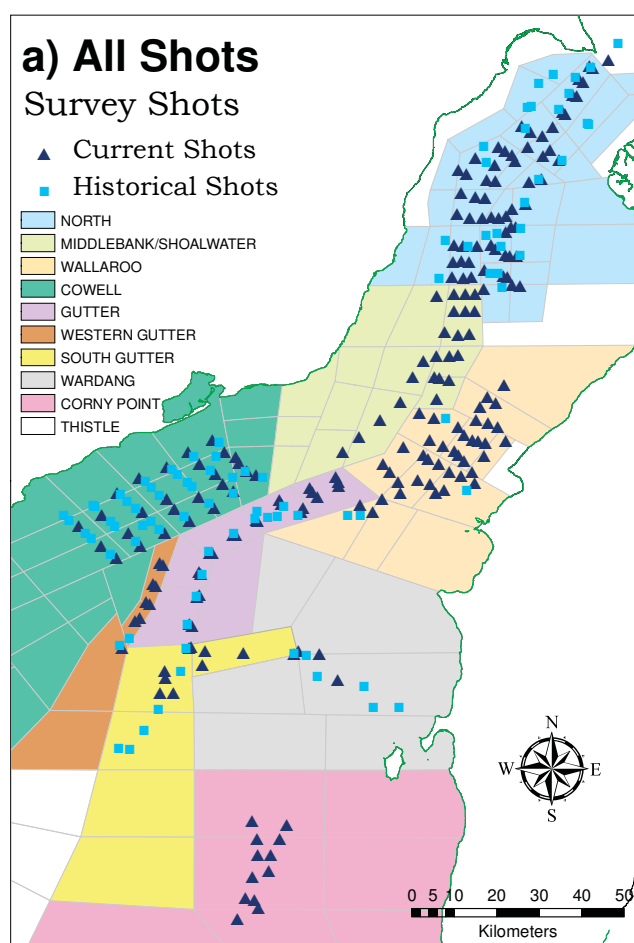


Figure 3.1 Map showing the regional distribution of 306 survey shots throughout Spencer Gulf that have been surveyed on occasions since 1982. Another 41 shots have been surveyed previously, but GPS data were not available. Current shots refer to the 209 survey shots that are required to be surveyed under the Management Plan.

Table 3.1 Number of stock assessment survey shots done in fishing regions of Spencer Gulf from February 1982 to April 2011.

Year	Month	North	M/bank/ S'water	Cowell	Gutter	S. Gutter	Wallaroo	W. Gutter	Corny Pt.	Wardang	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								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
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			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	62	22	27	22	8	40	9	12	5	207
2010	Feb	62	22	27	22	8	40	9	12	5	207
	Apr	62	22	27	22	8	40	9	12	5	207
	Nov	61	22	22	21	8	40	5			186
2011	Feb	62	22	27	22	8	40	9	12	5	208
	Apr	62	22	27	22	7	39	9	12	5	206

3.2.1 Standardised indices of relative biomass (survey CPUE)

To examine variability in survey catch rates (hereafter referred to as survey CPUE) associated with factors other than abundance, we used a generalised linear model (GLM; Nelder and Wedderburn 1972, McCullagh and Nelder 1983). The explanatory variables considered in the model were Survey Month, Vessel, Sea Surface Temperature (SST), Region, Location, Latitude, Tide Strength, Tide Direction and Moon Luminosity. Consistent data for all of these external factors were only available for the period 2004/05 to 2010/11. A series of models were fitted to this period of survey CPUE data to obtain a standardised index of abundance (Maunder and Punt 2004). Firstly, an appropriate error distribution for the model was determined by fitting survey CPUE ~ Season using four different distributional assumptions. These models were, a Gaussian (normal) GLM with a log link function fitted to survey CPUE, a Gaussian (normal) GLM with an identity link function fitted to log survey CPUE, a Gamma GLM with a log link function fitted to survey CPUE and a Gamma GLM with an identity link function fitted to log survey CPUE. Comparison of model residual and Q-Q plots identified the Gamma GLM with a log link function as fitting the observed data best.

Two separate analyses were undertaken to standardise survey CPUE. The first model considered annual estimates of total survey CPUE while the second analysis included an interaction between season and survey month to standardise Total survey CPUE for each survey. The models took the form

$$\text{CPUE} \sim \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n$$

where the X is the explanatory variables and β is the estimated model coefficients.

Three seasonal surveys were examined: November, February and April. Unique vessel identifiers were obtained from commercial logbook data. Average SST for Spencer Gulf was derived from satellite data for each survey night obtained from Physical Oceanography Distributed Active Archive Center (NASA 2011, Figure 3.2). Three measures were used to quantify the position of survey shots: Region (Figure 3.1); Location (Figure 3.3) and; Latitude. Tide Speed (m/s) was determined as the daily average tidal volume at Whyalla from tide tables (Anon 2011) and Tide Direction (AT = against tide, ST = slack tide, WT= with tide) was obtained from survey skipper logs. The percentage of the moon illuminated (Moon Luminosity) at midnight for Guam (equivalent to Australian Eastern Standard Time) was obtained for each survey night from the U.S. Naval Observatory (USNO 2011).

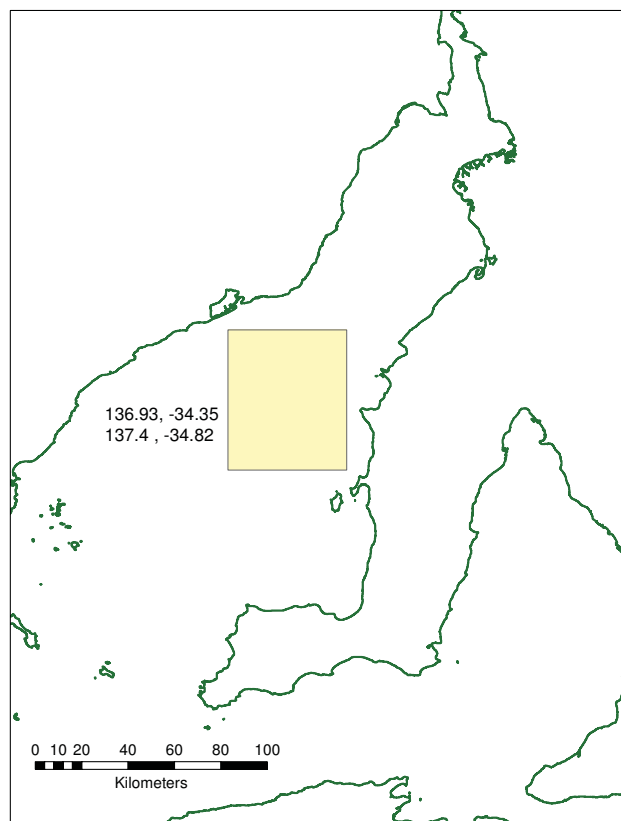


Figure 3.2 Area (shaded yellow) from which average SST was derived from satellite data from the Physical Oceanography Distributed Active Archive Center (NASA 2011)

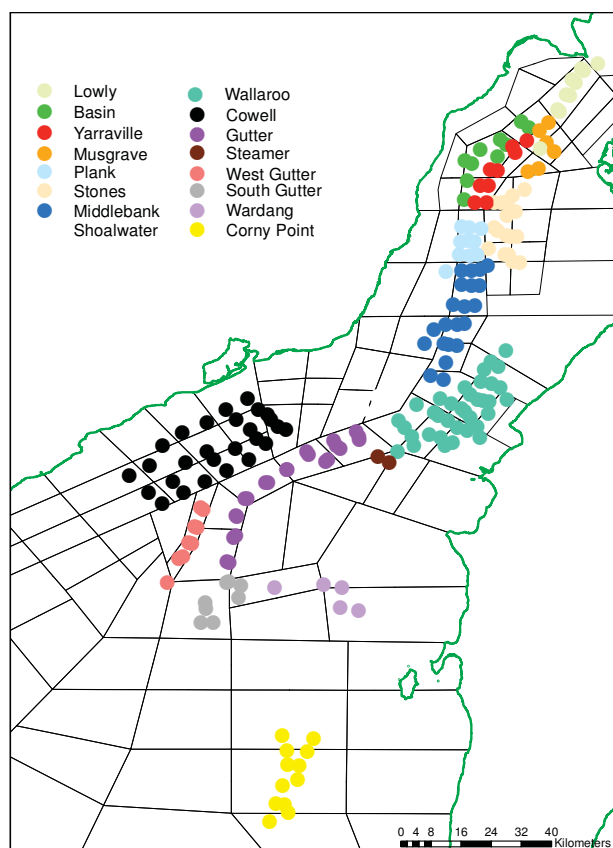


Figure 3.3 Locations of survey shots in Spencer Gulf.

To account for shots with zero survey CPUE under a log model, a small constant (0.01) was added to each record (shot) to include zeroes in the dataset. Latitude, SST, Tide Strength and Moon Luminosity were included as continuous variables. The remaining explanatory variables (Survey Month, Vessel, Region, Location and 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 forwards procedure, with terms added sequentially until the model was no longer statistically significant (Analysis of Deviance; $\alpha=0.05$). Only a single term was considered to represent the position of survey shots, thus once either Region, Location or Latitude were included the other terms were excluded. Interaction terms were not considered, the exception being the interaction of Season with Survey month which is required for the seasonal model.

In the annual analyses, standardised survey CPUE was obtained from the coefficients (β s) of the seasonal terms in the model. For the seasonal analyses, standardised survey CPUE was obtained from the coefficients of the season and survey month terms and the interaction between them for each survey.

Survey CPUE data are presented for the period 1986/87 to 2010/11. Because standardised estimates are determined relative to the first year of data, standardised estimates are provided for the period 2005/06 to 2010/11.

3.2.2 Prawn size

Data on prawn size were obtained from three independent measures per survey shot:

- 1) Length frequency data obtained from a sample of 100 prawns
- 2) "Bucket count" or the number of prawns per 7 kg sample
- 3) Prawn grade composition of the total catch per shot.

The mean size (carapace length, mm) of the surveyed population was determined as a weighted mean of all prawns measured (males and females combined) for each survey separately and for all surveys combined each fishing year. Length frequency samples were not available for all survey shots, particularly during 2004/05 and 2005/06 (Table 3.2).

Table 3.2. The number of length frequency samples collected during surveys conducted in November, February and April from 2004/05 to 2010/11.

Fishing year	November	April	February
2004/05	136	148	179
2005/06	162	140	174
2006/07	205	202	192
2007/08	205	206	205
2008/09	203	208	204
2009/10	207	206	200
2010/11	181	192	207

To compare trends in prawn size among methods, a mean bucket count was calculated, weighted by the catch rate of each shot, for each fishing year. Also, grade data were converted to a count of prawns per 7 kg using the methods described in Section 2.2.2. Each of these measures was available for almost all survey shots.

3.2.3 Egg production

The egg production model utilises much of the current knowledge of the biology of *P. latissulcatus* (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. Fertilization success for each size grade was determined visually from figures presented by Courtney & Dredge (1988). The following steps (1–11) 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) of prawns 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 prawn grade was determined from Courtney & 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 proportion of female prawns in each prawn grade was calculated from sex-specific length-frequency data;
- 10) Data from 8) and 9) were used to calculate the mean (SE) number of female prawns captured per hour;

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

3.2.4 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 2010/11 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 (survey CPUE)

Nominal survey catch rate has generally fluctuated within a consistent range for each survey month since 1985/86, with no long-term trends apparent (Figure 3.4). As documented in previous stock assessment reports (e.g. Dixon et al 2010), February survey catch rates were highly variable and apparently cyclical from 1996/97 to 2003/04. This was likely to be the result of highly variable pre-Christmas catches during this period influencing the strength of subsequent recruitment.

Standardised estimates of survey CPUE were very similar to nominal estimates for all measures (Figure 3.4a-d) despite the identification of several significant factors influencing both the annual and seasonal models (Tables 3.3 and 3.4). The optimal annual model included survey location, survey month, tide direction and tide strength (Table 3.3). Survey CPUE was highest at locations in upper Spencer Gulf and increased between the three surveys (November through to April). Survey CPUE was higher with the tide than against the tide or at slack tide and increased with increasing tide speed.

The optimal seasonal model included survey location, tide direction and the duration of survey shots (Table 3.4). Survey CPUE was highest at locations in upper Spencer Gulf, was higher with the tide than against the tide or at slack tide, and decreased slightly with increasing shot duration.

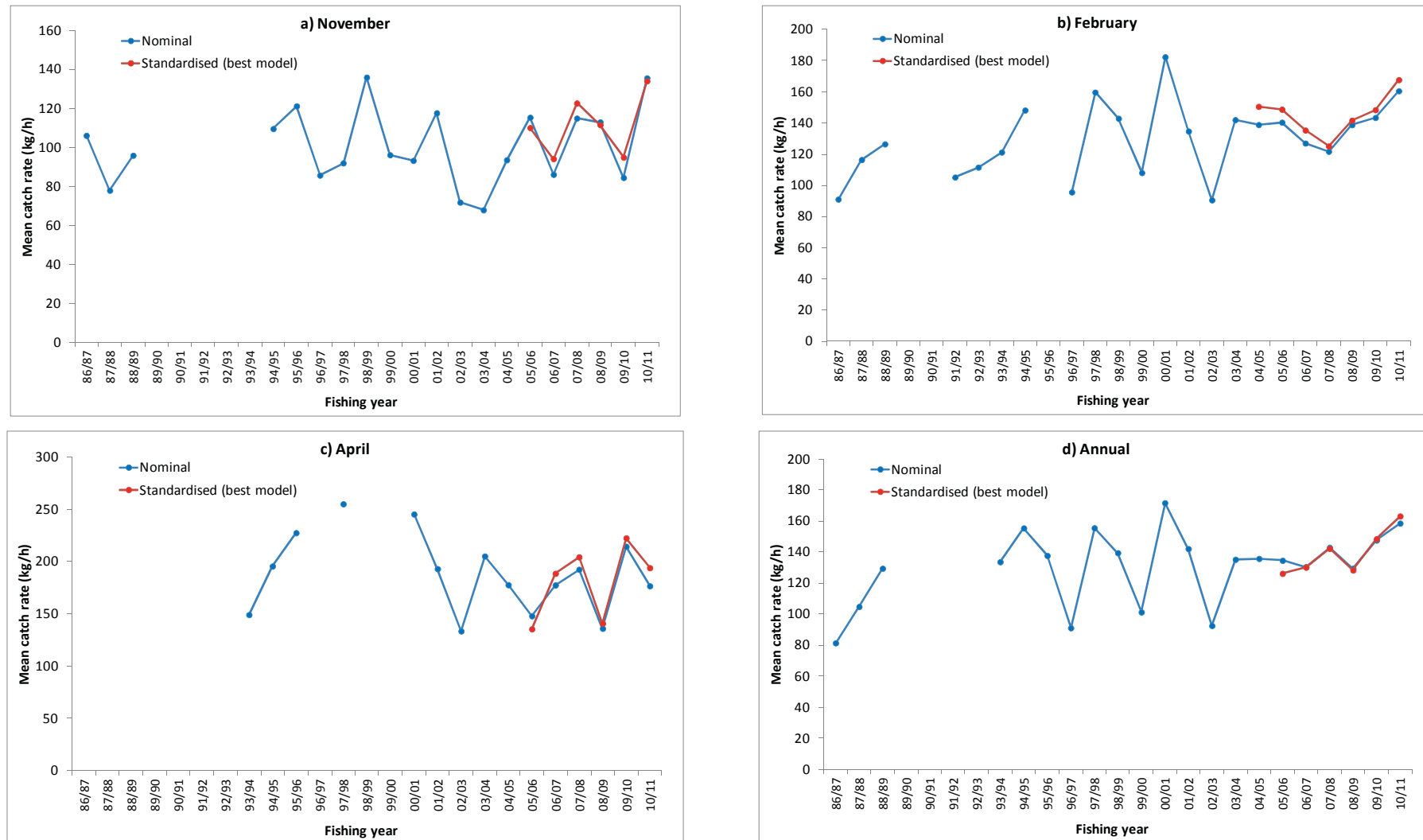


Figure 3.4 Nominal and standardised survey catch rate for a) November, b) February, c) April and d) all survey months combined (annual).

Table 3.3: Generalised linear model (GLM) results modelling the effect of environmental and fishery variables on annual survey CPUE. Explanatory variables include survey month (Survey), vessel, sea surface temperature (SST), region of survey shot, location of survey shot, latitude of survey shot, tide strength (Strength), tide direction (Direction), duration of survey shot (Minutes) and moon luminosity (Luminosity). Notation: Res. Dev = residual deviance; df = residual degrees of freedom; BIC = Bayesian information criterion; Δ BIC is the change in the Bayesian information criterion between the best (*) and candidate models. The null (Season only) model is also shown.

Model	Formula	Res. Dev.	df	BIC	Δ BIC	p-value
Null	CPUE ~ Season	3430.1	4302	50998.1	1563.4	-
1.6	CPUE ~ Season + Location	2574.3	4286	49758.4	323.6	<0.001
2.3	CPUE ~ Season + Location + Survey	2404.1	4284	49452.8	18.0	<0.001
3.6	CPUE ~ Season + Location + Survey + Direction	2387.1	4282	49436.3	1.5	<0.001
4.3*	CPUE ~ Season + Location + Survey + Direction + Strength	2382.1	4281	49434.7	0.0	0.001
5.3	CPUE ~ Season + Location + Survey + Direction + Strength + Minutes	2377.1	4280	49433.3	-1.4	0.001
6.1	CPUE ~ Season + Location + Survey + Direction + Strength + Minutes + SST	2376.2	4279	49439.8	5.0	0.157
6.2	CPUE ~ Season + Location + Survey + Direction + Strength + Minutes + Vessel	2313.2	4256	49506.3	71.5	<0.001
6.3	CPUE ~ Season + Location + Survey + Direction + Strength + Minutes + Luminosity	2375.0	4279	49437.5	2.81	0.04

Table 3.4: Generalised linear model (GLM) results modelling the effect of environmental and fishery variables on seasonal survey CPUE. Explanatory variables include survey month (Survey), vessel, sea surface temperature (SST), region of survey shot, location of survey shot, latitude of survey shot, tide strength (Strength), tide direction (Direction), duration of survey shot (Minutes) and moon luminosity (Luminosity). Season*Survey represents an interaction term between the season and the survey month. Notation: Res. Dev = residual deviance; df = residual degrees of freedom; BIC = Bayesian information criterion; Δ BIC is the change in the Bayesian information criterion between the best (*) and candidate models. The null (Season*Survey only) model is also shown.

Model	Formula	Res. Dev.	df	BIC	Δ BIC	p-value
Null	CPUE ~ Season*Survey	3197.0	4288	50775.0	1343.8	-
1.5	CPUE ~ Season*Survey + Location	2352.9	4272	49452.3	21.1	<0.001
2.6	CPUE ~ Season*Survey + Location + Direction	2335.2	4270	49433.6	2.4	<0.001
3.4*	CPUE ~ Season*Survey + Location + Direction + Minutes	2329.9	4269	49431.2	0.0	0.001
4.1	CPUE ~ Season*Survey + Location + Direction + Minutes + Temp	2325.7	4268	49431.3	0.1	0.003
4.2	CPUE ~ Season*Survey + Location + Direction + Minutes + Vessel	2261.6	4245	49492.9	61.7	<0.001
4.3	CPUE ~ Season*Survey + Location + Direction + Minutes + Strength	2329.6	4268	49439.1	7.9	0.459
4.4	CPUE ~ Season*Survey + Location + Direction + Minutes + Luminosity	2329.9	4268	49439.6	8.4	0.973

3.3.2 Prawn size

Carapace length varied considerably among months, being largest in November in all years and smallest in February in most years (Figure 3.5). The difference in size among months reflects differences in the abundance of recruits. While February is considered as the peak period of recruitment, it is interesting that mean size was smallest in April during 2008 and 2011.

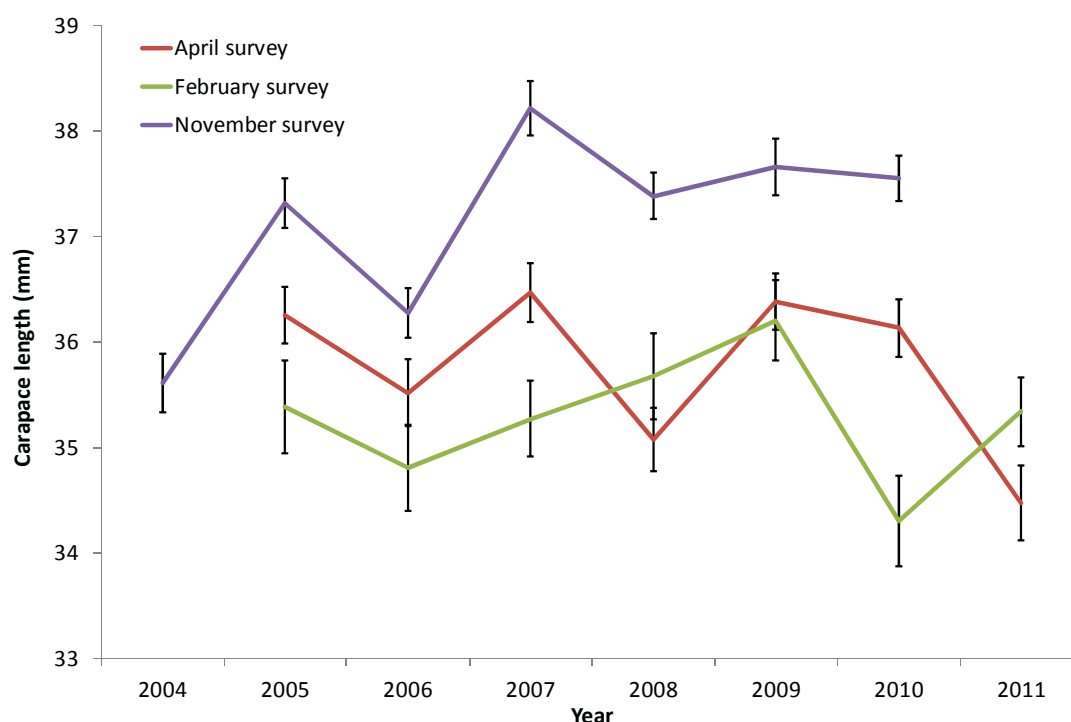


Figure 3.5 Mean weighted carapace length (mm) measured during November, February and April surveys from 2004 to 2011.

Comparison of prawn size measures indicated that bucket counts and mean carapace length generally increased from 2004/05 to 2008/09 before decreasing consecutively in the last two fishing years (Figure 3.6). Prawn size was smallest during 2010/11 for all three measures. The similarity between these two independent measures gives strength to the observed trends. Although trends in grade data were similar to the other measures from 2004/05 to 2006/07, they were substantially and consistently smaller thereafter.

There was, however, a strong correlation between bucket count and grade data at counts <600 prawns per 7 kg (Figure 3.7). At higher bucket counts, prawn grade data became biased because the smallest recorded prawn grade (grade 30+, mean weight 12.8 g, Table 2.2) overestimated the mean weight of prawns at these high bucket counts.

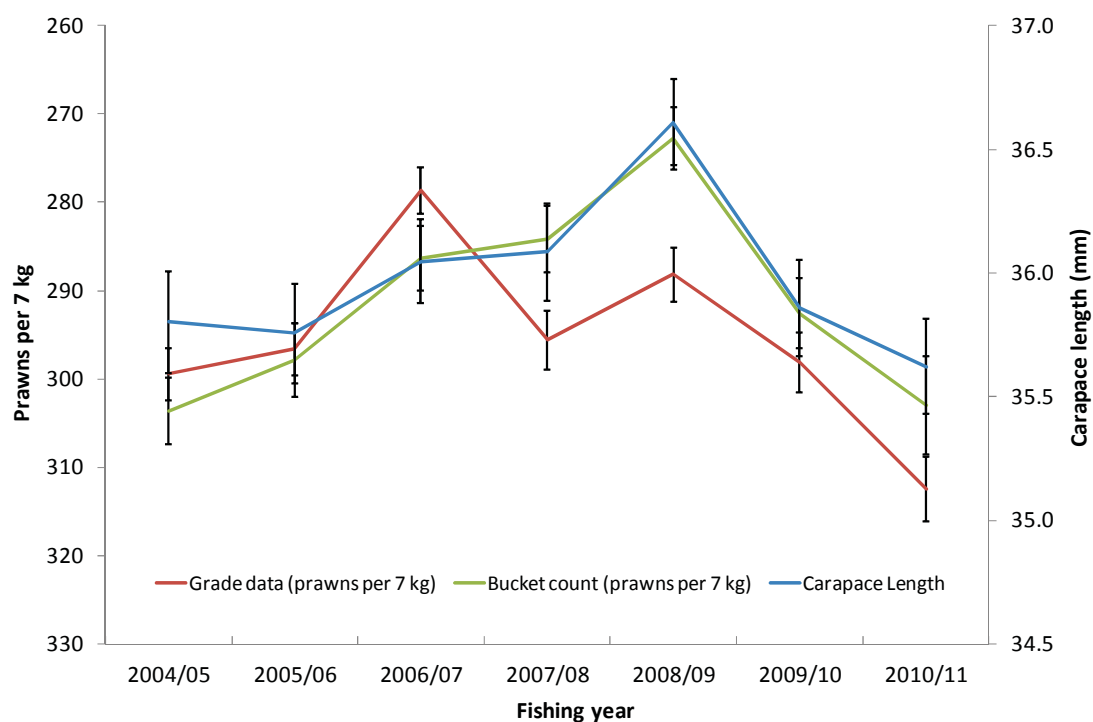


Figure 3.6 Comparison of annual measures of prawn size from length frequency data (carapace length), bucket counts and grade data from 2004/05 to 2010/11.

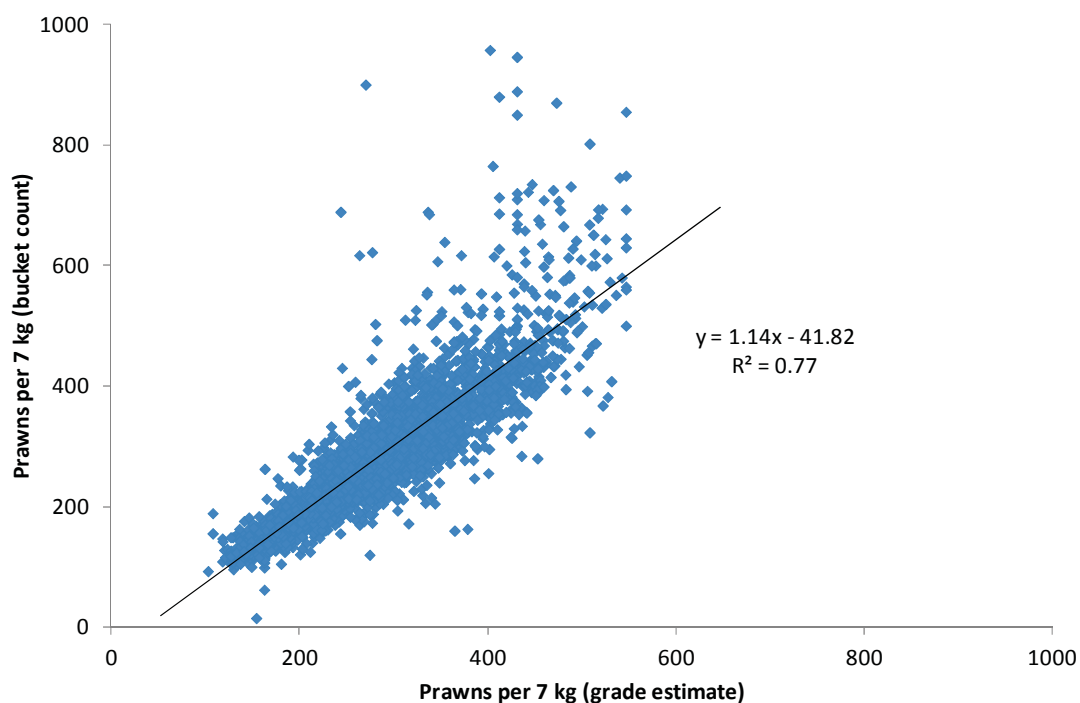


Figure 3.7 Correlation between bucket counts and prawn grade data from all samples collected between 2004/05 and 2010/11.

3.3.3 Egg production

Mean egg production per hour trawled during November 2010 (791 million/hr) was the second highest recorded and was well above the previous six-year average (mean 613 million/hr, range 416–874 million/hr, Figure 3.8).

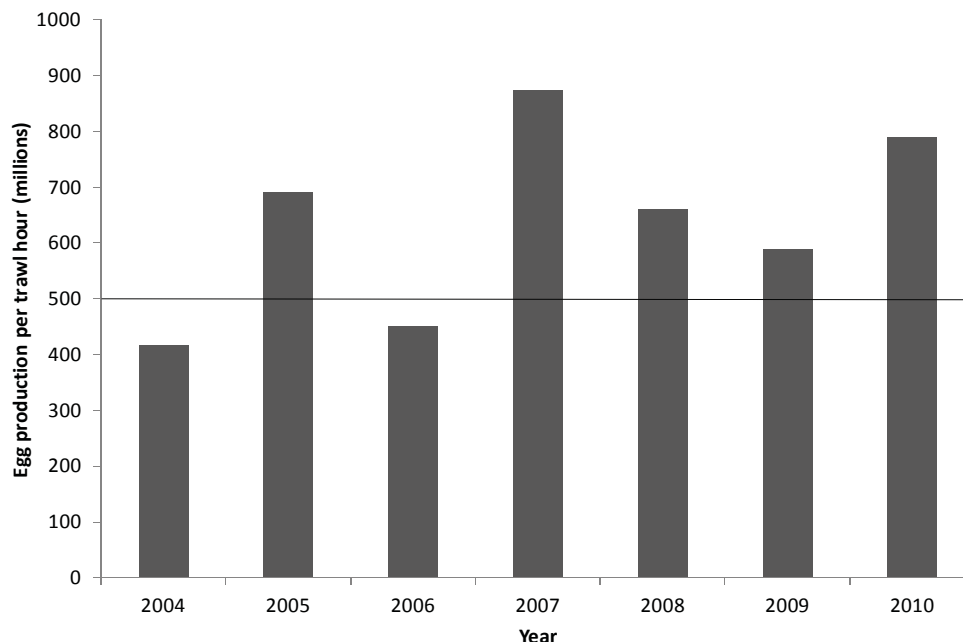


Figure 3.8 Total egg production for November surveys from 2004 to 2010.

3.3.4 Recruitment

The recruitment index was lowest during 2000 (~30; Figure 3.9) and greatest during 2001 (~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 reference level (35) for eleven consecutive years and for 21 of the 24 years that February surveys have been conducted since 1982. The recruitment index during 2011 (39.7) was the lowest observed since 2003.

Mean recruit abundance across all sites surveyed in Spencer Gulf was lowest in November during all years (Figure 3.10). While mean recruitment was generally much higher during February than April, the reverse was true in 2008 and 2011.

Regional assessment of recruit abundance indicated that recruitment was highest in the Northern and Middlebank/ Shoalwater regions, particularly during February (Figure 3.11). 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.

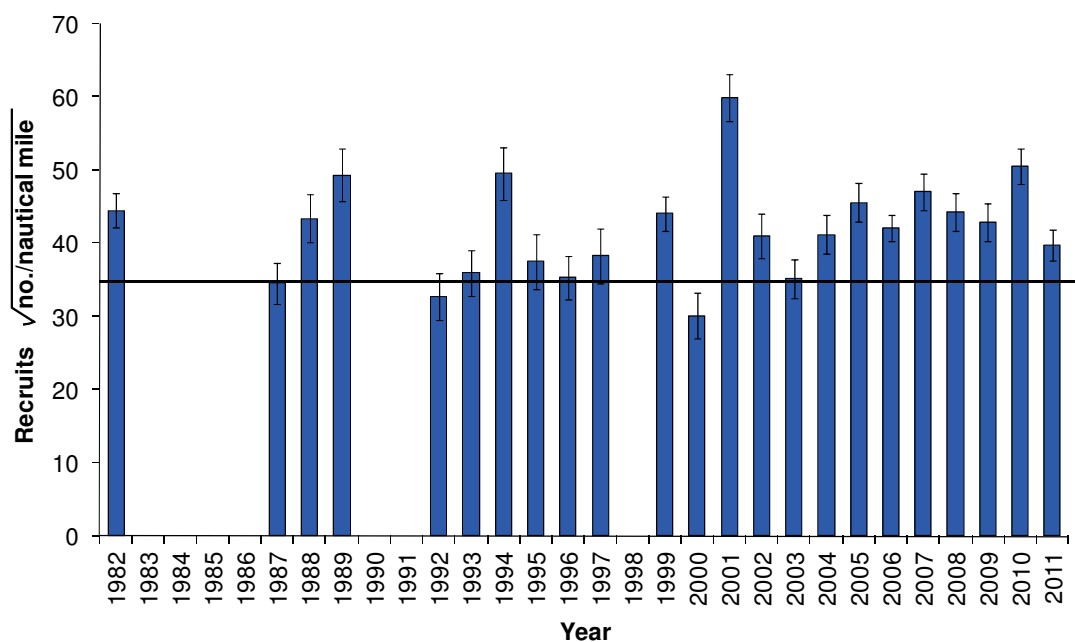


Figure 3.9 Mean (SE) recruitment index for up to 39 stations surveyed in February in the northern region of Spencer Gulf from 1982 to 2011. The horizontal line represents the limit reference point (35/nm).

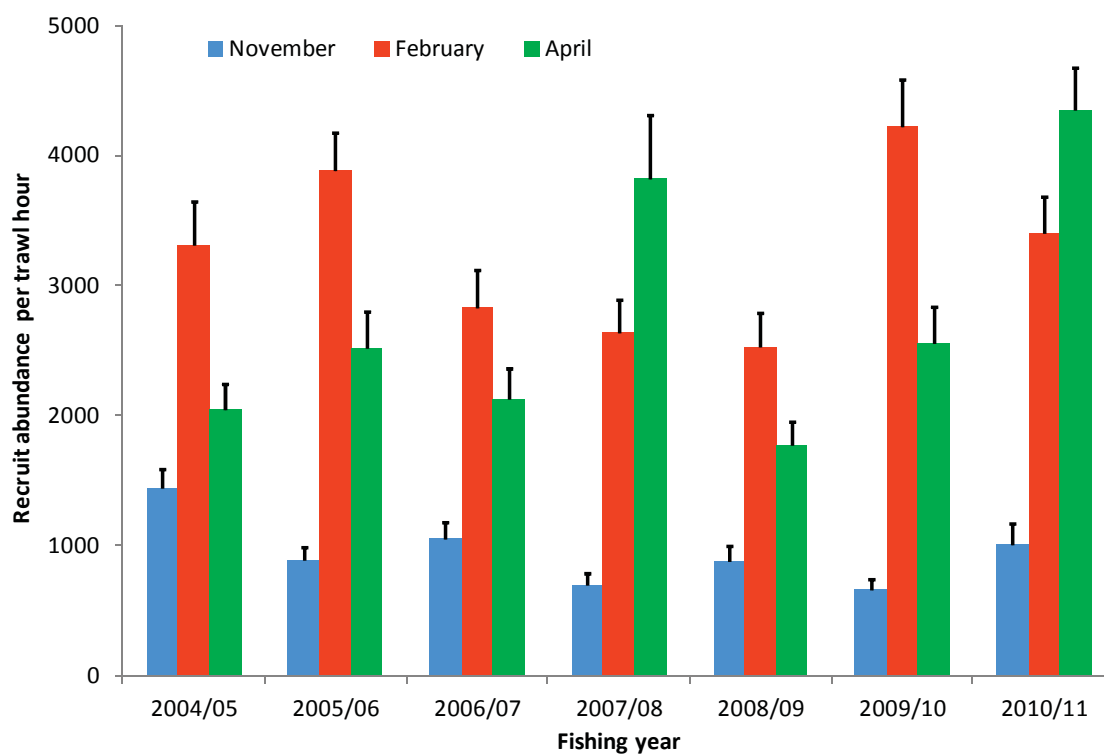


Figure 3.10 Mean (SE) recruit abundance throughout Spencer Gulf for surveys conducted in November, February and April from 2004/05 to 2010/11.

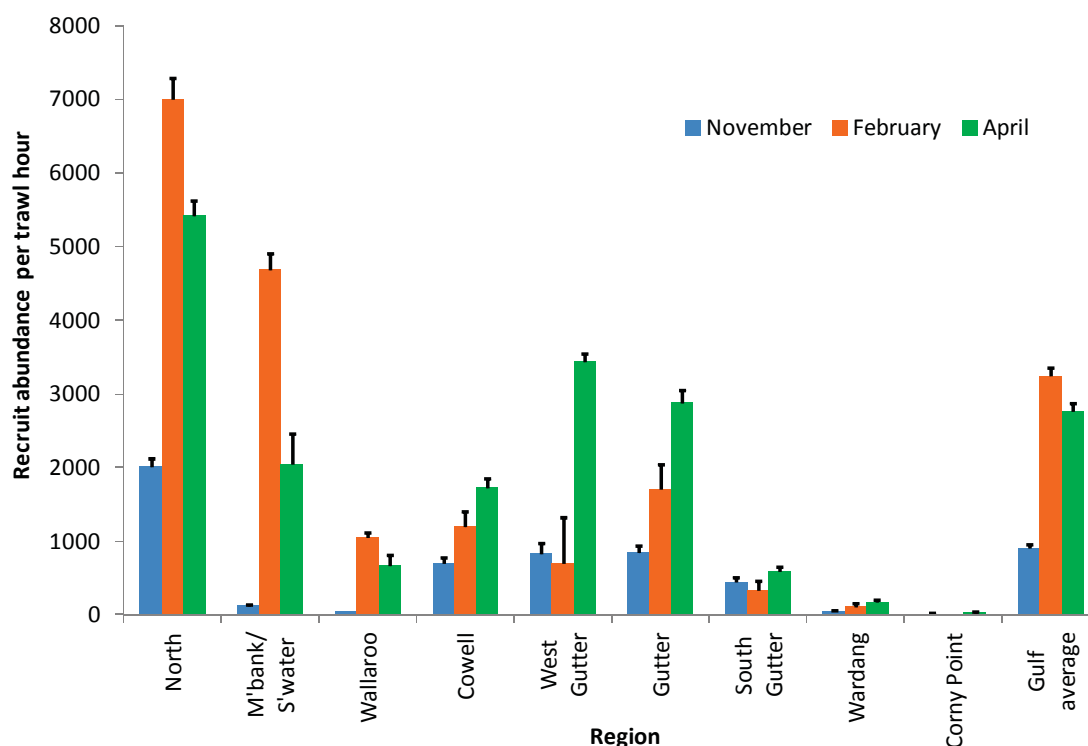


Figure 3.11 Mean (SE) recruit abundance from 2004/05 to 2010/11 for regions of Spencer Gulf for surveys conducted in November, February and April.

3.4 Discussion

Fishery-independent surveys have been conducted since February 1982 from up to 347 shots throughout Spencer Gulf, most frequently during the months of November, February and April. These data provide an excellent basis for assessment of the SGPF. Prior to 2004/05, the location of selected shots for any given survey was highly variable, a reflection of the style of harvest strategy development and the real-time management approach at that time. Since 2006/07, the locations of stock assessment survey shots have been fixed to enable robust comparisons of catch rate (index of relative biomass) and prawn size among years and survey months.

This report is the first to provide a standardised measure of biomass for the fishery. However, the differences between standardised and nominal estimates of survey CPUE were very small for seasonal and annual measures despite the analysis identifying several significant factors that affect survey CPUE. This results from the consistent spatial and temporal survey design that minimises variability in these effects between years. The most important factor for the annual and seasonal models was location, with higher CPUE in the northern parts of the gulf. For the annual model, survey month was the second most important factor, with CPUE

increasing each survey from November to April. Tide direction was a significant factor in both models, with higher catch rates when survey shots were conducted with the tide than either slack or against the tide. Tide strength was an important factor in the annual model but this may be confounded with season. For the seasonal model, survey CPUE decreased with increasing shot duration, suggesting that when possible, shot duration should be maintained at 30 minutes.

Trends in annual survey CPUE were most similar to those observed during February. This was evident throughout, with highly fluctuating CPUE from 1996/97 to 2003/04 and relative stability thereafter. As previously documented, the recent stability is likely the result of consistent pre-Christmas catches during this period (Dixon *et al.* 2010). The similarity between February and annual survey trends may reflect the influence of recruitment on total biomass measures. Future analysis of survey CPUE could consider modelling the mature and recruit biomass separately.

The annual measure of survey catch rate displayed a subtle increasing trend over time. As discussed in the previous assessment (Dixon *et al.* 2010), this increase likely reflects increases in vessel power over time. Changes in vessel power should be considered when determining appropriate performance measures for the fishery, particularly for a Management Plan that spans 5–10 years without review. One appropriate approach may be to include an agreed annual adjustment factor to survey catch rate reference points that are used to guide harvest strategy development. Alternatively, an analysis of vessel power could be conducted.

Data on prawn size is collected from three independent sources for each survey shot, with each having a different purpose. The bucket count provides a rapid assessment of the mean weight of prawns from a 7 kg subsample of the catch and these data are used to determine fishing areas. Length-frequency samples of 100 prawns for each shot provide data on sex-specific size structure and recruit abundance. These data are used to assess against the Performance Indicators presented in this report. Total catch weight by prawn grade (grade data) is gathered for rapid assessment of size structure, in particular for the weight of recruits (20+ grade) and is also used for determining fishing areas. Assumptions regarding the mean weight of prawns in each size grade enable grade data to be converted to a mean weight of prawns in the total catch for each shot.

Comparison of the three measures of prawn size indicated a strong similarity between trends in mean carapace length and bucket counts. Although these samples are collected independently, the correlation is not surprising as both samples are collected simultaneously from the sorting belt. Trends in grade data did not correlate well with the other two measures from 2007/08 to 2010/11. The reasons for the difference in trends from grade data are unknown. Correlations between bucket counts and grade data indicate a bias at bucket counts with very small prawns (>600 prawns per 7 kg). The strong correlation between the measures at bucket counts <600 prawns per 7 kg suggests that mean weight estimates from grade data could be useful as an additional measure of mean prawn size alongside bucket counts when determining fishing areas.

The mean carapace length of prawns varied between surveys with the largest prawns observed in November. The smallest prawns were generally observed in February, which reflects peak recruitment to the fishery. The lower mean size observed during April in 2008 and 2011 is reflective of a peak in recruitment that occurred after the February survey. An improved understanding of the factors affecting the timing of recruitment would aid assessment of the fishery.

Recruitment indices are determined from up to 39 shots in the North region that have been surveyed in February during most years since 1982. The recent investment in egg production by stabilising pre-Christmas harvest has seen a short-term, 25% increase in the mean recruitment index 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.

Analysis of mean recruit abundance throughout Spencer Gulf since 2004/05 provided in this report gives an improved understanding of recruitment to the fishery. In most years, peak recruitment was observed during February. However, as identified by differences in mean carapace length, recruitment was higher during April surveys in 2008 and 2011. During February, recruitment was highest in the North followed by the Middlebank/ Shoalwater regions, and combined, these regions produced 70% of all recruits. Interestingly, recruitment peaked in April in the Western Gutter and Gutter regions. These trends in overall recruitment to the fishery suggest that a recruitment index that is limited to a few shots in the northern region of Spencer Gulf during February is not the best measure for recruitment to the fishery. Future recruitment measures should include greater spatial and temporal replication.

The egg production model was first developed in 2007. An FRDC Project (2008/011) that will be completed within the next six months substantially improves our understanding of the stock-recruitment relationship in Spencer Gulf by combining improved knowledge on the reproductive and larval biology of western king prawns in Spencer Gulf with a validated hydrodynamic model of the gulf's waters. Until these results are obtained, annual comparisons of egg production from the current model should be interpreted cautiously.

Fishery-independent data on survey CPUE, prawn size, recruitment and egg production suggest that the fishery is currently being harvested in a sustainable manner. Further, standardised estimates of survey CPUE suggest that the use of nominal CPUE is a robust measure of relative biomass for harvest strategy determination and for performance assessment of the fishery. Analyses of recruitment data collected consistently over the last seven fishing years suggest that peak recruitment is not always detected in February surveys. This has implications for interpretation of the current Performance Indicator for recruitment.

4. HARVEST STRATEGY ASSESSMENT

4.1 Introduction

The harvest strategy for the Spencer Gulf Prawn Fishery has been a key factor in its success because it aims 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. 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 aims to assess the effectiveness of the real time management process by examining the size of prawns captured at fine temporal and spatial scales. Summary data are tabulated in this section, with detailed maps for each survey and harvest period provided in the Appendix.

Harvest 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 harvest 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. Harvest periods in November and December are primarily restricted by total catch limits, whereas harvest 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 November 2009, February, April, November 2010, and March and April 2011. 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 4.2).

Total catch and mean harvested size were assessed for each fishing year at a fine spatial scale (fishing block) and temporal scale (harvest period) from commercial logbook data. Eight harvest periods were assessed during 2009/10 and seven were assessed during 2010/11. Total catch and mean harvested size were summarised for each harvest period and assessed against the relevant criteria for minimum catch per vessel night (Table 4.1) and target harvested size (see Tables 4.2 and 4.3). Detailed maps for each survey and harvest period are provided in the Appendix.

Table 4.1 At-sea decision rules for the Spencer Gulf Prawn Fishery for minimum catch per night.

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

4.3 Results

Three surveys were conducted during each of 2009/10 and 2010/11 (Table 4.2). The limit reference for 20+ grade was achieved during all surveys, thus the nature of each harvest strategy was dependent upon total catch rate in each instance. Standard strategies resulted from surveys conducted during February 2009/10 and February and April 2010/11. A conservative strategy resulted from the survey conducted during November 2009/10. Increasing strategies resulted from surveys conducted during April 2009/10 and November 2010/11.

Table 4.2. Stock assessment survey results and the nature of harvest strategies for the SGPF during 2009/10 and 2010/11. 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 harvest strategy.

Fishing year	Survey	20+ grade (kg/h)		Total (kg/h)		Nature of strategy	Primary decision rule
		Limit ref.	Result	Range	Result		
2009/10	Nov	10	26	95–135	94	Conservative	<350 t
	Feb	50	78	120–160	152	Standard	<220 prawns/7kg
	Apr	40	68	160–200	252	Increasing	<260 prawns/7kg
2010/11	Nov	10	33	95–135	145	Increasing	<600 t
	Mar	50	72	120–160	158	Standard	<220 prawns/7kg
	Apr	40	87	160–200	197	Standard	<240 prawns/7kg

During 2009/10, 235 blocks were fished during eight harvest periods (Table 4.3). Prawns that did not meet target size criteria were harvested in 17 (7%) of these blocks, mostly during harvest periods 3 and 4. The total catch from these blocks was 350 t which represented 15% of the annual catch. Of the 49 nights fished, 7 of these nights did not achieve target size criteria, again mostly in harvest periods 3 and 4. Minimum nightly catch criteria were met during all fishing nights.

During 2010/11, 175 blocks were fished during seven harvest periods (Table 4.3). Prawns that did not meet target size criteria were harvested in 16 (9%) of these blocks, from harvest periods 3 to 7. The total catch from these blocks was 342 t which represented 17% of the annual catch. Of the 46 nights fished, 7 of these nights did not achieve target size criteria. Minimum nightly catch criteria were met during all but two fishing nights.

4.4 Discussion

Variable survey results culminated in a mix of standard, conservative and increasing harvest strategies during 2009/10 and 2010/11. As a result, the target-size criteria were also variable among harvest periods. Assessment of mean prawn size against target size criteria indicated that high proportions of prawns that did not meet target size were harvested during both years. However, most of this catch was harvested during periods when the target size was largest (<220 prawns per 7 kg) and thus reflects differences in the rules for target size rather than real differences in the mean size of prawns in the catch.

On some occasions during the past two fishing years, the target size in the Management Plan has been altered in a trade-off for reductions in effort (e.g. nights fished or trawl hours) in an agreement among industry and PIRSA Fisheries and Aquaculture. Given that sustainability does not appear to have been compromised by these decisions, reassessment of the harvest strategy decision rules to reflect current fishing practice may be warranted.

Table 4.3. Statistics of fishing performance regarding catch and prawn size criteria as assessed against the Management Plan for eight harvest periods in 2009/10 and seven harvest periods in 2010/11. *Blocks and total catch outside of size criteria do not include confidential catches.

Fishing year	Harvest 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
2009/10	1 (Nov)	<250	29	0	176	0	7	0	0
	2 (Dec)	<250	44	1	182	0.5	8	0	0
	3 (Mar)	<220	31	10	318	132	8	3	0
	4 (Apr)	<220	27	6	274	218	4	3	0
	5 (Apr)	<240	26	0	561	0	7	1	0
	6 (May)	<260	20	0	199	0	3	0	0
	7 (May)	<260	39	0	409	0	7	0	0
	8 (May)	<260	19	0	242	0	5	0	0
Sub-total			235	17	2361	350	49	7	0
2010/11	1 (Nov)	<250	16	0	369	0	6	0	0
	2 (Dec)	<250	26	0	163	0	6	0	0
	3 (Mar)	<220	33	5	184	42	5	2	1
	4 (Mar/Apr)	<220	11	4	208	191	3	3	0
	5 (Apr)	<220	20	3	273	43	6	1	0
	6 (Apr/May)	<240	41	3	490	39	10	1	0
	7 (May/Jun)	<240	28	1	293	27	10	0	1
Sub-total			175	16	1979	342	46	7	2

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 2008/09, 2009/10 and 2010/11 fishing years of the Spencer Gulf Prawn Fishery.

PI	Limit RP	'08/'09	'09/'10	'10/'11
Recruitment index	<35	42.9	50.5	39.7
Total commercial catch (t)	<1800	1,821	2,361	1,979
Mean commercial CPUE (kg/h)	<80	102	139	118
% vessel nights with mean size >280 prawns/7 kg	>2%	0.5%	1.0%	1.0%
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 Recruitment index

Recruitment indices were calculated as the square root transformation of the numbers of prawns (males <33 and females <35 mm carapace length) per nautical mile trawled (after Carrick 2003). The recruitment index of 50.5 during 2009/10 and 39.7 during 2010/11 were both above the limit RP.

5.2 Total commercial catch

Total commercial catch in 2009/10 (2,361 t) and in 2010/11 (1,979 t) were both above the limit RP for the fishery.

5.3 Mean commercial CPUE

Mean commercial CPUE in 2009/10 (139 kg/h) and in 2010/11 (118 kg/h) were both above the limit RP for the fishery.

5.4 Percent of vessel nights when mean size was >280 prawns/7 kg

The mean size of prawns harvested for each vessel night was calculated from commercial logbook prawn grade data. During 2009/10, prawns with an average size

smaller than 280 prawns/7 kg were harvested on 18 of 1902 (1.0%) vessel nights when prawn grade data were reported. During 2010/11, prawns with an average size smaller than 280 prawns/7 kg were harvested on 18 of 1788 (1.0%) vessel nights when prawn grade data were reported. This was above the limit RP for the fishery.

5.5 Fishery independent surveys

Three fishery independent surveys were conducted during 2009/10 and 2010/11.

5.6 Indices of current and future biomass

Indices of future biomass were above the limit reference point for all three stock assessment surveys. Standard strategies resulted from surveys conducted during February 2009/10 and February and April 2010/11. A conservative strategy resulted from the survey conducted during November 2009/10. Increasing strategies resulted from surveys conducted during April 2009/10 and November 2010/11. As there was only one conservative strategy for this period, this performance indicator was met successfully.

5.7 Committee comply with harvest strategy decision rules

The decision rule for a conservative strategy following the November 2009 stock assessment survey was exceeded as total pre-Christmas catch was 358 t (should not have exceeded 350 t). While harvest areas were determined following the agreed criteria for target size, resulting catches were not always harvested within target size.

5.8 Additional performance measures

The Management Plan provides a set of additional performance measures that are critically assessed if a key PI is breached (Table 5.2). As no key PI were breached during 2009/10 or 2010/11, the following is provided for information only. Triggering additional performance measures does not evoke a management response.

Table 5.2 Summary of additional performance measures for the 2008/09, 2009/10 and 2010/11 fishing years of the Spencer Gulf Prawn Fishery.

Performance Measure	Limit RP	2008/09	2009/10	2010/11
Recruit index November survey all shots	>12	13.1	10.1	12.1
Recruit index February survey all shots	>19	23.8	27.9	26.6
Recruit index April survey all shots	>15	25.2	21.2	29.5
Egg production (eggs*10 ⁶ / hr trawled)	>500	661	588	791
% of 20+ in the catch – Nov & Dec	<12%	3.7	3.9	3.9
% of 20+ in the catch – March to June	<7%	3.8	3.4	7.0
% of 16–20 in the catch – Nov & Dec	25–35%	26.3	20.7	29.6
% of 16–20 in the catch – March to June	<30%	26.2	32.4	30.2

PI breached

Recruitment Indices were calculated as the square root of the numbers of prawns (males <33 and females <35 mm carapace length) 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). During 2009/10 and 2010/11, recruitment indices were within the reference range for all surveys except November 2009.

Egg production estimates in 2009/10 (588 eggs*10⁶/ hr trawled) and 2010/11 (791 eggs*10⁶/ hr trawled) were above the limit RP.

The proportion of 16–20 grade prawns from March to June was outside of the reference range in both 2009/10 and 2010/11. All other measures of prawn size were within acceptable reference ranges.

5.9 Discussion

All of the seven key PI's were either achieved or were above the acceptable limit reference range during 2009/10 and 2010/11. The primary PIs do not relate to traditional measures of stock status but rather reflect adherence to harvest strategy decision rules. This has been recently 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 reference points.

The PI for "Committee comply with harvest strategy decision rules" can not be objectively assessed as there are currently no quantitative measures by which to assess harvest strategy development or management by the Committee-At-Sea. Whilst appropriate assessment of harvest strategy development requires scrutiny of the data from survey shots included in harvest strategies, assessment of harvest strategy management can be achieved by determining whether harvest strategy 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. Notably, infringements of these criteria occurred in 2009/10 and 2010/11, but technically the reference point was not triggered.

As discussed in previous reports (eg Dixon *et al.* 2010), 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 (e.g. 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 Current Status of the Spencer Gulf Prawn Fishery and uncertainty in the assessment

This report provides comprehensive analyses from several sources of highly reliable data and thus represents a robust assessment of the resource upon which the Spencer Gulf Prawn Fishery (SGPF) is based. As indicated in all recent stock assessment reports (Dixon *et al.* 2005a, 2007, 2008, 2009, 2010), 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 <37% of the 1978/79 peak; and mean harvested prawn size was larger in recent years than in 1978/79. This long-term success can be largely attributed to the fishery-independent surveys conducted since 1982 that have established an understanding of the patterns of prawn distribution and abundance to enable the development of harvest strategies that ensure sustainability. The development of a bio-economic model in the next few years will provide further improvement in the development of the harvest strategy and the assessment of the fishery.

This is the first report to provide standardised estimates of survey CPUE (2004/05 to 2010/11). There was a high degree of similarity among standardised and nominal measures, a result of the robust spatial and temporal replication of surveys in recent years. Although surveys conducted prior to 2004/05 were highly variable in their spatial extent, the model identified significant differences in CPUE among locations which may be used in future assessments to improve the reliability of historic survey data.

Survey CPUE data indicate that relative biomass has stabilised in the last seven fishing-years compared to the highly fluctuating levels observed from the mid 1990's. The similarity between February survey estimates and the annual measure suggest that recruitment strength is a primary driver of relative biomass, which adds further weight to the argument that the recent stability in recruitment, biomass and catch is a direct result of investment in constraining pre-Christmas catch. Future standardisation models should consider splitting the relative biomass into recruit and mature biomass. Further, an understanding of vessel power would also improve the model.

Total catches during 2009/10 and 2010/11 were above the historic average, the former being the third highest catch recorded. Interestingly, the high catch in 2009/10 was attained despite a low pre-Christmas harvest. Commercial CPUE was also very high during this period, being 22% higher in 2009/10 than the previous historic peak. While this likely reflects high prawn abundance during 2009/10, this was also affected by a decision to reduce the duration of trawl hours each night which demonstrates the difficulty in using nominal commercial CPUE as an index of abundance.

The mean size of prawns harvested during 2010/11 was the smallest since 2002/03. While not of biological concern, the size of prawns harvested can have significant impact on economic returns. The primary aim of the future bio-economic model is to determine optimum harvest times and target sizes throughout the fishing year. Once new decision rules have been developed, there will be a need for greater scrutiny in the assessment of harvested prawn size. Currently, there is some uncertainty in the estimates of mean prawn size, particularly differences among commercial graders and validation of the mean weight of prawns in each commercial size grade.

6.2 Performance Indicators of stock status

The Management Plan identifies seven key PIs and eight additional PIs for the fishery that form the basis of a performance framework that has been in place for five years. Several of the primary PIs do not relate to traditional measures of stock status but rather reflect adherence to harvest strategy decision rules. This issue was recently highlighted in the assessment of the Spencer Gulf Prawn Fishery during its certification by the Marine Stewardship Council (MSC). A more appropriate framework could be to have a primary biological PI(s) to assess annual “stock status”.

The principal PI for annual stock status should be a measure of “harvestable” biomass with associated target and limit reference points. This PI could be measured as the mean survey catch rate of prawns in the 16/20 size grade and larger as these are the size grades of highest commercial value. Harvestable biomass also reflects the spawning biomass of the fishery, although relative egg production by weight from the 16/20 prawn grade is less than half that of larger prawn grades.

Recruitment strength could be used as a secondary biological PI. The current recruitment index is based on the catch rate of recruits from a limited number of shots during February surveys, while there are additional PIs for recruitment in other survey months. Analyses in this report indicate that the timing of peak recruitment may vary temporally and spatially and thus a more appropriate PI should be established. Further, the recruitment index is calculated as a square root transformation to enable robust statistical comparisons among years and regions. In future the recruitment index should be reported on and measured against untransformed values to provide a more intuitive assessment.

While the secondary PI for egg production will be improved considerably in future assessments after the completion of the FRDC project 2008/011, it is unlikely that estimates of egg production will be reliable enough to use as a primary biological indicator of stock status. Currently, the additional PI for egg production should be interpreted cautiously.

Several of the existing PIs are not biological measures but could be useful for assessing economic “fishery status”. The PIs for total commercial catch and mean commercial CPUE are appropriate economic indicators.

6.3 Harvest Strategy

The use of the term “harvest strategy” in the Spencer Gulf Prawn Fishery Management Plan (Dixon and Sloan 2007) and in this report differs to the definition and use of the term for most other Australian fisheries. Here, a harvest strategy refers to the management of fishing effort for each harvest period through temporal and spatial closures, with several harvest strategies being developed and managed throughout each fishing year. The Commonwealth Fisheries Harvest Strategy Policy and Guidelines (Anon 2007b) defines a harvest strategy as the framework that “sets out the management actions necessary to achieve defined biological and economic objectives in a given fishery.” As with most fisheries, the Spencer Gulf Prawn Fishery is assessed against biological and economic objectives on an annual basis, and thus the current use of the term is inappropriate. A more appropriate term for the management of fishing effort throughout the year could be “fishing strategy”. This inconsistency was noted in the assessment of the fishery for MSC accreditation.

There is a need to develop appropriate decision rules tools to manage fishing effort in the post-Christmas harvest period. The current use of prawn size (exclusively) was

not effective during the last three fishing seasons. A combination of measures including reduced trawl hours and reduced total nights have been used in recent years to limit catch when conservative strategies are required.

Consideration should be given to the appropriate scale at which prawn size is measured. Currently, all performance indicators for prawn size are determined across an entire fishing year. Analyses in this report provide useful information on mean prawn size for the fleet for each day fished and for each fishing block during a harvest period.

6.4 Future Research

To date, the focus of this and previous assessments for the Spencer Gulf Prawn Fishery has been on biological sustainability. A revised Management Plan for the fishery is due for completion by June 2013 and it is expected to incorporate a stronger focus on economic objectives. Consequently, future research needs currently include approaches to address issues such as the optimisation of harvest (fishing) strategies or rationalisation of the fleet (e.g. transferability).

A common tool used to help address these economic issues is the development of a bio-economic model and funding has been recently obtained from the Australian Seafood CRC for model development beginning mid 2012. The primary objective of the model will be for the development of improved harvest strategies that aim to maximise profit, such as determining appropriate levels of pre-Christmas catch, the timing of harvest post-Christmas and the best target size for various biomass and size distributions. Once the model has been developed, it should also be possible to examine the economics of alternative management strategies such as a reduction in the size of the fleet, or the introduction of quota.

To date, the fishery has not needed to undertake biological modelling as it has maintained sustainability using cost effective measures of relative abundance from surveys. The bio-economic model will enable the development of PIs for biomass with explicit target and limit reference points and in doing so will address a primary condition of MSC re-certification. While these new PIs will clearly aid the development of a more robust and understandable harvest strategy, it is important that the Performance Framework continues to include the traditional measures of relative abundance.

The MSC process also provided a series of non-binding recommendations including the standardisation of commercial CPUE data and the testing of the design and interpretability of the stock assessment surveys. The development of the bio-economic model is likely to require standardisation of commercial CPUE. It will also provide a robust approach to examining and modifying the survey design. It is recommended that the current survey design be maintained until model testing can be conducted.

A current impediment to modelling is the considerable uncertainty in critical biological parameters including sex-specific growth and mortality rates. Cohort analyses of fishery-independent size-frequency data collected over the last seven years may provide indicative estimates of these parameters.

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”). It is likely that an assessment of vessel power will be a required input of the bio-economic model.

The current FRDC project 2009/069 “Bycatch and prawn size selectivity of conventional diamond versus novel trawl mesh” is investigating alternative gear types in the Gulf St Vincent Prawn Fishery with the dual aim of reducing bycatch and improving size selectivity of the catch. The potential for uptake of improved gear types such as the T90 mesh must be considered when evaluating and developing management strategies for the fishery in the future.

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8. APPENDIX

These figures 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 November 2009, February, April, November 2010, March and April 2011. Fishery-dependent “spot” surveys were conducted during December 2009, once each in March and May 2010 and once each in April and May 2011. 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 8.1 At-sea decision rules for the Spencer Gulf Prawn Fishery.

Harvest Period	Nov & Dec	Mar & Apr	May & June
Minimum catch (kg/vessel night)	350	400	400
Minimum mean size (prawns/7kg)	250	220	240

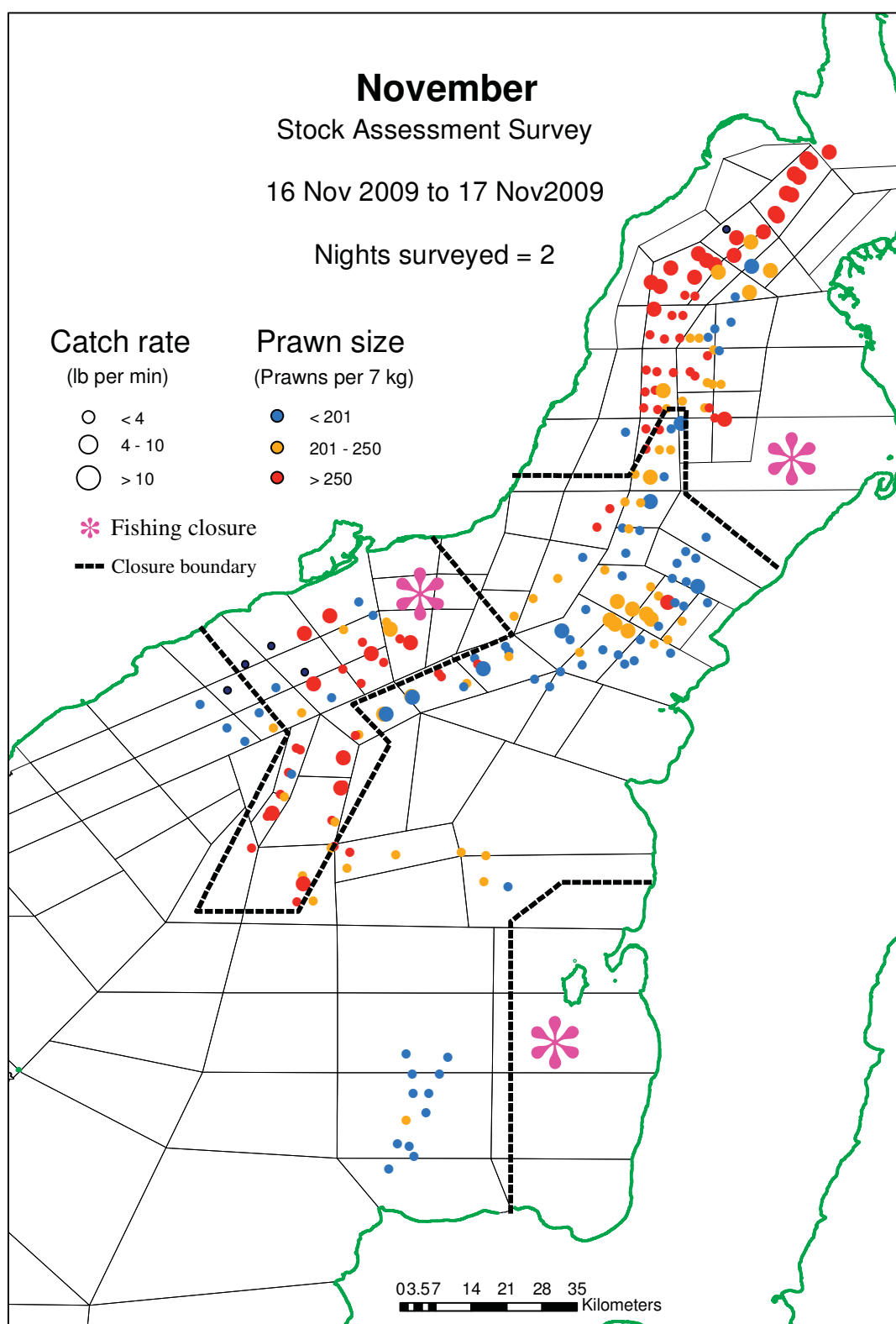


Figure 8.1 Catch rate and mean size during the November 2009 Stock Assessment survey, prior to harvest period 1. Black dotted lines represent harvest strategy closure lines.

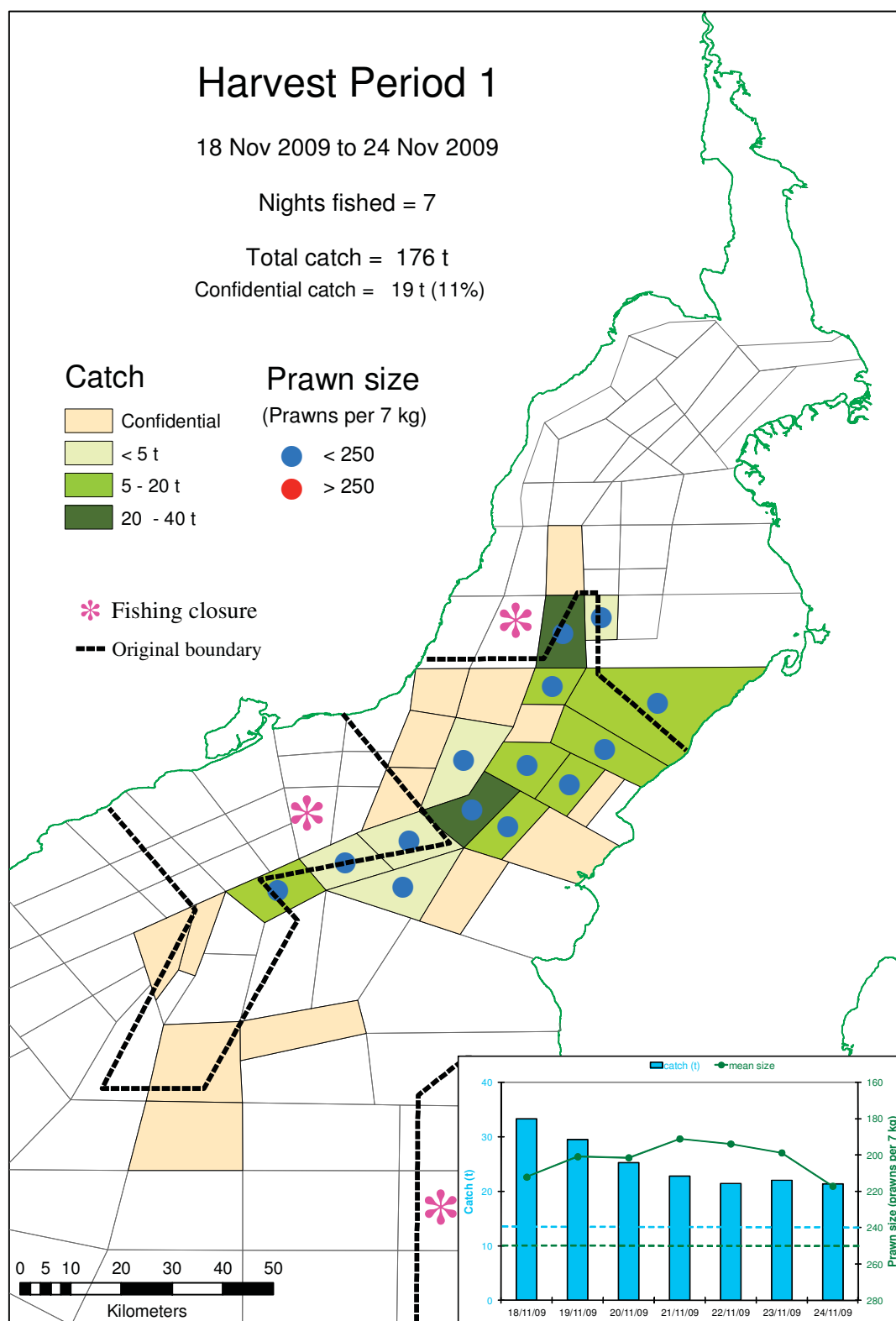


Figure 8.2 Commercial catch and mean size from blocks fished during harvest period 1 - 2009/10. Black dotted lines represent harvest strategy closure lines. Inset graphs display daily total catch (blue bars), daily mean prawn size (green line) and at sea decision rules for daily total catch (blue dotted line) and mean daily prawn size (green dotted line).

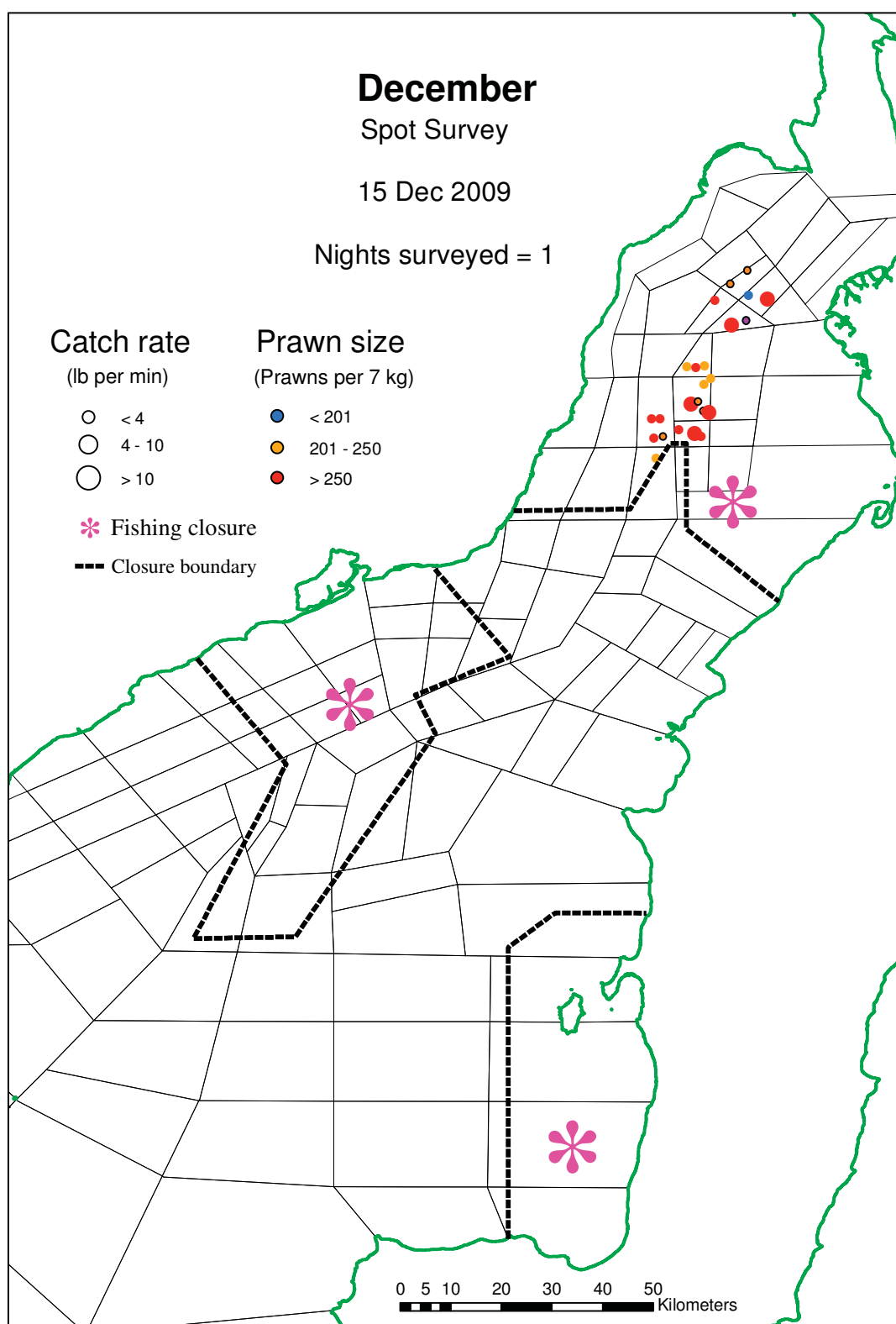


Figure 8.3 Catch rate and mean size during the December 2009 Spot survey, prior to harvest period 2. Black dotted lines represent harvest strategy closure lines.

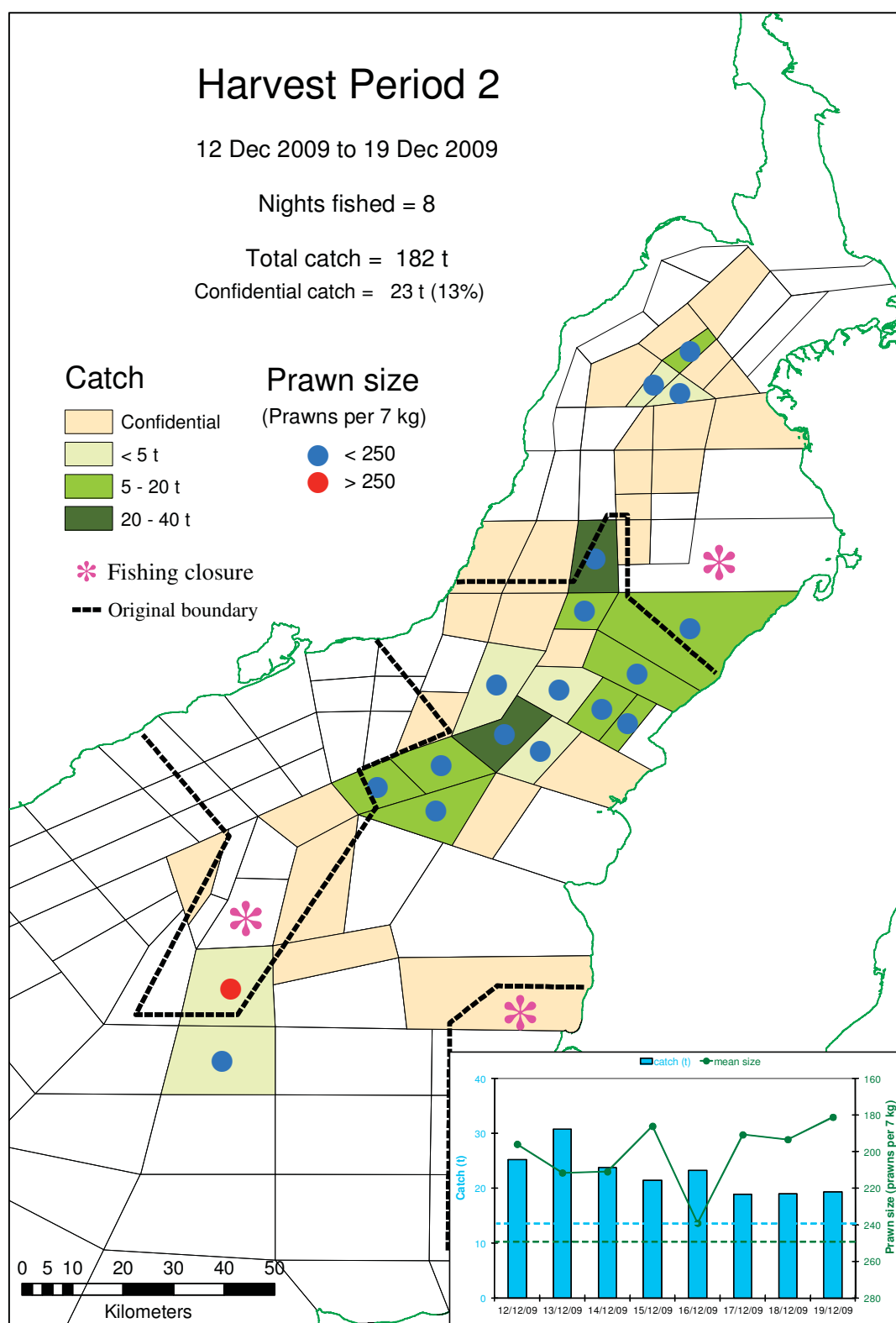


Figure 8.4 Commercial catch and mean size from blocks fished during harvest period 2 – 2009/10. Black dotted lines represent harvest strategy closure lines. Orange and blue dotted lines represent harvest strategy amendments. Inset graphs display daily total catch (blue

bars), daily mean prawn size (green line) and at sea decision rules for daily total catch (blue dotted line) and mean daily prawn size (green dotted line).

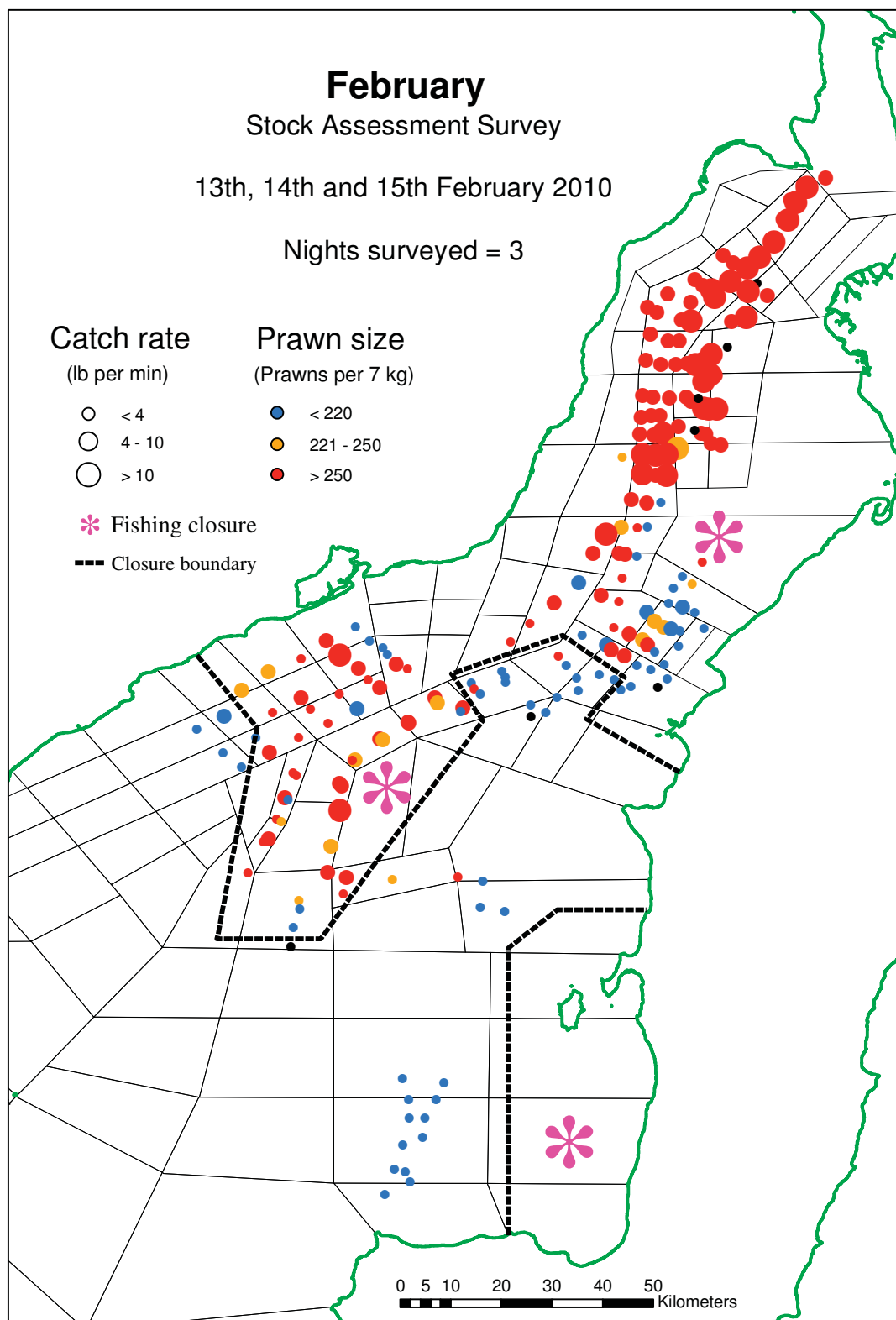


Figure 8.5 Catch rate and mean size during the February 2010 Stock Assessment survey prior to harvest period 3. Black dotted lines represent harvest strategy closure lines.

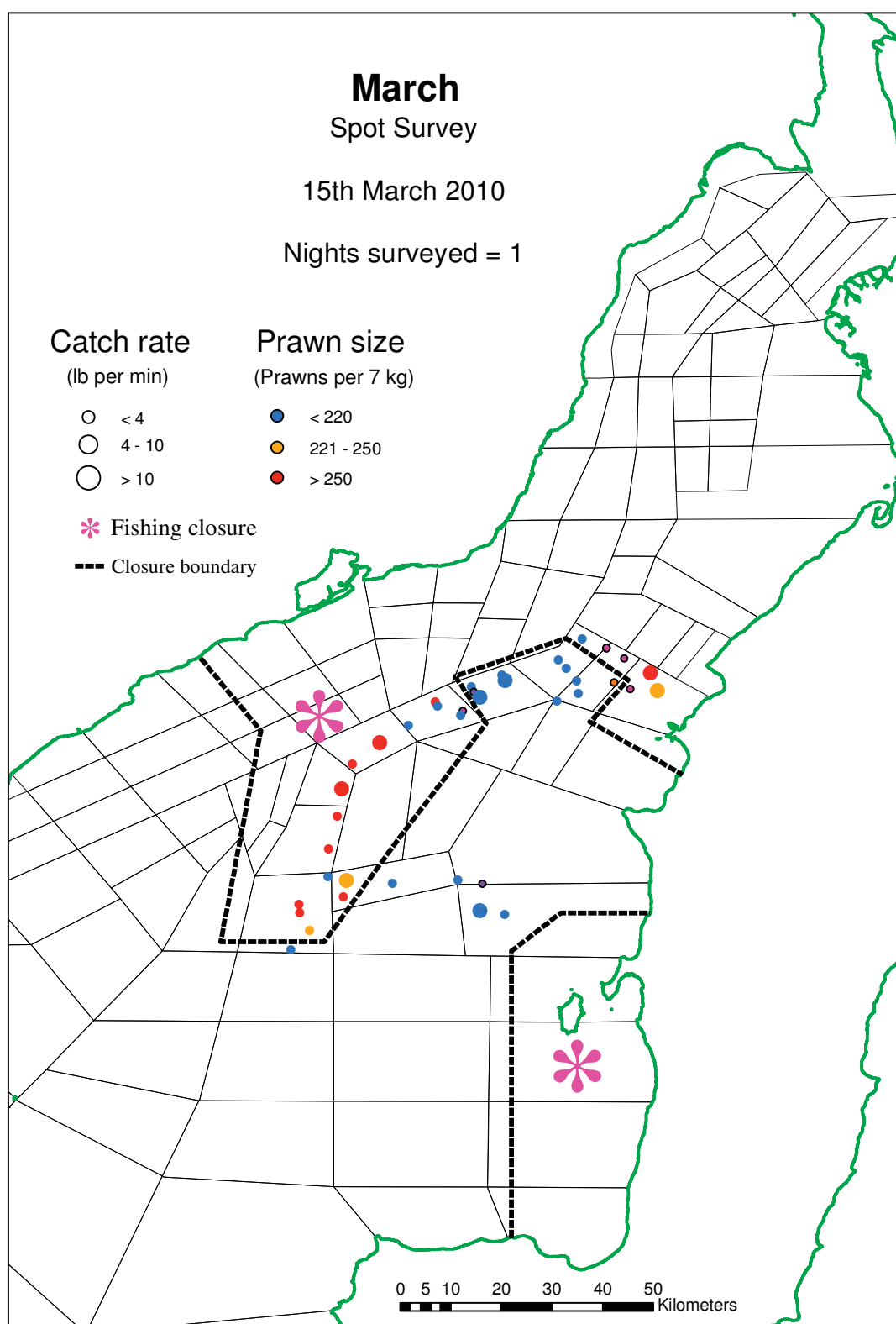


Figure 8.6 Catch rate and mean size during the March 2010 Spot survey, prior to harvest period 3. Black dotted lines represent harvest strategy closure lines.

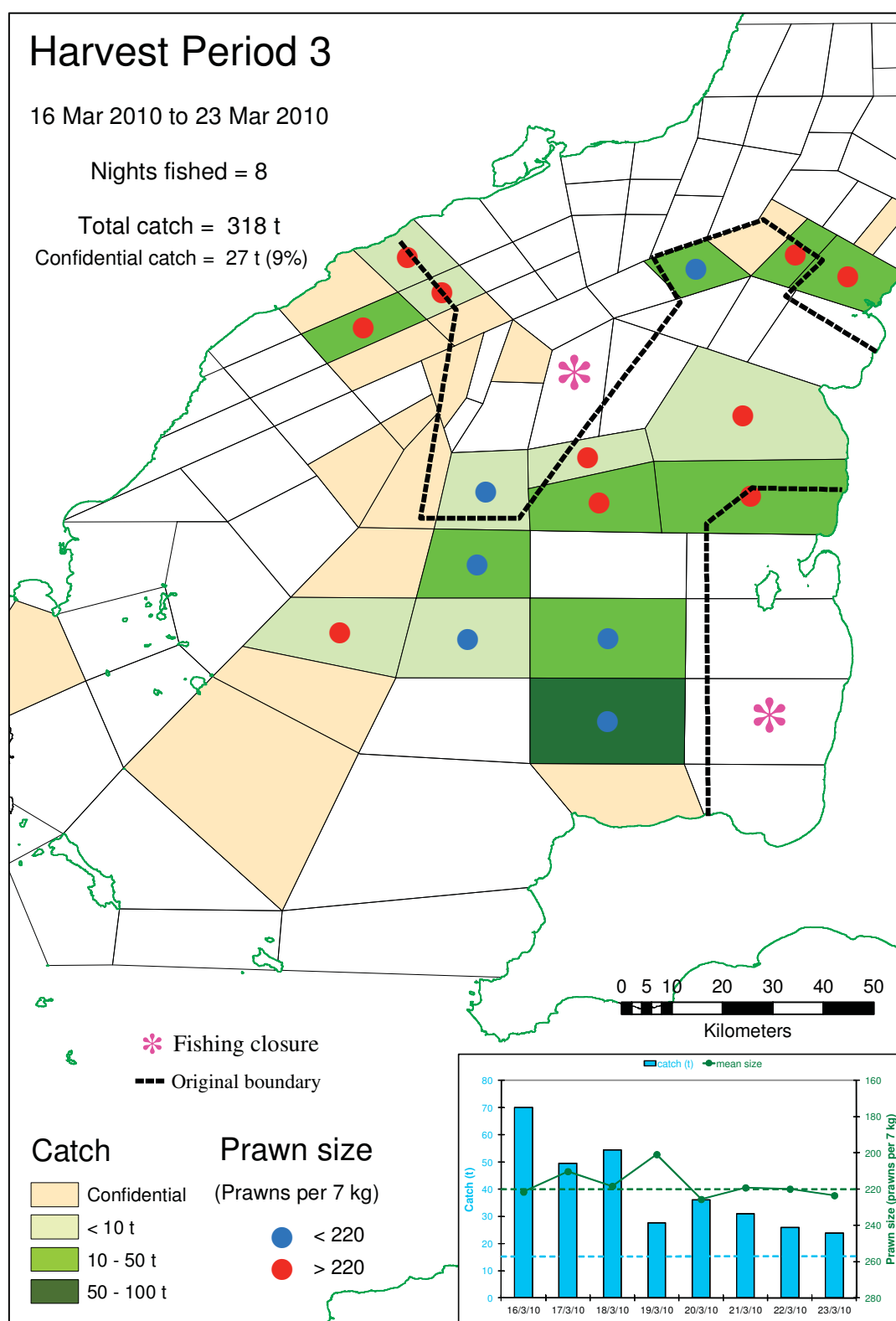


Figure 8.7 Commercial catch and mean size from blocks fished during harvest period 3 – 2009/10. Black dotted lines represent harvest strategy closure lines. Inset graphs display daily total catch (blue bars), daily mean prawn size (green line) and at sea decision rules for daily total catch (blue dotted line) and mean daily prawn size (green dotted line).

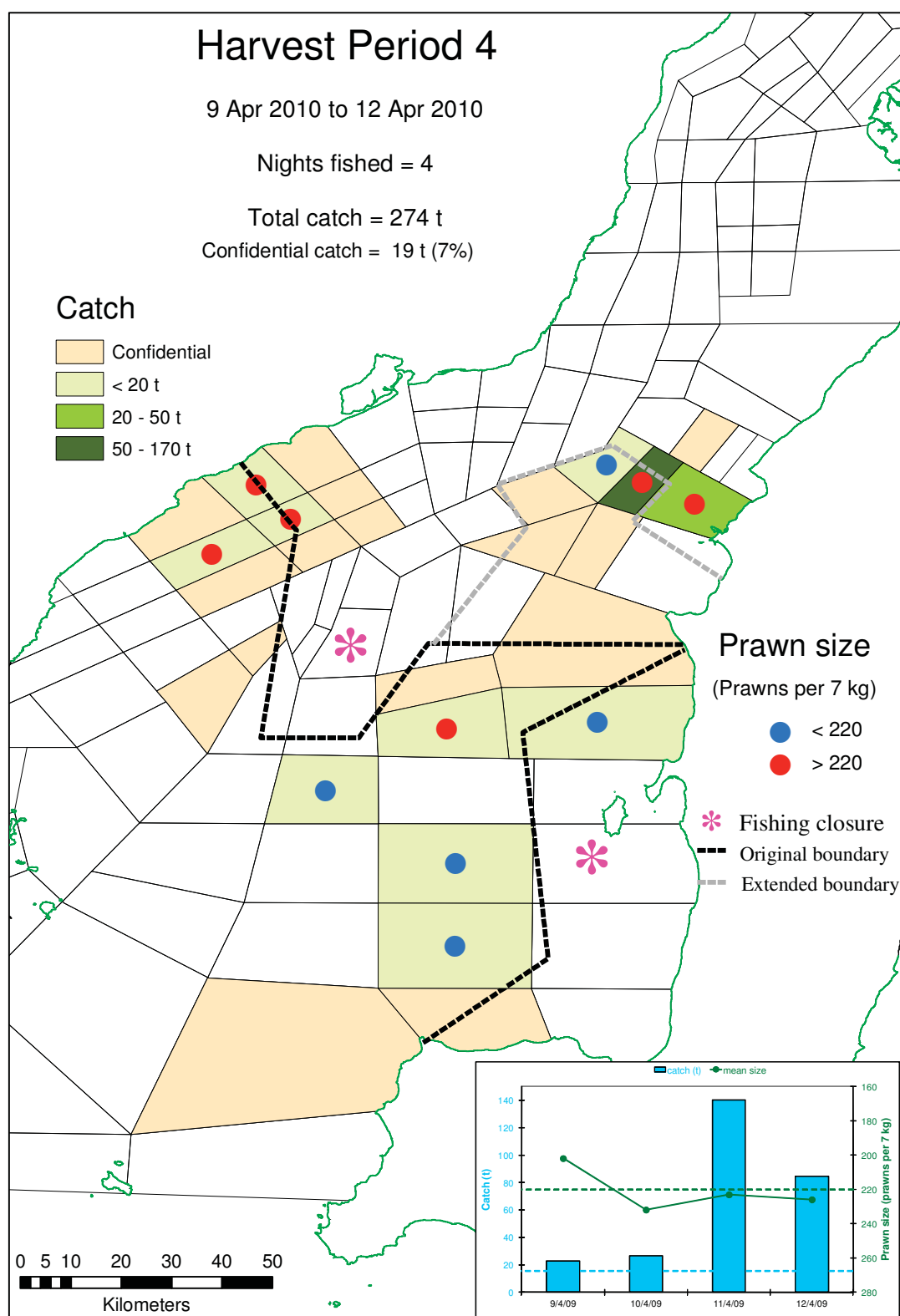


Figure 8.8 Commercial catch and mean size from blocks fished during harvest period 4 – 2009/10. Black dotted lines represent harvest strategy closure lines. Purple dotted line represents harvest strategy amendments for southern closure. Inset graphs display daily total catch (blue bars), daily mean prawn size (green line) and at sea decision rules for daily total catch (blue dotted line) and mean daily prawn size (green dotted line).

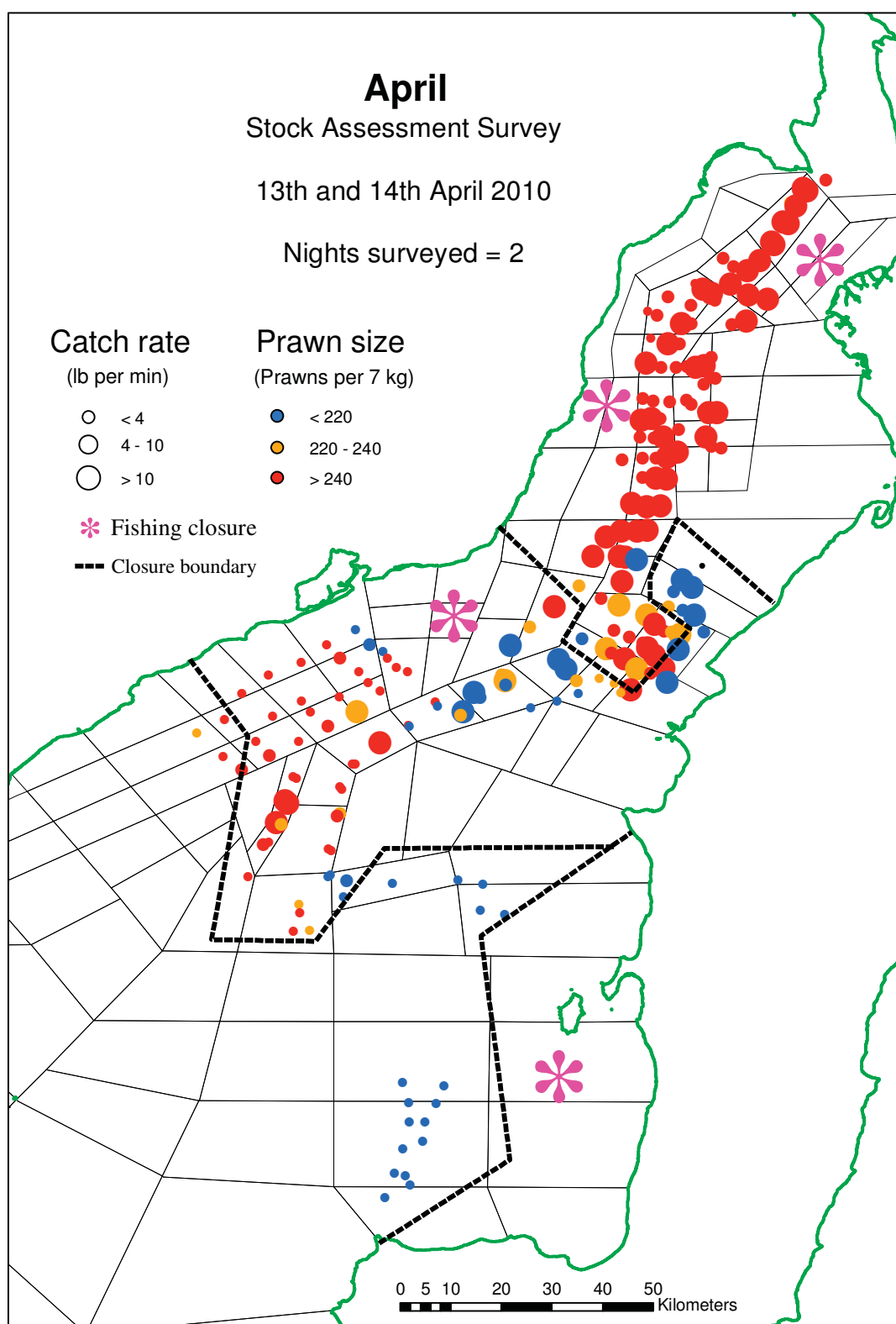


Figure 8.9 Catch rate and mean size during the April 2009 Stock Assessment survey, prior to harvest period 4. Black dotted lines represent harvest strategy closure lines.

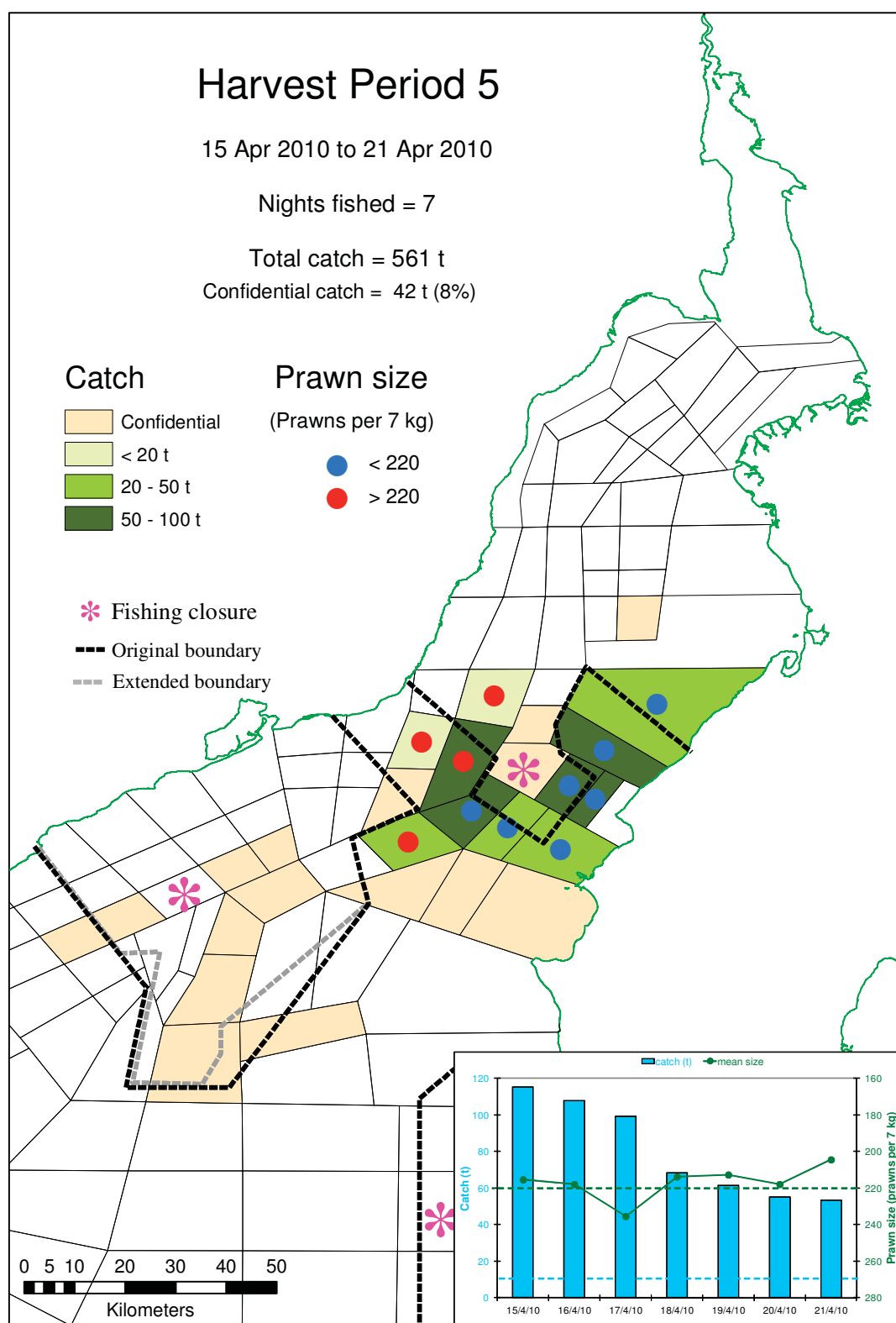


Figure 8.10 Commercial catch and mean size from blocks fished during harvest period 5 – 2009/10. Black dotted lines represent harvest strategy closure lines. Purple dotted line represents harvest strategy amendments for southern closure. Inset graphs display daily total catch (blue bars), daily mean prawn size (green line) and at sea decision rules for daily total catch (blue dotted line) and mean daily prawn size (green dotted line).

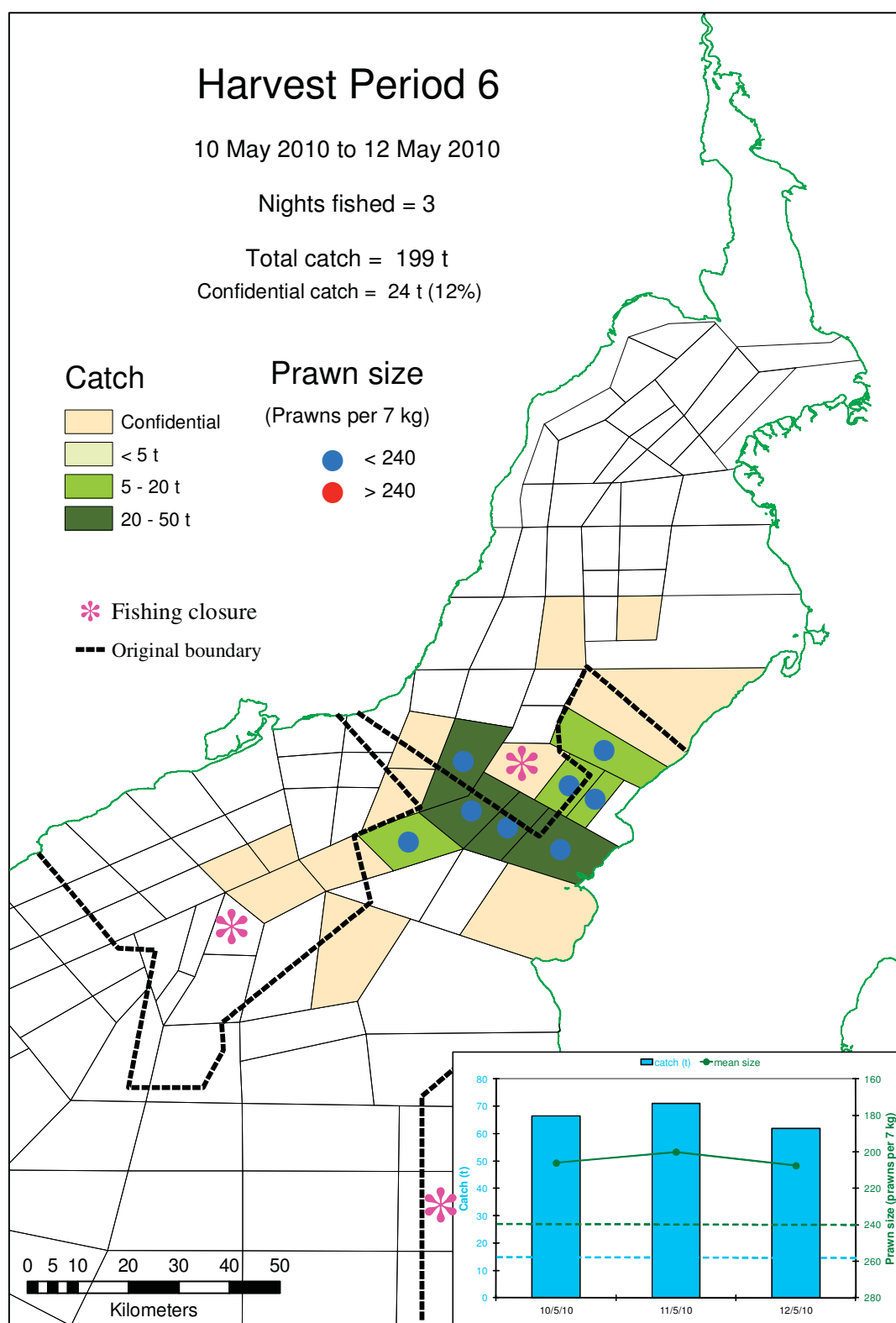


Figure 8.11 Commercial catch and mean size from blocks fished during harvest period 6 – 2009/10. Black dotted lines represent harvest strategy closure lines. Purple dotted line represents harvest strategy amendments for southern closure. Inset graphs display daily total catch (blue bars), daily mean prawn size (green line) and at sea decision rules for daily total catch (blue dotted line) and mean daily prawn size (green dotted line).

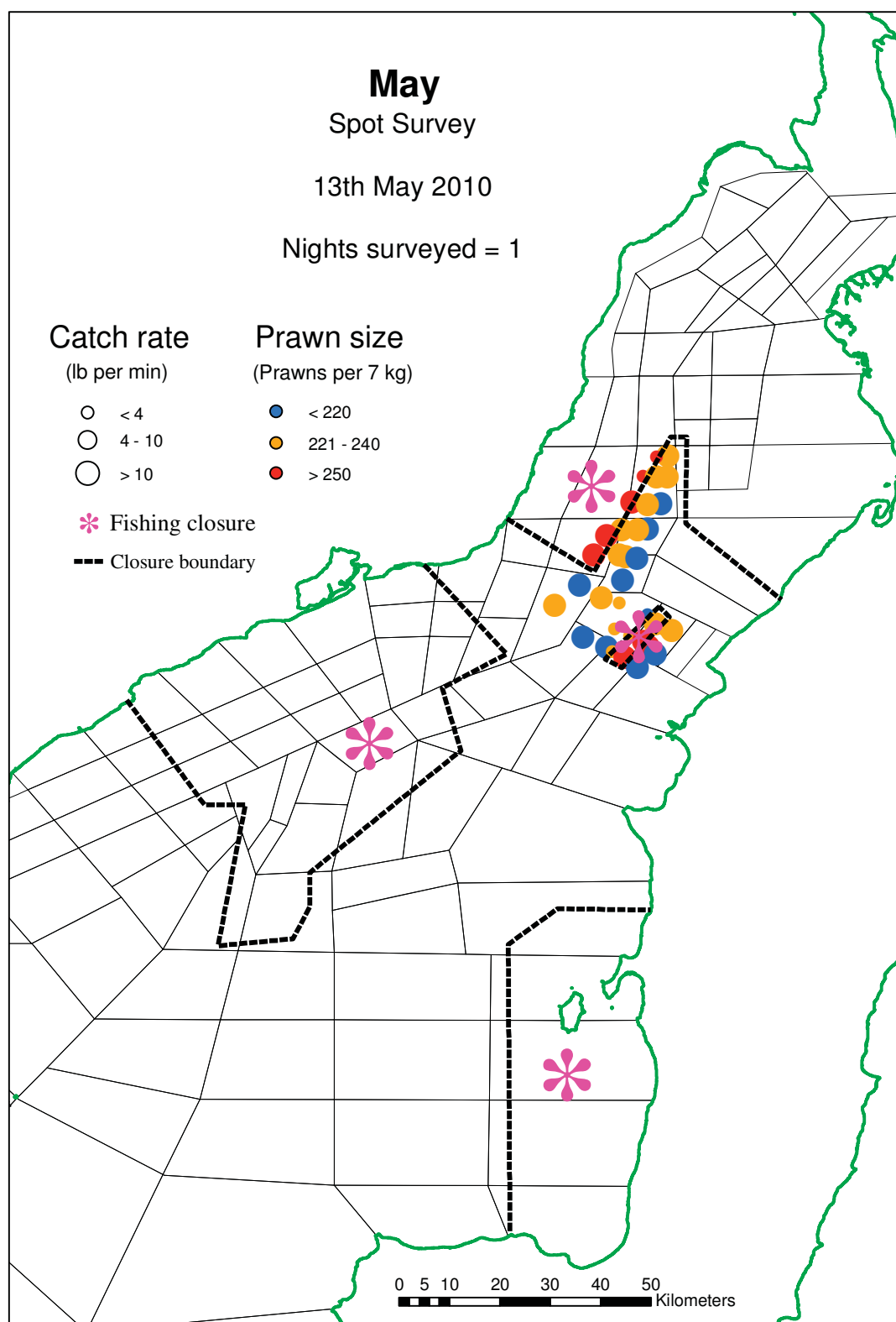


Figure 8.12 Catch rate and mean size during the May 2010 Spot survey, prior to harvest period 5. Black dotted lines represent harvest strategy closure lines.

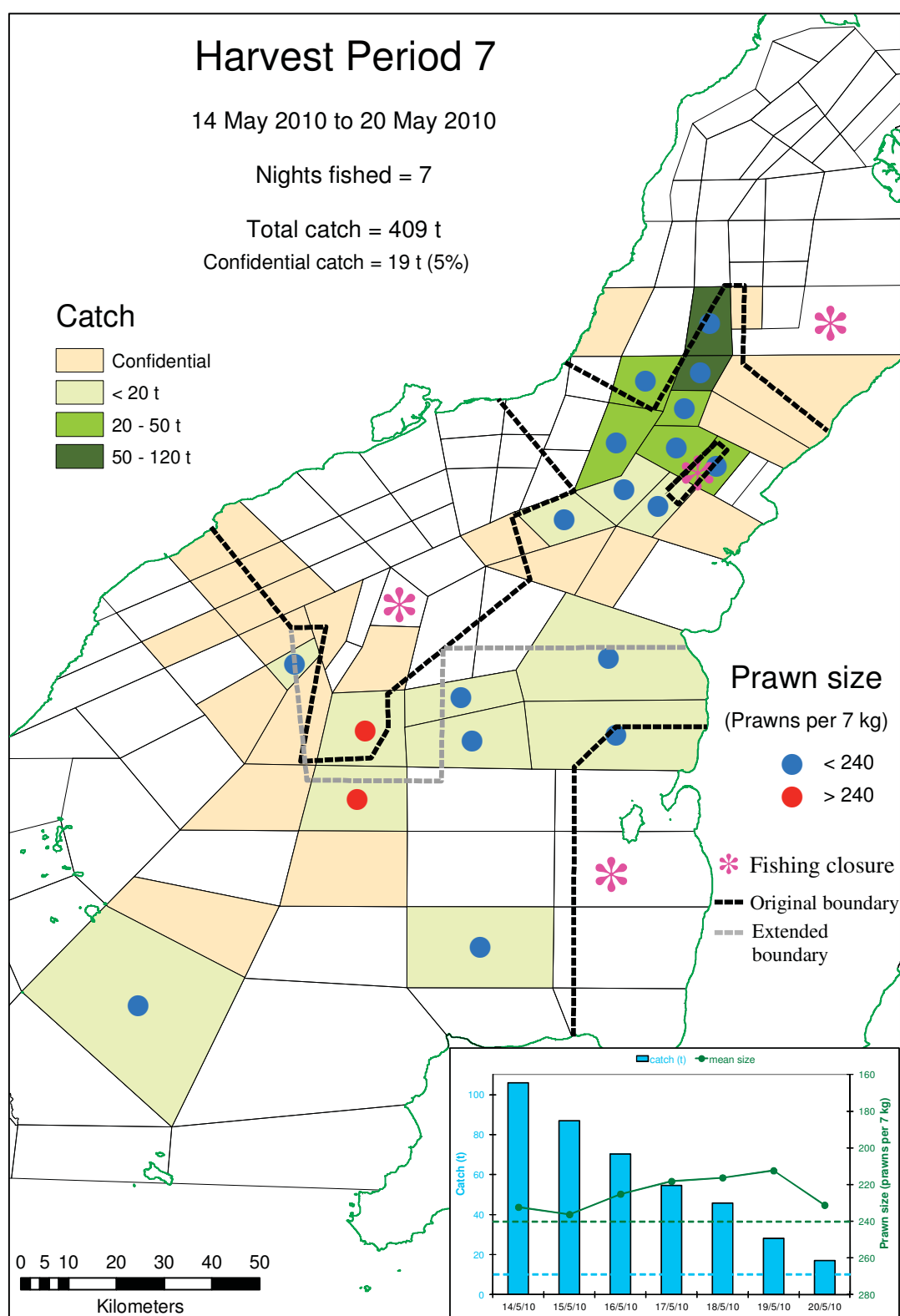


Figure 8.13 Commercial catch and mean size from blocks fished during harvest period 7 – 2009/10. Black dotted lines represent harvest strategy closure lines. Inset graphs display daily total catch (blue bars), daily mean prawn size (green line) and at sea decision rules for daily total catch (blue dotted line) and mean daily prawn size (green dotted line).

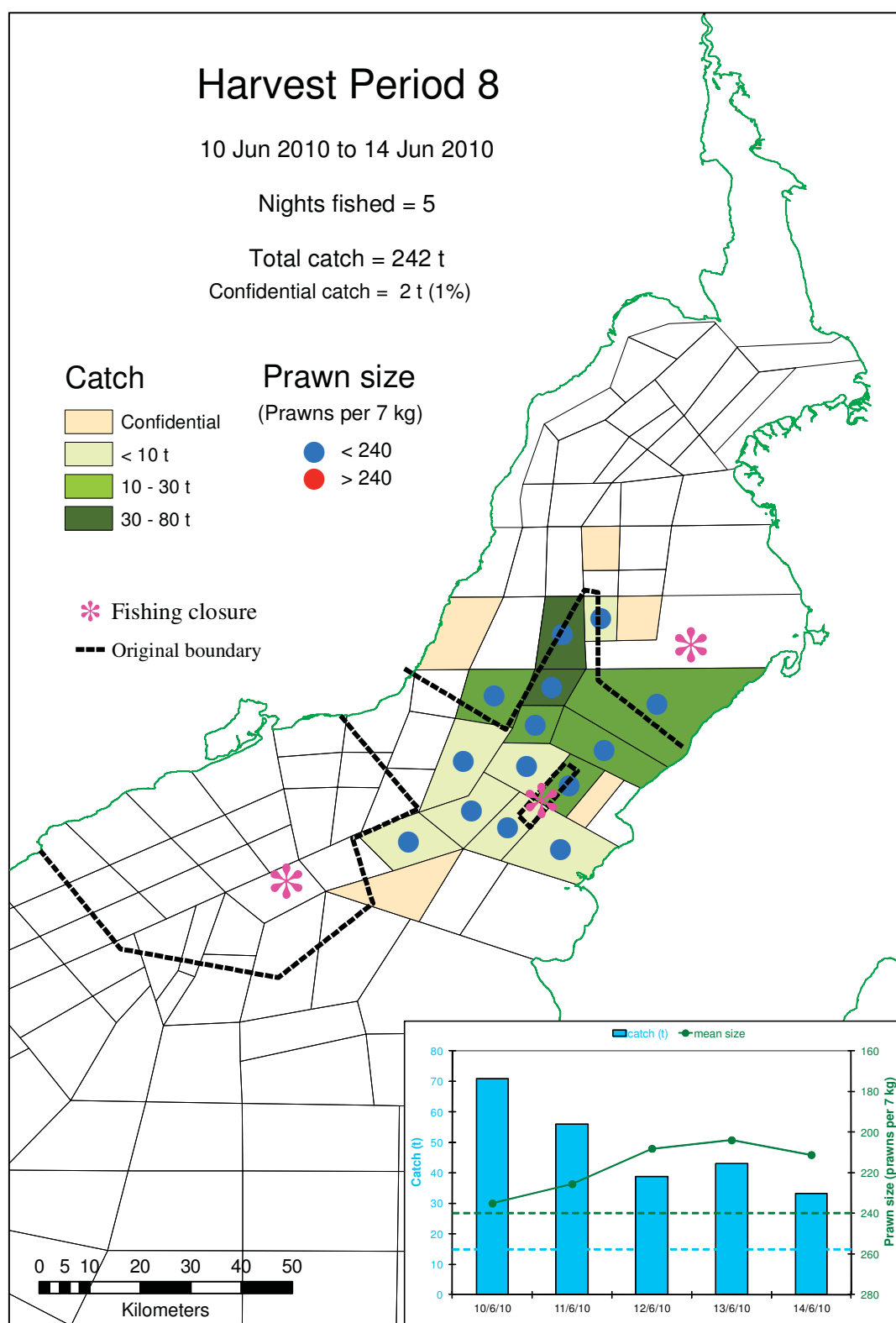


Figure 8.14 Commercial catch and mean size from blocks fished during harvest period 8 – 2009/10. Black dotted lines represent harvest strategy closure lines. Inset graphs display daily total catch (blue bars), daily mean prawn size (green line) and at sea decision rules for daily total catch (blue dotted line) and mean daily prawn size (green dotted line).

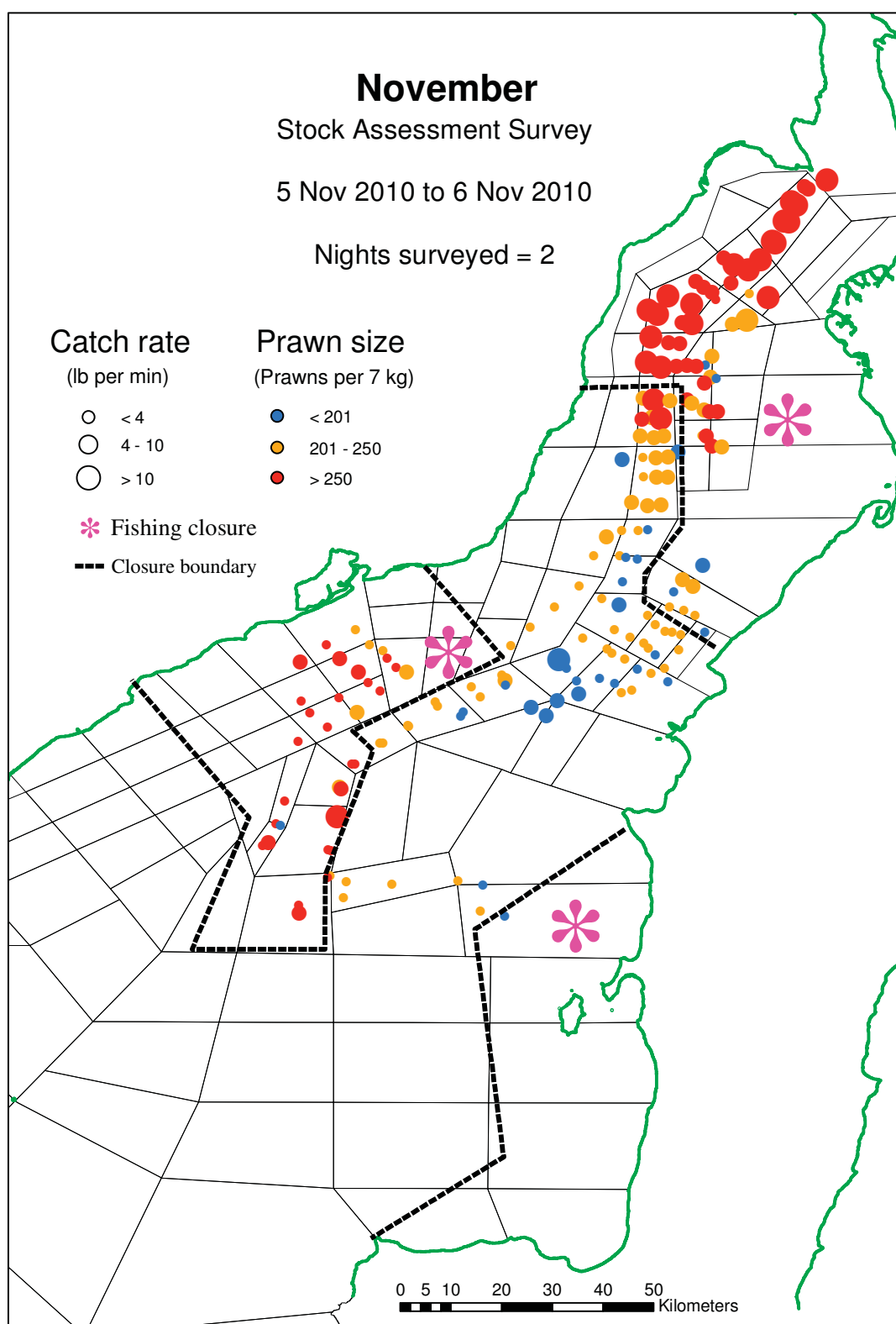


Figure 8.15 Catch rate and mean size during the November 2010 Stock Assessment survey, prior to harvest period 1. Black dotted lines represent harvest strategy closure lines.

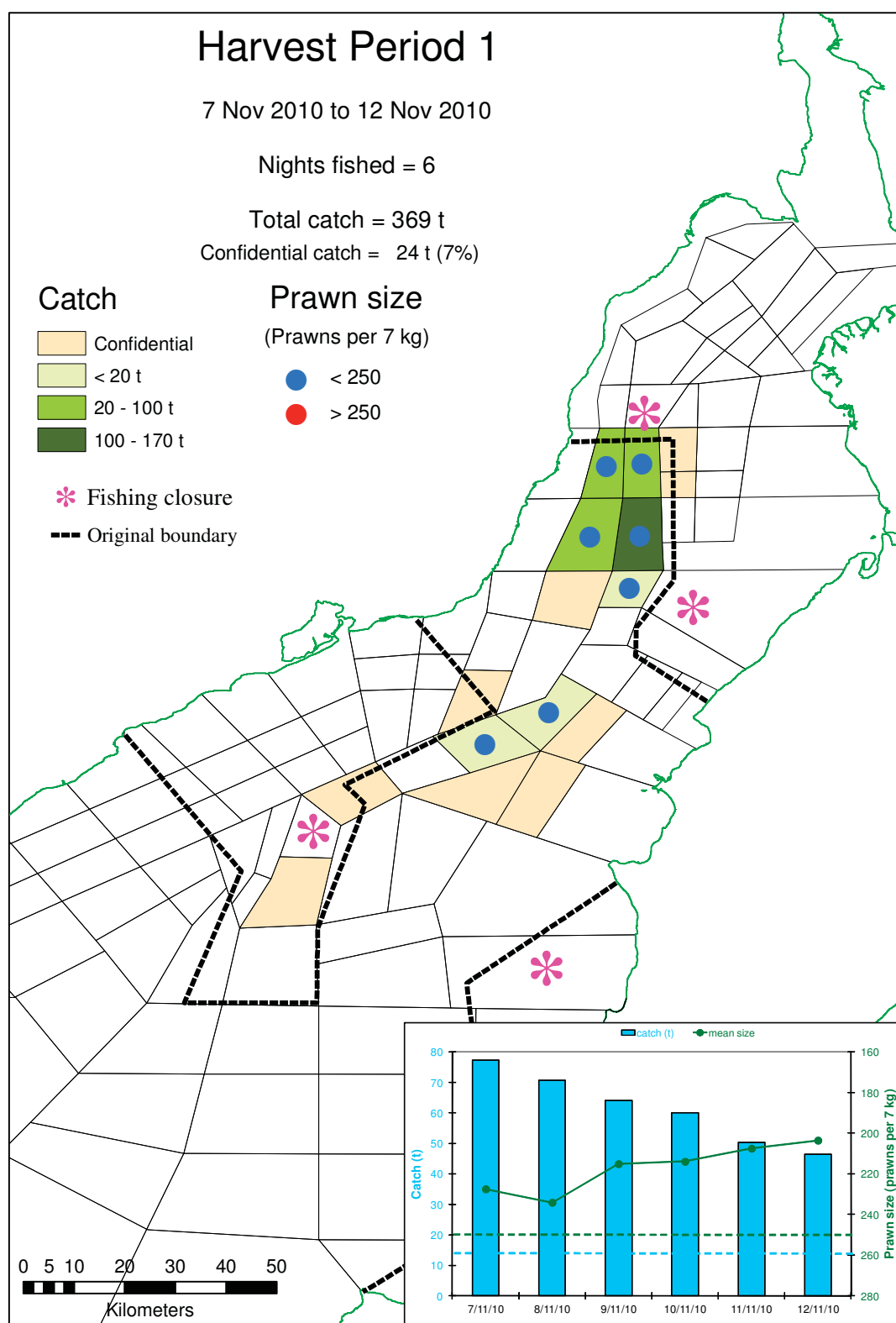


Figure 8.16 Commercial catch and mean size from blocks fished during harvest period 1 - 2010/11. Black dotted lines represent harvest strategy closure lines. Inset graphs display daily total catch (blue bars), daily mean prawn size (green line) and at sea decision rules for daily total catch (blue dotted line) and mean daily prawn size (green dotted line).

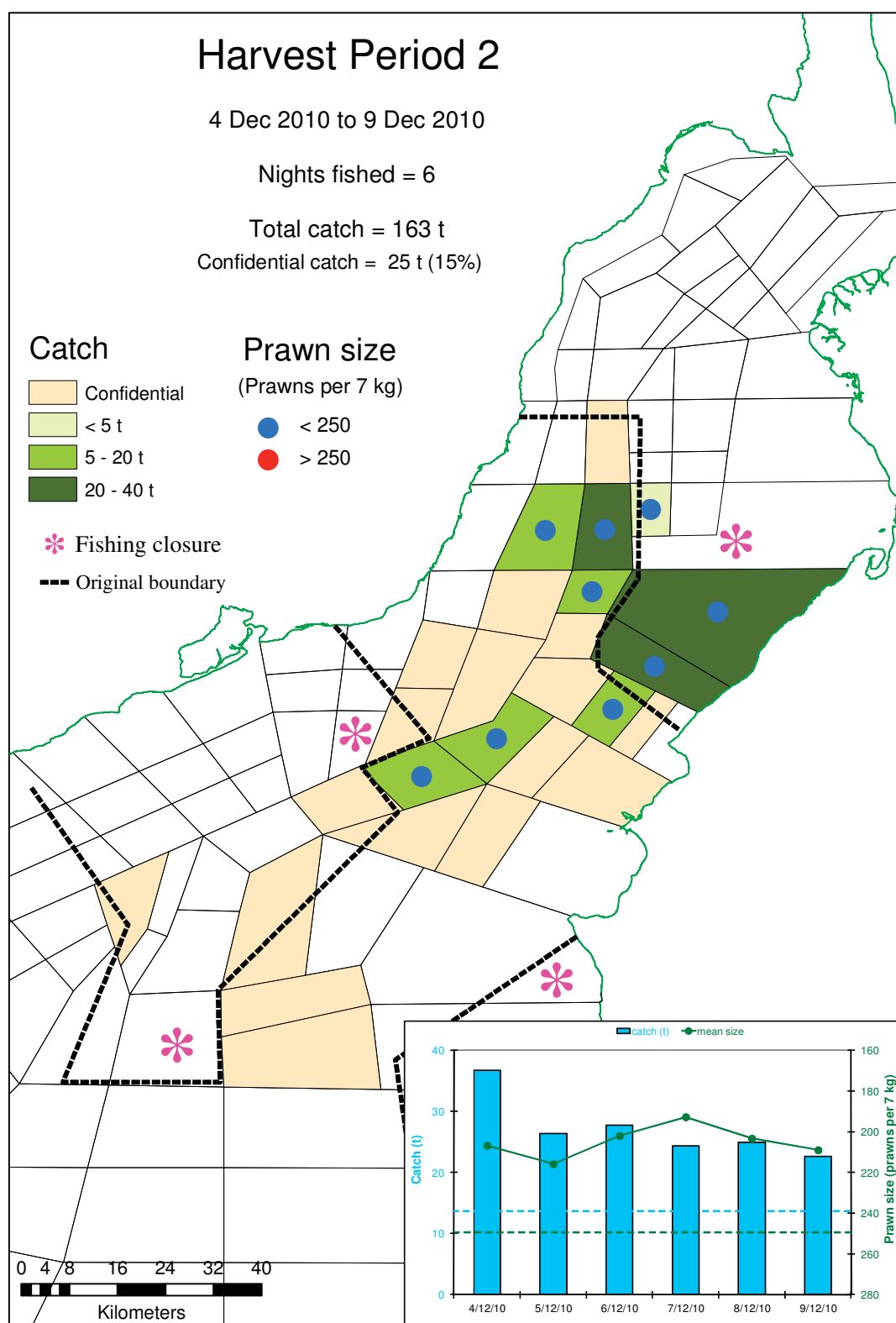


Figure 8.17 Commercial catch and mean size from blocks fished during harvest period 2 – 2010/11. Black dotted lines represent harvest strategy closure lines. Orange and blue dotted lines represent harvest strategy amendments. Inset graphs display daily total catch (blue bars), daily mean prawn size (green line) and at sea decision rules for daily total catch (blue dotted line) and mean daily prawn size (green dotted line).

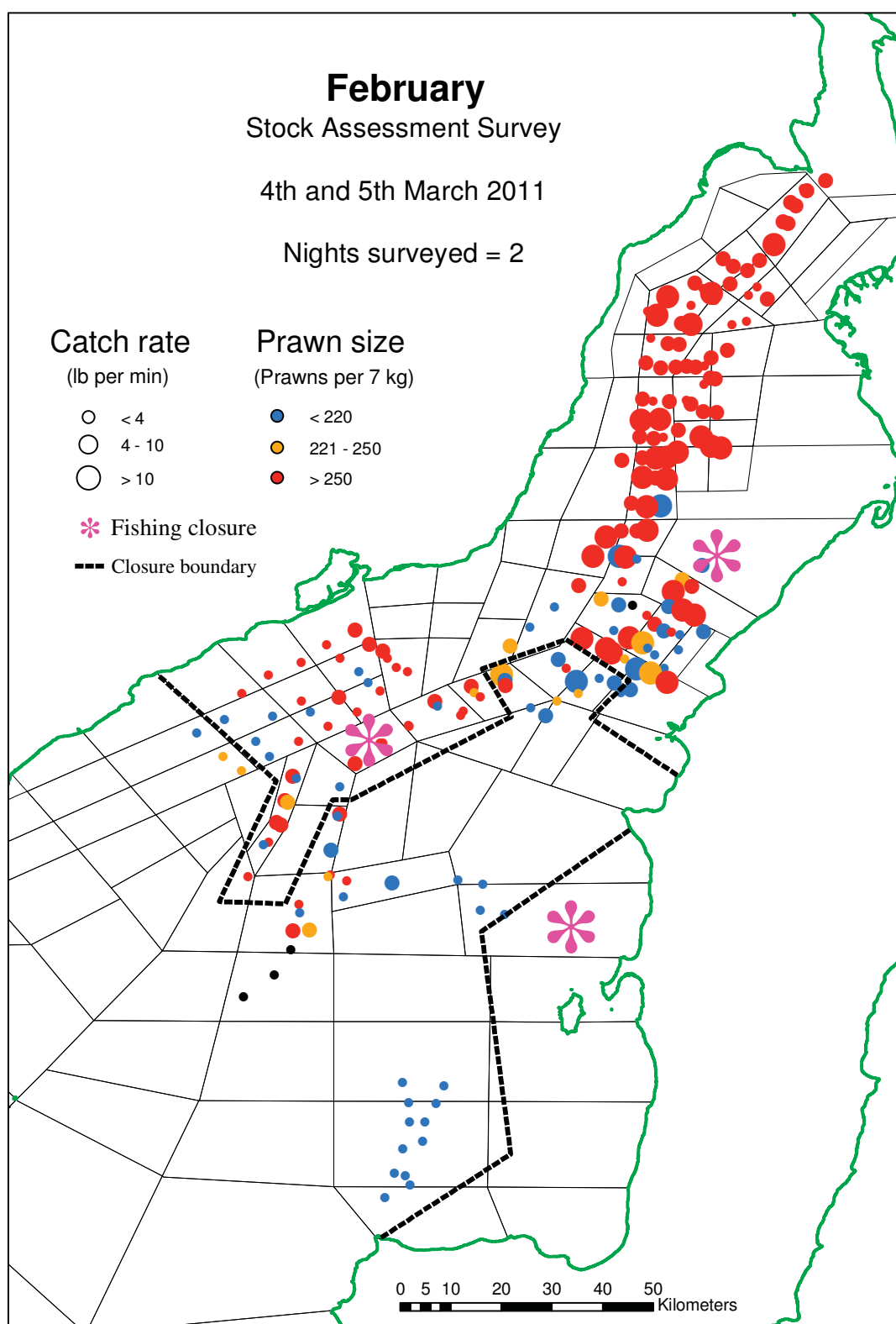


Figure 8.18 Catch rate and mean size during the February 2011 Stock Assessment survey prior to harvest period 3. Black dotted lines represent harvest strategy closure lines.

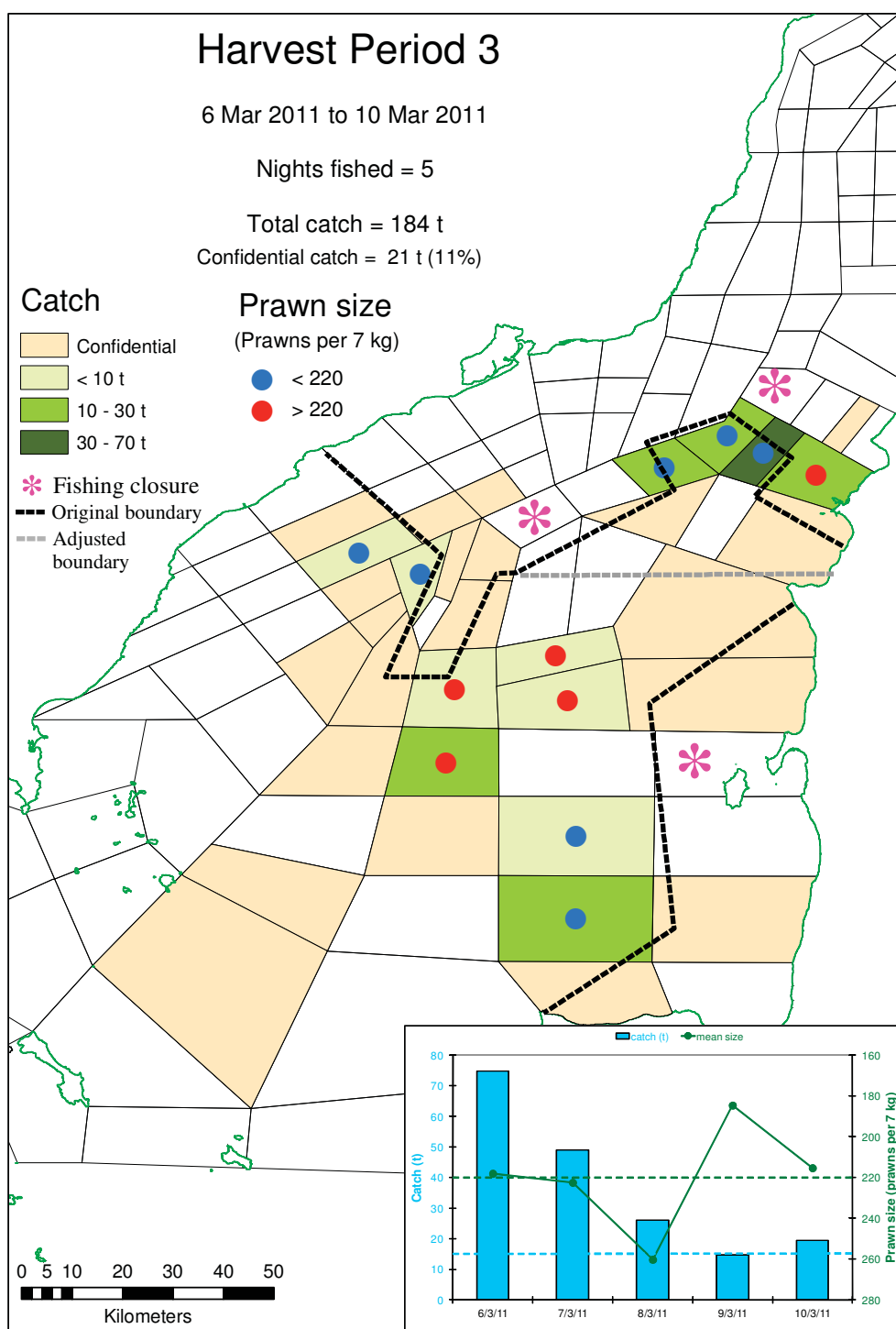


Figure 8.19 Commercial catch and mean size from blocks fished during harvest period 3 – 2010/11. Black dotted lines represent harvest strategy closure lines. Orange and blue dotted lines represent harvest strategy amendments. Inset graphs display daily total catch (blue bars), daily mean prawn size (green line) and at sea decision rules for daily total catch (blue dotted line) and mean daily prawn size (green dotted line).

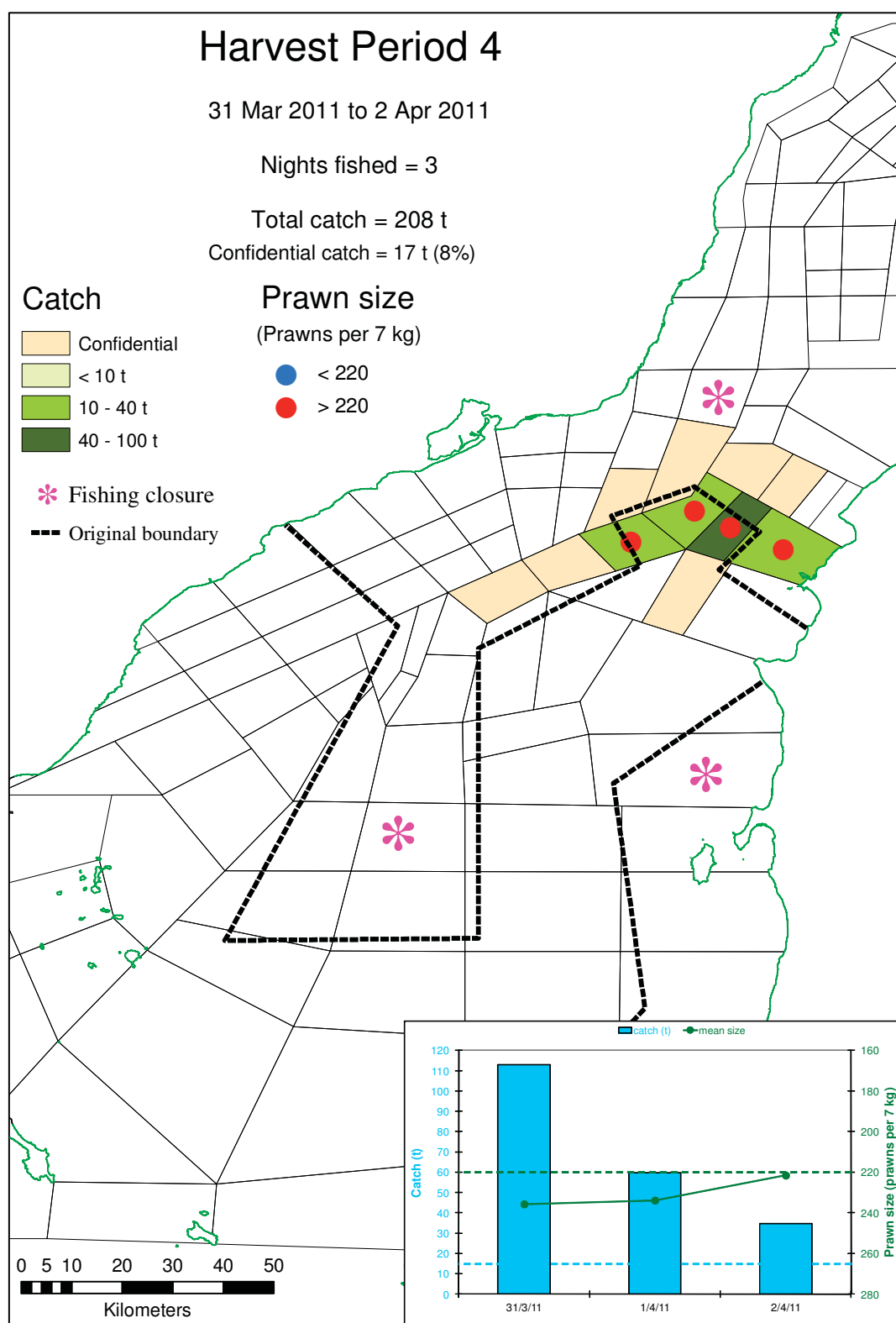


Figure 8.20 Commercial catch and mean size from blocks fished during harvest period 4 – 2010/11. Black dotted lines represent harvest strategy closure lines. Orange and blue dotted lines represent harvest strategy amendments. Inset graphs display daily total catch (blue bars), daily mean prawn size (green line) and at sea decision rules for daily total catch (blue dotted line) and mean daily prawn size (green dotted line).

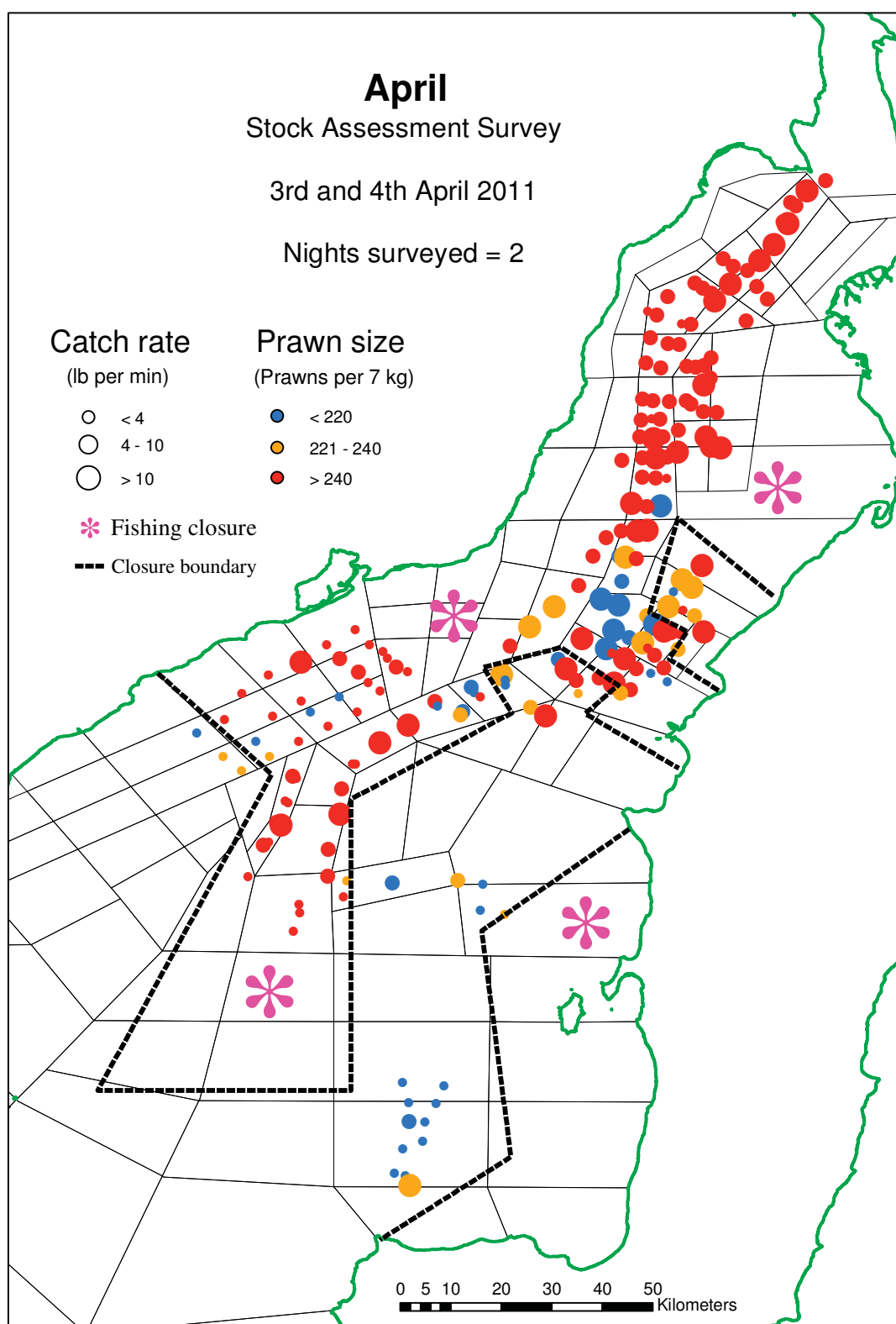


Figure 8.21 Catch rate and mean size during the April 2011 Stock Assessment survey, prior to harvest period 5. Black dotted lines represent harvest strategy closure lines.

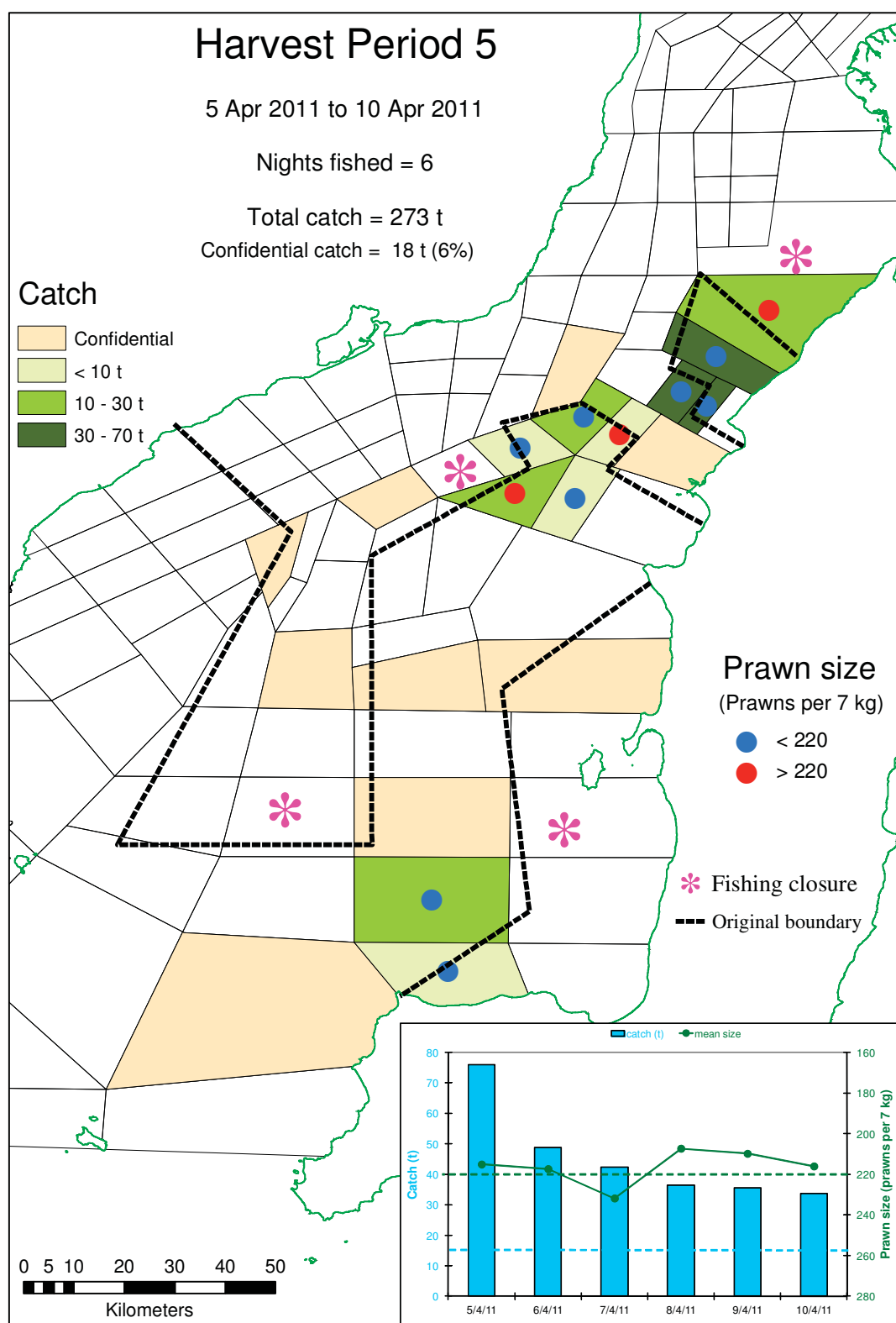


Figure 8.22 Commercial catch and mean size from blocks fished during harvest period 5–2010/11. Black dotted lines represent harvest strategy closure lines. Inset graphs display daily total catch (blue bars), daily mean prawn size (green line) and at sea decision rules for daily total catch (blue dotted line) and mean daily prawn size (green dotted line).

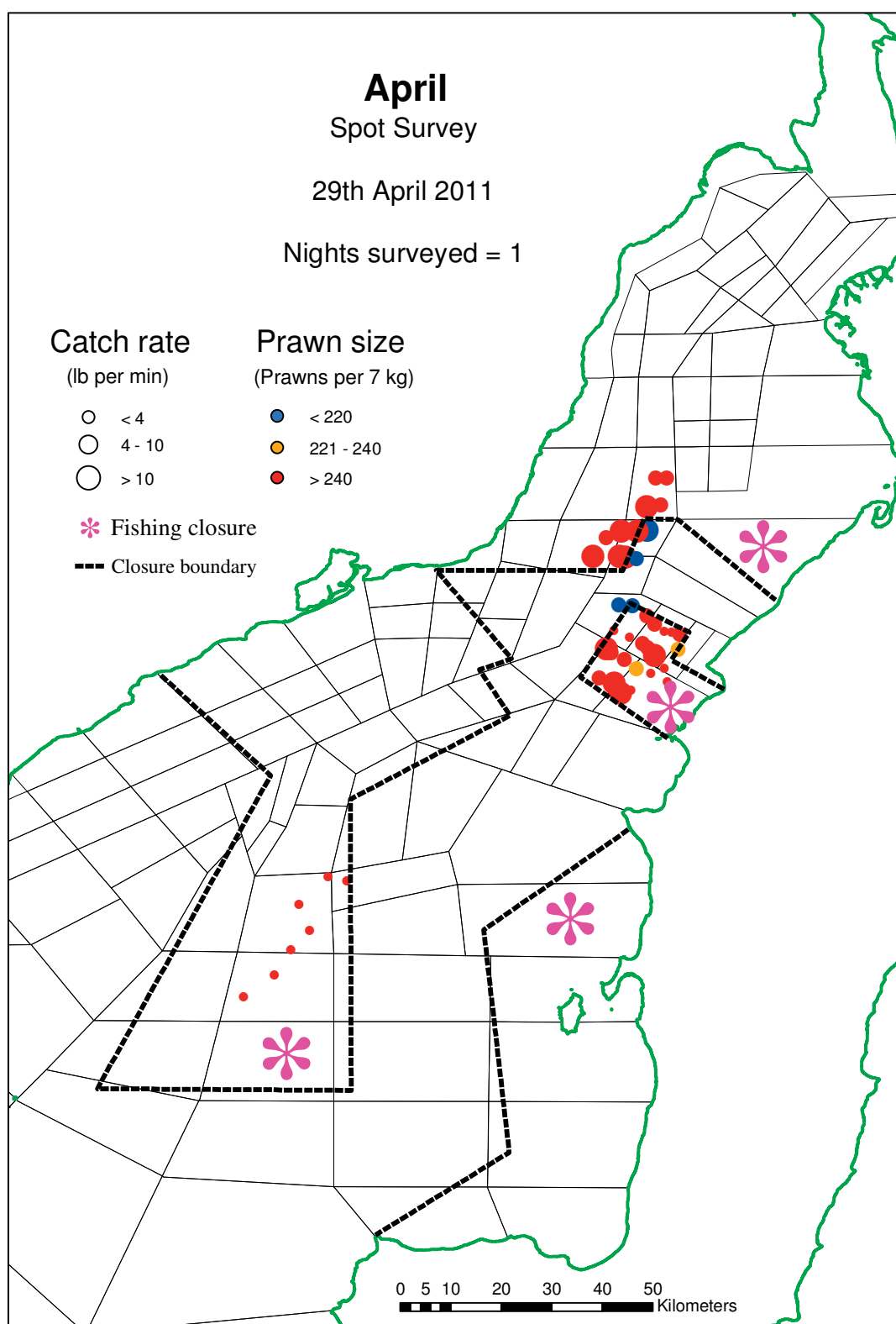


Figure 8.23 Catch rate and mean size during the April 2011 Spot survey, prior to harvest period 6. Black dotted lines represent harvest strategy closure lines.

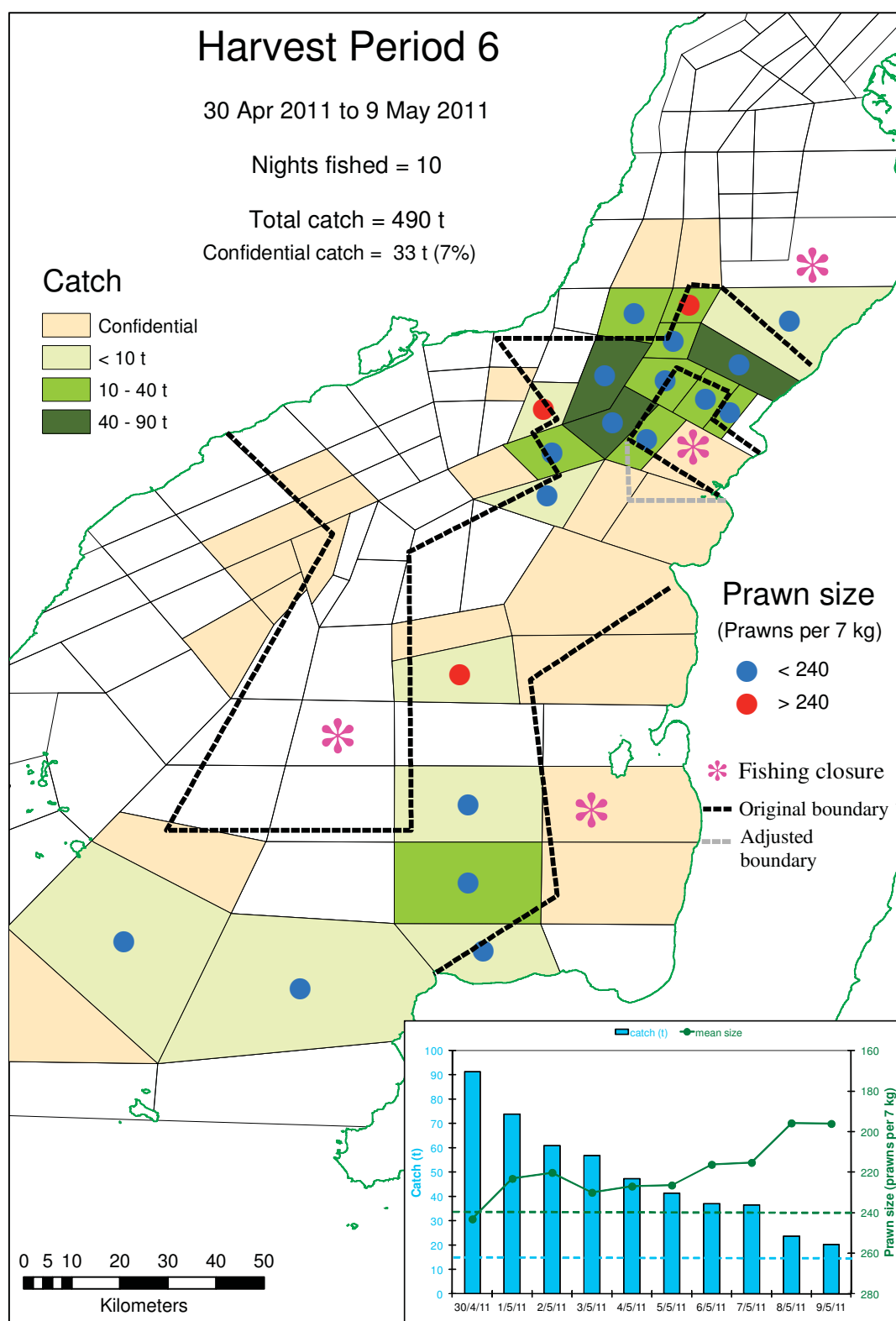


Figure 8.24 Commercial catch and mean size from blocks fished during harvest period 6–2010/11. Black dotted lines represent harvest strategy closure lines. Purple dotted line represents harvest strategy amendments for southern closure. Inset graphs display daily total catch (blue bars), daily mean prawn size (green line) and at sea decision rules for daily total catch (blue dotted line) and mean daily prawn size (green dotted line).

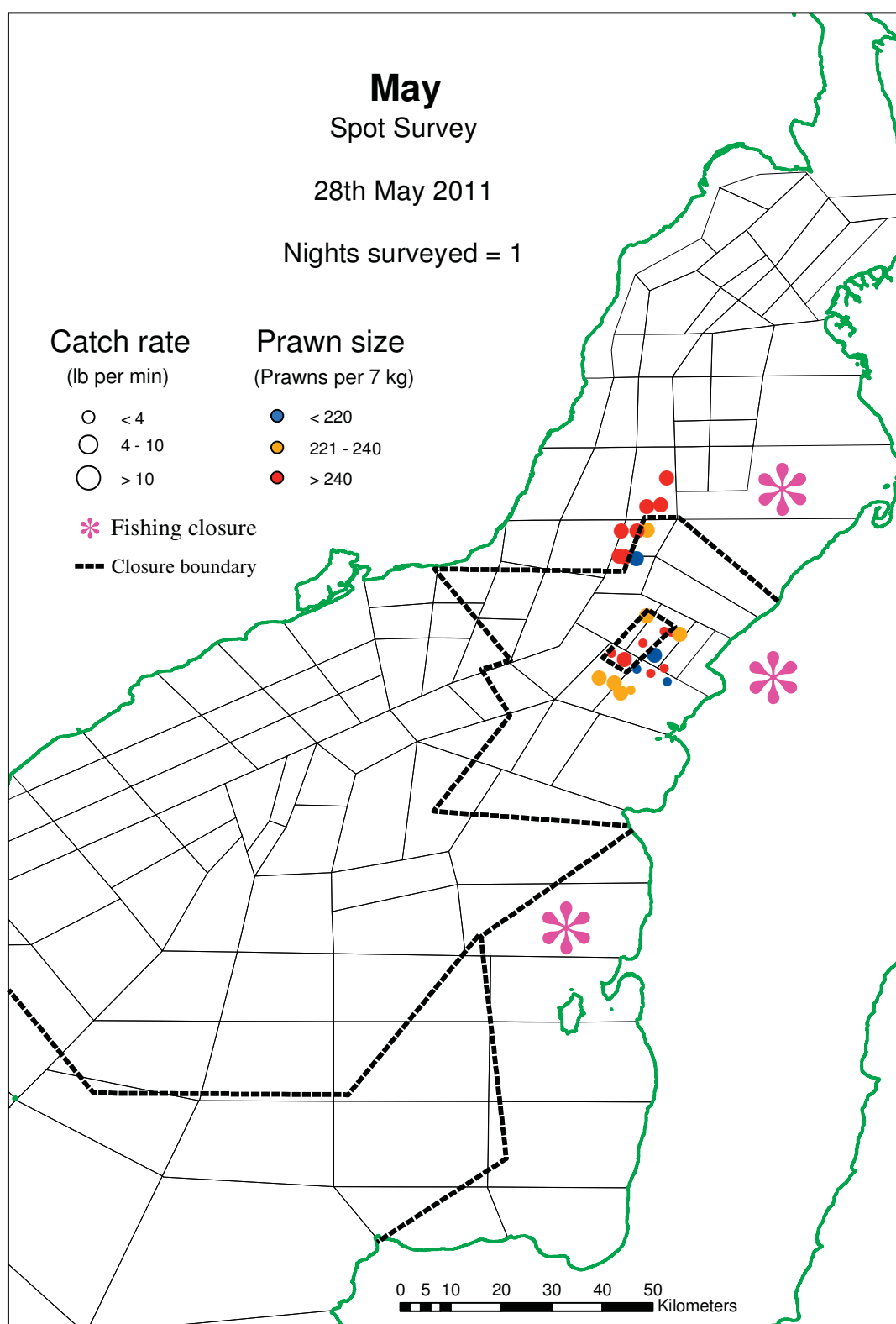


Figure 8.25 Catch rate and mean size during the May 2010 Spot survey, prior to harvest period 7. Black dotted lines represent harvest strategy closure lines.

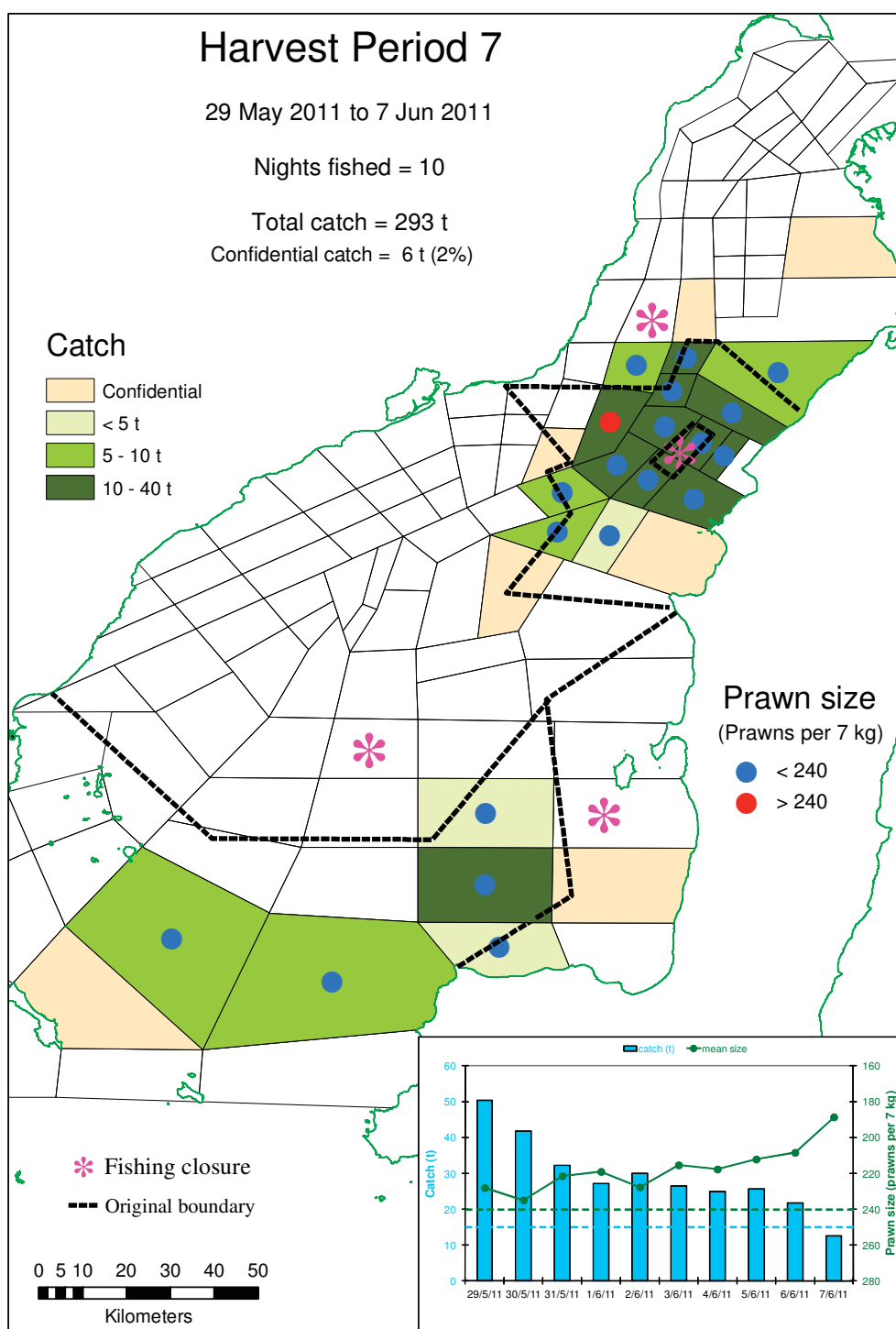


Figure 8.26 Commercial catch and mean size from blocks fished during harvest period 7 – 2010/11. Black dotted lines represent harvest strategy closure lines. Inset graphs display daily total catch (blue bars), daily mean prawn size (green line) and at sea decision rules for daily total catch (blue dotted line) and mean daily prawn size (green dotted line).