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Gulf St Vincent Prawn, *Penaeus (Melicertus) latisulcatus*, Fishery 2009/10

Dixon, C.D., Roberts, S.D. and Hooper, G.E

SARDI Publication No. F2007/000782-4
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SARDI Aquatic Sciences
PO Box 120 Henley Beach SA 5022

March 2011

Fishery Assessment Report to PIRSA Fisheries and Aquaculture

Government of South Australia

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This report documents the 2008/09 and 2009/10 fishing seasons for the Gulf St Vincent Prawn Fishery and is part of SARDI Aquatic Sciences ongoing assessment program for South Australia's Prawn Fisheries. The aims of the report are to synthesise information for the Gulf St Vincent Prawn Fishery, to assess the current status of the resource and consider the uncertainty associated with the assessment, to comment on the current biological Performance Indicators and Reference Points, and to identify future research needs for the fishery.

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EXECUTIVE SUMMARY

1. This report updates the fishery assessment report for 2007/08 and analyses data from the 2008/09 and 2009/10 seasons as part of SARDI Aquatic Sciences' ongoing assessment program for the Gulf St Vincent Prawn Fishery (GSVPF). The aims are to: (1) synthesise information for the GSVPF; (2) assess the current status of the resource and consider the uncertainty associated with the assessment; (3) comment on the current Performance Indicators and harvest strategy; and (4) identify future research needs for the fishery.

2. The need for stock recovery was identified in October 2004 and was made the key objective of the Management Plan for the period 2007 to 2011. Success of this strategy was primarily defined as consecutive annual increases in relative biomass (survey catch rate), commercial catch and commercial CPUE.

3. The current biomass of prawns in GSV is significantly higher than it was in 2004/05 but declined between 2008/09 and 2009/10.

4. Commercial catch increased from 187 t in 2005/06 to 288 t in 2008/09 but declined to 241 t in 2009/10. Commercial CPUE followed similar trends, reaching an historic high of 113.1 kg/h in 2008/09 and declining to 93.2 kg/h in 2009/10.

5. Declining trends in mean prawn size were observed in both commercial catch and fishery independent survey data. During 2009/10, the proportion of large prawns (grade U10 and larger) in the commercial catch was the lowest observed since the end of the closure in 1993/94. Also, the biomass of large prawns is significantly lower than it was during 2004/05. This has greatly reduced the potential egg production for the fishery.

6. The decline in biomass in 2009/10 and the shift in size structure of the population in recent years has been contributed to or resulted from highly effective targeting of large prawns. The current Performance Indicators and harvest strategy require modification.

7. Reduced exploitation on large prawns is required in the short term. While an increased focus on mixed prawns (grade 10/15 and 16/20) can ensure that the fishery continues to be harvested sustainably, this strategy is unlikely to result in a total catch that exceeds 2009/10. Similar or lower catches of lesser value prawns during 2010/11 will exert considerable economic pressure on the industry, particularly given that the landed value of the fishery in 2009/10 was the lowest since 1994/95. Alternative management arrangements to ensure profitable and equitable harvesting of the resource should be considered.

1. GENERAL INTRODUCTION

1.1 Overview

This Fishery Assessment Report for the Gulf St Vincent Prawn Fishery (GSVPF) is a "living" document, updated annually, and is part of the ongoing assessment program for South Australian Prawn Fisheries by SARDI Aquatic Sciences. The aims of the report are to: (1) synthesise information for the GSVPF; (2) assess the current status of the resource and consider the uncertainty associated with the assessment; (3) comment on the current Performance Indicators and harvest strategy; and (4) identify future research needs for the fishery.

The current research program aims to deliver timely and cost effective advice to underpin the adaptive management framework for the fishery. Fishery independent, stock assessment surveys have been conducted prior to each fishing period for the last six years and are the principal source of data for assessment and management. Measures of relative biomass from survey data are used to inform harvest strategies and to assess performance of the fishery. Data on catch, effort, CPUE and commercial harvest size are also analysed to augment the understanding of current status.

Historically, Fishery Assessment Reports were published more than 12 months after the completion of a fishing year. This report updates the previous report for the GSVPF (Roberts *et al.* 2009) with data from two fishing years: 2008/09 and 2009/10. This improvement in the timing of reporting was deemed necessary following the identification of issues with the current stock status. Recent advancements in data management and processing will ensure that future Fishery Assessment Reports are published prior to the commencement of the next season.

This report is a component of a broader review for the GSVPF to be conducted early in 2011. Other elements of the review include assessment of a revised Harvest Strategy developed by PIRSA and independent economic advice on several aspects of the fishery's management.

1.2 Description of the fishery

1.2.1 Fishery location

There are three commercial prawn fisheries in South Australia: Spencer Gulf, Gulf St Vincent and the West Coast (Figure 1.1). The GSVPF is the second largest of these, behind the Spencer Gulf Prawn Fishery, in terms of production and number of licence holders.

The waters of the GSVPF are bound between a line commencing at Mean High Water Springs closest to 35°13′26.90″ South, 137°00′00.00″ East, then beginning easterly following the line of Mean High Water Springs to the location closest to 35°39′37.06″ South, 138°13′38.09″ East (Porpoise Head), then south-westerly to the location on Mean High Water Springs closest to 35°48′06.93″ South, 138°07′29.06″ East (Cape St Albans, Kangaroo Island), then beginning south-westerly following the line of Mean High Water Springs to the location closest to 35°40′20.07″ South, 137°0′00.00″ East, then northerly to the point of commencement.

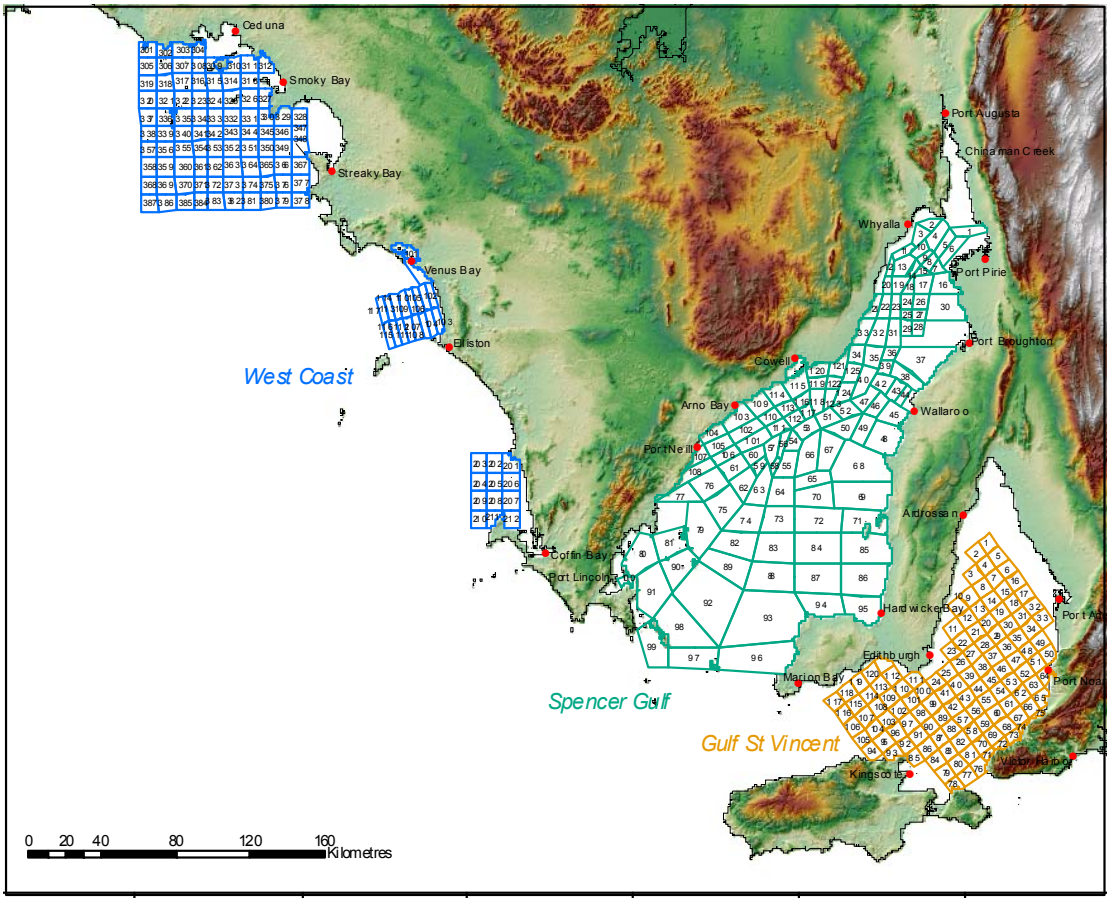


Figure 1.1 Location of South Australia's three western king prawn fisheries.

1.2.2 GSV environment

GSV is a large, relatively shallow embayment (generally <40m depth) with restricted water exchange with the open ocean due to: 1) dense upwelling of shelf waters at the mouth of the gulf, which effectively isolates gulf waters during summer and; 2) Kangaroo Island as a physical barrier, which also protects the gulf from high wave action (Middleton & Bye, 2007). Due to minimal freshwater input and high summer evaporation rates, it is an inverse estuary, with salinity increasing towards the head of the gulf (Tanner 2003), similar to Spencer Gulf (Nunes & Lennon 1986). Sediments are predominately fine sand, with mean grain size in the north of ~0.25 mm, with calcium carbonate predominating (Waters 1976).

Sea surface temperatures (SSTs) in South Australia are lower and more variable than in other northern fisheries that target *Penaeus* (*Melicertus) latisulcatus* (e.g. Broome and Shark Bay, Western Australia, Figure 1.2a). Figure 1.2b illustrates the warmer waters of both gulfs relative to other South Australian coastal waters, particularly in the northern regions of each gulf.

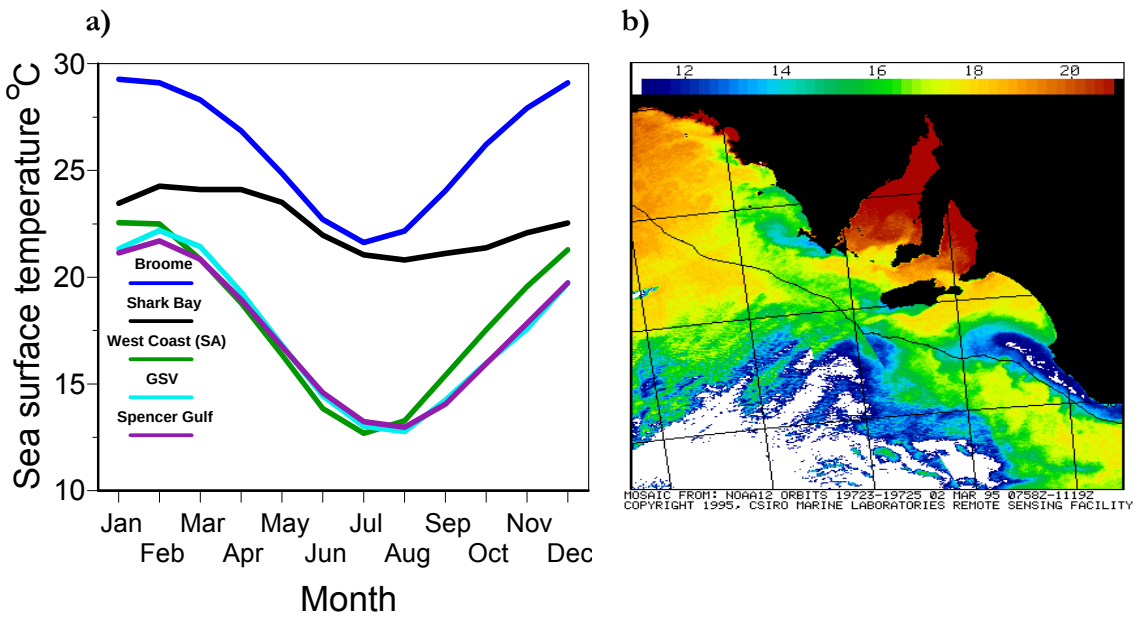


Figure 1.2a Comparison of mean monthly sea surface temperature (SST, ºC) for the Australian prawn fisheries that target *P. latisulcatus*. Figure reproduced from Carrick 2003. **1.2b** Sea-surface temperatures over the continental shelf of South Australia during late summer/early autumn, 1995. A colour-coded key in degree Celsius is situated at the top of the map. Figure from Middleton & Bye (2007), 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 mangrove systems (Kangas and Jackson 1998; Tanner and Deakin 2001). In GSV, juvenile prawn abundances were similar across the intertidal zone (Kangas and Jackson 1998), while in Spencer Gulf abundances were significantly higher in the mid intertidal zone compared to the lower and upper zones (Roberts *et al.* 2005).

Bryars (2003) documented a detailed inventory of important coastal fisheries habitats in South Australia. Fisheries Habitat Areas (FHA) that corresponded to each of the three South Australian prawn fisheries are: 1) West Coast Prawn Fishery: FHA 1–6, 8–12, 14–17, 19 (Nullabor to Sleaford Bay); 2) Spencer Gulf Prawn Fishery: FHA 20, 23, 25–37 (Thorny Passage to Formby Bay); 3) Gulf St Vincent Prawn Fishery: FHA 38–45, 55, 54, 62 (Foul Bay to Yankalilla Bay, and north-eastern Kangaroo Island).

Each FHA is separated into habitat types, including 'tidal flats' and 'mangrove forests', which both represent 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, which were summed across each fishery. The total length of coastline for each fishery was calculated from satellite imagery (http://earth.google.com). Table 1.1 summarises estimates for each South Australian Prawn Fishery.

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	508	51	245	25
GSV	11	551	225	41	79	14
West Coast	16	1310	310	24	45	3

The GSV and Investigator Strait coastline, including north-eastern Kangaroo Island from Cape Dutton to Kangaroo Head, was approximately 551 km in length. Of this, 225 km (41%) was tidal flat only and 79 km (14%) was mangrove forest (+ tidal flat) (Table 1.1). Far Northern GSV (~31 km of tidal flat only and 47 km of mangrove

forests (+ tidal flat)) and Outer Harbor (~41 km of tidal flat only and 32 km of mangrove forests (+ tidal flat)) were the areas with the highest abundance of these habitat types (Figure 1.3). These areas corresponded with sites in GSV that were previously found to contain high abundances of juvenile prawns (see Section 1.4.3).

The productivity of each fishery (Table 1.2) appears to be related to the extent of available juvenile habitat (Table 1.1), particularly with respect to the presence of mangroves. Of note, the importance of mangrove habitat for prawn recruitment has long been debated (see Lee 2004).

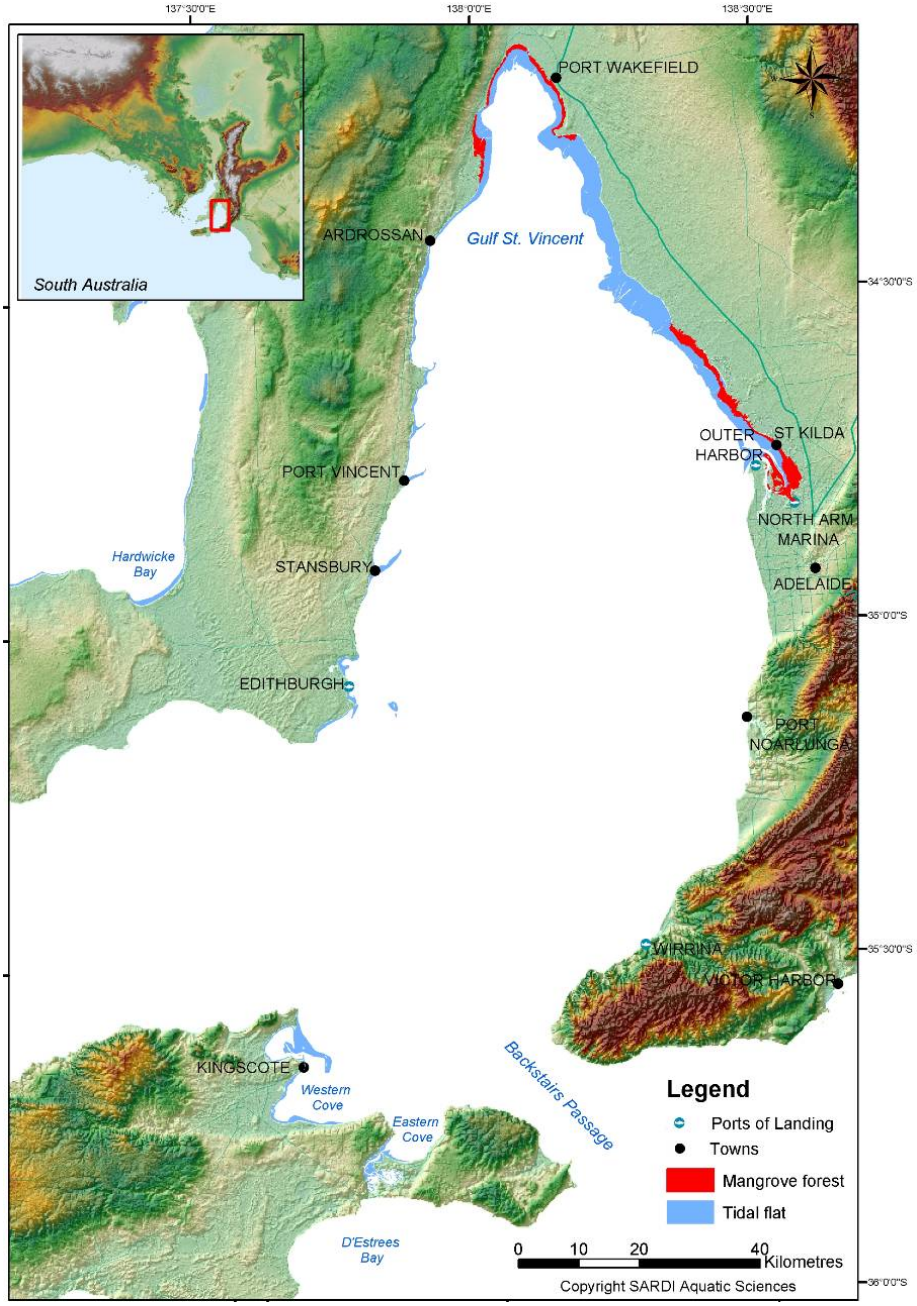


Figure 1.3 Important juvenile nursery habitat, mangrove forest and tidal flats, around coastal Gulf St Vincent. Reproduced from Bryars (2003).

1.2.4 Commercial fishery

The GSVPF is a single species fishery that targets the western king prawn, *Penaeus (Melicertus) latisulcatus*. This species was initially classified as *Penaeus latisulcatus* (Kishinouye, 1896), then subsequently reclassified by Perez Farfante & Kensley (1997) to raise the sub-genus *Melicertus* to generic rank (ie. *Melicertus latisulcatus*). However in light of recent genetic studies, Flegel (2007) revised the taxonomic name to *Penaeus (Melicertus) latisulcatus*. A smaller penaeid, *Metapenaeopsis crassima*, occurs in South Australian waters but is of no commercial value. Within South Australia, the GSVPF is the second largest prawn fishery in terms of production, value and number of licensed fishers (Table 1.2). Despite recent increases in catch, the landed value of the GSVPF in 2009/10 was the lowest since 1994/95 (Knight and Tsolos 2011).

Commercial quantities of prawns were first harvested in GSV in 1967. Fishers used single rigged trawls with few restrictions imposed on fishing seasons and areas. In 1968 the GSVPF was established through the issuing of permits and prohibiting trawling in areas < 10 m in depth. In 1969 the *Preservation of Prawn Resources Regulations* were introduced with commercial prawn fishing licenses issued. From 1975 to 1986/87, Investigator Strait was designated as a separate fishery. From 1977 to 1981, when waters >3 nautical miles off State shores were under the Commonwealth jurisdiction, Commonwealth endorsed vessels also fished in Investigator Strait. Two of these vessels remained when these waters were transferred to the State in February 1983.

During 1982 and 1983, single-rig trawls were replaced by triple-rig trawls, markedly increasing fishing efficiency. After an economic review of the GSVPF (Copes 1986), a buy-back scheme was introduced in 1987 resulting in the removal of five vessels. In 1990, one vessel surrendered its fishing licence, bringing the number of licences in the fishery to the ten that operate today. The fishery was closed for two seasons between June 1991 and February 1994 following a parliamentary review (Anon 1991). Table 1.3 documents the history of licence limitation in the fishery. Since the closure, seven vessels have been upgraded to larger vessels that are similar to those operating in Spencer Gulf (see Dixon *et al.* 2007).

Table 1.2 Production figures for South Australian prawn fisheries in 2009/10. Sources: Knight & Tsolos (2011).

Fishery	Production (t)	Landed value $ (million)	Licences
Spencer Gulf	2361	27.45	39
GSV	224	2.57	10
West Coast	84	1.12	3

Table 1.3 Number of licences issued in the Gulf St Vincent Prawn Fishery from 1969.

Period	Gulf St Vincent	Investigator Strait	Total
1969	5	-	5
1970 - 1973	10	-	10
1974	12	-	12
1975 - 1976	12	5	17
1977 - 1979	14	8	22
1980 - 1981	14	6	20
1982 - 1986	14	2	16
1987	10	2	12
1988 - 1989	11	-	11
1990 - current	10	-	10

Prawns are harvested at night using demersal otter-trawls. There are currently ten licence holders in the fishery, seven of who use large vessels that are restricted to double-rigged gear (Figure 1.4) and three with smaller vessels that use triple-rig. The differences in gear type aim to compensate for the differences in power between large and small vessels. Most vessels use “crab bags” to exclude mega-fauna by-catch from the cod-end (Figure 1.5). Large vessels use “hoppers” for efficient sorting of the catch allowing for rapid return of by-catch and “graders” to sort the prawns into marketable size categories (Figure 1.4).

The catch history of the GSVPF is characterised by two periods of increasing catch, followed by substantial declines (Dixon *et al.* 2006). The first of the declines was particularly influenced by the introduction of triple-rig gear in 1982, which increased effective effort in the fishery. During 1982/83 and 1983/84 the increases in efficiency resulted in a considerable increase in catch. Furthermore, a 2.5 fold increase in the catch of prawns during the early spawning season during these two years likely resulted in over-fishing of the spawning biomass and a reduction in recruitment to the fishery.

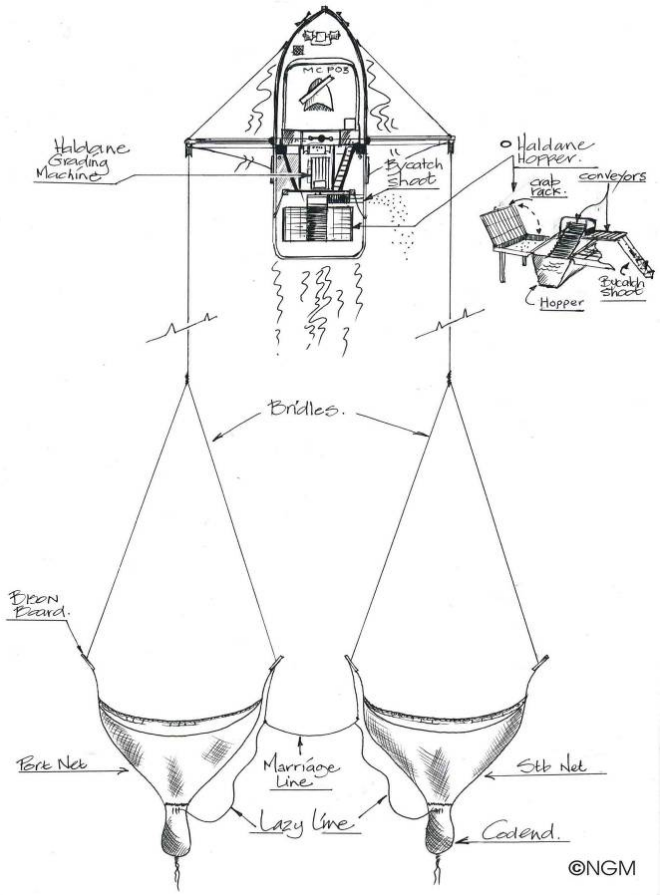


Figure 1.4 Double rig trawl gear and location of hopper sorting and prawn grading systems used in the Spencer Gulf Prawn Fishery. Figure from Carrick (2003).

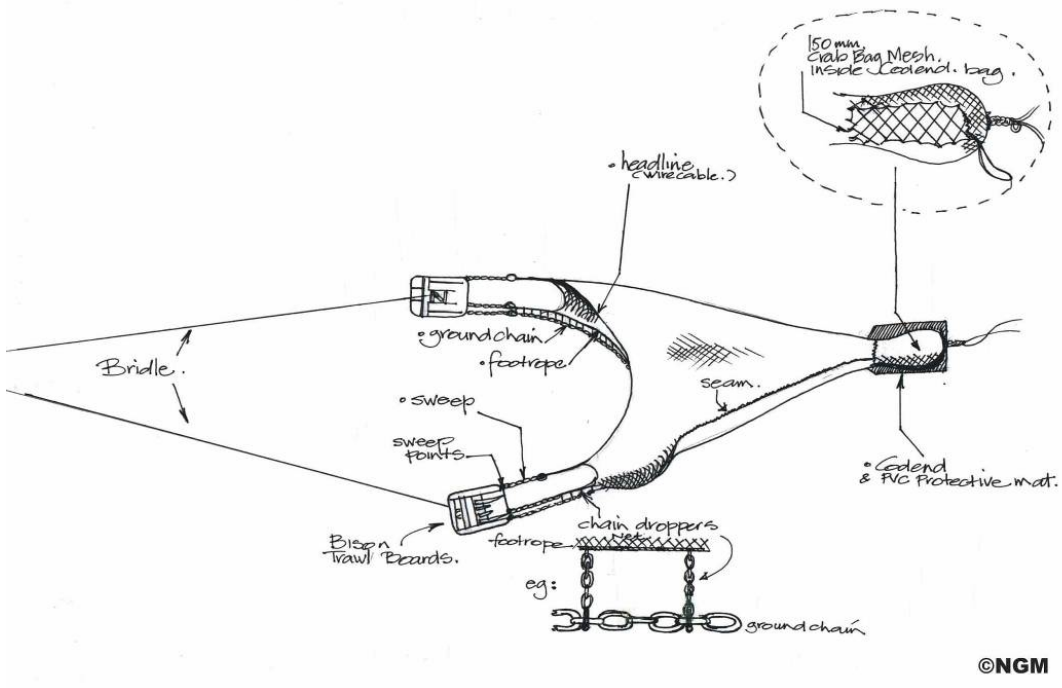


Figure 1.5 Trawl net configuration showing trawl boards, head rope, ground chain and cod end with crab bag. Figure from Carrick (2003).

The fishery was closed during 1991/92 and 1992/93 and there was no pre-Christmas fishing in 1993/94 and 1994/95. Effort, total catch, CPUE and mean prawn size increased after the closure, indicating a recovery in biomass. However, rapid increases in catch, harvest strategies that targeted large prawns, and increasing catches during the early spawning season, precipitated a second decline. Catch, effort, CPUE and mean prawn size declined from 1999/00 to 2003/04. In November 2004 a combination of factors including low total catches, increasing fuel prices and decreasing prawn prices due to import competition, prompted fishers to agree to embark on a program of stock recovery for the GSVPF.

1.2.5 Recreational, aboriginal traditional and illegal catch

Significant recreational catches of *P. latisulcatus* are precluded by fishery regulations that require the use of hand held nets in waters >10 m in depth. Levels of aboriginal traditional and illegal fishing are considered negligible (Anon 2003).

1.3 Management of the fishery

The GSVPF 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 are described in the Fisheries Management (General) Regulations 2007, with specific regulations located in the Fisheries Management (Prawn Fisheries) Regulations 2006. These three documents provide the statutory framework for management of the GSVPF. This is captured within the GSVPF Management Plan (Dixon & Sloan 2007) which provides the over-arching policy framework for daily management of the fishery.

1.3.1 Management history

Management arrangements have evolved in the Gulf St Vincent Prawn Fishery since its inception in 1967, with key milestones presented in Table 1.4.

1.3.2 Current fishery management

The GSVPF is a limited-entry, input-controlled fishery with 10 licensed operators. The fishery is managed through spatial and temporal restrictions on effort, as well as vessel size and power, type and number of trawl nets towed, maximum headline length and minimum mesh sizes. Fishing takes place between sunset and sunrise, once an independent survey has been undertaken two days after the last quarter of the moon through to the first quarter, generally in the months of December, March, April and May. Current management arrangements are summarised in Table 1.5.

Table 1.4 Major management milestones for the Gulf St Vincent Prawn Fishery

Date	Management milestone
1967	Commercial quantities of prawns first harvested in Gulf St Vincent.
1968	The GSVPF established with permits introduced and trawling prohibited in all waters less than ten metres.
1969	The Preservation of Prawn Resources Regulations 1969 is introduced and vessels licensed to fish for prawns.
1975	The fishery is split into two zones when five permits are issued to specifically fish in Investigator Strait.
1982	Number of Investigator Strait zone fishers reduced to two.
1982	Triple rig trawl nets introduced.
1986	Following an extensive review of the fishery, government introduces a licence rationalisation strategy.
1987	The Fisheries (Gulf St Vincent Prawn Fishery Rationalisation) Act 1987 is introduced.
1987	The two Investigator Strait entitlements removed and four Gulf St Vincent licences removed over the following four years and the two zones are once again amalgamated.
1990	The current number of licences (10) is achieved.
1991	Fishery closed from June 1991 to February 1994 inclusive.
1997	Management Plan first implemented (Zacharin, 1997).
2000	Fisheries (General) Regulations 2000 enabled “large” vessels to enter the fleet.
2004	Current fishery-independent surveys and harvest strategy process implemented.
2007	Management plan reviewed (Dixon & Sloan, 2007).

Table 1.5 Current management arrangements

Management tool	**Current restriction**
Permitted species	*Penaeus (Melicertus) latisulcatus*, *Ibacus* spp., *Sepioteuthis australis*
Limited entry	10 licences
Licence transferability	Permitted
Corporate ownership	Permitted
Spatial & temporal closures	Adjusted based on survey results
Closed areas	No trawling in waters shallower than 10m
Method of capture	Demersal otter trawl
Trawling times	Not during daylight hours
Trawl rig – large	Single or double rig
Trawl rig – small	Single, double or triple rig
Max. headline length – large	29.26 m
Max. headline length – small	27.43 m
Max. vessel length – large	15.2 – 22 m
Max. vessel length – small	<15.2 m
Max. vessel power – large	272 kW
Max. vessel power – small	224 kW
Min. mesh size	4.5 cm
Catch and effort data	Daily and monthly logbook submitted monthly

1.3.3 Prawn Fishery Management Plan

Zacharin (1997) developed the first Gulf St Vincent Prawn Fishery Management Plan that documented the management history, policy framework and Performance Indicators for the fishery. A review and update of the Management Plan (hereafter termed the Plan) was undertaken in 2007 (Dixon & Sloan 2007).

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 GSVPF for the life of the Plan is stock recovery. Other goals regard minimising impacts on the ecosystem and enabling cost-effective and participative management. The four stated goals are:

1. Stock recovery;
2. Ensure optimum utilisation and equitable distribution within the constraints of stock recovery;
3. Minimise impacts on the ecosystem;
4. Cost effective and participative management of the fishery.

The Plan is the first to contain guidelines on how to determine harvest strategies for the fishery. Harvest strategies are the mechanism for controlling exploitation rates using spatial and temporal closures, the aim of which is for the fleet to target limited areas of appropriately sized prawns, ensuring protection of a sufficient proportion of the stock to enable stock recovery. The Plan provides details on the data required for harvest strategy and the decision rules for its establishment.

1.3.4 Harvest Strategies

Harvest strategies are developed and refined for each fishing period in three stages; 1) exploitation levels are determined from mean survey catch rates, 2) spatial harvest areas are identified within given exploitation levels targeting particular sized prawns, and 3) harvest strategy adjustments are made during commercial fishing. Stages 1 and 2 (harvest strategy development) primarily focus on stock sustainability and are conducted by the GSVPF Research and Management Committee (PIRSA, Industry, SARDI) based on data obtained from fishery-independent surveys. It involves the establishment of closure lines to exclude fishers from areas where prawn size is sub-optimal. The Plan provides specific guidelines for the development of harvest strategies. Harvest strategy adjustment (stage 3) is the process by which the Committee At Sea (led by an industry “coordinator at sea”) adjusts, in “real time”, the closure lines during the fishing period, in accordance with ‘at sea’ decision rules to maximize the economic performance of the fishery. Harvest strategy adjustments are informed from data obtained during commercial fishing that are reported to the co-ordinator at sea. These adjustments to the harvest strategy are limited to reducing the size of the initial harvest areas identified by the GSVPF Research and Management Committee.

1.3.5 Performance Indicators

The extent to which the Plan is achieving the stated goals and objectives are assessed using a combination of Performance Indicators (PIs) designed to measure performance of the fishery. The primary biological and management PIs of the Plan that are assessed in this report are presented in Table 1.6. The full suite of PIs is documented in Dixon and Sloan (2007).

Table 1.6 Biological and management Performance Indicators and Limit Reference Points for the GSVPF (Dixon and Sloan 2007).

Performance Indicator	Limit Reference Point
Fishery independent surveys	4 surveys completed
Recruitment index	>250
Total commercial catch (t)	Increasing each year of the Plan
Mean commercial CPUE (kg/h)	Increasing each year of the Plan
Mean commercial size	Within target-size criteria in each harvest period
Indices of current biomass (defined in the Plan)	Decreases in two consecutive surveys
Indices of future biomass (defined in the Plan)	Falls below limits in two consecutive surveys

Limit Reference Points (LRPs) define the minimum acceptable level of performance. If LRP are 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 1.7). Triggering additional performance measures does not necessarily evoke a management response.

Table 1.7 Summary of the additional biological and management performance measures and associated limit reference points for the Gulf St Vincent Prawn Fishery (Dixon and Sloan 2007).

Performance Measure	Limit Reference Point
Recruit index December survey all shots	>100
Recruit index March survey all shots	>200
Recruit index April survey all shots	>250
Egg production (eggs*10^6/ hr trawled)	>500
% of >U10 in the catch – March to June	>25%
% of 21+ in the catch – Dec	<7%
% of 21+ in the catch – March to June	<5%

1.4 Biology of the western king prawn

1.4.1 Distribution and taxonomy

The western king prawn, *P. latisulcatus,* is distributed throughout the Indo-west Pacific (Grey *et al.* 1983). Its distribution in South Australia is unique, as it is at the lowest end of its temperature tolerance range, primarily restricted to waters of Spencer Gulf and GSV and along the West Coast, particularly off Ceduna, Venus Bay and Coffin Bay.

P. latisulcatus is a benthic species that prefers sandy areas to seagrass or vegetated habitats (Tanner and Deakin 2001). Both juvenile and adult prawns exhibit strong diel behaviour of daytime burial and nocturnal activity (Rasheed and Bull 1992; Primavera and Lebata 2000). Strong lunar and seasonal (attributed to temperature) differences in activity are also exhibited, where prawn activity and therefore catchability are greater during the dark phase of the lunar cycle and during warmer months (Penn, 1976; Penn *et al.* 1988).

The distribution and abundance of *P. latisulcatus* within gulfs and estuaries are 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 22–34‰, whilst 100% mortality occurred at salinities below 10‰ (Sang and Fotedar 2004). Juvenile *P. latisulcatus* are more efficient osmoregulators than adults, tolerating greater variation in salinity. Important nursery areas in Western Australia (WA) and South Australia are characterised as being hyper-saline (35–55‰) (Carrick 1982; Penn *et al.* 1988).

1.4.2 Reproductive biology

Adult prawns aggregate, mature, mate and spawn in deep water (>10 metres) between October and March (King 1977). Ovary development followed by spawning of fertile eggs occurs during a single intermoult period (30-40 days) (Penn 1980) where fertilisation presumably occurs immediately prior to or on release of the eggs by the female. Multiple spawning events may also occur as spawning frequency is related to moulting frequency (Penn 1980; Courtney & Dredge 1988). During the peak spawning period, the sex ratio of harvested *P. latisulcatus* is typically female-

biased, likely due to greater foraging activity (Penn 1976; Penn 1980; Svane & Roberts 2005).The ideal temperature range for spawning and fecundity seems to be between 17°C (Penn 1980) and 25°C (Courtney & Dredge 1988), which generally coincides with the spawning season in South Australia (~October to March). In both gulf fisheries in South Australia, the majority of spawning is constricted to earlier in the season, which likely relates to optimising reproductive success due to shorter larval durations and higher larval survival at that time of year (Roberts *et al.* submitted).

While females can mature at a small size, differences between tropical and temperate populations seem to be apparent. The smallest ripe female recorded in WA populations was 29 mm carapace length (CL) (Penn 1980). In GSV and Spencer Gulf, the smallest ripe females observed were 25 mm CL (December 2006 fishery-independent survey data, SARDI), and 22 mm CL (November 2005 fishery-independent survey data, SARDI) respectively. While females can mature at a small size, insemination success rate increases with size. Courtney & 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*.

Table 1.8 and Figure 1.6 presents the results of fecundity studies for *P. latisulcatus* undertaken in GSV (Kangas unpublished data, cited in Carrick 2003), Shark Bay (Penn 1980) and the North East Coast of QLD (Courtney and Dredge 1988). In all three fisheries, fecundity increased exponentially with carapace length (CL), however the increase was more pronounced in the cooler waters of GSV (Figure 1.6). Thus larger prawns make a greater contribution to total egg production due to both greater insemination rates and higher fecundity (Penn 1980; Courtney & Dredge 1988; Carrick 1996). However, ovarian senescence in very large (oldest) females may occur (Courtney *et al.* 1995).

Table 1.8 Fecundity relationships for *P. latisulcatus* in GSV, Western Australia and Queensland. Fecundity = $a \times$ carapace length^b

Location	*a*	*b*
GSV, 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

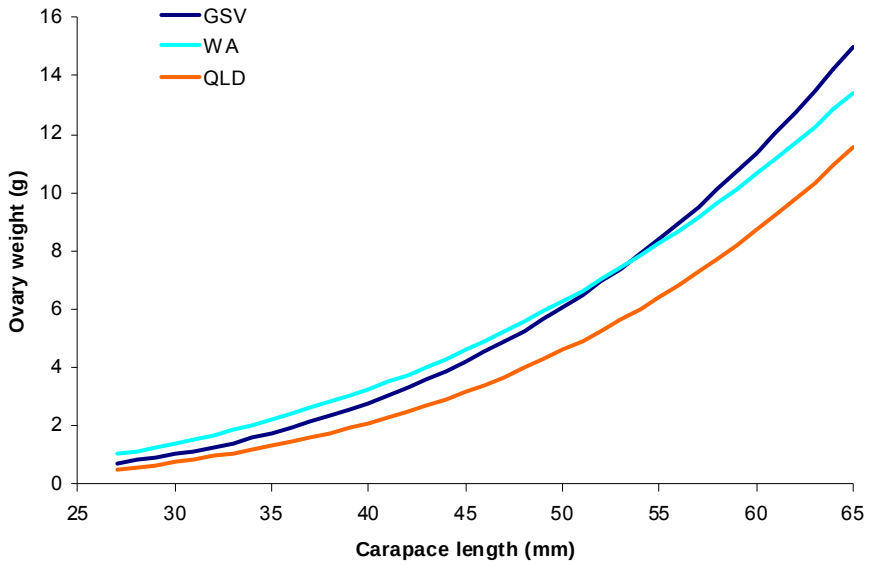


Figure 1.6 The relationship between fecundity (ovary weight) and carapace length (CL) for *P. latisulcatus* in GSV, Western Australia and Queensland, as determined from the fecundity relationships defined in Table 1.8.

Parasite load and disease status are limiting factors in marine animal populations, although generally overlooked in fisheries management (Harvell *et al.* 2004). Courtney *et al.* (1995) showed that parasitisation by bopyrid isopods affected the reproductive output of the eastern king prawn, *Penaeus plebejus*. Bopyrid isopods also parasitise *P. latisulcatus* in South Australia, although at low prevalence (Roberts *et al.*, 2010). In the Indian prawn, *Fenneropenaeus indicus*, it was shown that viral infections affected moulting and reproduction of Penaeid shrimp (Vijayan *et al.* 2003). In addition, environmental pollution from coastal industries 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 1.7). Prawn larvae undergo metamorphosis through four main stages: nauplii, zoea, mysis and post-larvae (Figure 1.8). 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). Roberts et al. (submitted) 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%).

Furthermore, in Spencer Gulf, larval duration was predicted to be significantly shorter in northern compared to southern spawning grounds (separated by latitude 34°S).

Prawn larvae are dispersed by wind-driven and tidal currents. Kangas (1999) modelled larval dispersion in GSV and demonstrated that spawning events in northern GSV were more likely to result in settlement in northern nursery areas than spawning in southern GSV (Figure 1.9). As demonstrated in Section 1.2.3, nursery habitats are more abundant in northern GSV than other regions. Juvenile prawn abundance correlates well with the distribution of these habitats (Figure 1.10). These results have implications on harvest strategy development during the spawning period.

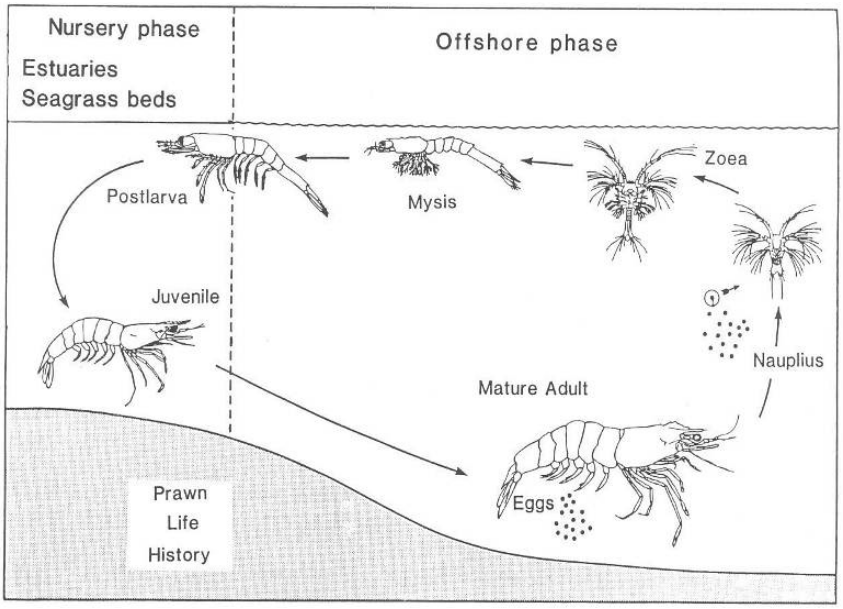


Figure 1.7 Life cycle of *P. latisulcatus* (Carrick 2003).

In GSV, Kangas (1999) showed that post-larvae settled in inshore nursery areas at 1 mm CL, with juveniles 2–7 mm CL comprising 90% of the surveyed population. The post-larvae produced from early spawning events settled in nursery areas during December or January, when growth was high, and then emigrated to deeper water in May or June (at ~20 mm CL). Alternatively, post-larvae produced from late spawning settled in nurseries from March and due to slow growth they “over-wintered” in the nursery areas, recruiting to the trawl grounds in the following summer (Kangas 1999).

Over-wintering mortalities in nurseries ranged from 0.2–16.5% (mean = 7.9%) per week in GSV, 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).

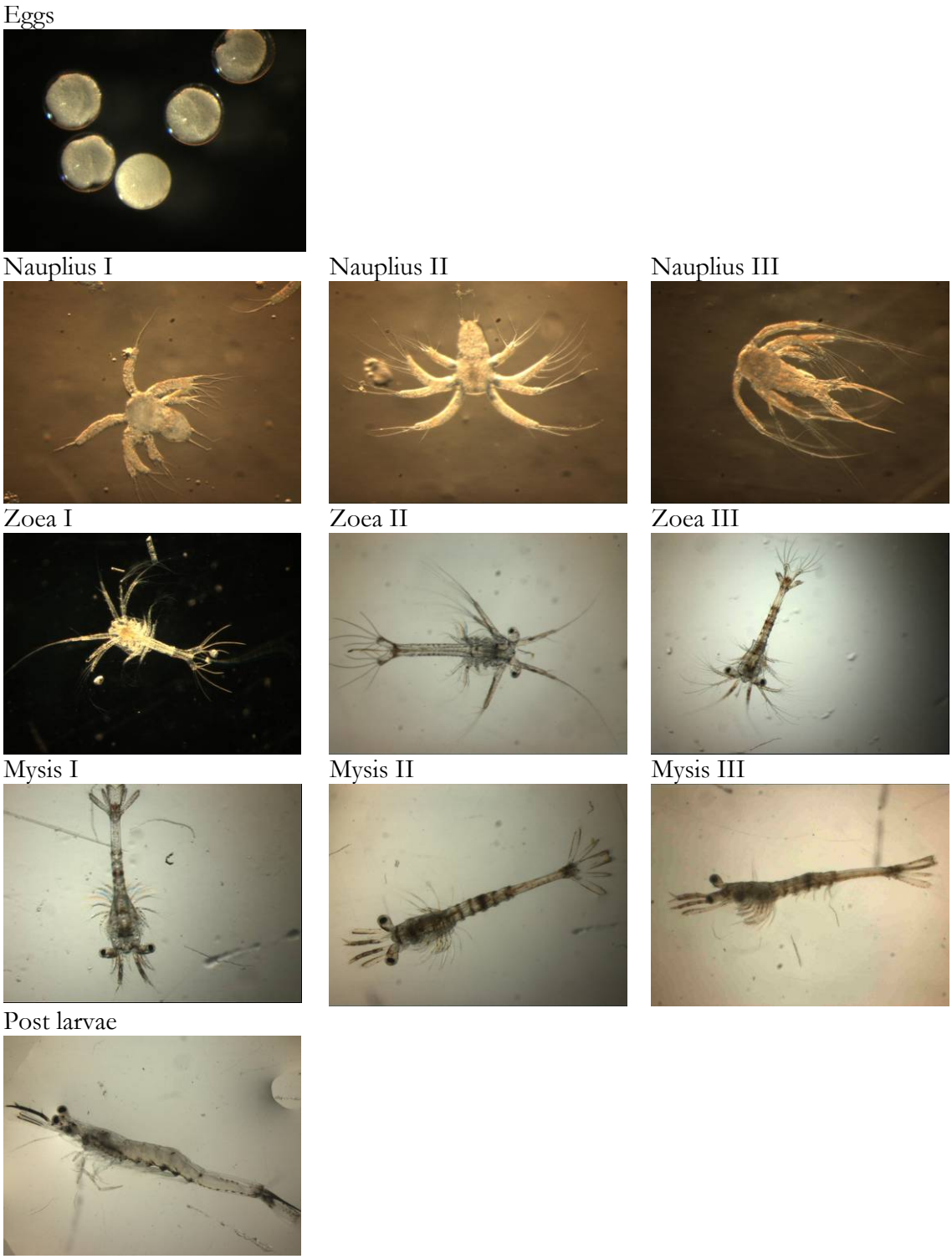


Figure 1.8 Western king prawn, *P. latisulcatus*, larval stages (egg to post larvae) (SARDI unpublished data as part of FRDC project 2008/011).

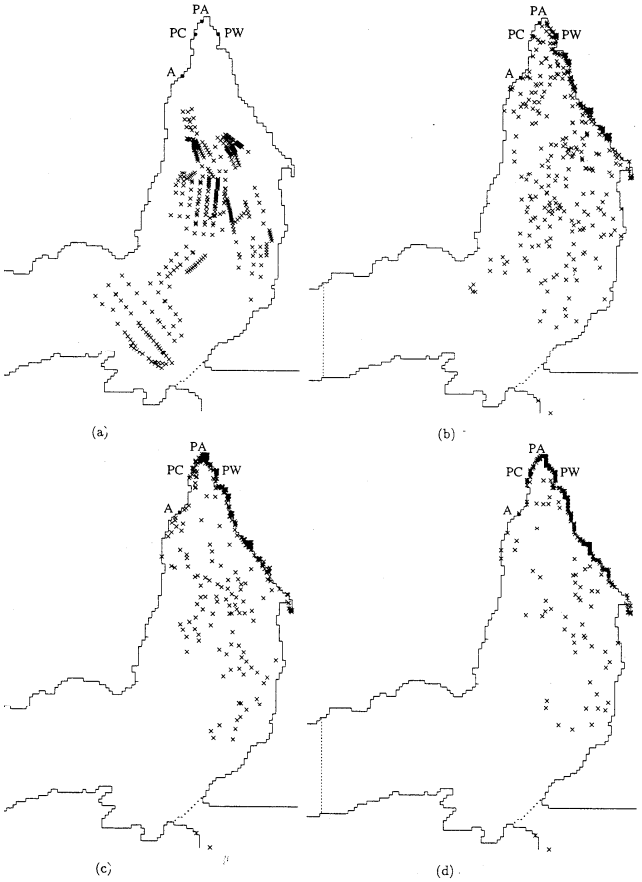


Figure 1.9 (a) Initial egg production of *P. latisulcatus* in GSV during November 1990 and (b) advection and diffusion of larvae at four, (c) six and (d) eight weeks after spawning as determined from a computer generated model (Kangas 1999). PW – Port Wakefield, PA – Port Arthur, PC – Port Clinton and A – Adrossan. Each point represents 30 million eggs.

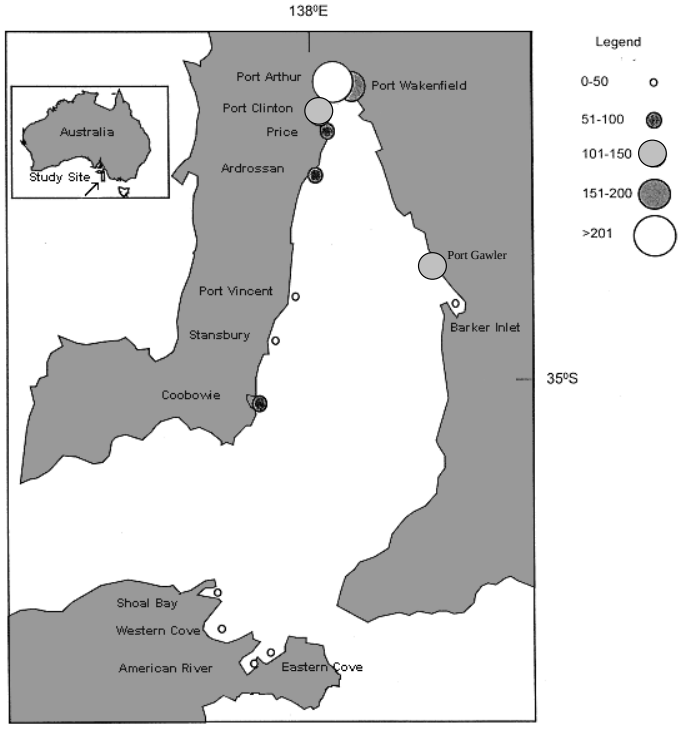


Figure 1.10 Relative abundances of juvenile prawns (number m^{-2}) found during sampling in 1989 and 1990 in GSV and at Kangaroo Island (Kangas & Jackson 1998).

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 (Carrick 2003). However, an analysis of the genetic structure of *P. latisulcatus* using electrophoresis suggests a homogenous stock in South Australia (Carrick 2003).

1.4.5 Growth

As with other crustaceans, prawns undergo a series of moults to increase their size incrementally. 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;
- ability to distinguish cohorts, effect of catchability, and net migration on cohort analysis;
- measurement error (both methods).

Tag-recapture studies of prawns in GSV were undertaken by King (1977) and Carrick (1982 and unpublished). Growth parameters were determined from 464 recaptures using a modified von Bertalanffy growth model by Kangas & Jackson (1997) (Table 1.9). Differences in growth were apparent between genders and within years. Maximum growth occurred in April for males and early March for females. Between October and December, growth did not increase with increasing water temperature, which may have been due to the allocation of energy to reproduction rather than growth.

Morgan (1995) provided growth estimates for GSV from several sources including commercial length-frequency, fishery independent length-frequency and tagging data. The mean value of Morgan's parameter estimates as well as estimates for the West Coast and Spencer Gulf Prawn Fisheries are provided in Table 1.9.

Table 1.9 Sex-specific growth parameters for *P. latisulcatus* estimated from tag-recapture and cohort analysis for the West Coast (Wallner 1985) and from tag-recapture in Spencer Gulf (Carrick 2003) and Gulf St Vincent (Morgan 1995, 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 (Morgan 1995)	Cohort & Tag	Male	0.61	49.7
		Female	0.61	64.1
GSV (Kangas & Jackson 1997)	Tag	Male	0.62	47.2
		Female	0.54	65.3

1.4.6 Length weight relationship

Length weight relationships have not been determined for adult prawns in GSV. The relationship between prawn carapace length (CL, mm) and weight (g) from Spencer Gulf was determined from a sample of over 2000 prawns (Carrick 2003). The power relationship described by the equation "Weight = $a \times$ carapace length^ b" varies between males (a= 0.00124, b=2.76) and females (a= 0.00175, b=2.66). Kangas (1999) determined the length weight relationship for juvenile prawns in GSV (a= 0.00066, b=2.91, N=325) (Figure 1.11). 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

Between December 1990 and September 1991, 37,000 prawns were tagged and released in GSV. An additional 4,000 individuals were tagged and released in May 1994. In total, 543 tagged prawns were recaptured (Kangas and Jackson 1997).

In general, tagged-prawn movements in GSV were predominately north to south. Whilst many moved only short distances from their release location (1-10 nautical miles), larger displacements of up to 22.4 nautical miles in seven days were common. Tag-recaptures from releases in eastern Investigator Strait showed a general west and north-west displacement, however, this was based on a small number of tag returns (Kangas & Jackson 1997).

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 prawns, it is

unclear how these tags affect prawn movement. These effects on growth and mortality can be reduced with the use of antibiotic/antifungal ointment on the tag to reduce post-tag mortality from infection (Courtney *et al.* 2001) and selective tag colour to reduce prawn predation (Benzie *et al*. 1995).

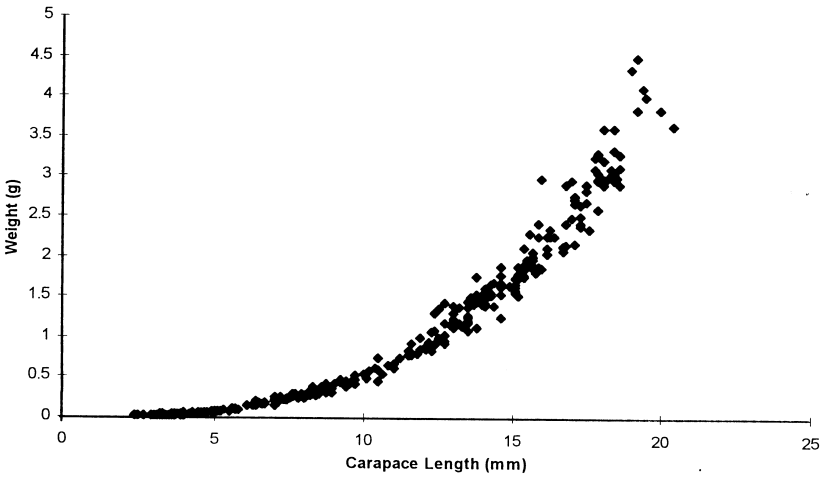


Figure 1.11 Length weight relationship for juvenile *P. latisulcatus* in GSV (Kangas 1999).

1.4.8 Natural mortality

The instantaneous rate of natural mortality for both sexes combined was estimated by Kangas & Jackson (1997) as 0.003 per day for GSV prawns. Morgan (1995) provided similar estimates of natural mortality from a range of empirical methodologies and models. These values are within the range of those estimated for *P. latisulcatus* in Spencer Gulf (0.003 to 0.005; King 1977), the West Coast Prawn Fishery (0.001 to 0.014; Wallner 1985) and WA (0.002 to 0.005; Penn 1976).

Morgan (1995) hypothesized that the difference in sex ratio observed in the population (generally a higher proportion of males than females) was the result of differential mortality, likely associated with higher mortality of females after spawning. Using change in ratio data, Morgan's estimates of instantaneous natural mortality were determined as 0.0035 per day for females and 0.0025 per day for males. However, these estimates assumed that catchability of males and females was equal, an assumption that was unable to be examined in the study. Interestingly, sex-specific estimates of natural mortality from Xiao and McShane (2000) provided an opposing result, with 0.0031 per day for females and 0.0034 per day for males.

1.4.9 Biosecurity and Prawn health

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). During a 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).

The health of South Australian populations of *P. latisulcatus* and the potential effects of coastal pollutants, parasites and disease on growth, survival and reproduction is poorly understood. 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 declined substantially since the early 1970's, probably due to human induced 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 the 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.

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

1.5 Stock Assessment

1.5.1 Reports and publications

Several reviews have been conducted for the GSVPF. Copes (1986) provided management recommendations that included: the amalgamation of GSV and Investigator Strait management zones; refinement of the target-size from 29–33 prawns per kg to <27 prawns per kg; increased mesh size; improved governance and communication arrangements, and; immediate effort reduction through a buyback scheme and on-going assessment and effort reduction. A follow up report (Copes 1990) reiterated several of the original recommendations including improvement in mesh selectivity, a greater understanding of an appropriate target-size, and further fleet rationalisation. A comprehensive, quantitative assessment of the current status of the fishery was provided by Morgan (1995). The assessment indicated that recruitment had increased following the closure but was not yet at historic levels. Morgan also suggested that although the fishery was lightly exploited compared to previous years, modest step-wise increases in annual exploitation was an appropriate precautionary approach.

Kangas and Jackson (1997) produced a fishery assessment report for the GSVPF that provided biological information, analyses of commercial catch and effort data and an assessment of fishing power of the GSV fleet. Annual fishery assessment reports have since been published documenting each fishing season (Xiao and McShane 1998; Boxshall *et al*. 1999; Boxshall and Williams 2000; Boxshall and Johnson 2001; Svane and Johnson 2003; Svane 2003; Svane and Roberts 2005; Dixon *et al*. 2006; Roberts *et al*. 2007a; Roberts *et al*. 2008; Roberts *et al*. 2009). Stock status reports have become a recent component of the assessment program. These reports aim to provide a brief end-of-season update of the status of the stock (Roberts *et al*. 2007b; Hooper *et al.* 2009).

1.5.2 Fishery statistics

SARDI maintains a comprehensive catch and effort database for the GSVPF using data collected from the compulsory fishing logbook system. Fishery-dependent (catch and nominal effort) data for the GSVPF are available from 1968. Annual data (1968–1972) and monthly data (January 1973 to June 1987) were obtained from South Australian Fishing Industry Council (SAFIC) annual reports. Data from July 1987 were obtained from daily commercial logbooks provided to SARDI. Commercial

logbooks from July 1987 to June 1991 provided data on estimated prawn catch, trawl time and fishing block. No fishing was conducted from July 1991 to February 1994. Logbooks from March 1994 onward provided data for each trawl shot including start/finish times, estimated prawn catch and fishing block. Estimated prawn catch for each shot was adjusted using validated post-harvest catches reported in monthly logbooks. Catch and effort data includes fishery-dependent "searching" and spot survey catches, as well as fishery-independent survey catches. These data are provided in Section 2 of this report.

1.5.3 Fishery-independent data

Fishery-independent data have been collected for the GSVPF since 1984 through fishery-independent surveys and on-board observing. These provide four separate datasets to inform assessment:

1. Surveys conducted in consecutive fishing periods (December, March, April and May) between 2004/05 and 2009/10 (Section 3 of this report)
2. Surveys conducted from April 1984 to February 1995 (Appendix 8.1)
3. Observer data collected during fishing between 1993/94 and 2003/04 (Section 2 and Appendix 8.2)
4. Surveys conducted during May between 2003 and 2008 (Appendix 8.4)

The first dataset (2004/05–2009/10) is an ongoing component of stock assessment for the GSVPF. Since December 2004, a rigorous survey design consisting of approximately 110 survey shots was implemented to aid stock assessment and to inform harvest strategy decisions for the GSVPF. These surveys have been conducted prior to each fishing period, from December 2004 to May 2010 generally by the large vessels of the fishery (except during May between 2005 and 2008 when small boats participated). Some additional survey shots were completed by small vessels on various occasions prior to 2008, but poor spatial and temporal replication prevents meaningful assessment.

Other datasets were not useful for determining trends in prawn abundance or biomass. Interpretation of these data is limited by poor and spatial replication, and uncertainty associated with changes in fishing efficiency. Some trends were generally informative, including prawn size and sex-ratio of commercial catches (fishery-independent on-board observations). Analyses of these datasets are provided in the Appendices and are fully documented in previous stock assessment reports.

1.6 Current Research and Monitoring Program

The current research program comprises five components: (i) administer a daily logbook program (ii) collate catch and effort information (iii) conduct independent stock assessment surveys to inform harvest strategies and assess the fishery against the Biological Performance Indicators, (iv) manage and analyse databases of by-catch, by-product and juvenile sampling and (v) produce annual status and stock assessment reports that assesses the status of the GSVPF, including assessment of the fishery against the Performance Indicators defined in the Management Plan.

1.7 Discussion

Generally, aspects of the biology of *P. latisulcatus*, the environment in which it is distributed and the management of the commercial fisheries that harvest this species within South Australia are well documented. However, several key elements of the Gulf St Vincent Prawn Fishery require further research.

Firstly, there is uncertainty in the available data on growth and mortality. Differences in growth rate occur seasonally and annually, and may also be affected by the density of con-specifics (Khoi and Fotedar 2010). While some historic tagging data are available, cohort analysis of fishery independent survey data from the last six years may provide opportunity to examine growth among months, years and densities. Also, previous research provides opposing views of sex-specific natural mortality. While the current adaptive management strategy approach for the fishery does not rely on estimates of growth and mortality, models based on an improved understanding of these parameters may be useful in the future to examine issues such as the optimal target-size for the fishery.

There is currently an FRDC project (2009/069) that aims to identify new gear technologies to optimise prawn size and reduce bycatch. Preliminary results have been encouraging, particularly for the “T90” mesh type but ongoing development is required. New gear designs have the potential to optimise the sustainability and economics of the fishery, and to satisfy the Commonwealth government requirements regarding bycatch and environmental sustainability.

Currently, there are no data available on the frequency of individual spawning events and the fertilization success of *P. latisulcatus* in temperate South Australian waters. While data were recently collected on the influence of temperature on larval growth

and survival, an improved understanding of larval dispersal, settlement and subsequent recruitment is required for GSV. These are controlled by a combination of factors including reproductive dynamics of the adults, their physiological tolerances (food availability, salinity and temperature), behaviour (i.e. vertical migration), and hydro-meteorological dynamics such as wind-driven and tidal currents.

Bio-physical models that aim to incorporate these parameters to predict larval dispersal and settlement provide useful tools for fisheries management. The current FRDC project 2008/011 "Prawn and crab harvest optimisation: a biophysical management tool" aims to address many of these issues for the Spencer Gulf. The first output from this project has recently been completed (Roberts *et al*., in review), and represents the basis for the biological component of the bio-physical model. This model 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. While the project is directly associated with the Spencer Gulf fishery, its outcomes are of relevance to the GSV fishery.

Juvenile prawn surveys are a useful tool for assessing the health of nursery habitats and may provide greater understanding of stock-recruitment relationships. Whilst the juvenile survey conducted in 2009 provided a snapshot of health status, there is insufficient historic or current data on juvenile prawn abundance to determine whether juvenile surveys can be used as a predictive index of stock status. Continuation of juvenile surveys over the next few years would provide: 1) a monitoring tool for the health of prawn nurseries; and 2) information to improve the understanding of the stock-recruitment relationship.

The most recent survey of prawn nurseries indicated that these habitats were currently free from marine pests and four key disease-causing (notifiable) viruses (Roberts *et al*, 2010). However the health status of adult prawn populations remain poorly understood. There is a need for understanding the effects of coastal pollutants, parasites and disease on growth, survival and reproduction of prawns in South Australia and a requirement for vigilant habitat assessment. This is primarily due to issues regarding 1) the risk of disease introduction associated with the use of imported prawns for bait, 2) dredging of the Port River and 3) effects from coastal development.

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 prawn-grade data between 2006/07 and 2009/10 and from on-board observer data between 1993/94 and 2003/04. Data from both sources were used to examine annual trends in commercially harvested size from 1993/94 to 2009/10. Commercial prawn grade data were also used 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 all commercial and survey catch and effort. In this report, a “fishing year” is defined as the period from November to October the following year. Currently, most fishing is done from December to May, 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 between two months. As the main spawning period for *P. latisulcatus* in GSV extends from November to March, catch is also presented for early (Nov. – Dec.), late (Jan. – Mar.) and non-spawning (Apr. – Oct.) periods.

From 1993/94 to 2003/04, industry vessels used a surveying strategy to locate areas of prawns of target-size and target catch rate. “Searching” survey shots were 20 minutes or less in duration and were conducted with the cod-end of only one net tied. All ten commercial vessels would “line up” and sweep areas of GSV in a single direction until target prawns were encountered and fishing would commence. During 2004/05, harvest strategies were modified, with the introduction of fishery-independent surveys at consistent sites throughout GSV (30 minute shots), replacing previous searching methods. Effort data were analysed as the proportion of searching to commercial effort to: 1) investigate patterns in the abundance of target-

sized prawns from 1993/94 to 2003/04; and 2) examine the efficiency of each searching approach for targeting commercial effort.

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

Mandatory reporting of commercial prawn-grade data in daily logbooks was introduced in 2005/06. Data were available from five large vessels from March 2006, six large vessels from March 2007, seven large vessels from December 2009 and on occasions by one small vessel from April 2007. Data analysed for this section was from commercial fishing nights only. The grade is determined from the number of prawns to the pound (i.e. U10 = under 10 prawns per pound, etc). In this section, data were reported as the proportion of the commercial catch occurring in each of 28 size classes, not including 'blank' and 'error' categories (see Table 2.1), and the number of prawns per kilogram calculated from grade data (Table 2.2). To facilitate interpretation of the prawn-grade data, grades were converted to five size categories based on the decision rules provided in Table 2.1. A sixth category, SB (Soft and Broken) was established for non-graded prawns.

Uncertainty associated with the calculation of prawn size arises from: data not available from the entire fleet; assumptions regarding the calculation of mean prawn size (converting reported grades to prawns per kilogram, Table 2.2), and; uncertainty associated with the unvalidated grade data provided in logbooks.

Table 2.1 Categories assigned to reported prawn grades from commercial logbook data.

Prawn grade	Categories in logbook
U8 (XL)	U6, U8, XL
U10 (Large)	U10, L
10/15 (Medium-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%)
21+ (Small)	20+, 19/25, 21/25, 21/30, 26+, 30+, 31/40, S, SM
SB (Soft & Broken)	S/B, B&D, MIX, REJ, SMS, blank, ERR

Historical data from on-board observers are likely representative of the fishery as sampling occurred across all months fished between 1993/94 and 2003/04 from at least six of the ten licensed vessels. To estimate the annual catch of prawns per size grade, sex-specific size-frequency data were converted to sex-specific weight-frequency using the length to weight relationships defined in Section 1.4.6. Prawns from each sex were then graded according to Table 2.2 (note that all estimates

ignore the prawn grade category 'Soft and Broken'). The weight-frequency distribution was summed across grades to determine the proportion weight of each grade as a proportion of the total sampled weight. These proportions were multiplied by the catch to determine the estimated weight of each prawn grade.

Table 2.2 Prawn grades and associated weight ranges from commercial processors

Prawn grade (No. prawns per pound)	U10	10–15	16–20	20+
Weight range (g)	>46	31–45	23–31	<23

Mean daily prawn size is a measure of the average size of prawns harvested by the fleet each day and is used to manage size criteria for the fishery. At sea it is estimated by industry using "bucket" counts, where 7 kg of prawns are weighed and counted on several occasions throughout a nights fishing. Here, we accurately determine mean daily prawn size by utilizing commercial grade data and compare the performance of the fishery against target-size criteria.

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 2.3.

Table 2.3 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 per kg 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 2.3):

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

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

Mean monthly prawn size (prawns per kg) was determined as the weighted mean prawn size from each daily catch per vessel:

$$\frac{\sum\left(\sum catch \times \sum\left(catch \times ppkg\right)\right)}{\sum\left(catch\right)}$$

where, *catch* is the total daily catch, *ppkg* is the mean daily prawns per kg.

Daily prawn size data are available from March 2006. The Management Plan stipulates that the target mean prawn size is 27–33 and <28 prawns per kg for the December and March to May harvest periods, respectively. In this section we consider only nights in December where prawns were caught at a mean size <33 prawns per kg as being caught outside of target criteria.

For each fishing month, the proportion of catch by weight was determined for nights when mean daily prawn size was within and outside of target-size criteria. This proportion was multiplied by the total catch for the month (for all graded and ungraded catch) to determine estimates of the total catch caught within and outside of target-size criteria.

2.3 Catch and effort

2.3.1 Inter-annual catch and effort

Total catches in 2008/09 and 2009/10 were 288 and 241 t, respectively, of which 15 and 18 t were harvested during fishery-independent and by-catch surveys. Total catch (fishing and survey) during 2008/09 increased by 19% compared to 2007/08 (243 t), before decreasing to similar levels in 2009/10. However it should be noted that the 2009/10 catch was 40% higher than the recent low catch of 172 t in 2003/04.

Although prawns were first harvested commercially from GSV in 1967, catch and effort reporting did not commence until 1968 (Figure 2.1). Catches increased steadily to >300 t over the next seven years, and peaked at 631 t in 1975/76. Catch declined to <400 t in 1981/82 and again increased to >500 t in 1982/83. Whilst catch exceeded 400 t in 1983/84, it fell rapidly thereafter, ranging between 134 and 261 t (mean 211 t) from 1984/85 to 1990/91.

No fishing was conducted during 1991/92 and 1992/93. The closure period enabled the biomass to begin recovery and catches were subsequently restricted to the late and non-spawning periods during the following two fishing years (1993/94 & 1994/95). Catch increased rapidly from 1996/97 (210 t) to peak at 400 t during 1999/2000, then declined annually to a low of 172 t in 2003/04 and have since remained above 184 t. It is noteworthy that the 4 –year period of peak catches following the closure (>300 t caught from 1998/99 – 2001/02) was approximately 200 t lower than the period of peak catches in the late 1970's.

Total effort (fishing and survey) in 2008/09 and 2009/10 was 2,547 and 2,582 h, respectively. Notably, total effort has been stable during the last five fishing-years (range: 2,442–2,657 h) and is currently among the lowest levels of nominal effort observed for the fishery.

From 1968–1976/77 trends in effort generally reflected trends in catch. From 1977/78–1979/80 commercial effort peaked (range: 18,035–20,569 h) despite decreasing catches during this period. Effort stabilized from 1980/81–1983/84 (range: 14,174–15,329 h) before declining sharply, again reflecting trends in catch. Since 1993/94, effort has been relatively stable (range: 1,815–4,038 h, mean: 3,169 h), and much lower than the levels of effort prior to the closure in 1991/92 (mean: 9,856 h).

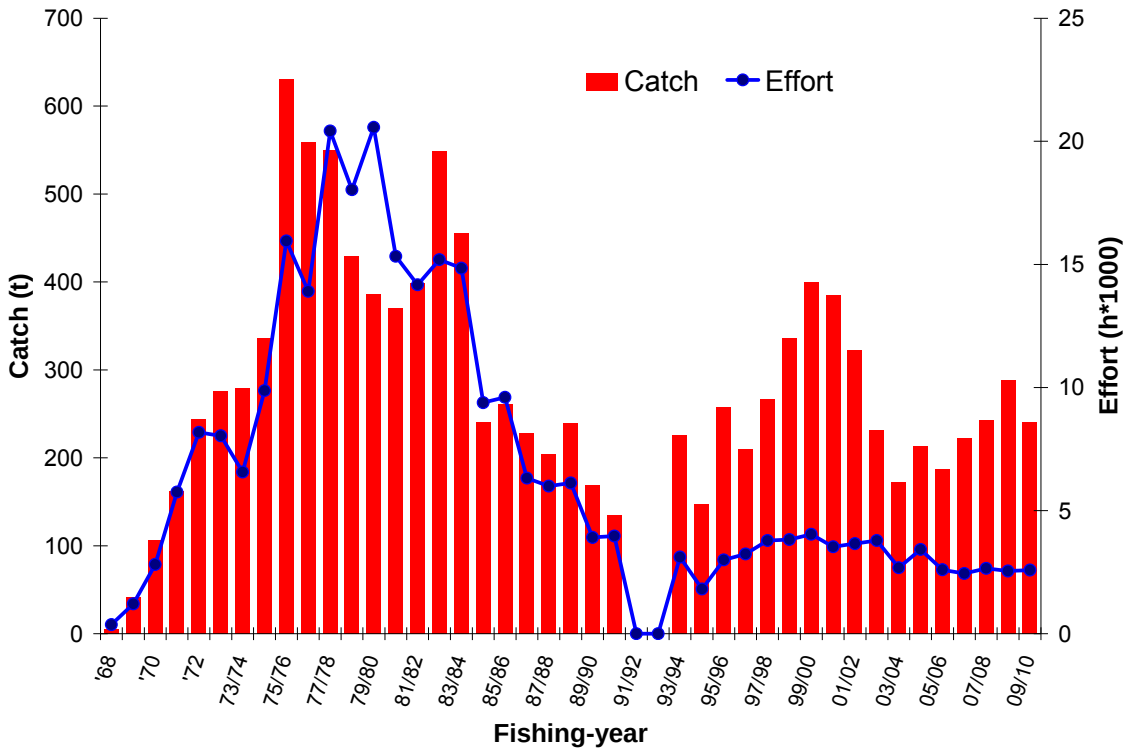


Figure 2.1 Total (fishing & survey) catch (t) and effort (h) for GSV from 1968 to current. Data for 1968–1973 are reported as calendar year. Data for 1973/74 are from January 1974 to October 1974. From 1974/75 data are reported in fishing years.

2.3.2 Intra-annual catch

The seasonal patterns in monthly catches have changed over the last 30 years (Figure 2.2). Monthly trends allow comparisons with historical catches when harvesting was not conducted during set harvest periods. Mean monthly catch peaked in November and was lowest in July, August and September. Since 1984/85 the temporal distribution of monthly catches has been similar, with peak catches occurring from March to May and few or no prawns being harvested during January and February and from July to October.

The traditional harvest of large catches during March in GSV is contrary to the understanding that has developed in Spencer Gulf regarding optimal harvest times. In principle, catches should be left as late as possible in the fishing year to maximise growth after the spawning period (see section 1.4.5).

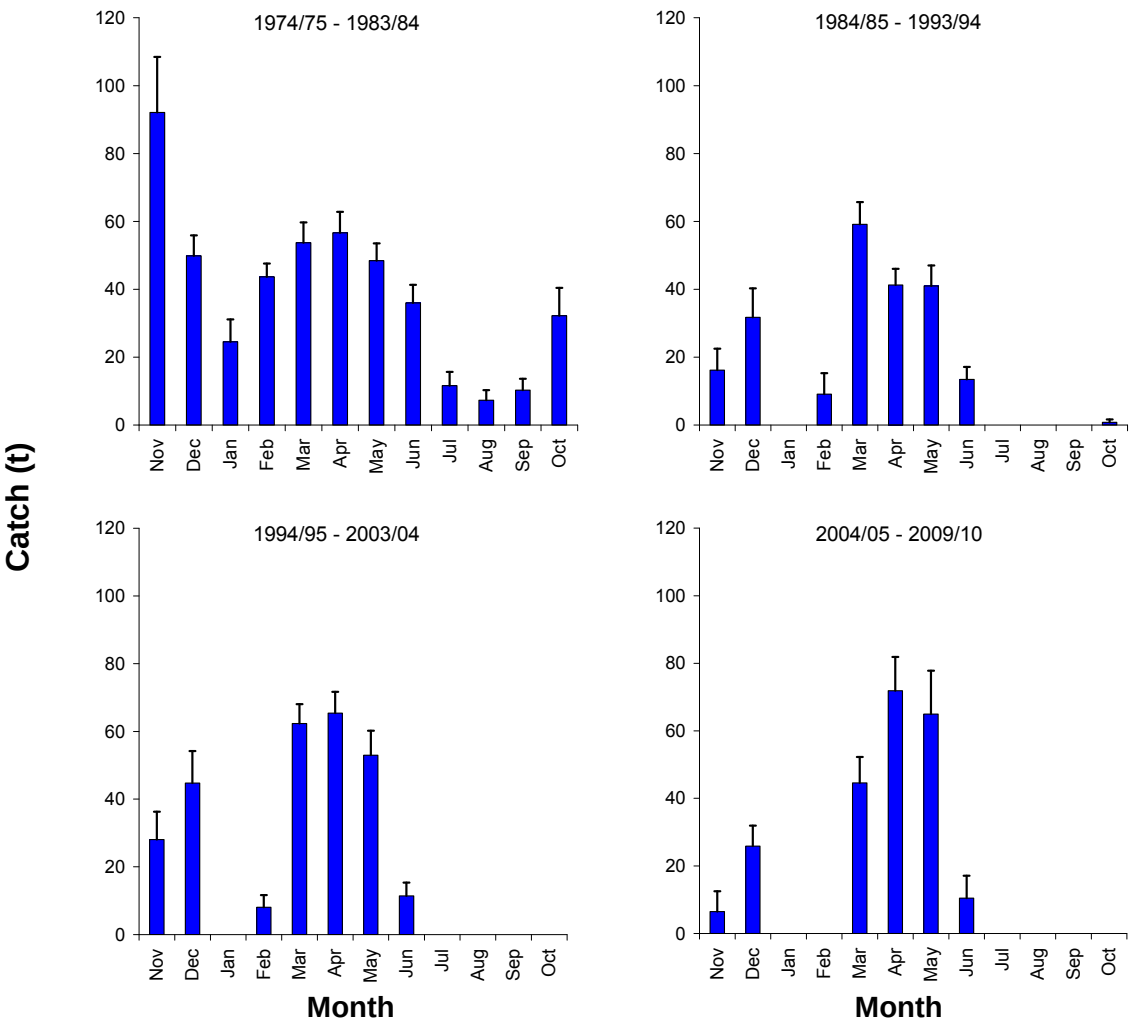


Figure 2.2 Average monthly catches from GSV for 10-year periods from 1974/75–2003/04 and for the six fishing-years from 2004/05 to 2009/10. Note: 1984/85–1993/94 includes the 2-year closure period.

2.3.3 Catches during the spawning season

During 2008/09 and 2009/10, totals of 39.7 and 34.0 t (which includes 2.6 and 3.2 t of survey catch), respectively, were harvested during the early spawning period of each year. This represents 14 and 15% of the annual catch, respectively. Importantly, the total and proportion of prawns harvested during the early spawning period in both 2008/09 and 2009/10 were lower than the historic average since 1973/74 (76 t, 24% of total catch).

From 1973/74 to 1981/82 catches from the early spawning period ranged between 72 and 138 t. During 1982/83 and 1983/84, totals of 287 and 241 t, respectively, were harvested during the early spawning period, representing >50% of the total catch during each of these fishing years. Total catch from the fishery declined substantially thereafter, from 455 t in 1983/84 to 241 t the following year. From 1984/85 to 1989/90 catches from the early spawning period ranged between 45 and 75 t (mean 63 t). From 1990/91 to 1994/95 only 5 t in total was harvested during the early spawning period. From 1998/99 to 2001/02 catches during this period were >100 t each year, peaking at 126 t in 2000/01. Since 2003/04, catches during the early spawning period have ranged between 14 and 45 t (mean 29 t).

There were no obvious trends in catches taken during the late spawning period.

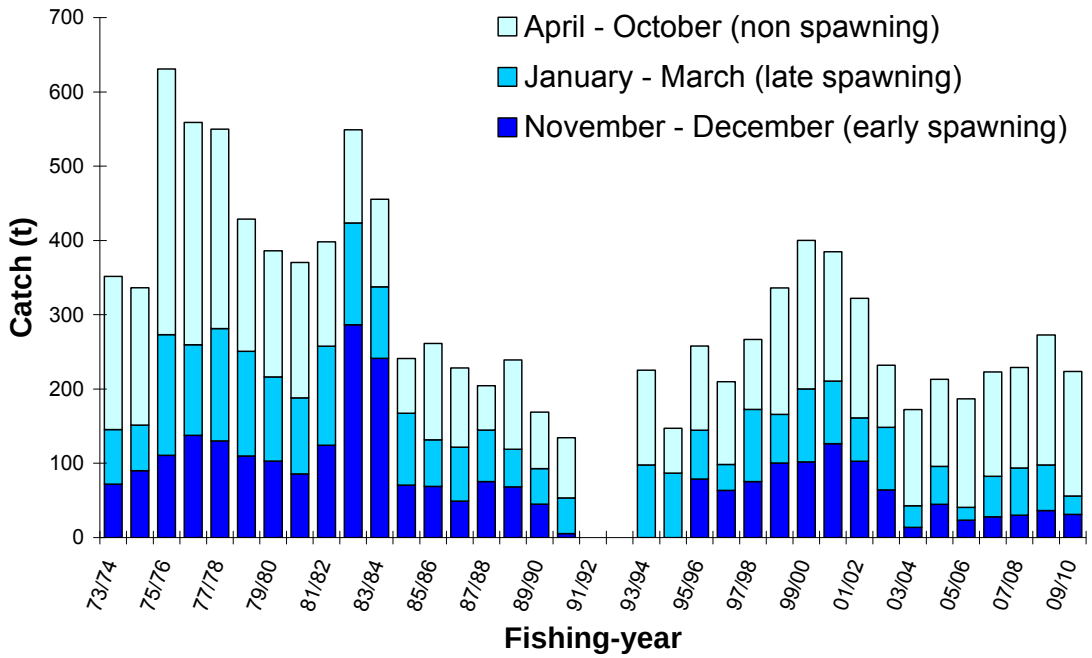


Figure 2.3 Catches (fishing & survey) from the early (November - December), late (January - March) and non-spawning (April - October) periods relative to the total annual catch from 1973/74 to 2009/10 in GSV.

2.3.4 Spatial distribution of effort from 1993/94 to 2009/10

From 1993/94 to 2003/04, trawl effort was distributed among more reporting blocks than for the subsequent period 2004/05 to 2009/10 (Figure 2.4). While this is particularly the case for reporting blocks with "low" levels of effort (<10 h per year), which reflects the differences in searching patterns among these two time periods, it should be noted that the average number of reporting blocks fished at "high" effort (>10 h per year) was much higher during the first 11 years (mean 34 blocks) compared to the last six years (mean 24 blocks). The number of reporting blocks fished at high effort has also declined since 2005/06 despite increases in total catch.

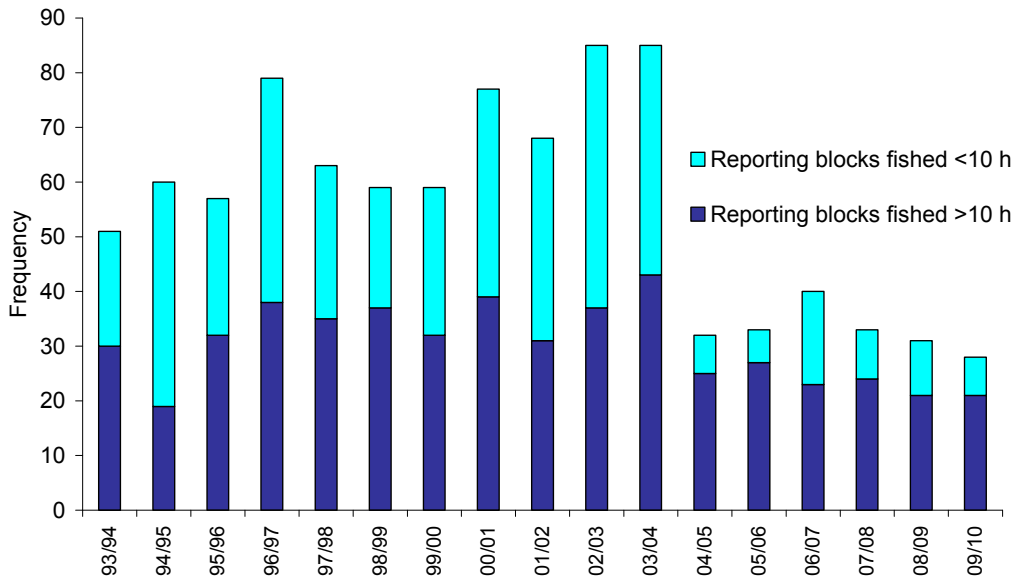


Figure 2.4 The number of reporting blocks fished from 1993/94–2009/10.

2.3.5 Seasonal distribution of effort from 1992/93 to 2009/10

Within season effort distribution has changed substantially in the 18 years post-closure. Generally, most of the change has occurred in the last six years, which reflects the period that harvest strategies have been developed using data from fishery-independent surveys. However, there also appears to be a consecutive shift in effort to fishing blocks further south between each of the three six-year time-periods for both the November/December and February/March harvest periods (Figures 2.5 and 2.6). Differences in the patterns of effort distribution are less obvious for April to June (Figure 2.7), however there was a notable increase in effort in blocks 39, 40 and 41 (adjacent to Troubridge Island) in recent years. The trends in effort distribution from November to March over time may reflect 1) different harvest strategy approaches, particularly closeness to home port (Port Adelaide) or 2) differences in the distribution and abundance of prawns.

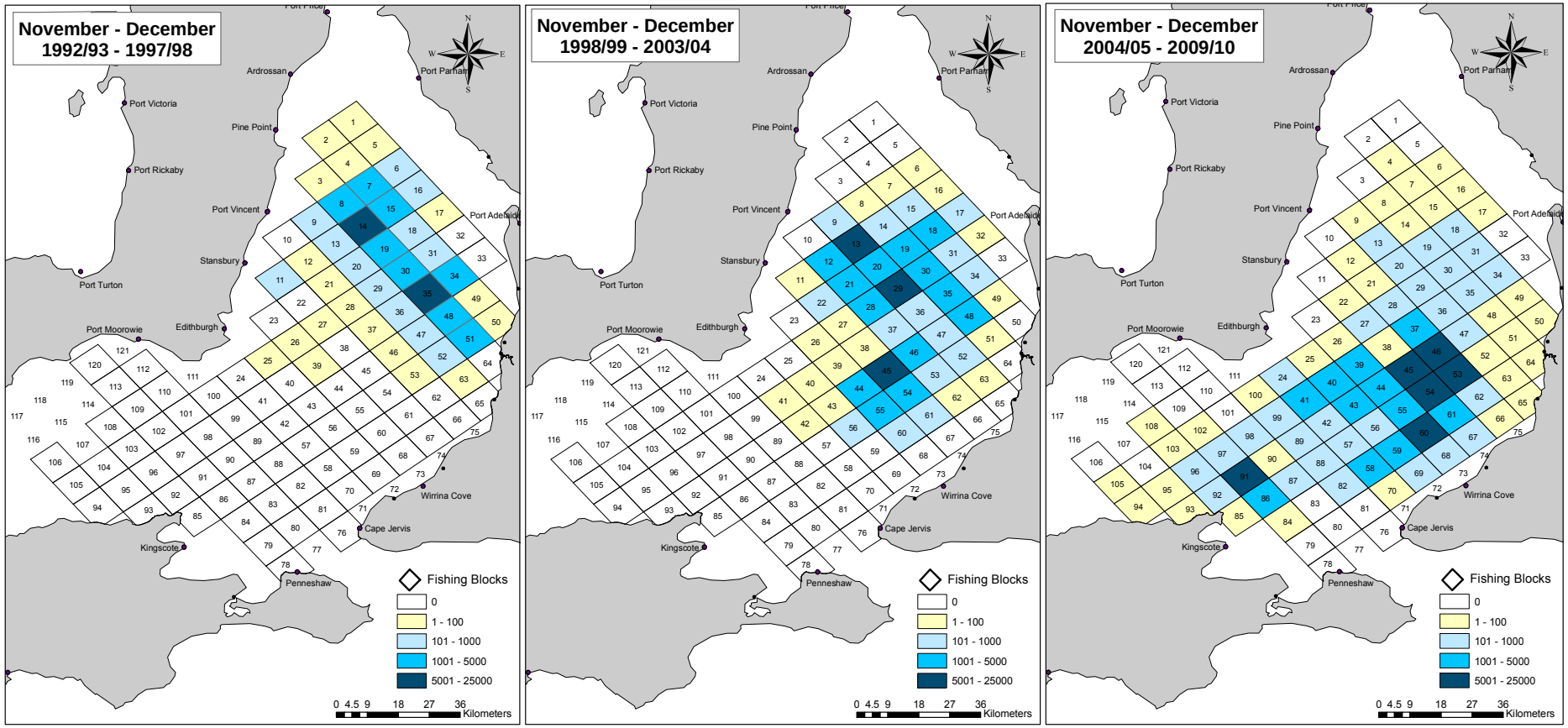


Figure 2.5 Fishing effort (average trawl hours per block) for the November and December fishing periods after the closure for six-year periods from 1992/93.

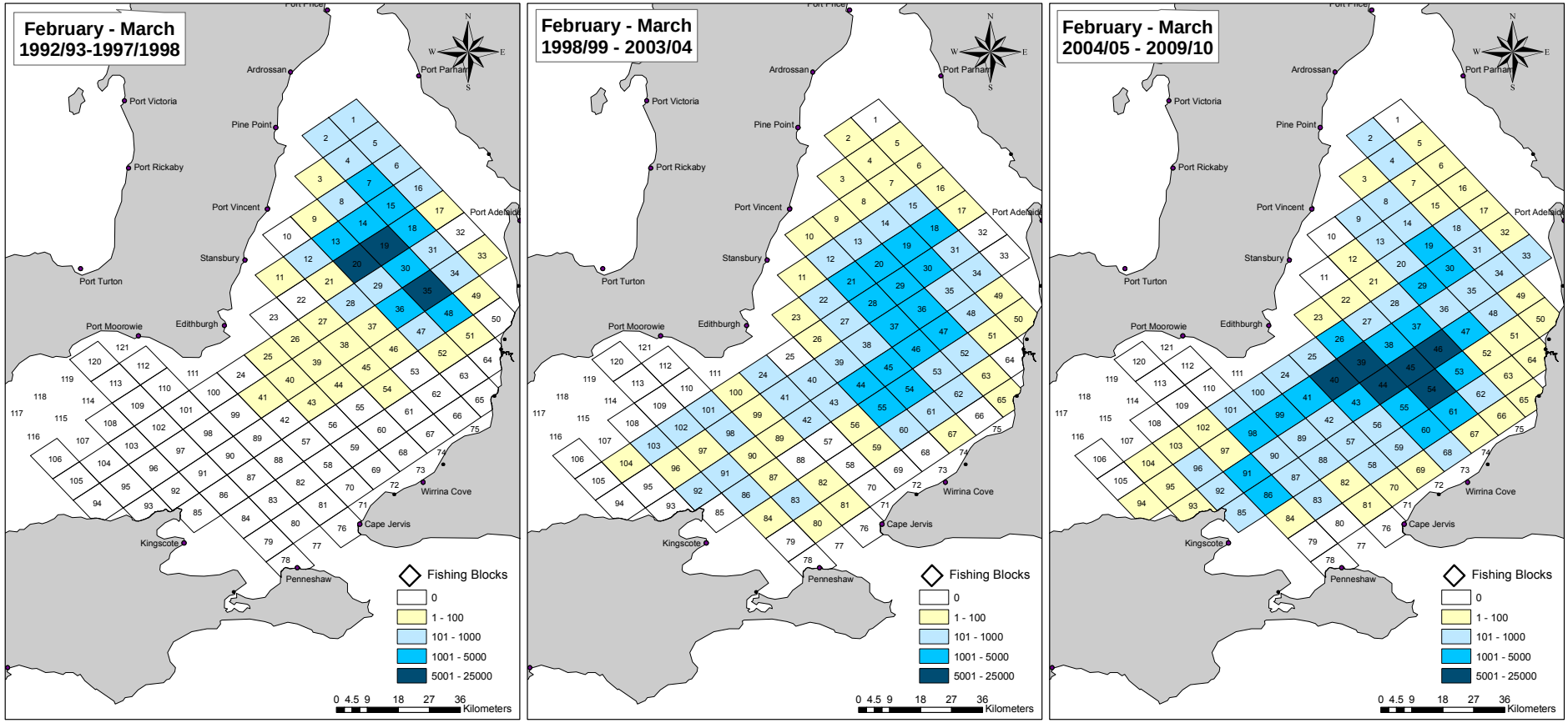


Figure 2.6 Fishing effort (average trawl hours per block) for the February and March fishing periods after the closure for six-year periods from 1992/93.

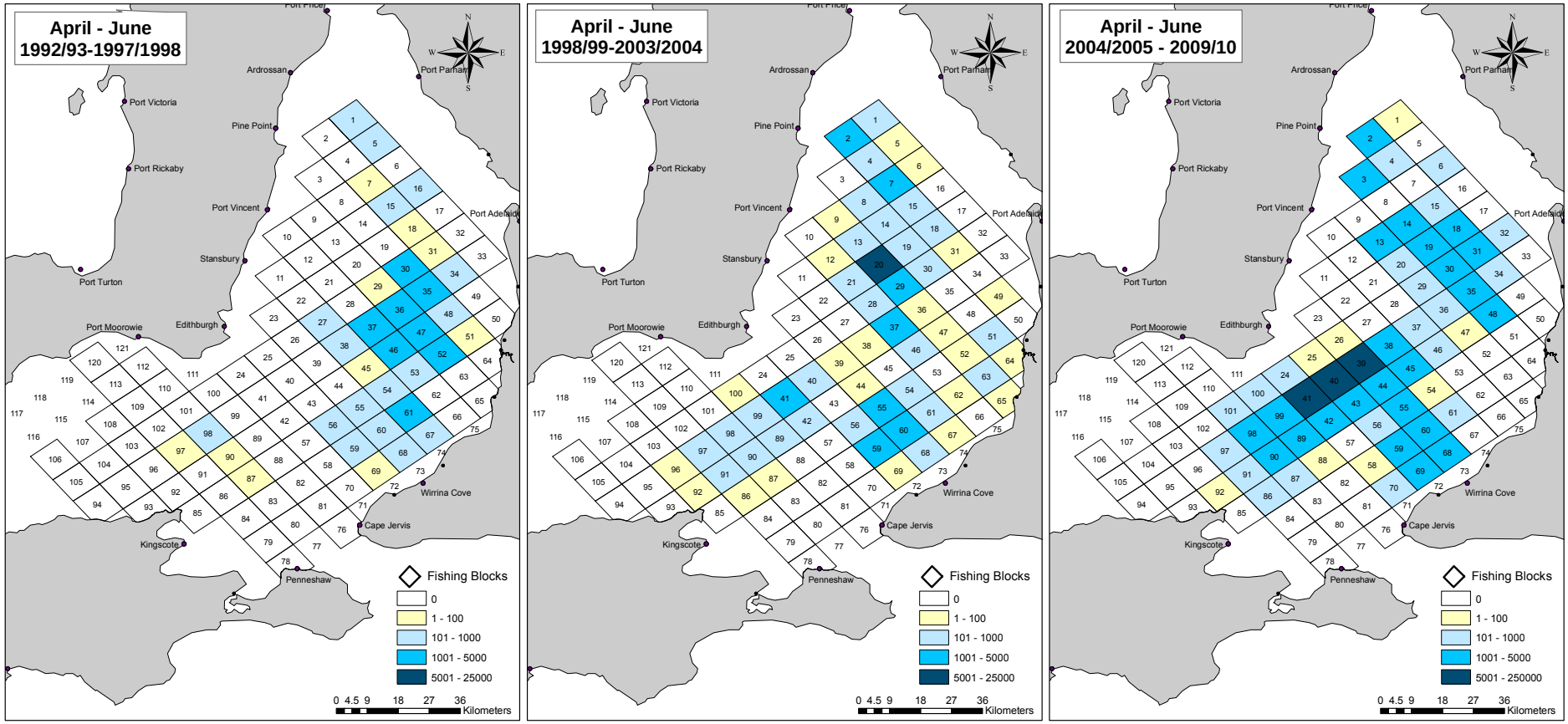


Figure 2.7 Fishing effort (average trawl hours per block) for the April to June fishing periods after the closure for six-year periods from 1992/93.

2.4 Inter-annual catch-per-unit-effort (CPUE)

Annual estimates of CPUE in 2008/09 and 2009/10 were 113.1 and 93.2 kg/h, respectively (Figure 2.8) with the former being the highest CPUE recorded for this fishery. The large increase in CPUE observed from 2005/06 to 2008/09 and the substantial decrease in CPUE between 2008/09 and 2009/10 are likely to be reflective of an increase and decrease in biomass during this period.

Annual CPUE has varied considerably since the inception of the fishery (Figure 2.8). During the first catch period (1969 to 1990/91), CPUE ranged from 18.8 to 43.2 kg/h (mean 32.5 kg/h). From 1976/77 to 1979/80, CPUE decreased from 40.2 kg/h to 18.8 kg/h, following trends in catch. CPUE and catch then increased until 1982/83, at which point gear efficiency increased substantially as vessels were converted from single to triple rig. Thereafter, CPUE generally increased up to the closure period despite declining catches. In the second catch period (1993/94–2003/04), CPUE was higher, ranging from 61.2 to 109.0 kg/h (mean 79.2 kg/h). From 1996/97 to 2002/03, CPUE increased from 64.9 to 109.0 kg/h and then decreased again to 61.2 kg/h. These substantial fluctuations are likely to be reflective of changes in biomass during this period.

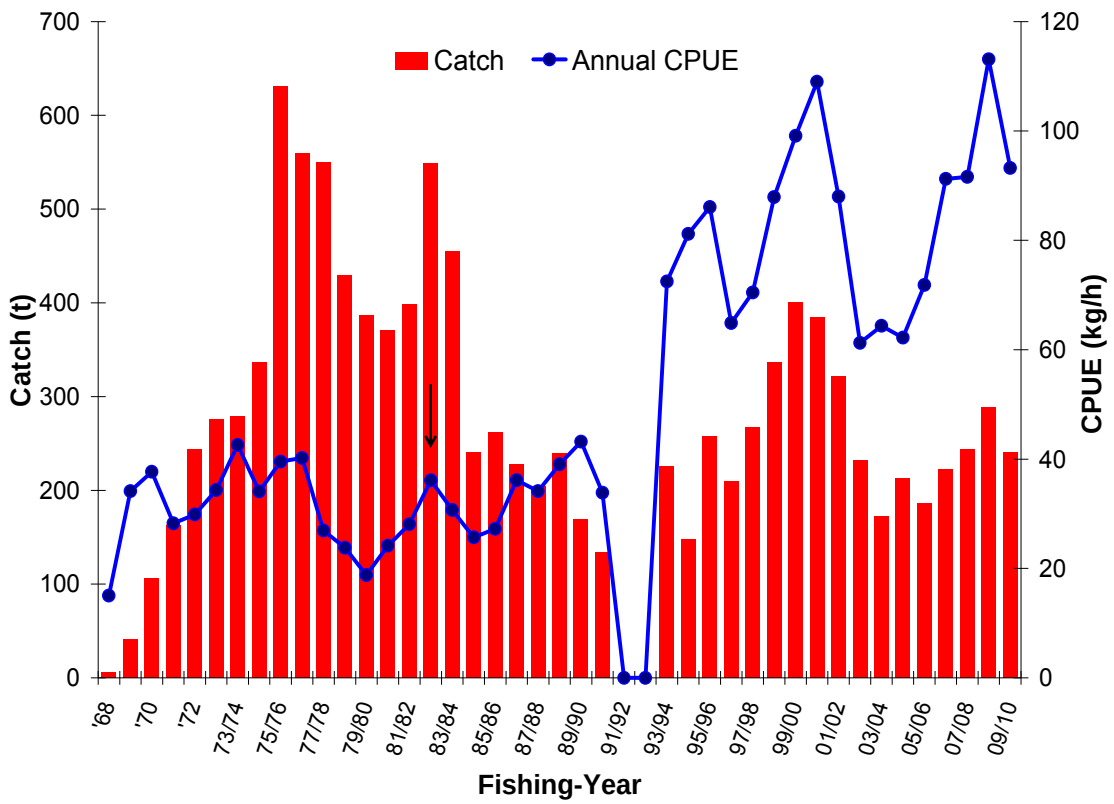


Figure 2.8 Annual catch and catch-per-unit-effort (CPUE) for GSV (fishing & survey) from 1968 to 2009/10. Data for 1968–1973 are reported as calendar year. Data for 1973/74 are from January 1974 to October 1974. From 1974/75 data are reported in fishing years. ↓ indicates introduction of triple-rig gear.

2.5 Searching effort

During 1993/94, searching effort was at its lowest (62 h) and represented only 2% of total trawl hours (Figure 2.9). Searching effort increased thereafter, peaking at 16% (603 h) in 2001/02. Whilst total searching effort then declined, the proportion of searching effort increased to 20% (531 h) in 2003/04.

The high proportion of searching effort, particularly from 2000/01 to 2003/04, represents a reduction in the abundance of target-sized prawns. The introduction of fishery-independent surveys in 2004/05 has effectively halved the searching effort for the fishery. This represents an approximate 10% reduction in nominal effort and a considerable economic efficiency. During 2008/09 and 2009/10, searching effort was <9% (242 h) of total trawl hours, a similar proportion to that in 1999/00.

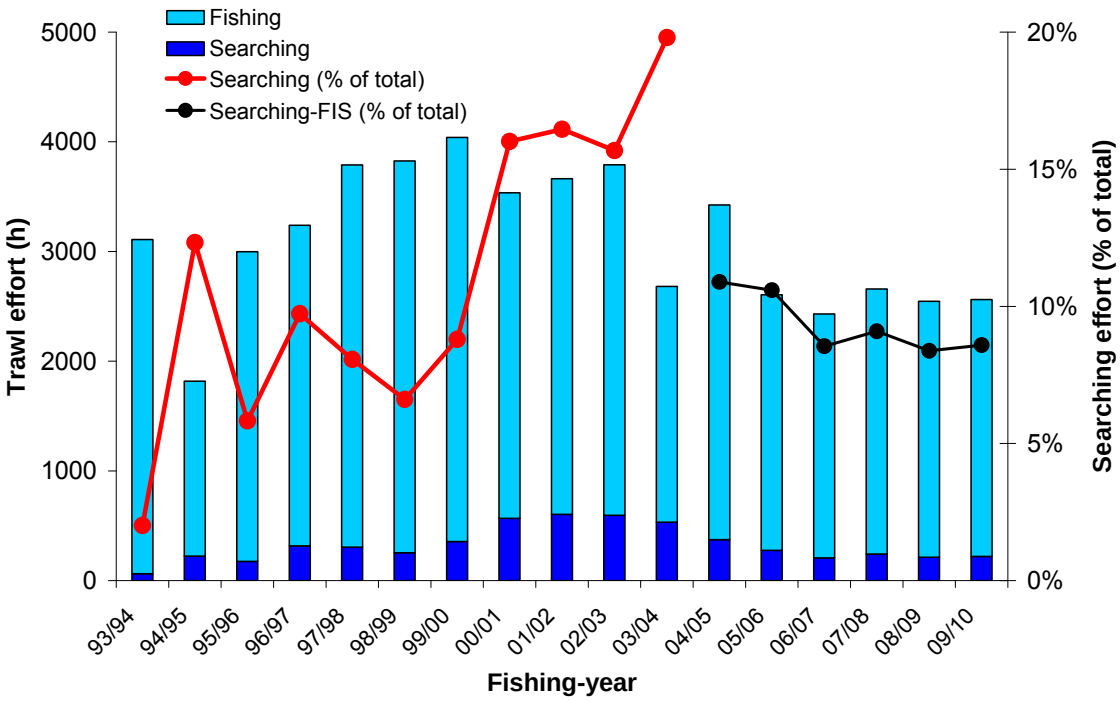


Figure 2.9 Fishing effort (light blue bars), searching effort (dark blue bars) and % of searching effort (line) from 1993/94 to 2009/10 in GSV. Note that searching effort from 2004/05 to 2009/10 represents effort done during fishery-independent surveys.

2.6 Prawn size

2.6.1 Inter-annual trends in prawn grades from 1993/94 to 2009/10

There are considerable differences in the size structure of the commercial catch in recent years compared to the period following the two-year closure. From 1993/94 to 2003/04, the proportion of prawns of size grade U10 and larger ranged from 32–51% (mean 42%). From 2006/07 to 2009/10, this proportion has sequentially declined from 35–23%. The commercial sizes harvested in 2006/07, 2007/08 and 2008/09 when the current harvest strategy approach was in its third, fourth and fifth year were similar to that harvested during 2003/04, the contemporary low catch year (172 t) at the end of a four-year decline. Clearly, most of the change in the size structure of the commercial catch has occurred in the 2009/10 season (Figure 2.10).

It is noteworthy that the size structure of the commercial catch in GSV in 2009/10 was very similar to that harvested in Spencer Gulf during 2009/10, where 17% were U10>, 47% 10–15, 33% 16–20 and 4% were 21+ (Hooper *et al.* 2010).

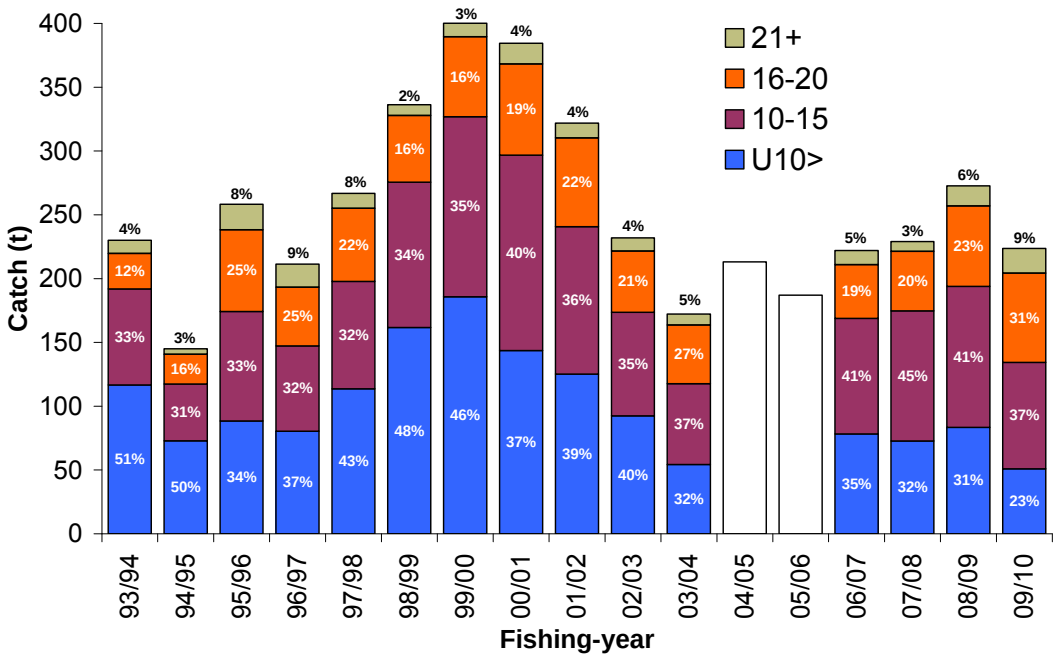


Figure 2.10 Estimated grade weights of the commercial catch from 1993/94 to 2009/10. Labels indicate the proportion by grade. Data were not available for 2004/05 and 2005/06.

2.6.2 Mean daily prawn size per vessel

In December, prawn size was generally within the target range in all years except 2009/10 when prawns of mean size smaller than 33 prawns per kg were caught on 60% of vessel nights (Figure 2.11). In March, target-size prawns were caught on most nights during 2005/06 (83%) and 2008/09 (65%) but rarely during 2006/07

(21%) and 2007/08 (31%) and not at all during 2009/10. Target-size prawns were generally caught on most nights during April from 2005/06 to 2007/08, however during 2008/09 and 2009/10 they were only caught on 17 and 18% of vessels nights, respectively. While the proportion of nights when the target-size was achieved in May has generally decreased over time, target-size criteria were met on at least 50% of nights in all years except 2009/10, when it was achieved on 20% of all vessel nights.

The proportion of catch harvested during nights that were outside of target-size criteria generally increased over time (Figure 2.12). Of concern, a high proportion of the total catch was harvested during nights when target-size criteria were not met, particularly from April 2009 onward. It must be noted that during April and May 2010 the target criteria was relaxed to <30 prawns per kg, in combination with more conservative exploitation rates, to enable some fishing to take place prior to review of the harvest strategy in the Management Plan (Alice Fistr, PIRSA, pers comm.).

Of concern, interrogation of the data on mean prawn size and catch weight identified ten occasions during the past two fishing years where catches of 1–2 t per vessel night were harvested at mean daily sizes 37–41 prawns per kg. These high catches of very small prawns suggest that the rules governing the committee at sea which encourage movement away from areas of small prawns were often ignored.

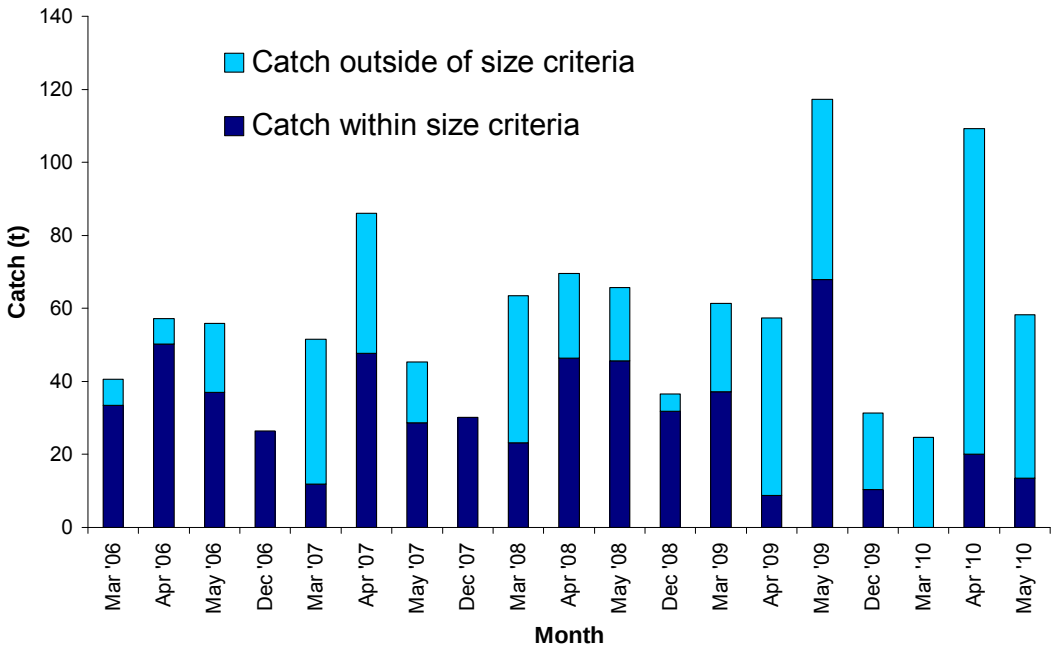


Figure 2.12 The estimated catch of prawns during nights when vessel catches were either within or outside of the size criteria from 2005/06 to 2009/10. The size criteria during December is considered as prawns smaller than 33 prawns per kg. All other months the size criteria is 28 prawns per kg.

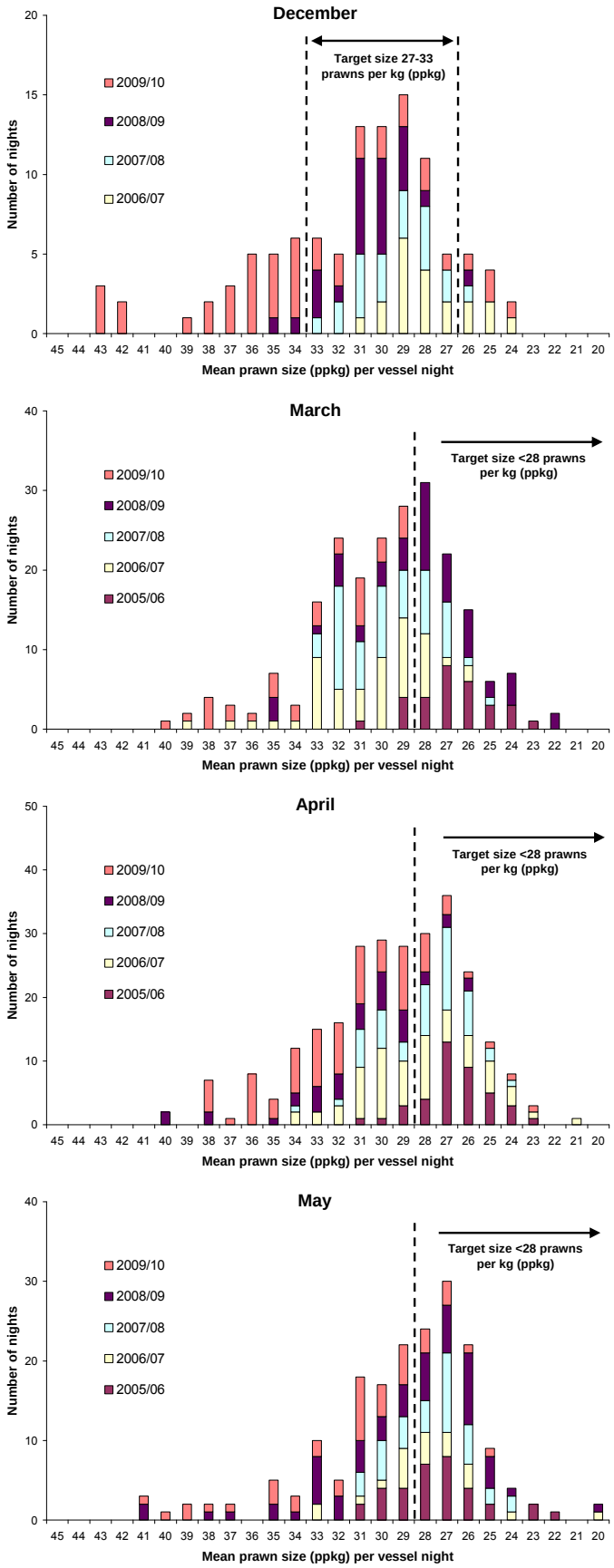


Figure 2.11 Mean daily prawn size estimated from prawn grade data provided in commercial logbooks for the December, March, April and May harvest periods from 2005/06 to 2009/10.

2.7 Discussion

Commercial logbook data provide valuable information on catch, effort, CPUE and harvested prawn size to aid assessment of recent trends in prawn biomass. These data indicate that the stock has undergone considerable recovery since the low commercial catch in 2003/04 as evidenced by increases in commercial catch and CPUE from 2004/05 to 2008/09. The introduction of fishery-independent surveys to determine harvest strategies during this period has increased the efficiency of fishing effort and decreased the area fished. Indeed, the targeting of large prawns from survey data may have been too effective and contributed to or resulted in the recent decline in commercial catch, CPUE and prawn size observed in 2009/10.

Total catch increased consecutively from 187 t in 2005/06 to 288 t in 2008/09. CPUE increased similarly during the same period and reached a historical high in 2008/09 (113 kg/h). However, during 2009/10 both commercial catch and CPUE decreased back to the levels observed during 2007/08. While CPUE data are affected by a number of factors including gear types, season, location and environmental conditions, large differences in CPUE over short time periods such as these are considered indicative of changes in biomass if differences in gear types, harvest strategies and environmental conditions are minimal.

The timing of harvest is an important consideration for South Australia's temperate prawn fisheries. Since 2003/04, catches during the early spawning period (November and December) have remained low in an historical context (<40 t per year) with the aim of maintaining egg production. This approach has likely contributed to the stock recovery observed in recent years. In contrast, the harvest of relatively large catches in March throughout the history of GSV, including recent years, does not make biological sense as growth rates are highest during April and May. The limitation of catches during March would seem a sensible approach during the period of stock recovery particularly given the difficulties in harvesting prawns of an appropriate size that has occurred during March in recent years (see Section 4).

Fishery-independent surveys have reduced the amount of searching effort required for the fishery. Until 2004/05, harvest strategies were based on fishery-dependent, searching surveys with searching effort increasing from 62 hrs in 1993/94 to 603 hrs in 2001/02. The new approach has halved the proportion of searching versus fishing effort, resulting in a substantial increase in efficiency for the fleet. This efficient

approach has resulted in a reduction in the number of reporting blocks fished in recent years despite increases in total catch. Also, spatial analyses indicate that the distribution of fishing effort has moved further south since the closure, particularly in November/ December and February/ March. It is not known if the observed patterns in effort are the result of differences in harvest strategy or the spatial distribution of the prawn population. The effects of 1) a reduction in the total area fished and 2) changes in the distribution of fishing effort, on the biomass and fishery are poorly understood.

On-board observer (1993/94 to 2003/04) and commercial prawn grade data (2006/07 to 2009/10) provide useful information on the size structure of the commercial catch following the closure. Prior to 2003/04, large prawns (prawn grade U10 and larger) regularly comprised 40–50% of the commercial catch. This reduced to 32% in 2003/04 when the fishery reached a contemporary low catch (172 t) at the end of a four-year decline. Grade data from commercial logbooks indicate that the proportion of U10's in the catch slowly declined from 2006/07 to 2008/09 but was considerably lower in 2009/10 (23%). Although the decline in both total catch and proportion of catch for the U10 and larger grades suggests that too many large prawns were harvested in recent years, this does not infer recruitment overfishing which by definition is overfishing of the spawning biomass to a level that is incapable of producing sustainable levels of recruitment.

The higher proportions of U10's and the higher total catches observed in the late 1990's may be explained by two hypotheses: 1) the total biomass of prawns post-closure was substantially higher than the current biomass; and/or 2) the size structure of the population in the 1990's comprised a high proportion of large prawns with relatively lower levels of recruitment. Without comparable fishery-independent survey data it is difficult to assess the relative biomass of prawns between the two periods. However, given their short life span (~4 years) and rapid growth rates during warmer months, it seems likely that after the two-year closure the size structure of the population shifted to one with a higher proportion of large prawns. It is noteworthy that the grade composition remained the same during the first three years of decline (2000/01 to 2002/03) which may suggest that the decline in the biomass of large prawns was not associated with a concurrent increase in the abundance of recruits.

Although no commercial grade data were available for 2004/05 and 2005/06, the commercial catch composition was similar in 2003/04 to that harvested from 2006/07

to 2008/09. While there was a clear decline in the proportion of large prawns in 2009/10, there was also a concurrent increase in the proportion of very small prawns harvested. These trends are likely to be reflective of growth overfishing, which is defined as the harvesting of animals at a size that is smaller than the size that would produce the maximum yield per recruit. Section 4 will demonstrate this in greater detail through a series of maps and figures at various spatial and temporal scales for the 2008/09 and 2009/10 fishing years.

3. FISHERY-INDEPENDENT SURVEYS

3.1 Introduction

Fishery-independent surveys utilising a consistent and rigorous methodology have been conducted since December 2004, providing an ongoing dataset for aiding assessment of the status of the GSVPF. This chapter provides analyses that document trends in relative biomass (catch rate), egg production, recruitment, sex-ratio and water temperature from 2004/05 to 2009/10. Statistical analyses are used to determine whether the stock is significantly different from 2004/05 when an objective of stock recovery was agreed. Analyses from previous reports of historical fishery-independent survey datasets are provided in the Appendices. Small-boat surveys without independent observers conducted since 2004/05 were not considered in this section (with the exception of May surveys from 2005–2008 as described in the methods).

3.2 Methods

Surveys using large commercial vessels with fishery-independent observers on-board, were conducted in GSV prior to the December, March, April and May harvest periods from 2004/05 to 2009/10. Each survey generally took two nights to complete and was conducted on the second and third nights after the last quarter of the moon, except for May 2005 to 2008 which were done during one night on the dark of the moon with large and small vessels to ensure consistency with previous May surveys (see Appendix 8.4). The effect of the difference in lunar phase between May surveys and other months was ignored in analyses and thus results pertaining to May should be interpreted cautiously. Up to 112 stations were surveyed on each occasion with 105 of these surveyed on at least 20 of the 24 survey occasions since December 2004/05. The consistent spatial and temporal replication enabled valid comparison among months and regions.

Survey shots were done at semi-fixed sites (Figure 3.1). Each shot began close to a known location (later fixed by Global Positioning System, GPS) and then continued in a specific direction for a specified period of time (usually 30 minutes). The distance trawled depended on trawl speed, which was influenced by vessel power, tide and weather conditions. The data collected during surveys included total catch, trawl time and distance, catch weight by prawn grade, sex-specific length-frequency, sex ratio, prawns per kg from a bucket count and water temperature.

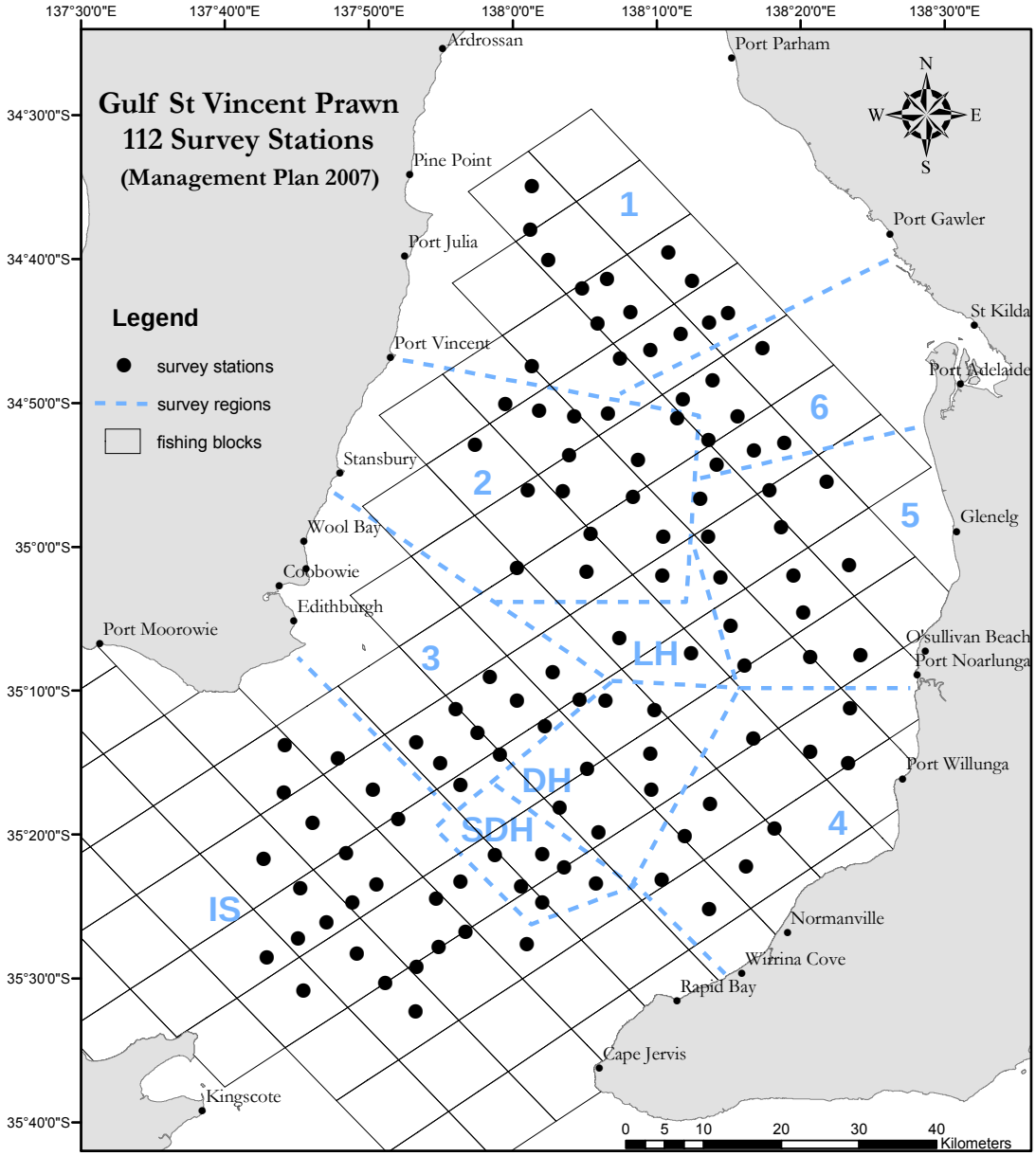


Figure 3.1 Survey stations, regions and fishing blocks of the GSV Prawn Fishery

For statistical analyses, ANOVA and Tukey post-hoc tests were used to test for differences at various temporal scales. Homoscedasticity and normality of the data were determined by Levene's test and visually assessing residual plots. Where necessary, $\log_{10}$ (n + 10) transformations of data were employed to ensure homogeneity of variances. In all cases, significance was accepted at $P<0.05$. Data analyses were performed using SPSS software (SPSS, version 18.0) and values are presented as mean ± standard error (SE).

3.2.1 Relative biomass

Mean survey catch rate was used as a measure for relative biomass in the fishery. As with CPUE data, there are several sources of uncertainty in the interpretation of survey catch rates including: differences in gear efficiency such as vessel power and gear configuration; the effect of the environment on catchability (e.g. water temperature); and, the assumption that surveyed sites are representative of the population. While not included explicitly in analysis of relative biomass, where possible these factors have been considered individually to inform assessment.

Survey catch rate was measured as the mean total catch rate (lb/min) for all nets fished, across all stations surveyed each fishing year as stipulated in the Management Plan. Survey catch rate was also broken down to the mean catch rate for three different prawn size classes: grade U10 and larger (referred to hereafter as large prawns), grades 10/15 and 16/20 (referred to hereafter as 10/20 or mixed prawns) and grade 20+ and smaller (referred to hereafter as small prawns). The calculation of catch rate by size class was achieved by 1) determining the abundance of prawns by sex in each size class from length frequency data (large >45 mm CL, mixed 35–45 mm, small <35 mm) 2) calculating the theoretical weight of prawns in each size class based on the sex-specific length-weight relationship (Section 1.4.6), and 3) applying the fraction of the theoretical weight in each size class to the estimate of total mean survey catch rate.

The use of mean catch rate from consistent survey stations to determine trends in relative biomass relies on the assumption that survey stations are representative of the biomass within the surveyed area. While survey stations are distributed throughout the main fishing grounds of the GSV Prawn Fishery, some are clustered closely together and others more disparate (Figure 3.1). To assess potential bias associated with spatial clustering, we calculated mean survey catch rate using fishing blocks as a spatial unit. A simple approach was undertaken, with the 105 consistent survey stations allocated to a single reporting block based on visual assessment of GPS data of the start and finish location. If the station crossed the boundary between reporting blocks, the assignment was made based on the relative proportion of the trawl distance within each block. As blocks were the same shape and size (Figure 3.1), each block was considered an equal unit. The 105 consistent stations fell within 62 reporting blocks, with the number of stations per block ranging from one to four. The mean monthly catch rate for each block was calculated as the mean of the stations within each block (i.e. up to four stations). The annual mean survey catch

rate was then calculated as the mean catch rate across all reporting blocks each month.

We also compared mean catch rates for all surveyed stations each year (up to 447 stations per year), as opposed to consistent stations only (up to 417 stations per year). This latter comparison was done to evaluate the influence of the inclusion of a low number of variable survey stations on the measure of relative biomass.

3.2.2 Egg production

Egg production was estimated for each year from 2004 to 2009 using December survey data that included catch rate, weight of prawn grades and the proportion of females in the catch. Detail for the calculation of egg production is provided in Appendix 8.5. These estimates reflect the potential egg production of female prawns captured during December surveys, and are used as an additional performance measure in the Management Plan (see Section 5.8).

The egg production model uses the current understanding of the biology of *P. latisulcatus* (see Section 1.4). A current FRDC project aims to improve the understanding of the biology that underpins the egg production model. As such, there remains considerable uncertainty associated with the current outputs.

3.2.3 Recruitment index

A recruitment index was also calculated for each survey, defined as male prawns <33 mm CL and female prawns <35 mm CL according to the Management Plan. Recruitment index (recruits per hour trawl shot) was calculated for 96–105 consistent shots surveyed with available length-frequency data for each month from 2004/05–2009/10. It should be noted that the use of square mesh cod-ends significantly reduces the abundance of recruit prawns in the catch (Broadhurst *et al.* 1999). The use of square mesh cod-ends by vessels during these surveys has not been documented and is not accounted for in these calculations. It is our understanding that whilst cod-end configurations may vary slightly among vessels, there have been few changes in mesh type for individual vessels during the survey period.

3.2.4 Sex-ratio

Sex-ratio was determined from length frequency data scaled up to a standardised 30 minute survey trawl. Thus the data presented represent the proportion of females within the surveyed population (assuming equal catchability).

3.2.5 Water temperature

The catch rate of prawns is affected by abiotic factors that include season, moon phase and water temperature (Penn, 1976; Hill, 1985; Penn *et al.*, 1988). It has previously been suggested that increasing water temperature positively affects catchability of *P. latisulcatus* in tropical fisheries (Penn, 1976; Penn *et al.*, 1988).

GSV is a relatively shallow embayment where waters are well mixed (Middleton & Bye, 2007). Bottom water temperature (BT) was recorded consistently during surveys in 2006/07 to 2009/10 by attaching data loggers (Sensus Ultra, by Reefnet ®) to the otter board of each survey vessel. Sea surface Temperature (SST) data were collected by observers on most large vessels during surveys in GSV from December 2004 to May 2010. BT and SST data are presented as an average of available data for each survey. Uncertainty in analyses of SST data includes variations among the thermometers used, the method of measurement, and the regional consistency of data collected.

3.3 Results

3.3.1 Relative biomass

Mean total survey catch rate differed significantly among seasons ($F_{5,2653}$=21.2, P<0.001), with an increase observed between 2004/05 (1.59 lb/min) and 2008/09 (2.67 lb/min) prior to a decrease in 2009/10 (2.34 lb/min) (Figure 3.2). While the total catch rate remains significantly higher than it was in 2004/05 and 2005/06, the total catch rate in 2009/10 does not differ significantly from 2006/07 to 2008/09.

The biomass of large prawns increased slightly but not significantly from 2004/05 to 2007/08 and declined thereafter. The biomass of large prawns in 2009/10 was significantly lower than all previous years. Trends in the biomass of mixed and small prawns were similar, with increases observed from 2004/05 to 2008/09 followed by decline in 2009/10. The biomass of mixed prawns was >50% of the total biomass during each survey.

Trends in catch rate among months and size classes were generally consistent with the exception of December surveys from 2004/05 to 2006/07, where declines in catch rate were apparent. Some caution must be applied to comparisons between May 2007/08 and 2008/09 as the timing of surveys was shifted during 2008/09.

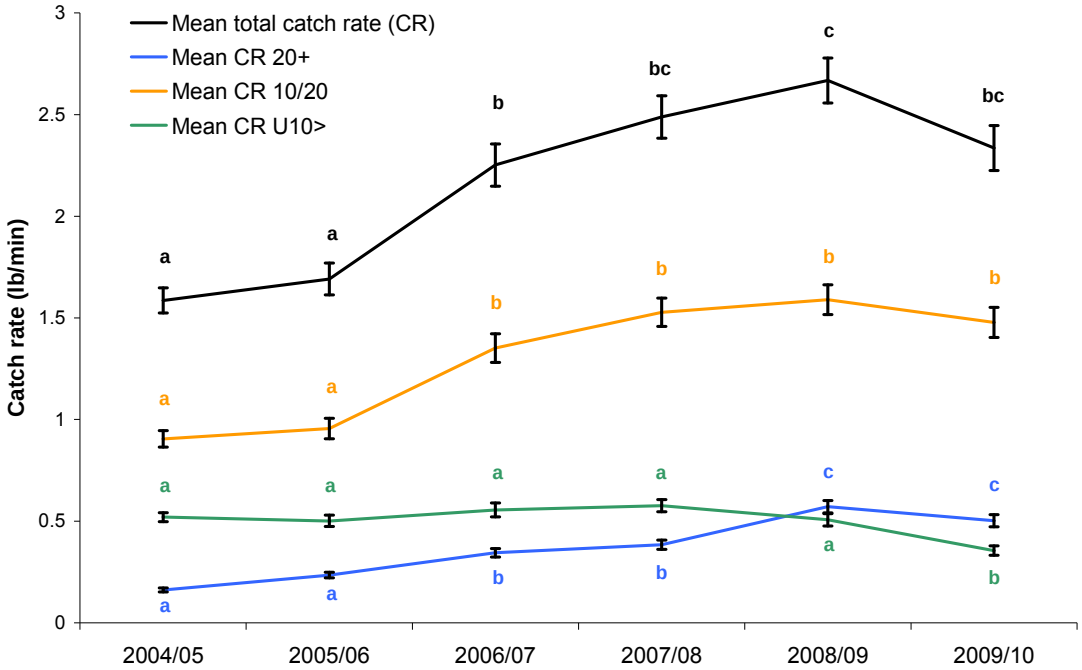


Figure 3.2 Mean total catch rate and mean catch rates of 20+, 10/20 and U10 and larger prawn grades, obtained from surveys conducted from 2004/05 to 2009/10. Letters identify significant differences among years.

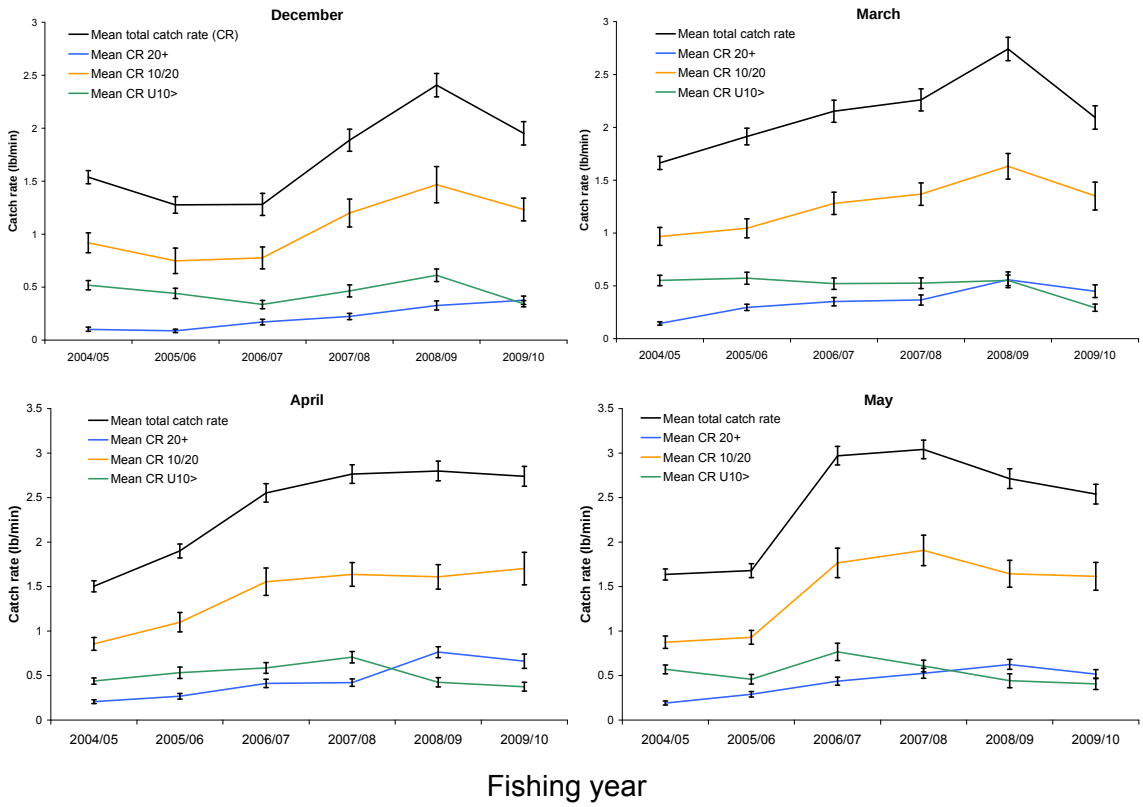


Figure 3.3 Mean total catch rate and mean catch rate of prawns grade 20+ and smaller, 10/20 and U10 and larger for each month surveyed from 2004/05 to 2009/10.

While there were some minor differences among the three approaches tested for measuring relative biomass, all methods showed similar trends over time (Figure 3.4). Further, there were no apparent trends in the differences among estimates. For example, estimates for the reporting block approach were lowest in 2007/08 and 2009/10, and highest in 2008/09. This simplistic approach ignores the variance within reporting blocks each month and thus standard errors for the reporting block data are indicative only. Despite this uncertainty, there was considerable overlap in standard errors among estimates for each year, suggesting that all three approaches for estimating relative biomass determining exploitation rates are appropriate.

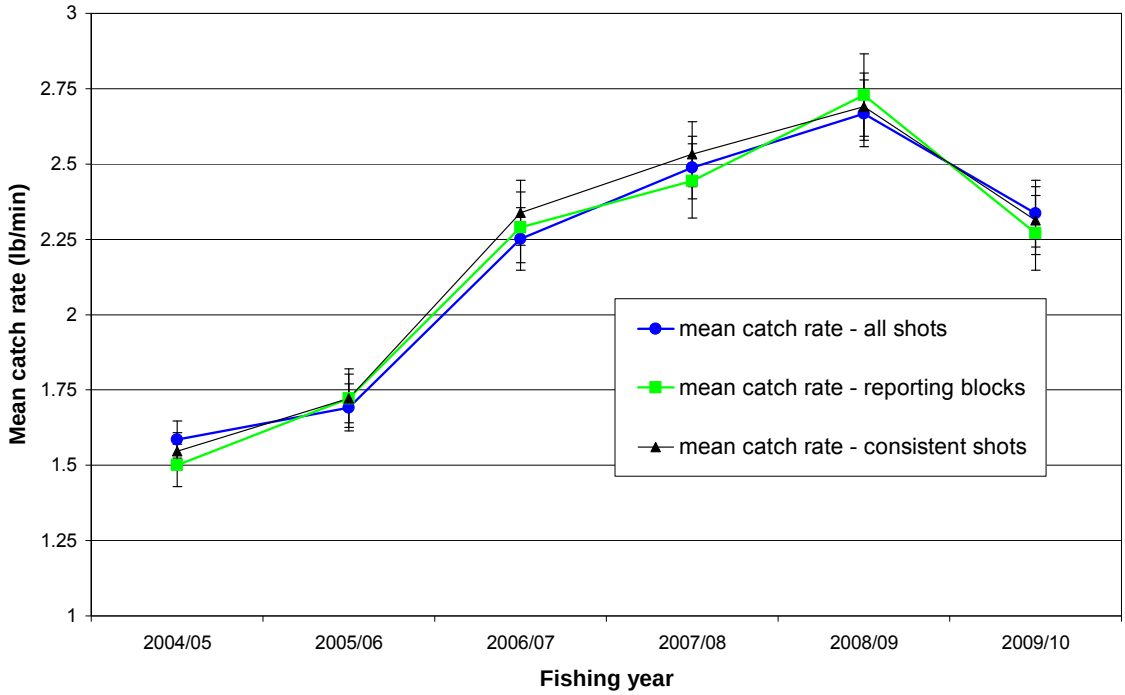


Figure 3.4 Results from three different approaches to estimating average relative biomass (± SE) from survey data; 1) mean of survey catch rate from all shots, 2) mean of survey catch rate from consistent shots and 3) mean of catch rates from reporting blocks.

3.3.2 Estimates of egg production

From 2004 to 2008 estimates of egg production ranged from 423 to 717 million eggs per hour (Figure 3.5). Egg production in 2009 was the lowest observed in the last six fishing years at 388 million eggs per trawl hour. Of particular concern, the reduction in abundance of U10 and U8 size prawns has led to a large decrease in total egg production.

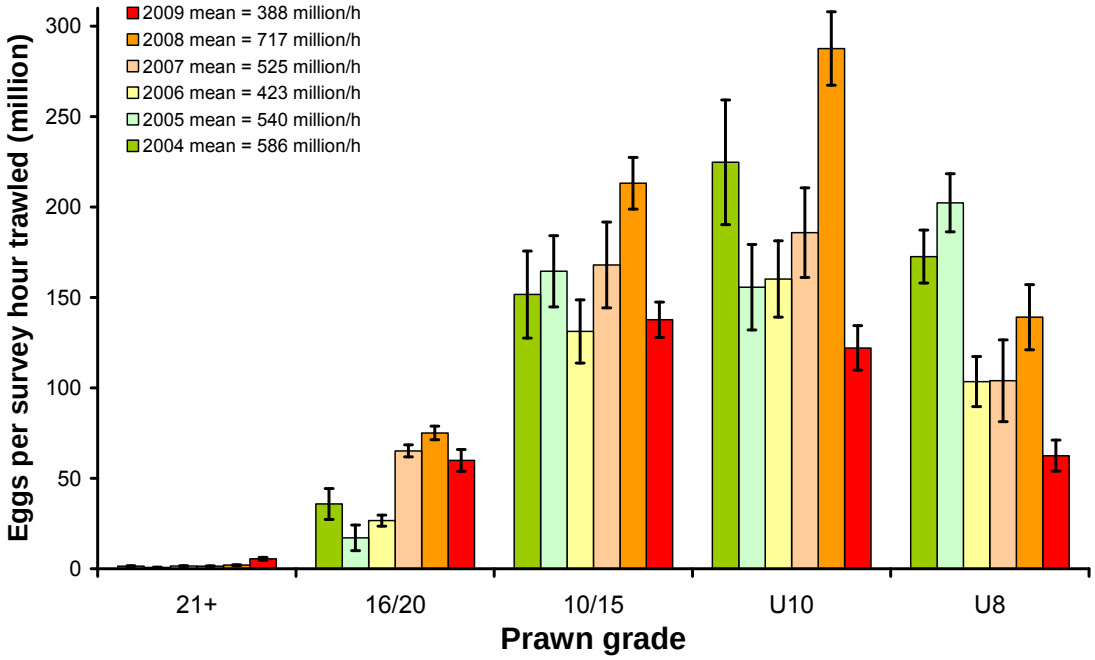


Figure 3.5 Mean (SE) number of fertilised eggs (million per trawl hour) produced by females captured during December surveys conducted from 2004 to 2009.

3.3.3 Trends in recruitment

Recruitment patterns followed similar trends to total mean survey catch rates (section 3.3.1) with general increases between 2004/05 and 2008/09 followed by a decline in 2009/10 (Figure 3.6). Recruitment was lowest in December in all years as overwintering juveniles are yet to reach the fishing grounds (see Carrick 1996). The timing of peak annual recruitment was variable, occurring in April during 2004/05, 2006/07, 2008/09 and 2009/10, in March during 2005/06 and in May during 2007/08. The timing of May surveys was moved from the dark of the moon to two nights after the last quarter in 2007/08, to ensure consistency among months. While this means there is uncertainty in comparisons between 2007/08 and 2008/09, the comparison with 2009/10 is valid.

3.3.4 Trends in sex-ratio

From 2004/05 to 2009/10 the proportion of females ranged from 45% to 51% (Figure 3.7). Although there were no apparent trends among months, there appeared to be a higher proportion of females in the population in all months during 2006/07. Subsequently, the proportion of females in the population has been generally stable.

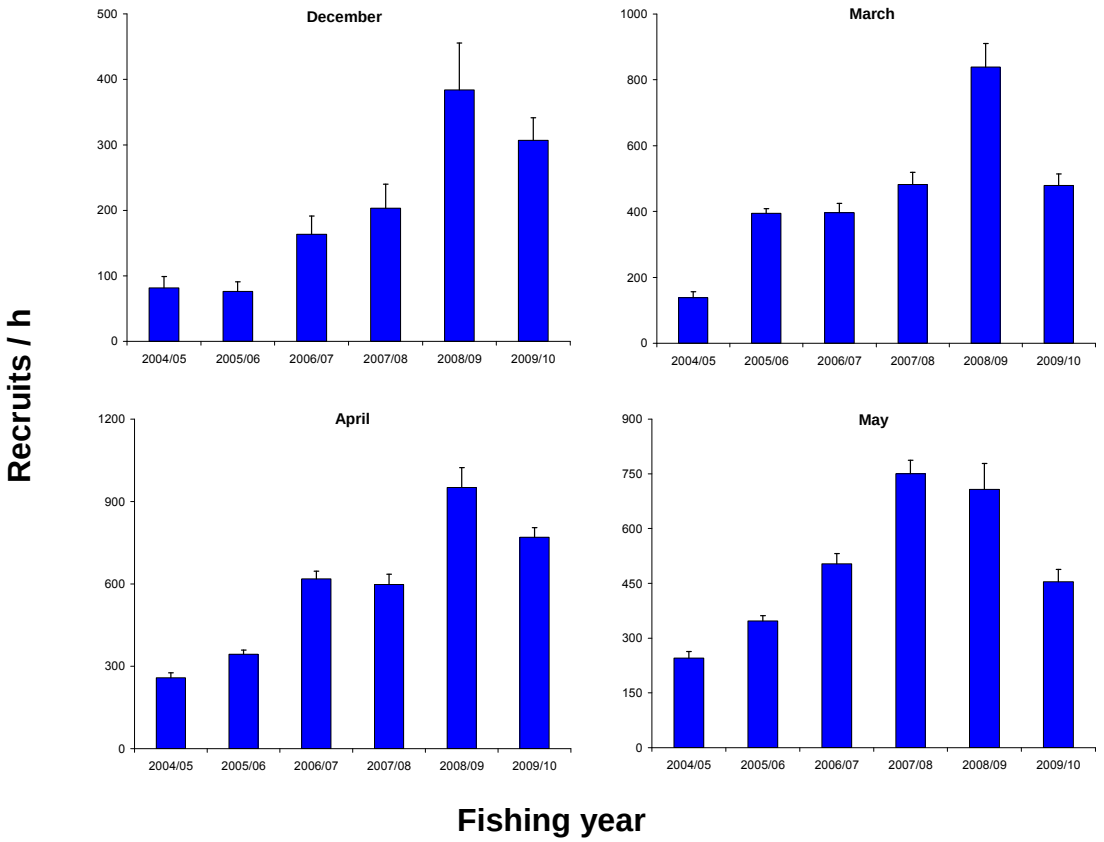


Figure 3.6 The mean (SE) number of recruits per trawl hour during surveys conducted between 2004/05 and 2009/10 during December and March to May. Note that May surveys were conducted on the dark of the moon from 2004/05 to 2007/08.

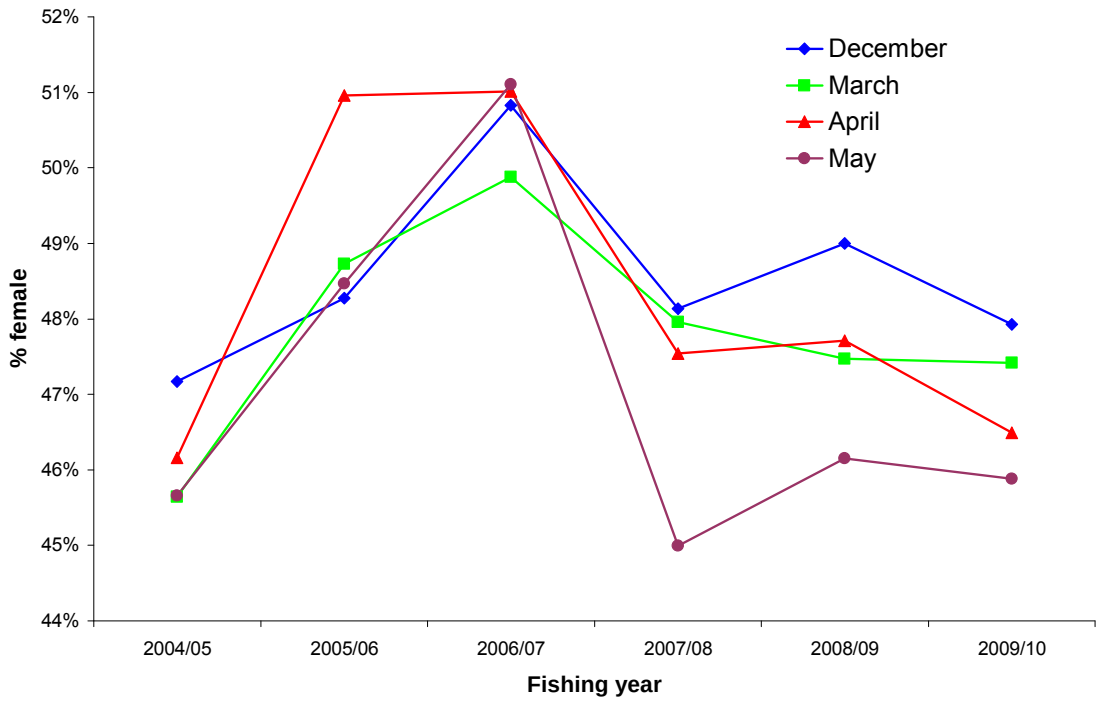


Figure 3.7 The proportion of females within the surveyed population for December, March, April and May 2004/05 to 2009/10.

3.3.5 Water temperature

Estimates of SST among years ranged from 17.3–18.8°C in November/December, 20.1–21.5°C in March, 17.7–20.5°C in April and 15.3–18.9°C in May (Table 3.1). BT data were similar to SST data on most occasions.

Although water temperature may influence catch rates to some degree, differences in water temperature do not detract from the general trends in relative biomass observed from 2004/05 to 2009/10. In particular, the relatively warm SST and bottom water temperatures observed in April and May 2009/10 do not explain the decline in biomass observed in 2009/10.

Closer examination of trends in relative biomass among months (Figure 3.3) suggests that it may be beneficial to include water temperature as covariate in future estimates of relative biomass. For example, the cold water observed in May 2005/06 (Table 3.1) coincides with a low estimate of relative biomass for that month when compared to the differences among years in March and April when water temperatures among years were similar.

Table 3.1 Mean (SE) sea surface temperature (°C) (SST) and bottom water temperature (BT) during surveys conducted between 2004/05 and 2009/10.

Source	Year	Nov/Dec	March	April	May
SST	2004/05	18.8 (0.5)	20.1 (0.3)	17.7 (1.0)	18.2 (0.4)
SST	2005/06	17.3 (0.2)	21.1 (0.3)	17.9 (0.3)	15.3 (0.3)
SST	2006/07	18.2 (0.2)	21.5 (0.3)	20.4 (0.3)	17.9 (-)
SST	2007/08	18.4 (0.2)	20.5 (0.3)	19.1 (0.3)	17.8 (0.3)
SST	2008/09	17.4	20.4	19.4	17.6
SST	2009/10	18.8	20.6	20.5	18.9
BT	2006/07	18.8 (0.1)	21.2 (0.1)	19.9 (0.0)	18.3 (0.0)
BT	2007/08	18.7 (0.1)	20.0 (0.1)	19.3 (0.0)	17.7 (0.0)
BT	2008/09	17.9 (0.1)	20.6 (0.0)	19.6 (0.0)	17.4(0.0)
BT	2009/10	18.9 (0.1)	20.5 (0.1)	20.3 (0.1)	18.6 (0.0)

3.4 Discussion

Fishery-independent surveys conducted between 2004/05 and 2009/10 at up to 112 stations provide a robust spatial and temporal assessment of the GSV prawn stock. Data suggest that the relative biomass of prawns in GSV is significantly higher now than in 2004/05 but the size structure of the population has become dominated by small and medium-sized prawns. Increases in recruitment have likely resulted from conservative fishing during the early spawning period. Recent reductions in the biomass of large prawns have likely resulted from overly effective targeting of the largest prawns when determining harvest areas. The decline in large prawns may compromise egg production in the short term and thus the rebuilding of the spawning biomass is an immediate priority for the fishery. Monitoring recruitment levels will also be an important consideration in determining appropriate harvest strategies for the next two years.

Mean catch rate from all survey shots is used as an index of relative total biomass for the fishery and is an integral component of the Management Plan to control exploitation. Relative total biomass increased substantially and significantly from 2004/05 to 2008/09 before declining in 2009/10. Relative total biomass was also split into three size categories: large, mixed and small prawns. Mixed prawns comprised >50% of the total biomass for all surveys. The biomass of large prawns did not differ from 2004/05 to 2008/09, but declined significantly in 2009/10. The biomass of small prawns has increased considerably and now represents >20% of the total biomass for the fishery. Trends in relative biomass were generally consistent among months and size categories with the exception of December surveys in 2005/06 and 2006/07.

While the current harvest strategy links exploitation to total catch rate (i.e. relative total biomass), a more appropriate strategy would have been to link exploitation with the biomass of target-sized prawns (predominately large prawns in the current harvest strategy). If this was the case, the 13% decline in abundance of large prawns observed between 2007/08 and 2008/09 would have required a reduction in total catch. Instead, as the total relative biomass in this period increased, the commercial catch was increased by ~45 t. This may have prevented the decline of large prawns observed in the last two years. While the high biomass of mixed and small prawns indicates that the current status of the fishery is sustainable, the recent decline in biomass of large prawns requires immediate revision of the harvest strategy.

The importance of maintaining abundance of large prawns is best demonstrated by outputs from the egg production model. Despite higher total catch rates in 2009/10, the significant reduction in abundance of large prawns, particularly in the U8 size category, suggests that the potential egg production for the fishery is currently the lowest that it has been since fishery-independent surveys began. It is accepted that egg production estimates from December surveys are not an ideal predictor of egg production and hence recruitment because catch rates from December are a poor indicator of relative biomass. However, the decline in abundance of the large prawns was observed during recent surveys in March, April and May 2010, suggesting that the predicted decline in egg production is real. The slight decline in recruitment observed in 2009/10, combined with low egg production suggests that recruitment may decline further in the next couple of years.

There are several sources of uncertainty that affect the interpretation of survey data, some of which are assessed in this report. Firstly, as with the Spencer Gulf Prawn Fishery, surveys are conducted on a consistent moon phase to ensure that the effects of moonlight and tide are minimised among months and years. The key difference between gulfs is that Spencer Gulf surveys are conducted on the dark of the moon whereas GSV surveys are held two nights after the quarter so they can be used for both stock assessment and harvest strategy development. One uncertainty of the data collected in GSV regards the changing of May surveys from the dark of the moon to two nights after the quarter during 2008/09. While this may have affected interpretation of trends between 2007/08 and 2008/09, this does not affect the decline observed in 2009/10.

Secondly, there is uncertainty regarding how well survey stations represent the relative biomass of prawns in the Gulf. We consider that survey stations are representative of the biomass because: a) trends in survey catch rate are consistent among years across all survey months (other than December on some occasions); b) there are 112 survey stations distributed throughout the relatively smaller grounds of GSV compared to ~200 survey stations distributed throughout Spencer Gulf and; c) mapping of survey results shows broad distributions of prawns across several stations (see Section 4) rather than sporadic high/low catch rates that could be suggestive of random distributions. To further investigate these concerns, we conducted analyses on the impact of the spatial clustering of stations and the inclusion of up to seven ‘irregular’ stations per survey, on the trends in mean survey

catch rate. The results indicated that the general trend of recent decline in abundance and biomass did not change at these different spatial scales.

Water temperature also affects the catchability of prawns. Both bottom temperatures and SST have not varied greatly among recent years for each survey month, but notably water temperature was warmer in April and May 2009/10 than most previous years. Previous studies suggest that water temperature is positively correlated with catch rates of prawns (Penn, 1976; Penn *et al*., 1988) which suggests that external environmental factors are not likely to explain the decline in abundance and biomass observed in 2009/10.

The final concern regarding the interpretation of survey catch rates is the effect of changes in gear efficiency. While it is difficult to determine such changes without complex statistical analyses, a recent report for the Spencer Gulf Fishery (Dixon *et al.* 2010) suggested that long-term mean increases in survey catch rate of ~1% per annum were likely to have been caused by increases in gear efficiency. If this was also the case for the GSV survey vessels, current estimates of total mean survey catch rate would be inflated by ~5% compared to 2004/05, which would worsen the prognosis of recent decline. While the effect on harvest strategy measures that are determined between years is only small, it is suggested that a rule of thumb increase (e.g. 1%) per year be built into future harvest strategies.

4. ASSESSMENT OF HARVEST STRATEGIES

4.1 Introduction

This section provides an assessment of the effectiveness of 1) harvest strategy development (determining harvest areas) and 2) harvest strategy management 'at-sea', during each harvest period. Harvest strategy development (designating spatial harvest areas) is underpinned by fishery-independent survey data. The Management Plan provides measures for determining exploitation levels (December <30 t; March–May an area up to 18% of the observed biomass on the survey) and target prawn size (December: 27–33 prawns/kg; March–May: <28 prawns/kg). Harvest strategy management occurs during commercial fishing and is guided by 'at-sea' decision rules (target prawn size and minimum nightly catches). If prawns are harvested at sizes that do not reach target criteria for any fishing night, the "committee-at-sea" notify PIRSA the following morning and the area is either closed or harvest strategy boundaries are adjusted.

4.2 Methods

This section details fishery-independent and fishery-dependent data for the 2008/09 and 2009/10 fishing years summarised in 16 maps (two for each harvest period) and eight figures. The first map for each period presents survey information on catch rate and mean size collected prior to commercial fishing, from which the harvest strategy was developed (boundaries are shown on each map). The second map presents the resulting commercial catch and mean prawn size data by fishing block. Daily commercial catch per vessel and daily mean size are presented as a figure for each harvest period, assessed against the relevant criteria of the Management Plan.

Fishery-independent surveys were conducted during December, March, April and May in each of 2008/09 and 2009/10 (see Section 3). The start and end dates of the survey and the number of nights surveyed, are also presented. Fishery-dependent data on mean prawn size were determined from commercial logbooks following section 2.2.2. Only nine of ten licence holders agreed to provide access to confidential catch and effort information and thus the data from one licence holder was not included in calculations of mean size or total catch when less than five licence holders fished in a block. The start and end dates of the harvest period and the number of nights fished are presented on each commercial catch map. Note that commercial catch and size data are presented on occasion for blocks that appear outside the harvest strategy region. This has likely resulted from: 1) minor

discrepancies between the GPS systems used at sea and the software used to present these data, and/or 2) misreporting of blocks by fishers.

Both daily catch and prawn size are used as 'at-sea' decision rules for harvest strategy adjustment during commercial fishing. Decision rules for harvest period 1 are: 1) a maximum total catch of 30 t, 2) minimum average catch per vessel night of 350 kg over 2 consecutive nights and 3) target prawn size of 27–33 prawns/kg. Decision rules for harvest periods 2–4 (March to May) are: 1) minimum average catch per vessel night of 450 kg over 2 consecutive nights, and 2) target prawn size of <28 prawns/kg. Failure to achieve the target-size or catch for any night's fishing requires notification to PIRSA and adjustment of the harvest strategy (i.e. closing the harvest area or adjusting its boundaries).

All results in the following section are discussed in terms of the regions defined in Figure 3.1. Catch rates of <2 lb/min are referred to as "low", 2–4 lb/min as "medium", and >4 lb/min as "high". For the November/December harvest period, prawn size categories in both survey and commercial catch maps are defined as "large" for <27 prawns per kg, "medium" for 27–33 prawns per kg and "small" for >33 prawns per kg. For all other harvest periods and for definition within this section only, prawn size in both survey and commercial maps are defined as "large" for <28 prawns per kg, "medium" for 28–30 prawns per kg, "small-medium" for 30–33 prawns per kg and "small" for >33 prawns per kg. 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 being just greater than the highest catch per block for that period.

Uncertainty associated with direct comparisons between survey shot and fishing block information include: 1) an error in reported trawl time during surveys, which may affect mean survey catch rate calculations (Figure 3.2), 2) the potential error associated with bucket count measures of prawn size, 3) the number of vessels from which mean harvested size data are available per fishing block (range: 1–5 vessels), 4) assumptions regarding the calculation of mean prawn size from grade data (Section 2.5) and; 5) uncertainty associated with the unvalidated grade data provided in commercial logbooks. Also, note that commercial prawn grade data are provided per night, whereas catch data are provided per shot. Thus, where two or more fishing blocks are fished in one night, mean prawn size is assumed as equal among fished blocks.

4.3 Results: 2008/09

4.3.1 Harvest Period 1 - 2008/09

A stock assessment survey was conducted on 23 and 24 November 2008 at 111 stations. High catch rates were observed for 22 stations but only one comprised prawns of large size, while 13 stations comprised medium sized prawns (Figure 4.1). The harvest area determined was fished for four nights and prawns were harvested within size criteria in all four reporting blocks (Figure 4.2). 'At sea' decision rules for both daily catch and mean prawn size were within limits for all four nights.

4.3.2 Harvest Period 2 – 2008/09

The second stock assessment survey was conducted on 21–23 March 2009 at 110 stations. High catch rates were observed for 26 stations, four of which contained large prawns at adjacent stations in the south-east of GSV (Figure 4.3). Fourteen stations contained high catch rates of small prawns in a large area of western GSV. Three harvest areas were determined enclosing the majority of large prawns observed. Of the eight blocks fished, only four were harvested within the size criteria (Figure 4.4) and over the eight nights fished, the target-size was met on three nights only. The minimum catch was achieved during all nights.

4.3.3 Harvest Period 3 -2008/09

The third stock assessment survey was conducted on 19 and 20 April 2009 at 112 stations. High catch rates were observed for 28 stations of which two met target-size criteria (Figure 4.5). Two harvest areas were developed that encompassed most of the prawns of target-size, and the areas were fished for six nights. After the first night of fishing the following five nights were not fished due to poor weather (Figure 4.6). Of the 13 blocks fished, only one was fished within target-size criteria. The target-size was only met during one fishing night. The minimum catch was not met on the second last night of fishing and that harvest area was immediately closed.

4.3.4 Harvest Period 4 – 2008/09

The fourth stock assessment survey was conducted on 19 and 20 May 2009 at 112 stations. High catch rates were observed for 27 stations of which four met target-size criteria (Figure 4.7). Notably, 19 of the 27 high catch rates stations comprised of small prawns. Three harvest areas were fished for a total of eight nights. Four of the six blocks were fished within target-size criteria, however the target-size was met on only four of the eight fishing nights (Figure 4.8). The minimum catch was not met on the first night of fishing and that harvest area was immediately closed.

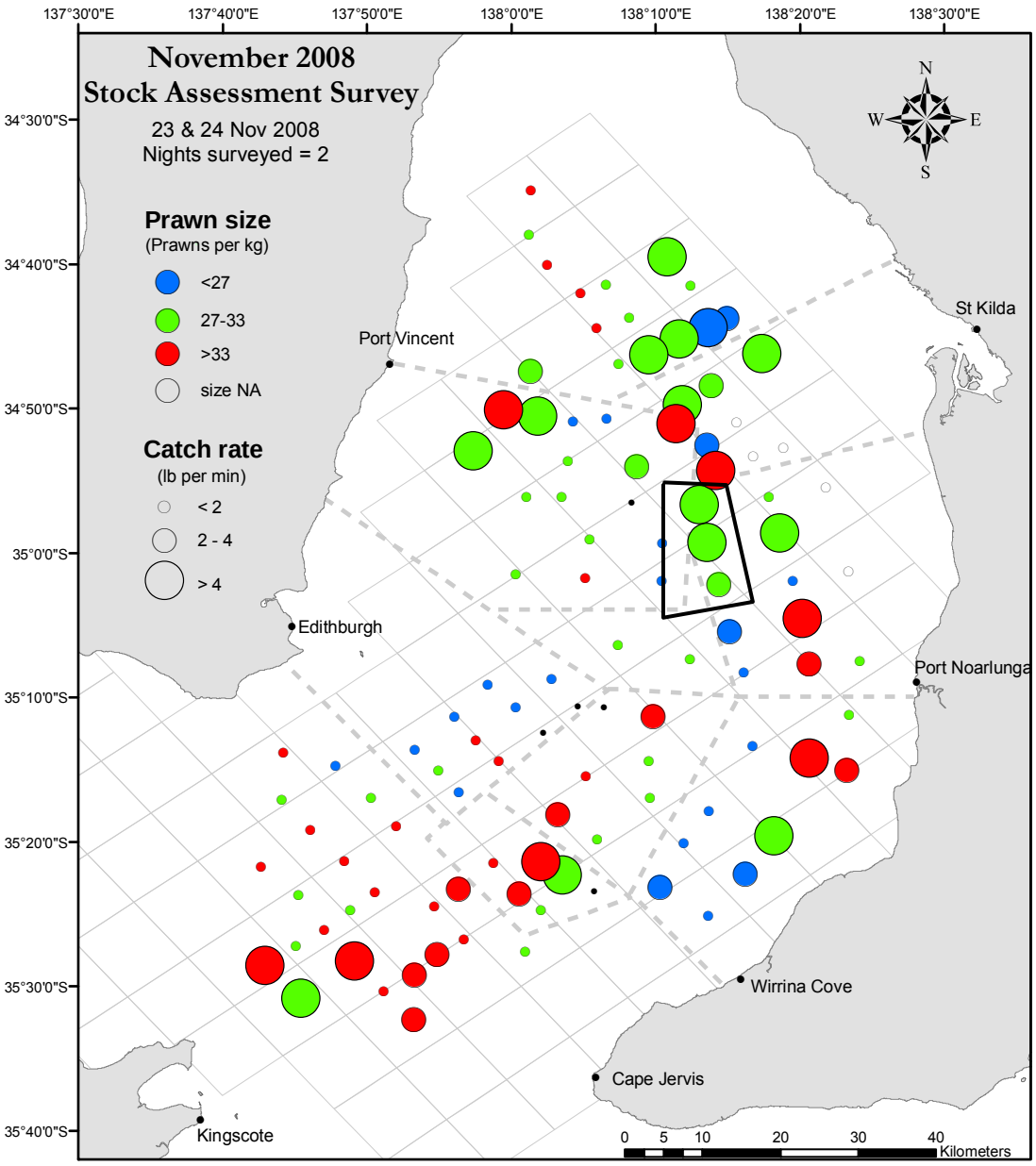


Figure 4.1 Catch rate and mean size during the November 2008 stock assessment survey, prior to harvest period 1. The polygon (black line) represents the maximum area opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented.

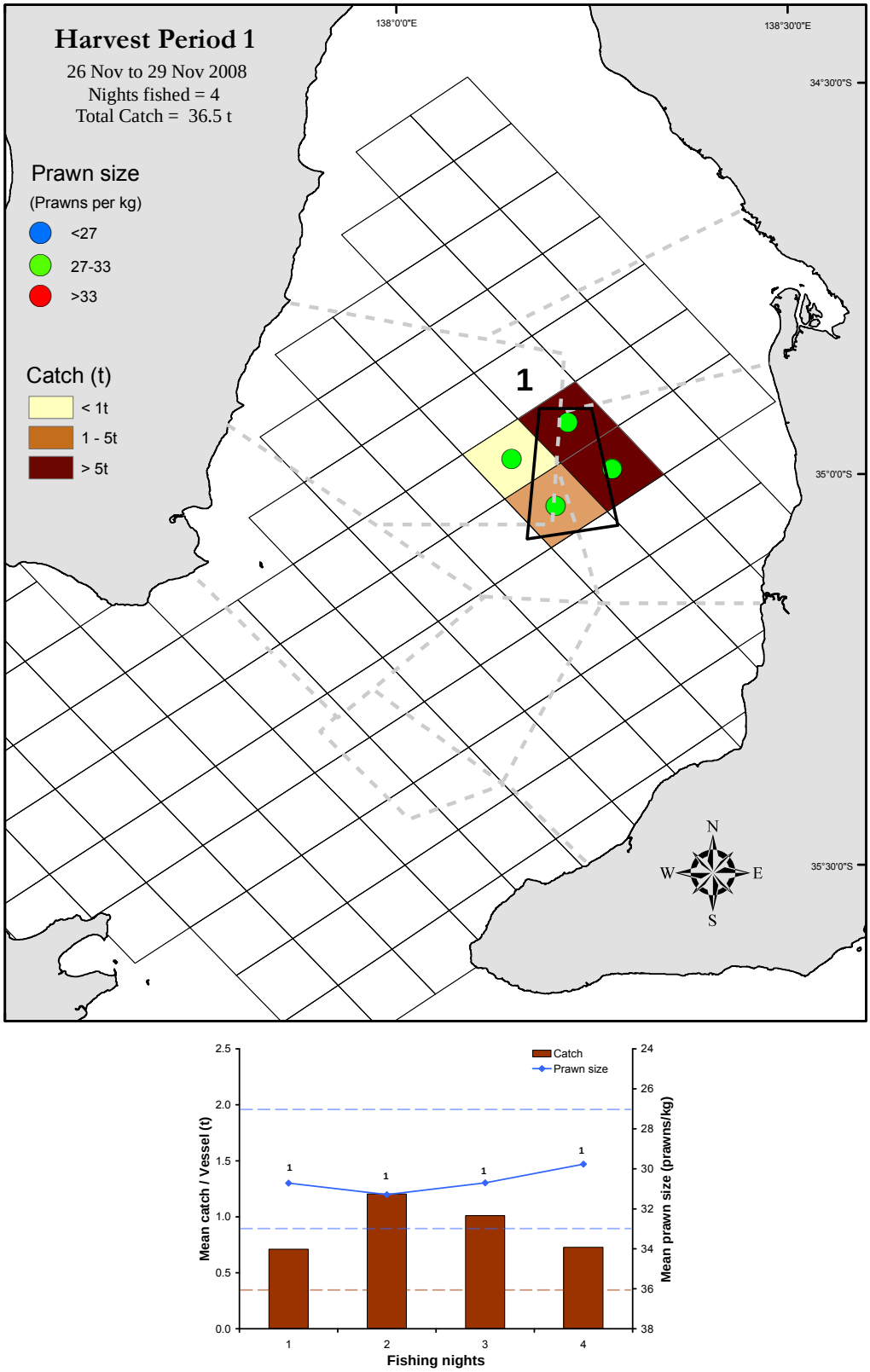


Figure 4.2 Map: Commercial catch (t) and prawn size (prawns/kg) from blocks fished during harvest period 1. The polygon (black line) represents the maximum area opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented. **Graph:** Mean daily commercial catch (t) per vessel and mean prawn size (prawns/kg) during harvest period 1. Orange dashed line represents the minimum daily catch per vessel (350 kg), while the blue dashed lines represent target-size range (27–33 prawns/kg) for harvest period 1. Numbers indicate harvest areas fished.

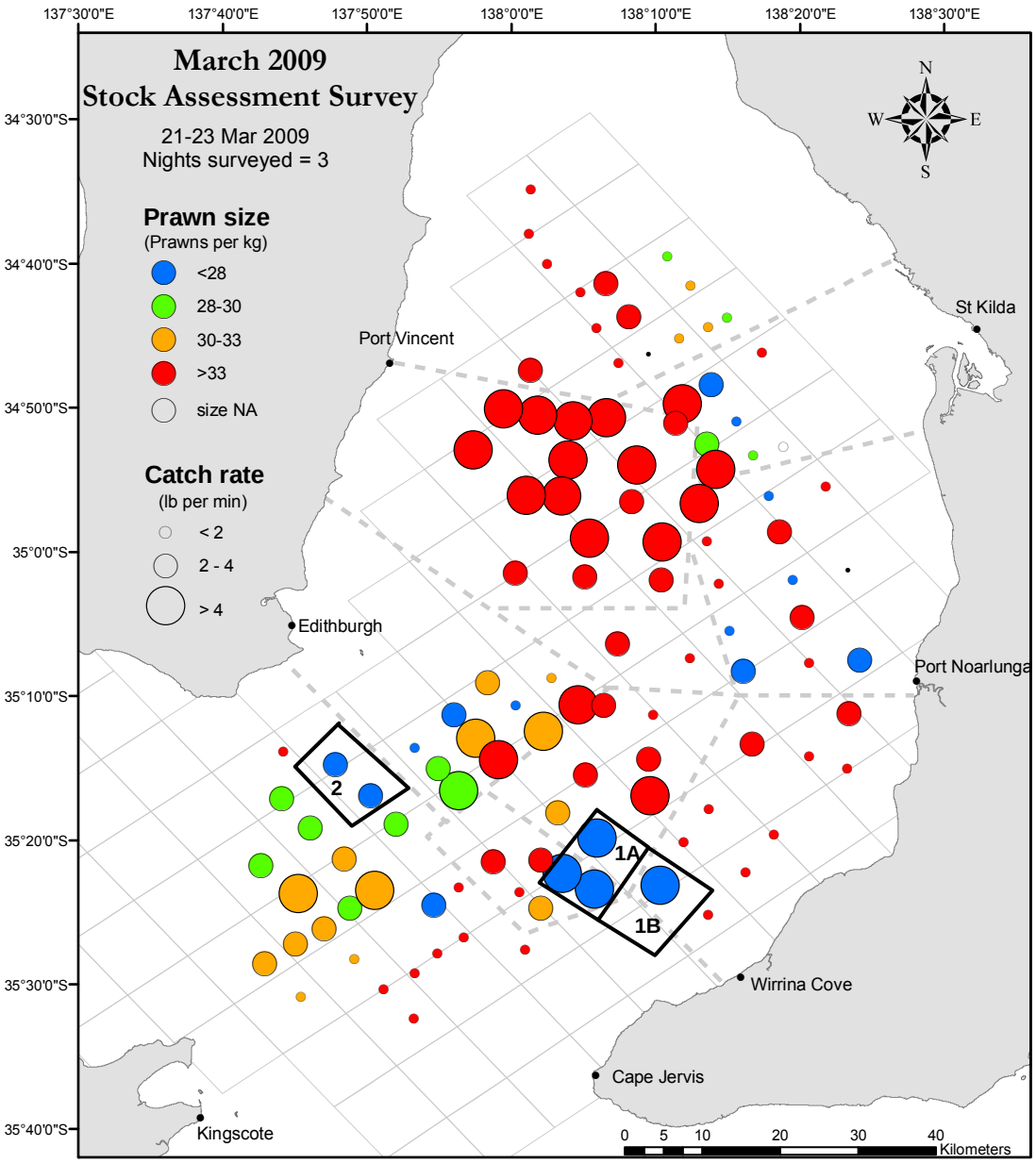
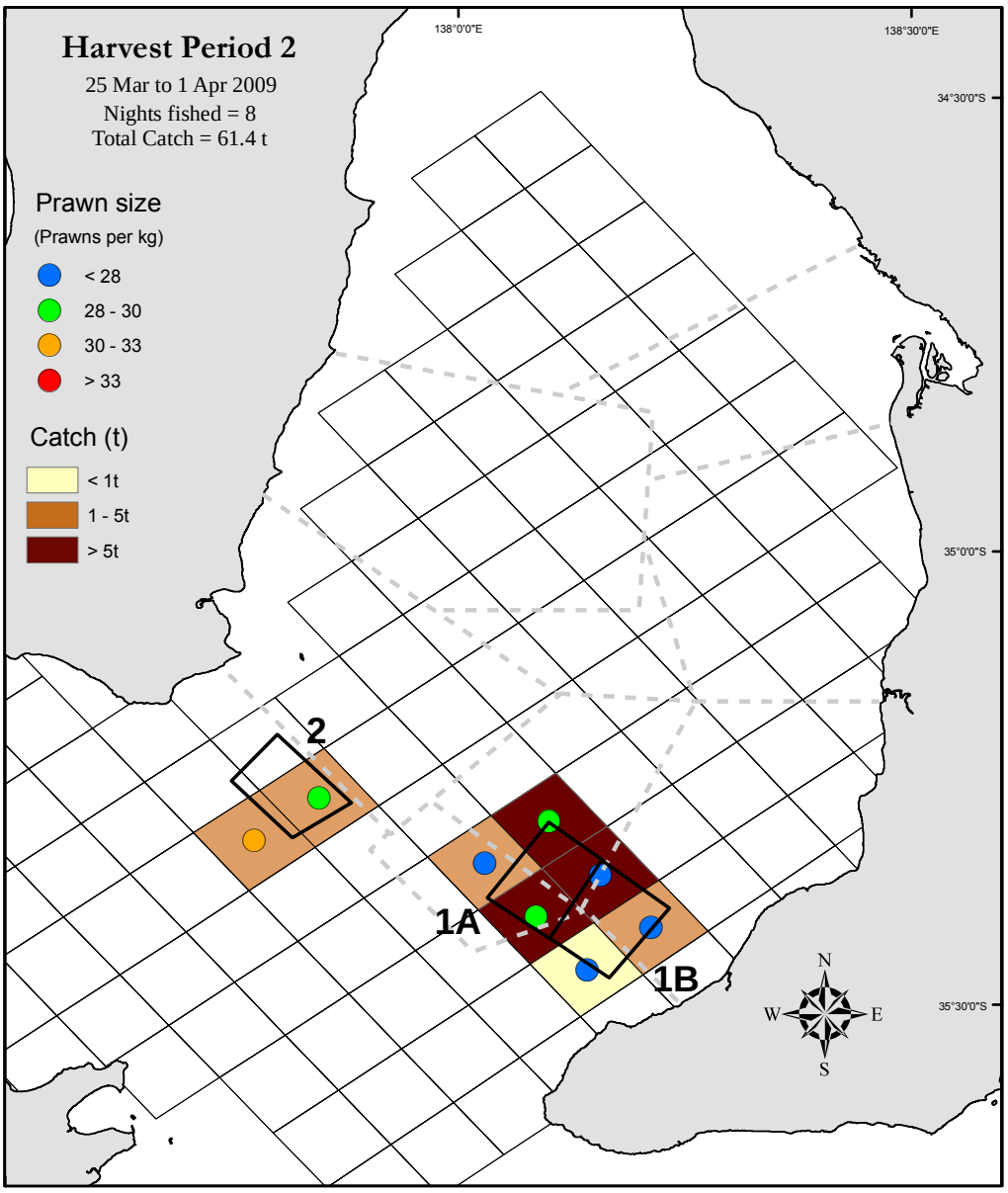


Figure 4.3 Catch rate and mean size during the March 2009 stock assessment survey, prior to harvest period 2. Polygons (black line) and west of the black line in the Investigator Strait represents the maximum areas opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented.



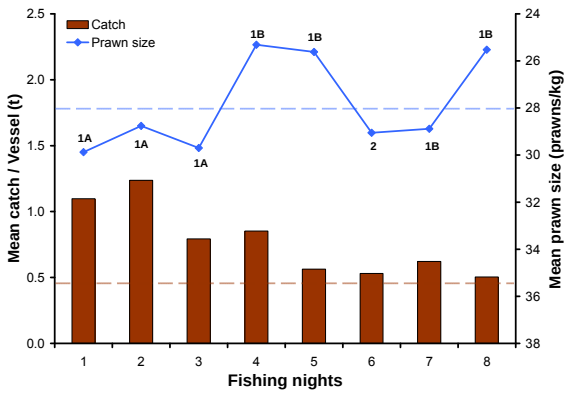


Figure 4.4 Map: Commercial catch (t) and prawn size (prawns/kg) by blocks fished during harvest period 2. Numbered polygons (black line) represent the maximum areas opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented. **Graph:** Mean daily commercial catch (t) per vessel and mean prawn size (prawns/kg) during harvest period 2. Orange dashed line represents the minimum daily catch per vessel (450 kg), while the blue dashed line represents target-size (<28 prawns/kg) for harvest periods 2-4. Numbers indicate harvest strategy areas fished, while an asterisk indicates that an amendment was made to a harvest strategy area.

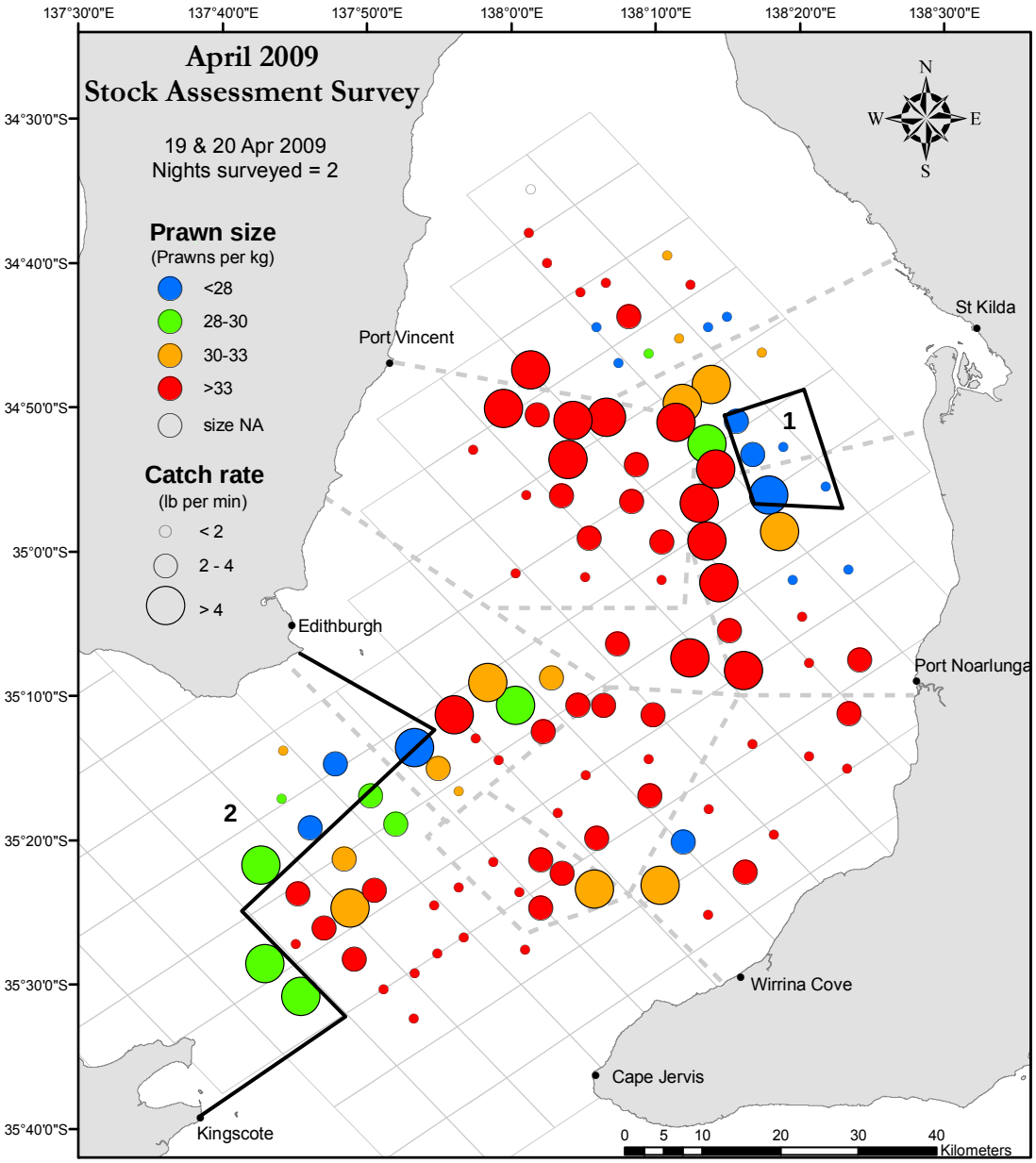


Figure 4.5 Catch rate and mean size during the April 2009 stock assessment survey, prior to harvest period 3. Polygons (black line) represent the maximum areas opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented.

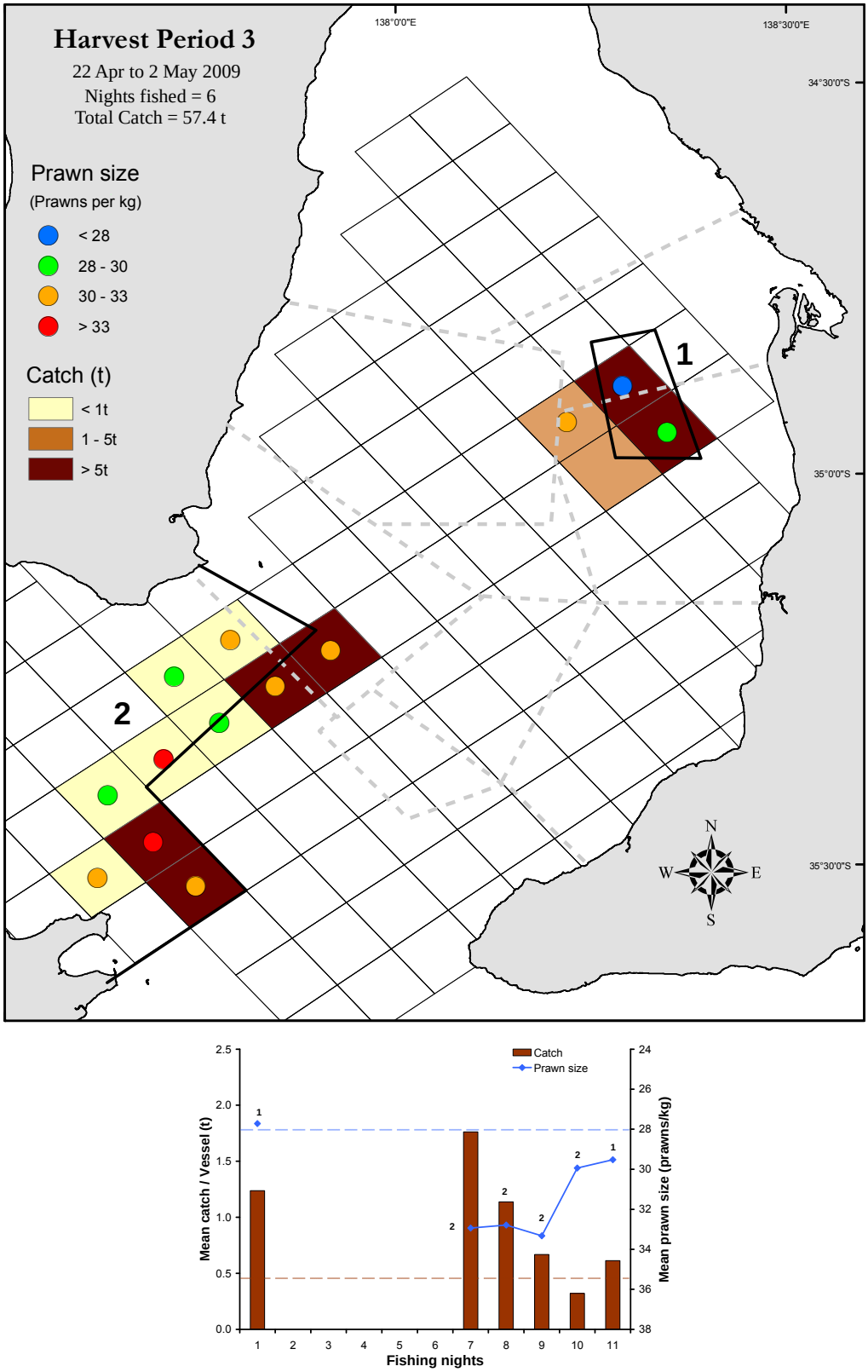


Figure 4.6 Map: Commercial catch (t) and prawn size (prawns/kg) from blocks fished during harvest period 3. Polygons (black line) represent the maximum areas opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented. **Graph:** Mean daily commercial catch (t) per vessel and mean prawn size (prawns/kg) during harvest period 3. Orange dashed line represents the minimum daily catch per vessel (450 kg), while the blue dashed line represents target-size (<28 prawns/kg) for harvest periods 2-4. Numbers indicate harvest strategy areas fished.

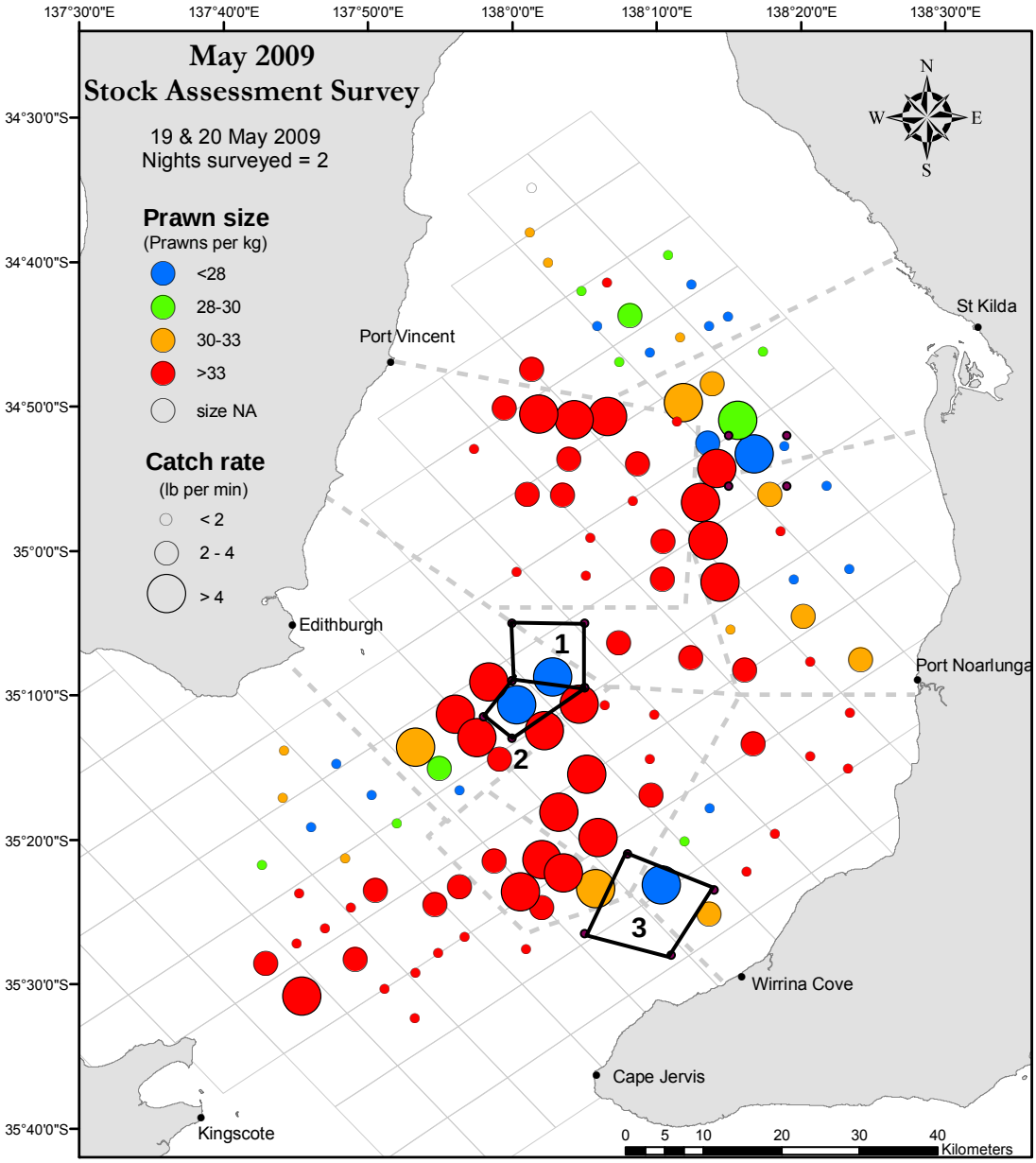


Figure 4.7 Catch rate and mean size during the May 2008 Stock Assessment survey, prior to harvest period 4. Polygons (black line) represent the maximum areas opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented.

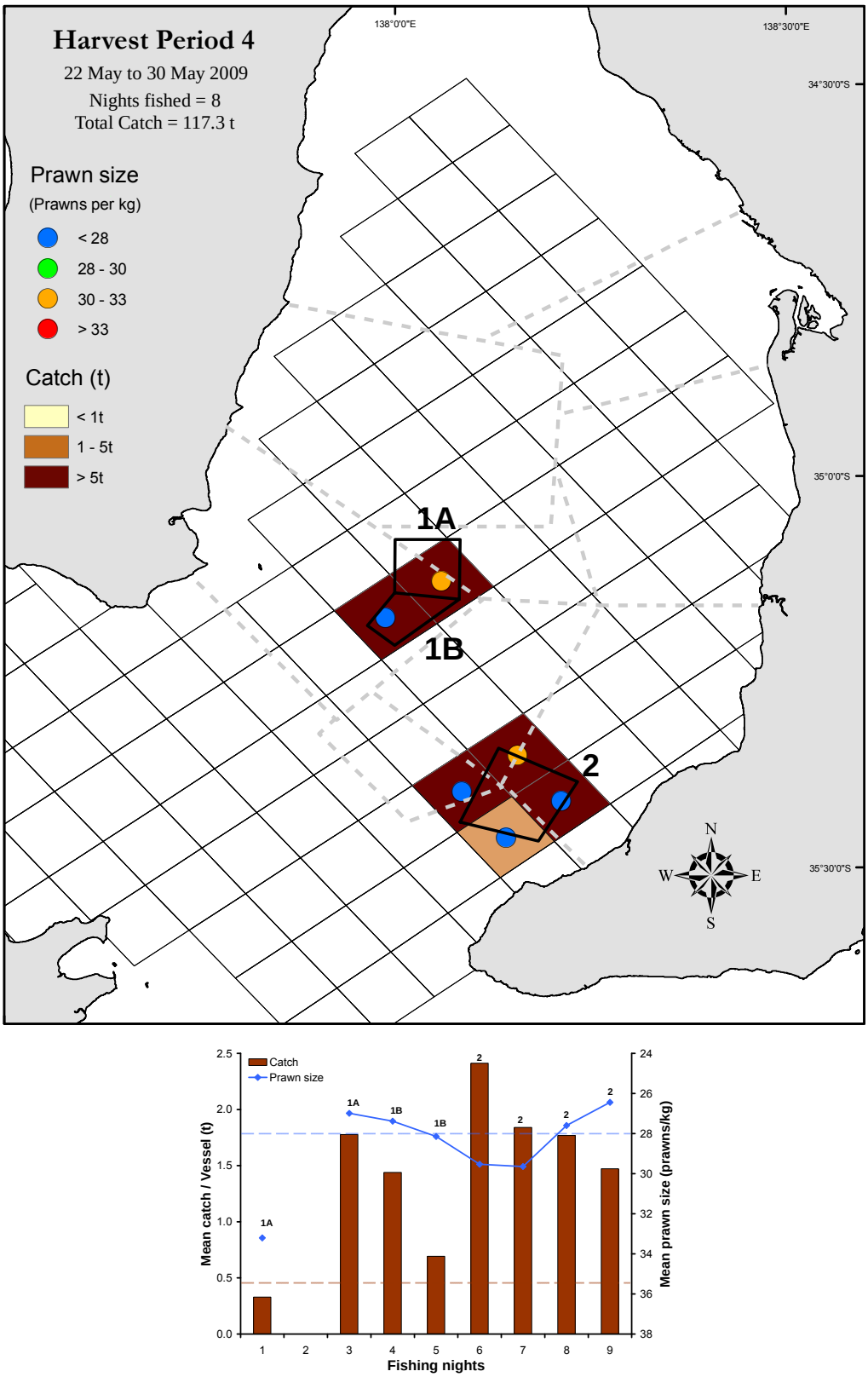


Figure 4.8 Map: Commercial catch (t) and prawn size (prawns/kg) from blocks fished during harvest period 4. Polygons (black line) represent the maximum areas opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented. **Graph:** Mean daily commercial catch (t) per vessel and mean prawn size (prawns/kg) during harvest period 4. Orange dashed line represents the minimum daily catch per vessel (450 kg), while the blue dashed line represents target-size (<28 prawns/kg) for harvest periods 2-4. Numbers indicate harvest strategy areas fished.

4.4 Results: 2009/10

4.4.1 Harvest Period 1 - 2009/10

A stock assessment survey was conducted on 11 and 12 December 2009 at 108 stations. High catch rates were observed for nine stations, none of which comprised prawns of large size and only one station was within target-size (Figure 4.9). Several harvest areas were developed and fishing was conducted over six nights. Prawns smaller than the target range were caught in six of 11 fishing blocks and during four of the six nights (Figure 4.10). The minimum catch per night was not achieved during one night of the six fished.

4.4.2 Harvest Period 2 – 2009/10

The second stock assessment survey was conducted on 10–12 March 2010 at 110 stations. High catch rates were observed for 16 stations, none of which contained target-size prawns (Figure 4.11). Several harvest areas of moderate catch rates were developed from stations that were within and just outside of target-size. The target-size was not achieved within any of the seven blocks fished or four nights fished (Figure 4.12). Minimum catches were not met during two of the four fishing nights.

4.4.3 Harvest Period 3 – 2009/10

The third stock assessment survey was conducted on 8 and 9 April 2010 at 112 stations. High catch rates were observed for 25 stations of which one was target-size (Figure 4.13). A decision was made by the Management Sub-Committee responsible for harvest strategy development to reduce the target-size criteria to 30 prawns per kg for the April 2010 harvest period to enable some fishing to take place (Alice Fistr, PIRSA pers. comm.). A compromise was reached to consequently reduce the proportion of the biomass accessed (i.e. exploitation rate). Three harvest areas were developed and fishing was conducted for ten nights. Of the seven blocks fished with prawn size data available, only one was fished within the revised target-size criteria (Figure 4.14). The revised target-size was achieved during three of the ten nights fished. Minimum catches were obtained on all nights fished.

4.4.4 Harvest Period 4 – 2009/10

A stock assessment survey was conducted on 8 and 9 May 2010 at 109 stations. High catch rates were observed for 23 stations of which five met target-size criteria (Figure 4.15). Three harvest areas were developed comprising predominately prawns of target-size, however the target-size was not achieved for any of the eight blocks or five nights fished (Figure 4.16). The minimum catch was achieved on all nights.

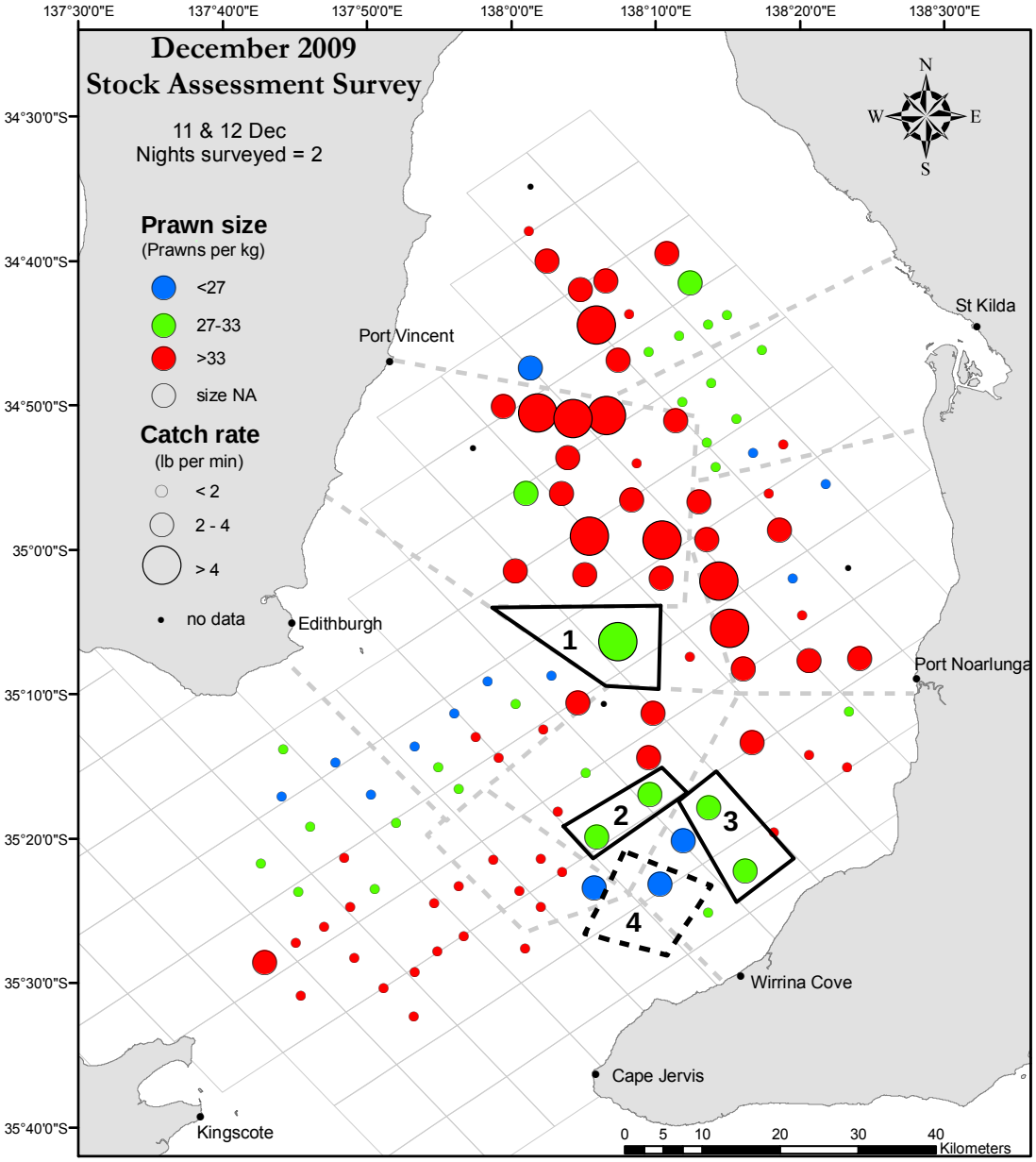


Figure 4.9 Catch rate and mean size during the December 2009 stock assessment survey, prior to harvest period 1. The polygon (black line) represents the maximum area opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented.

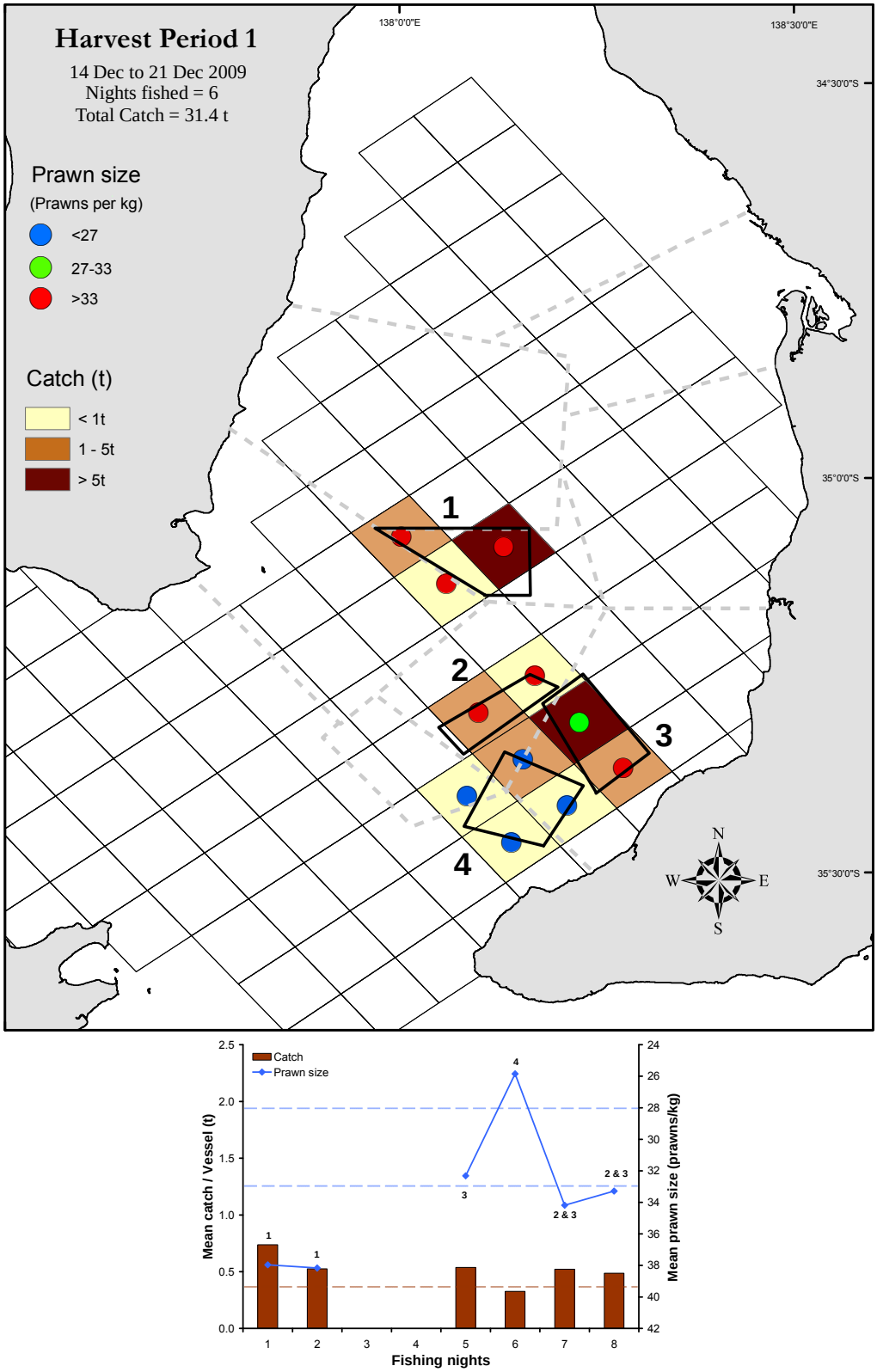


Figure 4.10 Map: Commercial catch (t) and prawn size (prawns/kg) from blocks fished during harvest period 1. The polygon (black line) represents the maximum area opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented. **Graph:** Mean daily commercial catch (t) per vessel and mean prawn size (prawns/kg) during harvest period 1. Orange dashed line represents the minimum daily catch per vessel (350 kg), while the blue dashed lines represent target-size range (27–33 prawns/kg) for harvest period 1. Numbers indicate harvest strategy areas fished.

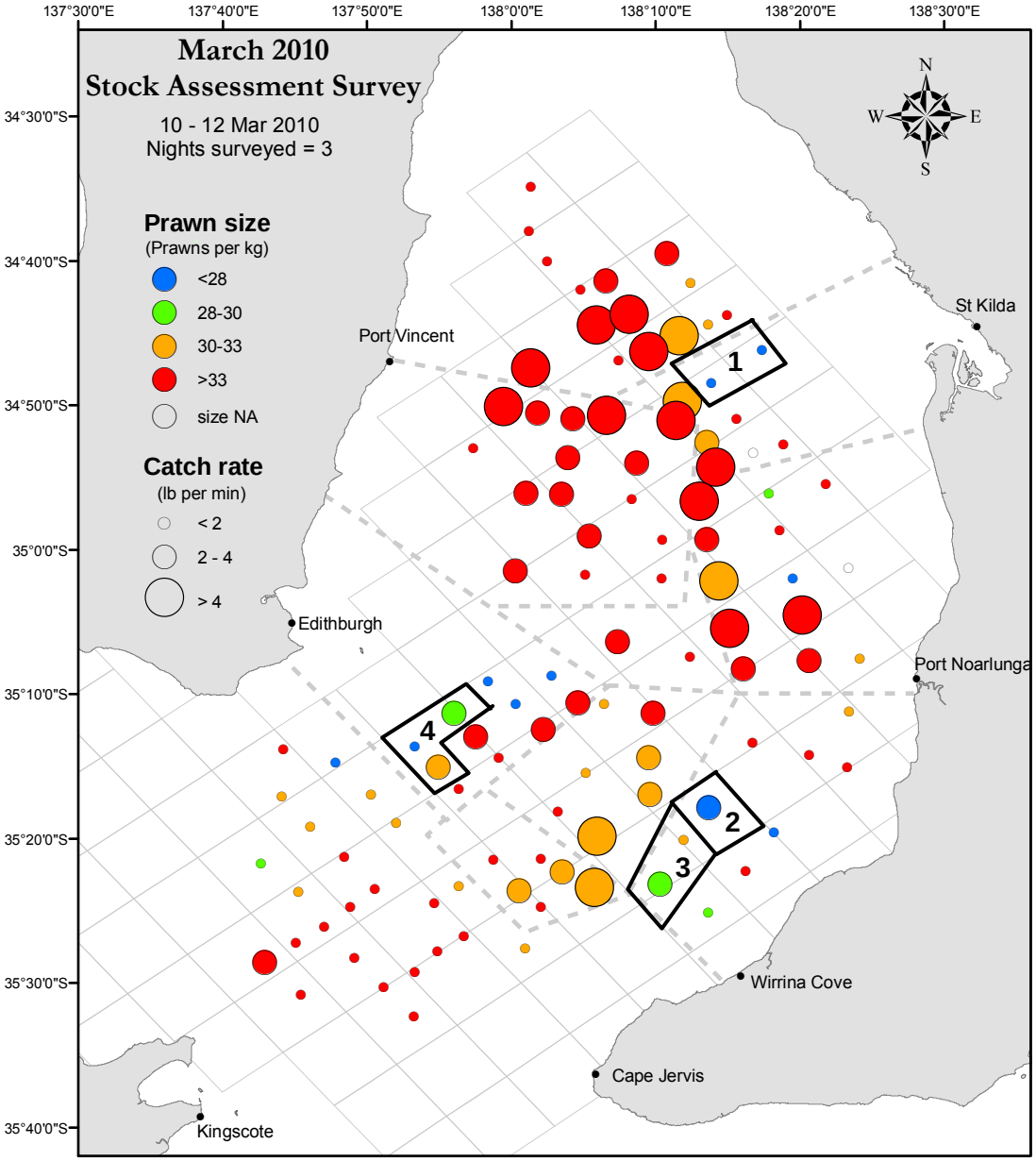


Figure 4.11 Catch rate and mean size during the March 2010 stock assessment survey, prior to harvest period 2. Polygons (black line) and west of the black line in the Investigator Strait represents the maximum areas opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented.

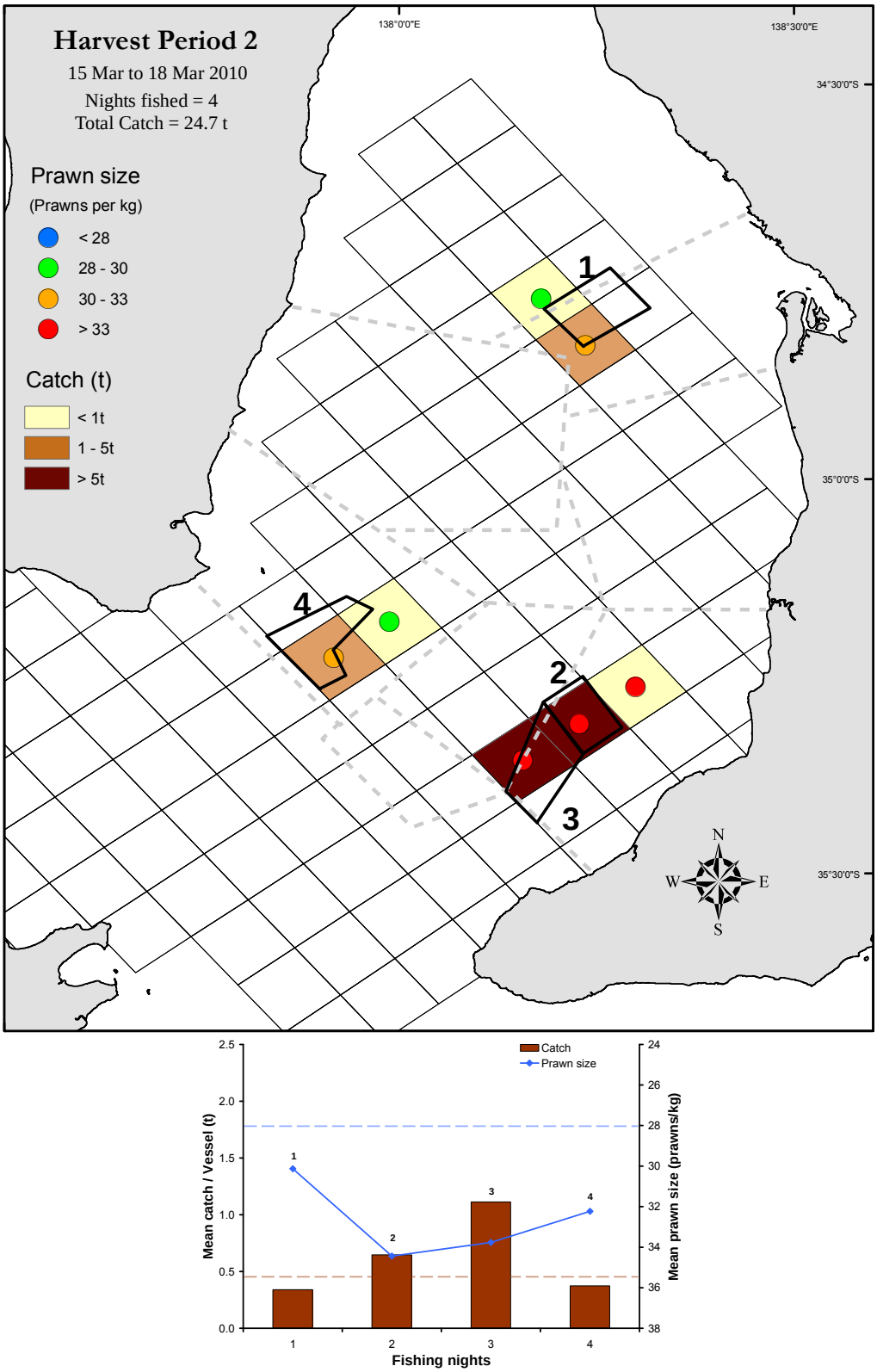


Figure 4.12 Map: Commercial catch (t) and prawn size (prawns/kg) by blocks fished during harvest period 2. Numbered polygons (black line) represent the maximum areas opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented. **Graph:** Mean daily commercial catch (t) per vessel and mean prawn size (prawns/kg) during harvest period 2. Orange dashed line represents the minimum daily catch per vessel (450 kg), while the blue dashed line represents target-size (<28 prawns/kg) for harvest periods 2-4. Numbers indicate harvest strategy areas fished, while an asterisk indicates that an amendment was made to a harvest strategy area.

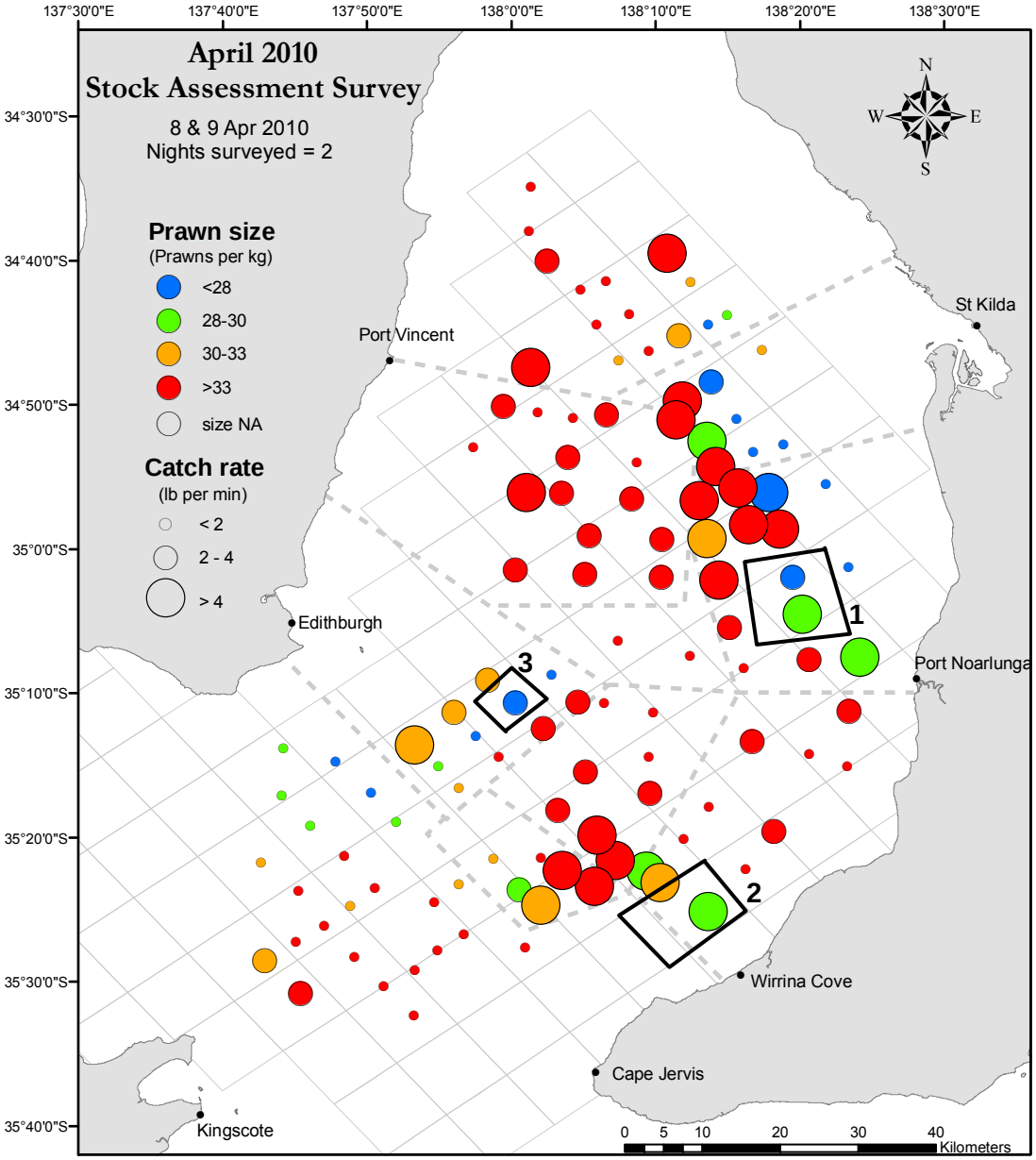


Figure 4.13 Catch rate and mean size during the April 2010 stock assessment survey, prior to harvest period 3. Polygons (black line) represent the maximum areas opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented.

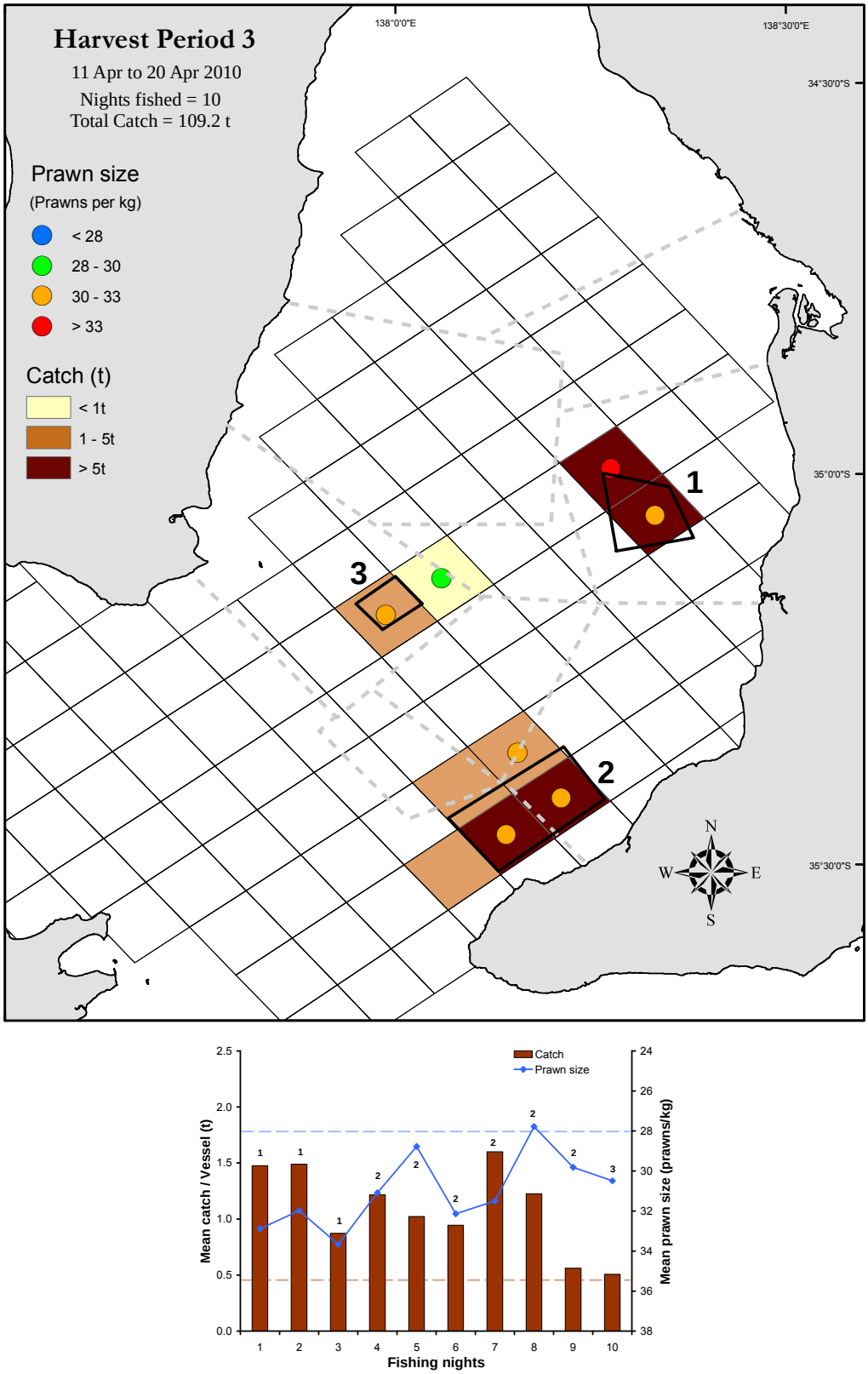


Figure 4.14 Map: Commercial catch (t) and prawn size (prawns/kg) from blocks fished during harvest period 3. Polygons (black line) represent the maximum areas opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented. **Graph:** Mean daily commercial catch (t) per vessel and mean prawn size (prawns/kg) during harvest period 3. Orange dashed line represents the minimum daily catch per vessel (450 kg), while the blue dashed line represents target-size (<28 prawns/kg) for harvest periods 2-4. Numbers indicate harvest strategy areas fished.

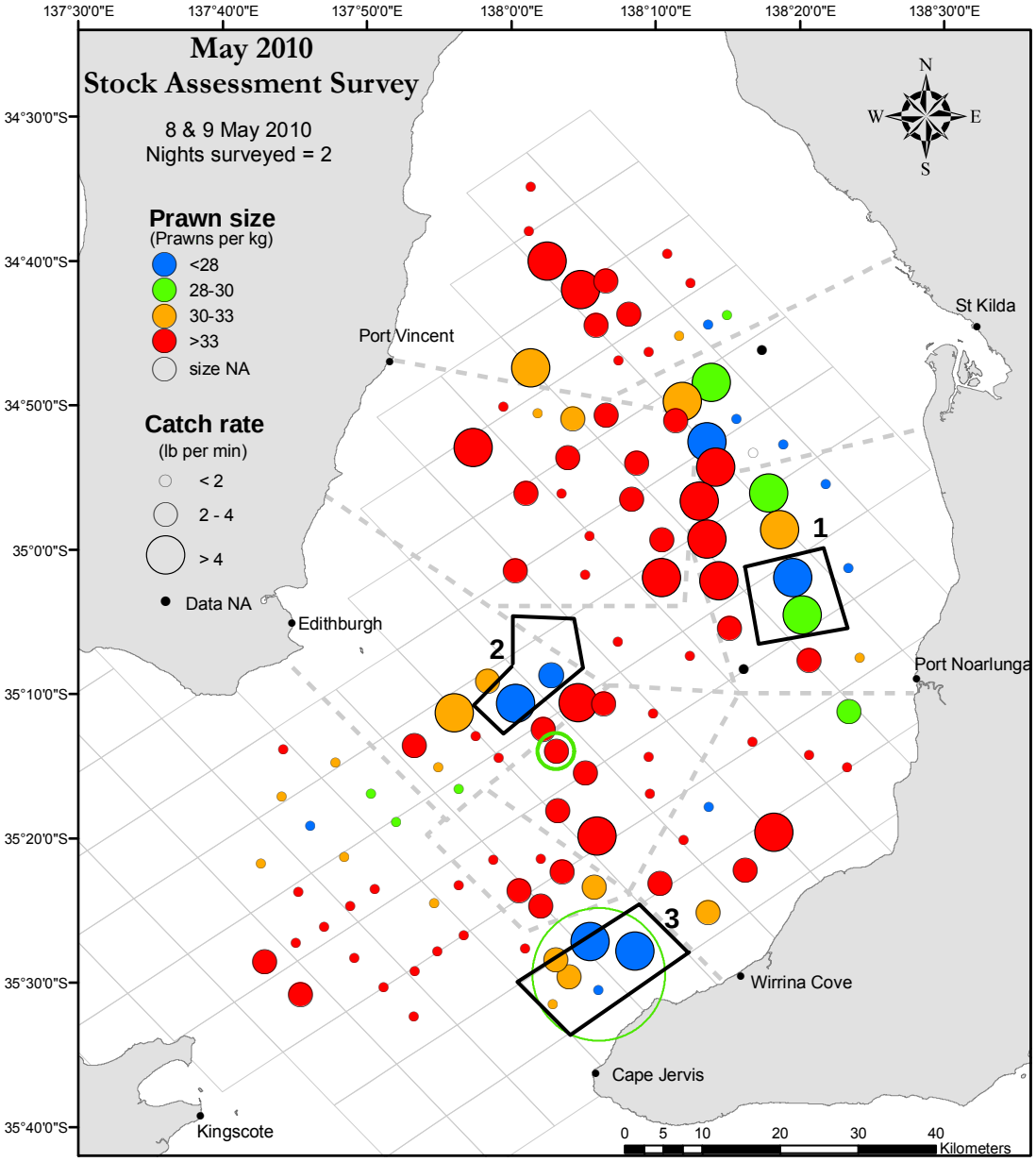
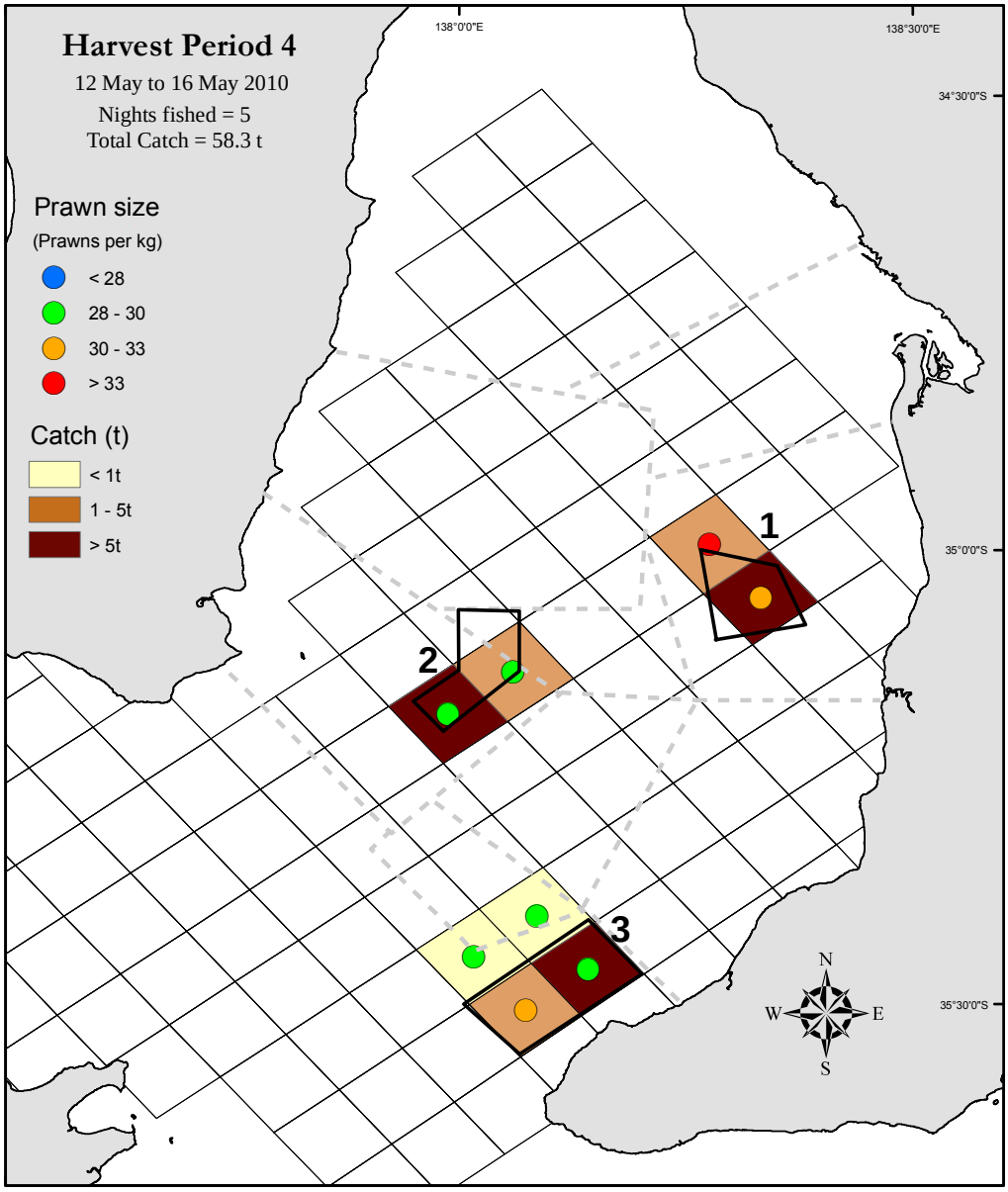


Figure 4.15 Catch rate and mean size during the May 2010 stock assessment survey, prior to harvest period 4. Polygons (black line) represent the maximum areas opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented. Note that the green circles encompass additional survey shots.



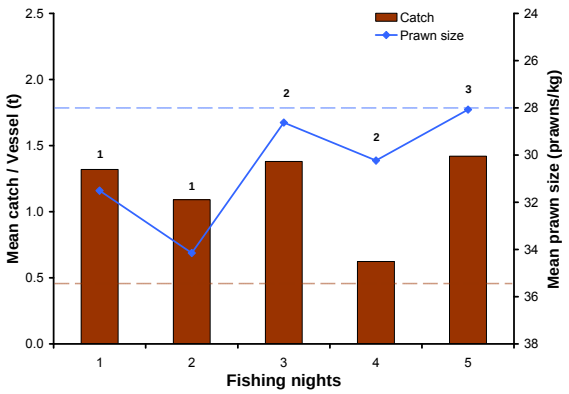


Figure 4.16 Map: Commercial catch (t) and prawn size (prawns/kg) from blocks fished during harvest period 4. Polygons (black line) represent the maximum areas opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented. **Graph:** Mean daily commercial catch (t) per vessel and mean prawn size (prawns/kg) during harvest period 4. Orange dashed line represents the minimum daily catch per vessel (450 kg), while the blue dashed line represents target-size (<28 prawns/kg) for harvest periods 2-4. Numbers indicate harvest strategy areas fished.

4.5 Discussion

This section provides an assessment of the effectiveness of 1) harvest strategy development (determination of harvest areas) and 2) harvest strategy management 'at-sea', particularly with respect to prawn size. These analyses suggest that several aspects of harvest strategy development and management require modification.

As identified in the previous report for the fishery (Roberts *et al.* 2009), the size structure of the commercial catch does not always reflect that observed during prior surveys. Whilst surveys provide a strong indication of harvested size, commercial catches generally comprise smaller prawns (usually 1–2 prawns per kg). Although this may result from the uncertainty associated with bucket count estimates of prawn size, the consistent difference among surveys and fishing suggest contribution from other factors such as moon phase. Survey prawn size tends to be a poorer predictor of harvested prawn size when survey catch rates are medium or low and as the time difference between survey and fishing increases. Future harvest strategies should account for likely effects on size structure between surveys and commercial fishing.

The current harvest strategy approach appears to have been highly effective at targeting and depleting the largest prawns in the population (see Sections 2 and 3). On almost all occasions during 2008/09 and 2009/10, harvest areas were developed that incorporated almost all of the stations with prawns at the largest mean sizes observed in the gulf. Future harvest strategies should ensure that some large prawns are conserved during harvest strategy development.

The targeting of large prawns and the mixing of recruits in the population has led to consecutive decline in the mean size of prawns harvested over time. In recent years this has led to poor adherence to the rules governing prawn size at-sea which enable management actions to be undertaken when target size is not met (i.e. modify or close the current harvest area). During 2009/10, the target-size for prawns across the fleet was rarely adhered to at the scale of fishing block or night fished. As identified in Section 2.6.2, this may have resulted from high catches of very small prawns that were regularly harvested but not reported to the committee-at-sea. Further, anecdotal evidence suggest that substantial catches of very small prawns were dumped at sea and not recorded in logbooks. The likelihood of non-reporting increases when harvest areas are large and the fleet spreads out. Future management at sea may require smaller harvest areas to be developed so that the majority of fishers are aware of the sizes of prawns being harvested within fishing blocks.

5. PERFORMANCE INDICATORS

In this section, performance of the fishery is assessed against the Performance Indicators (PIs) identified in the Management Plan (Dixon and Sloan 2007). The Plan provides a set of key PIs and LRPs (Table 5.1) that, if breached, evoke a management response. That response includes an assessment of additional performance measures (Table 5.2). The Management Plan was implemented in September 2007, prior to the 2007/08 fishing season.

Table 5.1 Summary of Performance Indicators (PI) and Limit Reference Points (LRP) for the 2007/08– 2009/10 fishing years. Shaded cells indicate PI triggered.

PI	LRP	'07/'08	'08/'09	'09/'10
Recruitment index (May: recr/h)	>250	693	707	454
Total commercial catch (t)*	Increasing each year of Plan	229	273	223
Mean commercial CPUE (kg/h)*	Increasing each year of Plan	93	113	93
Mean prawn size	Within target criteria each harvest period	No	No	No
Fishery independent surveys	4 surveys completed	Yes	Yes	Yes
Indices of current biomass	Decreases in 2 consecutive surveys	No	No	Yes
Indices of future biomass	Falls below limits in 2 consecutive surveys	No	No	No

* Total commercial catch and CPUE do not include survey catch

5.1 Recruitment index

Recruitment index is calculated as the mean number of juvenile prawns (males <33 and females <35 mm carapace length) captured per trawl hour from all shots surveyed during May. Length-frequency data were available for 108, 105 and 102 survey shots during May 2007/08, 2008/09 and 2009/10, respectively. The recruitment indices were well above the Limit Reference Point (250 rec/h) in each of the last three fishing years.

5.2 Total commercial catch

Total commercial catch increased from 229 to 273 t from 2007/08 to 2008/09 but declined by 50 t in 2009/10 (223 t). The failure for commercial catch to continue increasing in 2009/10 triggers this Limit Reference Point.

5.3 Mean commercial CPUE

Mean commercial CPUE closely followed the trends in catch with an increase from 2007/08 (93 kg/h) to 2008/09 (113 kg/h) but then a decline in 2009/10 (93 kg/h). The failure to continue increasing the commercial CPUE in 2009/10 triggers this Limit Reference Point.

5.4 Mean prawn size

During 2007/08 mean harvested prawn size was outside of the target range in March but was within the target range during all other months. During 2008/09, prawns size was within the target range during December and March but was outside of the target range during April and May. During 2009/10 prawn size was outside of the target range during all months fished.

5.5 Fishery independent surveys

Four fishery independent surveys were conducted during each of 2007/08, 2008/09 and 2009/10.

5.6 Indices of current biomass

The index of current biomass (mean survey catch rate) increased between years for subsequent surveys in December, March and April in 2008/09 but a decrease was observed in May. In 2009/10, decreases were observed during all four fishery independent surveys. Thus, decreases have been observed for five consecutive surveys and the PI for indices of current biomass has triggered during 2009/10.

5.7 Indices of future biomass

Mean catch rate of 21+ size prawns was above the reference level for all surveys during 2008/09 and 2009/10. As such, the PI for indices of future biomass was not triggered.

5.8 Additional performance measures

The Management Plan provides a set of additional performance measures that are critically assessed if a key PI is triggered (Table 5.2). Triggering additional performance measures does not evoke a management response.

Table 5.2 Summary of additional performance measures for 2007/08 to 2009/10 fishing years of the Gulf St Vincent Prawn Fishery (Dixon and Sloan 2007).

Performance Measure	LRP	'07/'08	'08/'09	'09/'10
Recruit index December survey all shots	>100	191	363	314
Recruit index March survey all shots	>200	452	823	469
Recruit index April survey all shots	>250	570	947	737
Egg production (eggs$\times 10^6$/h trawled)	>500	525	717	388
% of >U10 in the commercial catch – March to June	>25%	30	29.1	21.5
% of 21+ in the commercial catch – Dec	<7%	2.7	6.8	14.2
% of 21+ in the commercial catch – March to June	<5%	3.2	5.6	7.6

Recruitment index was determined for December, March and April from all survey stations conducted during 2007/08, 2008/09 and 2009/10. Recruitment indices were all above the Limit Reference Point (LRP) in all months during all three fishing years.

Egg production estimates were determined from the model presented in Appendix 8.5. Egg production was below the LRP in 2009/10 (388 million) and was the lowest estimated since December 2004.

Data on prawn grades from the commercial catch were available for all months during 2007/08, 2008/09 and 2009/10. The proportion of prawns between March and June of the >U10 prawn size grade category were within acceptable limits in 2008/09 but not so in 2009/10. The proportion of prawns in December for the 21+ prawn size grade category were also within acceptable limits in 2008/09 but were more than double the acceptable limit during 2009/10. The proportion of prawns between March and June of the 21+ prawn size grade category were above acceptable levels in both the last two fishing years.

5.9 Discussion

The current suite of primary Performance Indicators (PIs) and additional PIs are useful for identifying issues of concern for the fishery. However, the current structure of these indicators does not reflect traditional approaches to fishery performance assessment i.e. indicators of stock status and fishery status with target and limit reference points. Further discussion on a more appropriate framework for performance assessment of the fishery is provided in section 6.2.

During 2008/09, PI's for recruitment, commercial catch, commercial CPUE, conduct of fishery-independent surveys and indices of current and future biomass were all within acceptable levels. However, the PI for mean prawn size harvested was

triggered. All additional performance measures were within acceptable limits during 2008/09 except for the proportion of 21+ grade prawns harvested from March to June.

During 2009/10, PI's for recruitment, conduct of fishery-independent surveys and indices of future biomass were all within acceptable levels. The PI's for commercial catch, commercial CPUE, mean prawn size harvested and for indices of current biomass were all triggered. The three additional performance measures for recruitment were within acceptable limits during 2009/10 but the three additional performance measures for prawn grades and the measure for egg production were all triggered.

The PIs and additional PIs that triggered during 2008/09 and 2009/10 do reflect issues for the fishery. In particular, the PI's and additional measures for harvested prawn size and egg production reflect the changes in size structure of the population. The triggering of PI's for indices of current biomass, commercial catch and commercial CPUE indicate that the objectives of stock recovery and increasing commercial yield were not met.

Refinement of the measure for egg production is needed for future assessment. Currently, the Limit Reference Point (LRP) for egg production is determined as a fixed value. As the model for egg production is likely to be modified in the future, a more appropriate approach may be to use a LRP of % change to a reference year (e.g. 2004/05).

Further, there is a need to collect information on the fishing power of the fleet and document any changes in gear (particularly mesh type and size). These data are critical for interpreting changes in CPUE that underpin the PI for mean commercial CPUE and for indices of current and future biomass. In the absence of formal assessment of vessel power, a rule of thumb adjustment such as an annual increase of 1% (see Dixon *et al.* 2010) could be applied to measures of survey catch rate.

6. DISCUSSION

6.1 Current status of the GSVPF and uncertainty in the assessment

The most recent Fishery Assessment Report for the Gulf St Vincent Prawn Fishery (Roberts *et al.* 2009) indicated that stock recovery was tracking positively in all size classes up to 2007/08. This report provides analyses for two years of additional data (2008/09 and 2009/10) which confirm that the current harvest strategy has led to a significant increase in the biomass of prawns since 2004/05. However, highly effective targeting of the largest prawns has likely contributed to a decline in the biomass of large prawns in the last two years and has greatly reduced potential egg production for the fishery. While the high biomass of small and mixed prawns indicates that the current status of the fishery is sustainable, the abundance of large prawns in the population needs to be increased. Levels of recruitment to the fishery in the next two years will also be a critical factor in determining sustainable catch.

Fishery-independent survey data indicate that the total relative biomass increased from 2004/05 to 2008/09 and then decreased in 2009/10. These trends were also apparent for size categories of mixed and small prawns. While the biomass of large prawns increased slightly from 2004/05 to 2007/08, consecutive decreases in biomass were observed in 2008/09 and 2009/10. During 2009/10, the biomass of large prawns was significantly lower than all previous survey years.

The decline in biomass of large prawns is likely to have resulted from effective targeting of the largest prawns in the population and is symptomatic of two limitations in the current harvest strategy. Firstly, the use of bucket counts to determine harvest areas and the high value of large prawns have in combination resulted in the consistent targeting of the largest prawns available during each fishing period (except December). The resultant serial decline in average prawn size was highlighted in 2008/09 and 2009/10 when available harvest areas encompassed the majority of large prawns in the population. Secondly, exploitation rates are linked explicitly to total biomass and not to biomass of harvestable prawns. During 2008/09, increases in total biomass, driven by increases in the biomass of small prawns, enabled increases in exploitation rates despite slight declines in the biomass of large prawns that were being targeted. Future harvest strategies should 1) ensure appropriate conservation of large prawns in the population for future egg production and 2) link exploitation with the biomass of harvestable prawns.

Commercial catch and effort data support the implied trends in population biomass and size structure from surveys. The proportion of large prawns in the commercial catch decreased slightly from 2006/07 to 2008/09 before declining considerably in 2009/10 to the lowest levels observed since the closure. Despite problems with commercial CPUE data, trends in CPUE were the same as trends in total biomass. Trends in commercial catch also followed these patterns but are more likely to reflect harvest strategy decision rules rather than biomass.

Commercial prawn size data indicate that growth overfishing occurred during 2009/10 as the procedures for reporting the capture of small prawns from the fleet to PIRSA via the Committee At Sea proved ineffective. This was highlighted by several occasions (from more than one vessel) where large catches (>1 t) of very small prawns (up to 40 prawns per kg) were harvested. Further, there is anecdotal evidence that substantial catches of very small prawns were dumped at sea and not recorded in commercial logbooks.

The decrease in biomass of large prawns may have been influenced by factors other than harvest strategy. Searching effort and area trawled have clearly reduced in recent years which represent a significant reduction in operating cost and habitat disturbance. In addition, there appears to have been a shift in the distribution of effort further south since the closure period (1993/94). It is unknown if the reduction and redistribution of habitat disturbance has affected the productivity of prawns in GSV. Also, it is plausible that density dependence in the growth rates of smaller size classes may have slowed the productivity of the population (Khoi and Fotedar 2010). Finally, there appears to be a strong inverse relationship between the abundance of snapper in GSV (very high) and Spencer Gulf (very low) and the abundance of both prawns and blue crabs (both low in GSV and high in SG) in recent years. While snapper are an important predator of both these crustacean species (Currie and Sorokin 2010), the magnitude of these potential effects is unknown.

Analyses of factors affecting survey catch rate suggest that the current approach to estimating relative biomass for the fishery is robust. The simple analytic approach of estimating relative biomass on an area based scale (using commercial reporting blocks) provided similar trends to the current approach. The inclusion of additional survey shots (up to 7 per survey) in some years did not influence trends either, likely due to the high number of consistent shots (107 total) among survey months and years. Finally, analysis of water temperature data (bottom and SST) suggest that

differences in water temperature among years would not explain the decrease in biomass observed during 2009/10. It should be noted that the Spencer Gulf Prawn Fishery is much larger in area and has an annual harvest >2,000 t, yet robust estimates of relative biomass have been obtained from approximately 200 survey stations for almost 30 years.

There is also uncertainty in other aspects of the assessment. Firstly, prawn size data obtained from commercial logbooks do not include data from all vessels. Also, there are several assumptions in the estimates of mean prawn size that have not yet been validated (e.g. differences in the mean size per grade among commercial graders.

6.2 Annual Performance Indicators of stock status

The Management Plan provides a suite of primary PIs and additional PIs to assess performance of the fishery in achieving the goal of stock recovery. However, several of the primary PIs do not relate to traditional measures of stock status but rather reflect adherence to harvest strategy decision rules. A more appropriate framework for the future Management Plan (to be revised in 2013) could be to have a primary 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 (i.e. mixed and large prawns combined) as these are the size grades of 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.

Several of the current PIs do not reflect stock status but could be useful for assessing “fishery status”. The PIs for total commercial catch and mean commercial CPUE are appropriate indicators for assessing fishery status. However it may be more relevant to apply traditional target and limit reference points to these PI to obtain a more accurate reflection of fishery status rather than the current approach of aiming for annual increases during the period of stock recovery.

The PI for mean prawn size has triggered in each of the last three years but the current approach provides no indication of how the size structure of the commercial catch has changed over time. A more appropriate approach to assess fishery status

would be to determine limit reference points against target-size criteria, even if this means splitting the PI into target-size categories for different harvest periods.

The current recruitment index is based on the catch rate of recruits from May 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 from March to May and thus it is suggested that the future annual recruitment index should reflect an average of recruitment across these months.

6.3 Harvest strategy

Harvest strategies provide the framework for managing effort in the GSVPF. Unlike most other fisheries, separate harvest strategies are determined for South Australia's prawn fisheries within each fishing year. In GSV, four harvest strategies (December, March, April and May) are determined using data obtained during fishery independent surveys conducted prior to fishing. Harvest areas are determined through a series of complex decision rules that primarily aim to link relative biomass with commercial exploitation rate, expressed as a proportion of access to the resource. While this approach is sound in principle, analyses in this report suggest that there are several limitations in their current application. These include: ineffective control of exploitation rates; inappropriate performance measures; failure to protect large prawns; inappropriate target size, and; ineffective at-sea management.

Of primary concern, exploitation rates are only constrained on a monthly basis and do not consider the overall status of the resource. After publication of the Plan, informal rules were developed to ensure that the percent increase/decrease in annual commercial catch did not exceed the percent increase/decrease in annual survey catch rates, measured as the mean (total) survey catch rate across March, April and May. It is unclear if this rule of thumb, which has been evoked in May for the last three years, is adequately conservative to prevent further declines in biomass. Formal rules for controlling annual exploitation are needed to ensure sustainable exploitation in the future. Alternative approaches to the current area based method for limiting exploitation, such as total catch or effort, could also be considered.

The rules regarding the level of exploitation for each harvest period must also be modified. Rules should be underpinned by annual stock status but should also take into account measures of current biomass from each survey. The existing

performance measure “total biomass” should be replaced by a measure for target-size prawns. We suggest that the biomass of “large” and “mixed” prawns should also be measured separately because of the importance of maintaining the biomass of large prawns. A measure of recruitment to the fishery should also be considered for harvest strategy decision rules. These “harvest strategy PIs” should have associated trigger, limit and target reference points established for each survey month.

The current target size that focuses on the largest prawns found each March, April and May should be reconsidered, particularly given the immediate need to increase the abundance of large prawns in the population. The high biomass of ‘mixed’ prawns (size grade 10/15 and 16/20) currently in GSV provides an opportunity to target exploitation on this size class while enabling the abundance of large prawns in the population to increase. The Spencer Gulf Prawn Fishery is economically viable harvesting a catch that comprises predominately 10/15 and 16/20 grade prawns albeit at much higher annual catches per vessel.

If different size classes are targeted (i.e. large and mixed), total exploitation rate must be split into an appropriate exploitation rate for each size class. Determining the appropriate exploitation rate for each size class may be difficult initially but as more surveys and fishing are conducted, a greater understanding of appropriate levels will be obtained. It is likely that the level of total exploitation applied for each fishing period in recent years was too high because as previously discussed, the informal annual exploitation rules were evoked in each of the last three years. In the short term, it would seem be prudent to reduce the total exploitation each month below the current levels of the Management Plan (12, 15 or 18%).

The use of bucket counts for determining harvest areas has become problematic in recent years due to mixing of size classes. An alternative approach could be to utilise grade data collected during surveys. For example, an appropriate rule for mixed prawns could be to target areas with a high proportion (e.g. >85%) by weight of the size grades 16/20 and 10/15. A similar strategy could be employed for the targeting of large prawns.

Rules regarding prawn size must prevent large catches of very small prawns (size grade 21+ and smaller) to avoid growth overfishing. The failure of the fleet to adequately report the harvest of very small prawns through the Committee-At-Sea during 2008/09 and 2009/10 is also of particular concern in this regard. In recent

years, a specific objective of the Management Sub-Committee when determining harvest strategies has been to open large areas for fishing when possible to allow fishers to search the area for target-size prawns. Unfortunately it is this practice that has resulted in regular harvests of prawns of sub-optimal size. Future harvest strategies should consider reducing the size of areas that fishers can operate within to increase compliance with size criteria among the fleet.

Recent analyses for the Spencer Gulf Prawn Fishery (Dixon *et al.* 2010) indicate that in years when substantial harvests were made in late February or early March, annual catches were lower. This is probably due to the rapid growth that occurs after the investment into reproduction has ceased in February/March in Spencer Gulf. Data on growth rate and reproductive investment indicate that these trends are also apparent in Gulf St Vincent. This suggests that optimal harvest for GSV would also involve low catches of prawns from December to March. This would be a particularly sensible approach given the high catches of small prawns harvested during March in recent years and the need to rebuild the biomass of large prawns in the population.

As pre-Christmas catches are fixed in the Management Plan (i.e. <30 t) to provide protection to the spawning biomass during stock recovery, the current status for the December survey does not influence harvest strategy development. Also, December surveys have proved the least reliable index of relative biomass as the catchability of prawns is affected by spawning condition. Consideration can be given to replacing the December fishery-independent survey with a structured spot survey conducted by industry. Similar data on catch rate, bucket count and grade weights would be required to determine appropriate harvest areas but this would provide a considerable reduction in cost. The level of catch for the December period should be explicitly linked to the PIs for annual stock status from the previous season. An appropriate alternative measure for egg production would also be required.

With the substantial increase in biomass of small and mixed prawns since 2004/05, the biological sustainability of the fishery appears sound. Advice provided in this report regarding harvest strategies suggests some of harvest strategy decision rules and Performance Indicators require modification. We also suggest that until an appropriate biomass of large prawns is replenished, exploitation rates should be conservative with an increased focus on mixed prawns. As a result, it is unlikely that the commercial catch in 2010/11 will exceed that obtained in 2009/10. This prognosis of stable or lower catches, including a higher proportion of prawns of less value, has

considerable and immediate economic implications for the fishery. This is particularly important given that the landed value (average beach price × production) of the fishery in 2009/10 ($2.57 M) was the lowest since 1994/95 (Knight and Tsolos 2011).

6.4 Future research

Future research objectives for the Gulf St Vincent Prawn Fishery have altered considerably due to the recent changes in stock status and economic outlook. The research program has developed over the past six years to provide cost-effective and reliable advice to inform assessment of the fishery and to underpin development of the harvest strategy. While the program does provide a sound platform for understanding the current status of the resource, arguably for the first time in the fishery's history, additional targeted research could improve outcomes for the industry.

The development of a fishery model could augment assessment, particularly for the determination of optimal harvest size (or mix of sizes). 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 six years may provide reliable estimates of these parameters. In turn, these data could be used to inform a fishery model.

The current economic status of the fishery will likely prompt consideration of alternative management arrangements to improve economic efficiency (e.g. the unitisation of catch or effort). While consistent fishery independent survey data have provided robust assessments of the resource, these data can also provide the framework for development of novel management approaches that may also fulfil the economic and social objectives of the fishery.

The current FRDC project 2009/069 "Bycatch and prawn size selectivity of conventional diamond versus novel trawl mesh" is investigating alternative gear types with the duel 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.

There is considerable uncertainty on the effects of the changes in effort distribution on the fishery. In particular, it is unknown if the reduction in the area trawled has

affected the productivity of the fishery. A well designed Before-After-Control-Impact (BACI) experiment in areas that have not been fished for several years could provide opportunity to understand these issues. Such an experiment could also involve further testing of alternative gear types.

An improved understanding of prawn grade data, including studies on the size composition of prawns within various grades and the variability between commercial grading machines would reduce the uncertainty associated with prawn grade data. Also, data from commercial processors would enable size data to be collected from "wet boats" in the fleet and would ensure validation of commercial prawn grade data from "freezer boats".

Several other key elements of the biology of *P. latisulcatus* of the Gulf St Vincent Prawn Fishery remain poorly understood, particularly regarding spawning and recruitment success and issues of prawn health. Finally, the collection of information to determine changes in fishing power of the fleet is needed for interpretation of the CPUE data that underpins performance assessment and the development of harvest strategies.

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8. APPENDIX

8.1 Surveys conducted between 1984 and 1995

Analysis of data from surveys conducted between 1984 and 1995 are not useful for determining trends in prawn abundance or biomass during this period. Interpretation of these data is limited by poor temporal replication, poor spatial replication, and uncertainty associated with changes in fishing efficiency. In the following sub-sections, trends in catch rate, prawns size and sex-ratio are presented at various temporal and spatial scales, with the primary aim of documenting these data.

The timing (years and months), location and number of surveyed shots varied considerably between 1984 and 1995 (Table 8.1a, b). Further, temporal replication with respect to the lunar phase was also highly variable (Table 8.2).

Shots were most frequently conducted throughout Regions 1, 2 and 5, sporadically conducted in Regions 3, 4 and IS, and infrequently conducted in the DH region (Table 8.1a, b). The two shots in the LH region were only surveyed during April 1985. There were no shots surveyed in Region 6 or the SDH region. Surveys were conducted on 1–5 occasions during each year. April was the month most frequently surveyed (9 of 12 years), followed by November and June (6 years each) and February (5 years).

Catch rate of prawns can be influenced by the lunar phase (Wassenberg and Hill, 1994; Primavera and Lebata, 2000). Table 8.2 provides information on the timing of surveys and the lunar cycle. From 1984 to 1995, surveys were inconsistent in both their duration (from 1 to 6 nights) and timing with respect to the lunar phase (from 1 night before the last quarter to 5 nights after the first quarter).

Data were pooled ignoring all temporal and spatial variability and are presented in Sections 8.1.1 and 8.1.2. Subsequent to these analyses, data were refined to constrain temporal and spatial variability by comparing between years and blocks for particular months of the year. The timing of surveys with respect to the lunar phase was not considered. Whilst this approach minimised bias in the data, results were uninformative and are not presented in this report.

Table 8.1a Stock assessment survey shots (shaded) conducted in blocks 1, 2, 3 and 4 of GSV from April 1984 to February 1995.

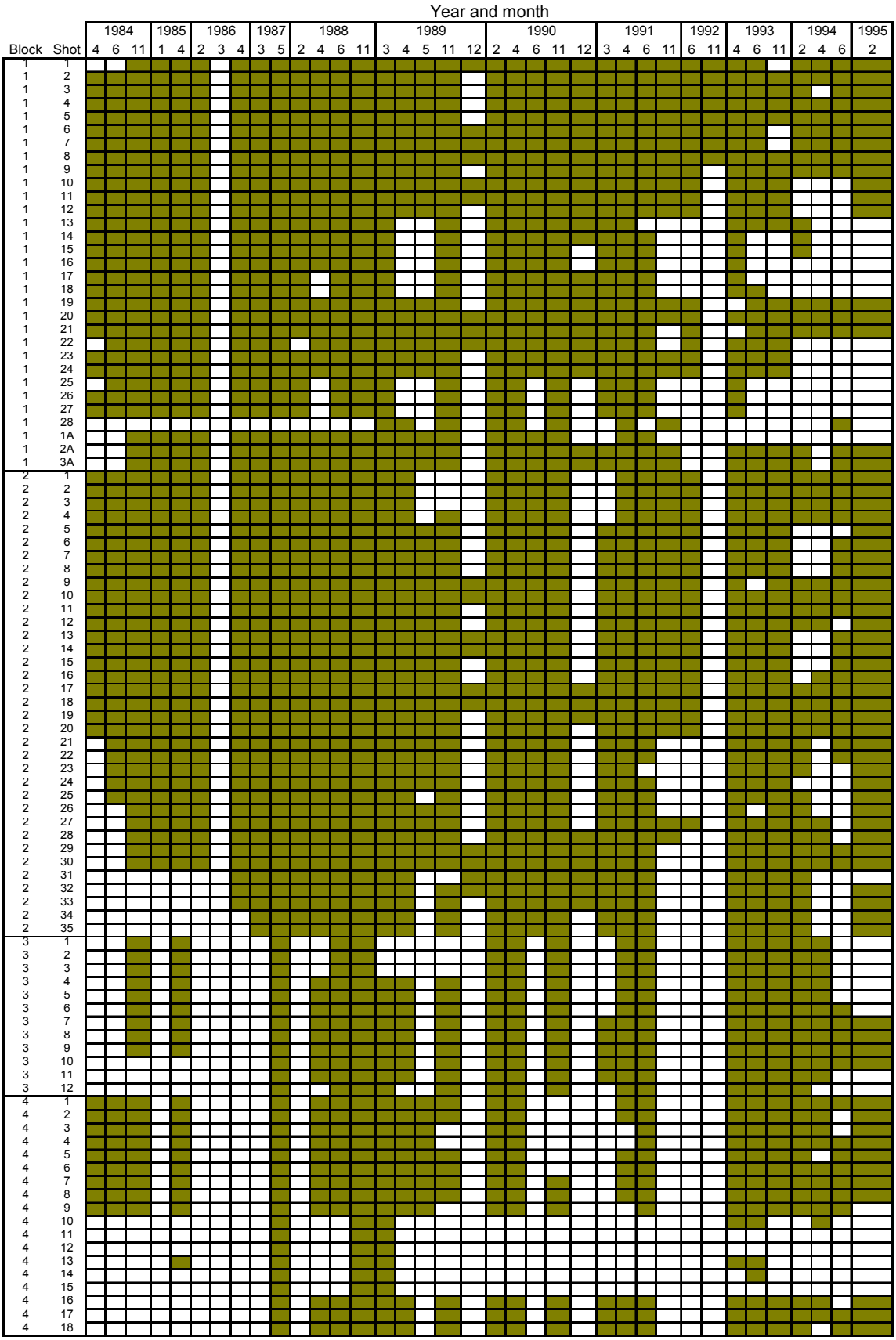

Table 8.1b Stock assessment survey shots (shaded) conducted in blocks 5, Deep Hole (DH), Little Hole (LH) and Investigator Straits (IS) of GSV from April 1984 to February 1995.

Table 8.2 The timing and number of stock assessment survey shots in relation to the new moon during surveys conducted in GSV from April 1984 to February 1995.

Night of the new moon **last quarter** **first quarter**

		Number of days from the new moon																					
Year	Month	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	10	11	12
1984	April																		20	34	20	15	
	June																			18	33	35	9
	November																	6	16	14	23	28	30
1985	January														27	15	31	13	15	6			
	April																	27	40	20	39		
1986	February																		18	18	40	29	13
	March			3	8																		
	April																			27	27	9	9
	June											1											
1987	March												8		54	41	15	8	7				
	May																	83	54	42			
1988	February				48	6	24																
	April				64	49	9																
	June				92	81																	
	November				80	72																	
1989	March				76	73																	
	April			77	74																		
	May					97																	
	November		66	59																			
	December	19																					
1990	February																					13	11
	February				90	42																	
	April			85	88																		
	June					12	15	15	15	14													
	November				88	51																	
	December				40																		
1991	March		74			15																	
	April		42	95																			
	June				50	48	40																
	November																25	25					
1992	June														18	19	8	9					
	November					8																	
1993	April				57	32	59																
	June				54	55	29																
	November				40	80																	
1994	February																	48	61				
	April			34	32																		
	June	20	36				26	17															
1995	February				89																		

8.1.1 Mean catch rate and prawn size from pooled data

Annual mean catch rate generally increased over the survey period (Figure 8.1). The lowest catch rate was obtained during 1984. The two highest catch rates (1992 and 1995) were obtained in years with the fewest number of survey shots conducted, and as such any interpretation should be made with caution. The mean annual prawn size increased over the survey period (shown as a decreasing number of prawns/kg).

Few seasonal trends in catch rate were apparent from pooled data obtained during 1984–1995 (Figure 8.2). That catch rate was lowest during January but peaked in February, further indicates the unreliability of these estimates. A strong seasonal trend in prawn size was evident, with an increasing number of prawns/kg observed, reflecting a general decrease in the mean size of prawns, particularly after February (Figure 8.2). This result is consistent with recruitment to the fishery.

Catch rate ranged considerably among regions, with lows of 3.9 and 4.0 kg/nautical mile (nm) in the Investigator Straits (IS) and Region 4, and a high of 11.7 kg/nm in the Deep Hole (DH) region (Figure 8.3). Of note, commercial CPUE was also lowest in the IS region and Region 4 for the period 2000/01–current (see Roberts *et al.*, 2008). However, CPUE was not highest in the DH region. The high DH catch rate presented here was likely due to the low number of shots conducted (123 shots), most of which were done during the latter years of the survey period (see Table 8.1b) when mean annual catch rates were highest (Figure 8.1).

Mean prawn size also varied considerably among regions (Figure 8.3). The number of prawns/kg was similar and lowest in Regions 3 and DH, reflecting a large mean prawn size. The number of prawns/kg was greatest (mean size the smallest) in Region 4 and Region 1.

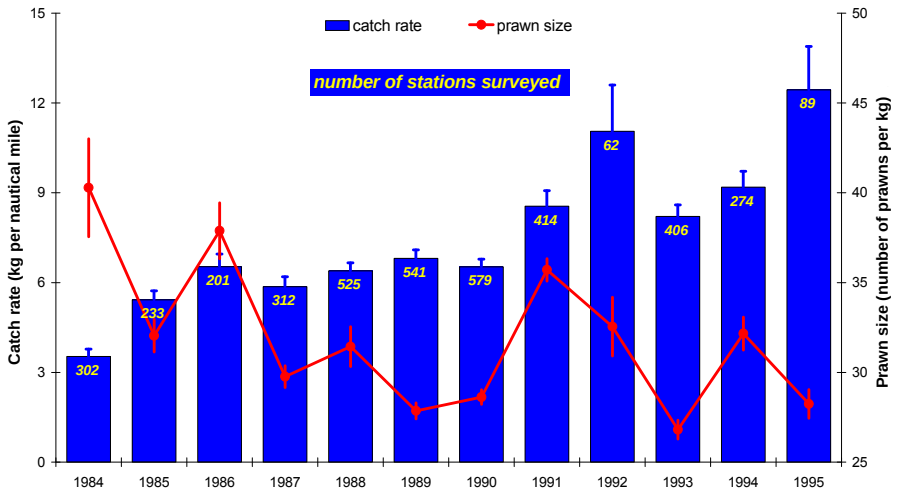

Figure 8.1 Mean (SE) catch rate (kg/nm) and the mean (SE) number of prawns/kg across months and blocks surveyed from 1984 to 1995 in GSV.

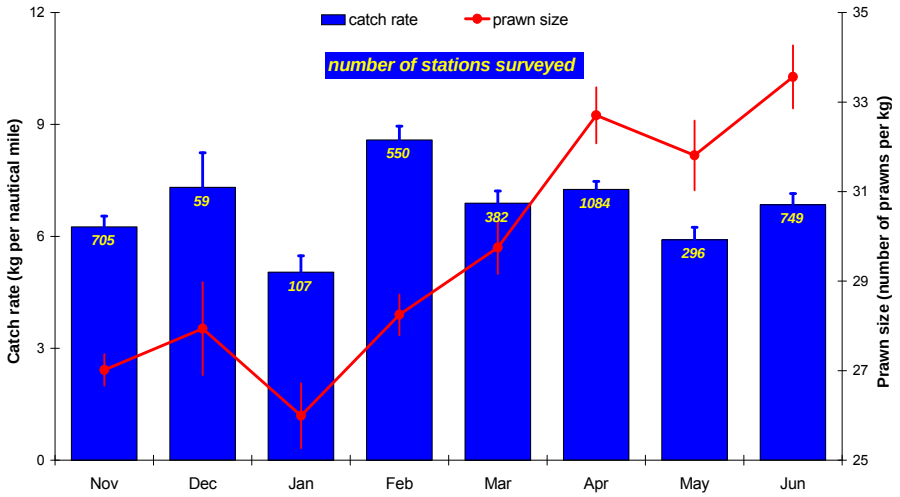

Figure 8.2 Mean (SE) monthly catch rate (kg/nm) and the mean (SE) monthly number of prawns/kg across years and blocks surveyed from 1984 to 1995 in GSV.

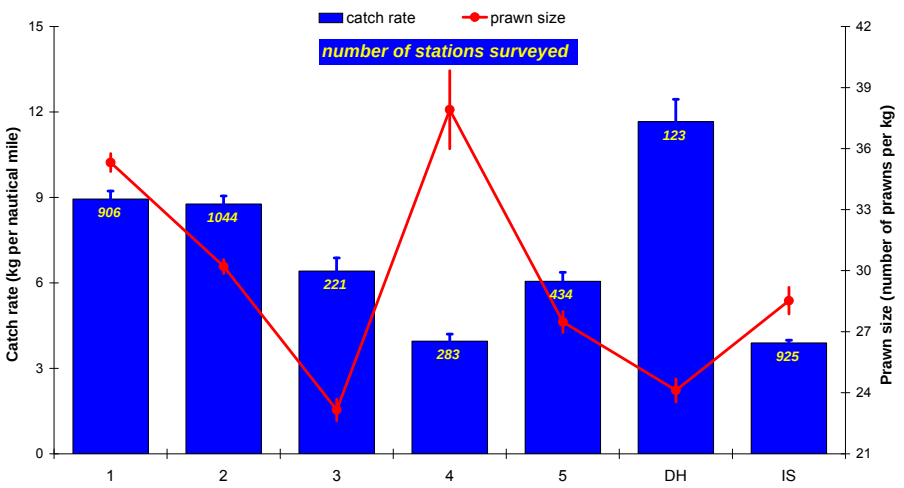

Figure 8.3 Mean (SE) regional catch rate (kg/nm) and the mean (SE) regional number of prawns/kg across years and months surveyed from 1984 to 1995 in GSV.

8.1.2 Sex ratio from pooled data

The proportion of males in the sampled population ranged from 47.1–53.7% during 1984–1995 (Figure 8.4). Few trends in sex-ratio can be meaningfully ascertained.

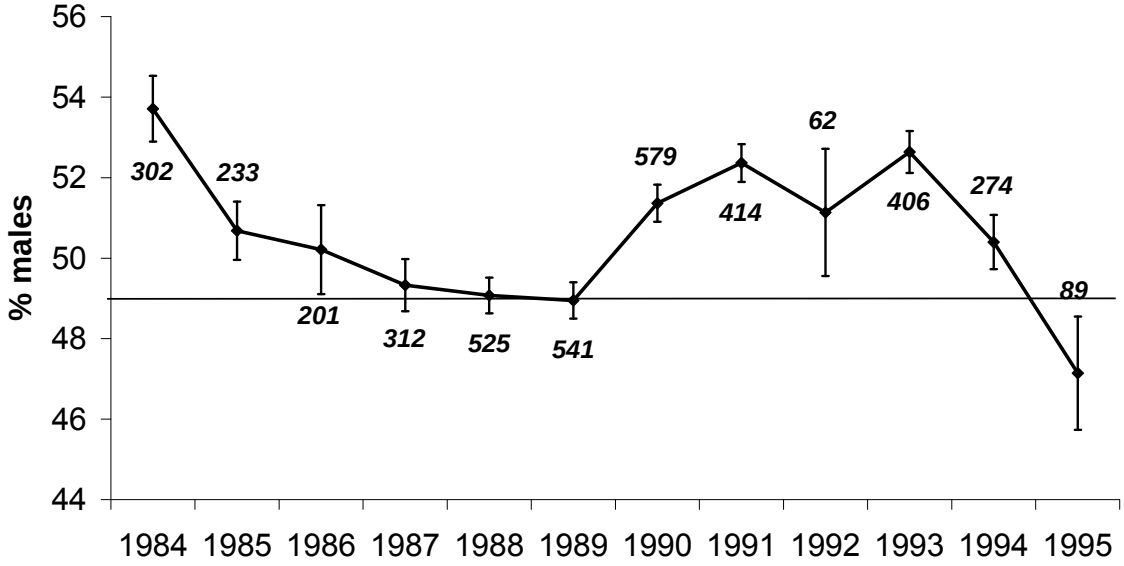

Figure 8.4 Mean (SE) annual % of males in the sampled population from GSV surveys done during 1984–1995. Numbers indicate the numbers of shots done.

The % of males in the sampled population varied between months (Figure 8.5). Sex-ratio was generally female biased during the spawning season (Nov-Mar) and male biased thereafter. These results are consistent with other fishery-independent survey data (see Section 3.3.3).

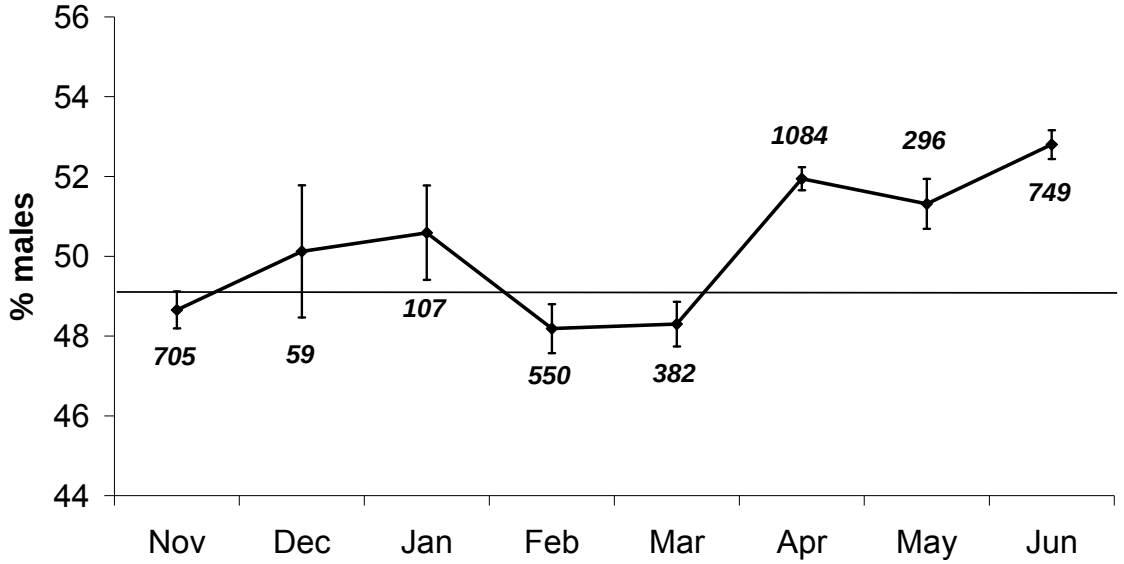

Figure 8.5 Mean (SE) monthly % of males in the sampled population from GSV surveys done during 1984–1995. Numbers indicate the numbers of shots done.

8.2 Fishery-independent on-board observation

Fishery-independent observer data were collected during fishing operations on commercial vessels in the GSVPF between 1993/94 and 2003/04. Data were not collected during 2004/05. Observers collected one bucket of prawns (~7 kg) randomly from the commercial catch, usually on 1–4 occasions during each fishing night. The weight of the sample was not measured and was assumed as 7 kg for analyses. Prawns were sorted into males and females and the carapace length measured to the nearest mm. Prawn samples were not collected during fishery-dependent survey shots (see Section 2.4).

During 1993/94, >30,000 prawns were measured (Table 8.3). The number measured reduced over the next seven fishing years, with <3,000 measured during 2000/01. From 2001/02 sampling again increased, with >9,000 measured during the three following fishing years. The number of prawns measured declined thereafter with 2,901 measured during 2000/01. Sampling increased from then, with >9,000 prawns measured in the following 3 years.

In 1997/98, 23 fishing nights were sampled, representing 5.2% of the 439 fishing vessel nights for the fishing year. Over the next three fishing years sampling reduced, with 7 nights (1.6% of total vessels nights) sampled in 2000/01. From 2001/02 to 2003/04, >20 nights (representing >5% of total vessel nights) were sampled each fishing year. Of the ten licensed vessels in GSV, at least 6 vessels were sampled in each fishing year between 1997/98 and 2003/04. During 2001/02, samples were measured on-board all 10 vessels.

Table 8.3 Sampling details from on-board observation on commercial vessels in the GSVPF between 1993/94 and 2003/04. Sampling detail, other than prawns measured, was not available for the 1993/94 to 1996/97 fishing years.

fishing year	93/94	94/95	95/96	96/97	97/98	98/99	99/00	00/01	01/02	02/03	03/04
nights sampled					23	16	12	7	25	25	21
vessel nights					439	446	486	450	461	503	376
% of vessel nights					5.2%	3.6%	2.5%	1.6%	5.4%	5.0%	5.6%
vessels surveyed					7	6	8	6	10	8	7
buckets measured					59	42	35	17	54	65	65
prawns measured	31,693	25,067	22,089	8,618	9,934	7,129	4,885	2,901	9,037	10,186	11,434

8.2.1 Trends in sex-ratio and prawn size of the commercial catch

The proportion of males (sex-ratio) observed in the commercial catch varied from 46–55% between 1993/94 and 2003/04 (Figure 8.6). There were no consistent trends in sex-ratio observed during this period.

Mean prawn size harvested was within the limit reference (27 prawns/kg; Zaccharin 1997) during all years (Figure 8.6). It was largest during 1993/94, 1994/95, 1998/99 and 1999/2000, exceeding the target reference (24 prawns/kg) in each of these years. These years correspond with the first two years after the closure, and the year of and prior to the contemporary peak catch (400 t, 1999/2000). Few other trends in prawn size were evident.

Sex-ratio and prawn size of the annual catch are likely to be influenced by: the seasonal distribution of the catch; changes in management practices such as targeted prawn size, and; the introduction of gear changes such as the use of square mesh cod-ends.

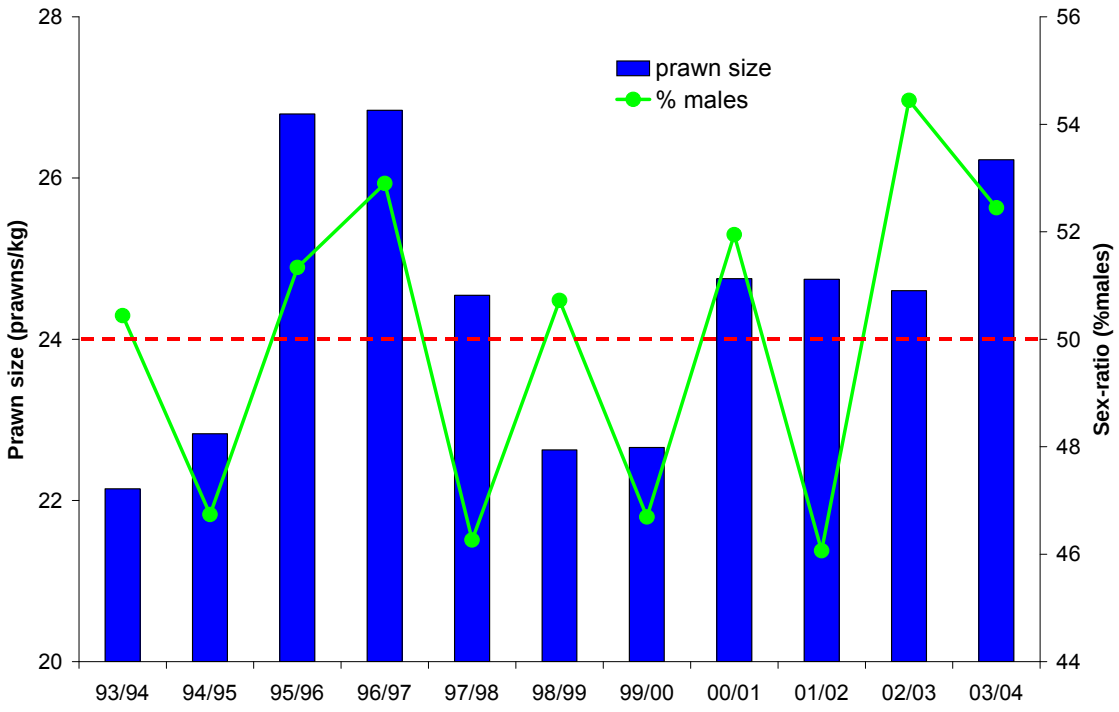

Figure 8.6 Sex-ratio (% males) and prawn size (prawns/kg) from data collected during commercial fishing operations in GSV from 1993/94 to 2003/04. The dotted red line indicates the target-size of 24 prawns/kg and an equal sex-ratio.

The mean and modal size (mm CL) of female prawns was larger than that for males during all years from 1993/94 to 2003/04 (Figures 8.7a, b). The modal size of male prawns was 35–39 mm during 1995/96, 1997/98, 2001/02 and 2003/04, and 40–44 mm during all other years. The modal size of female prawns was 50–54 mm during 1993/94, 1998/99 and 2002/03, and 45–49 mm during all other years.

The mean size of female prawns was highest during 1993/94 (48.5 mm), immediately following the closure. Female mean size declined to 44.5 mm in 1996/97, before increasing to 48.3 mm in 1998/99. Mean size decreased again thereafter to 45.5 mm in 2003/04. The mean size of male prawns followed similar trends to female prawns, however the highest mean size (40.5 mm) was attained in 1999/2000.

Mean carapace length of both male and female prawns fluctuated between 1993/94 and 1998/99, and declined substantially thereafter (Figure 8.7b).

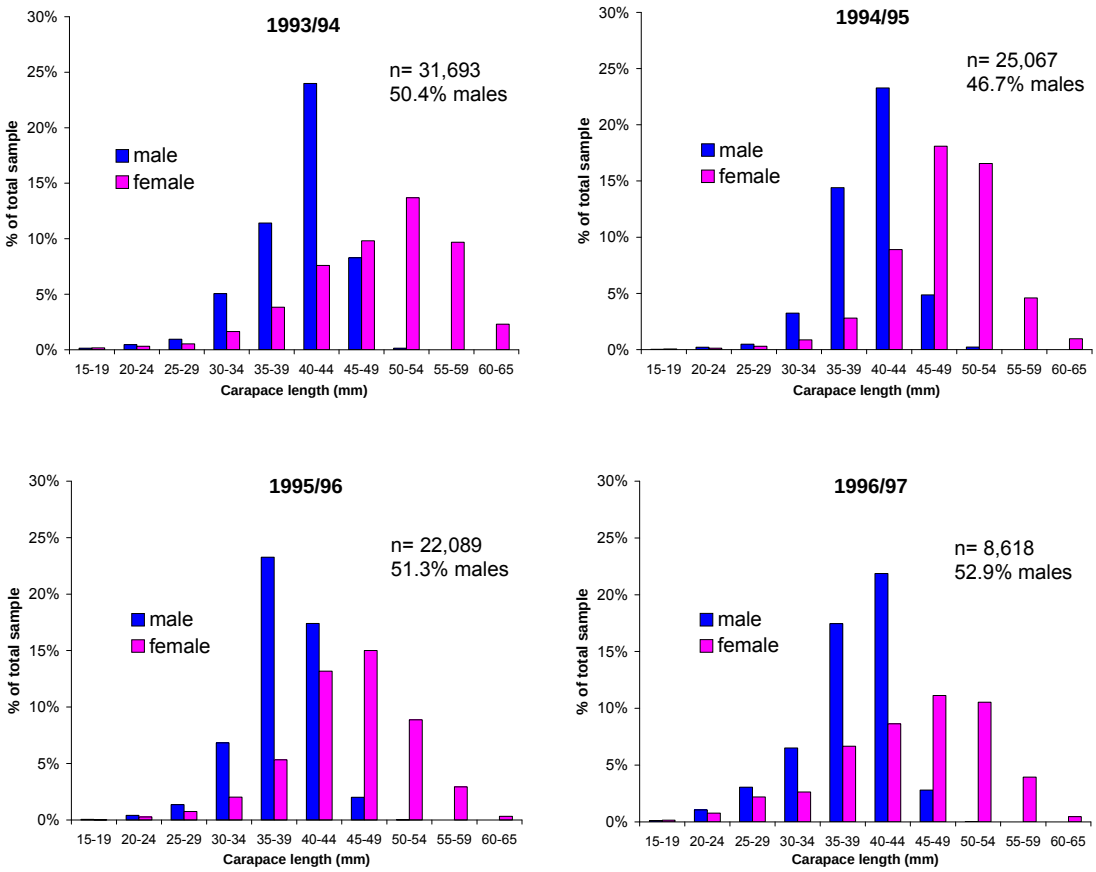

Figure 8.7a Size-frequency distributions from data collected during commercial fishing operations in GSV from 1993/94 to 1996/97.

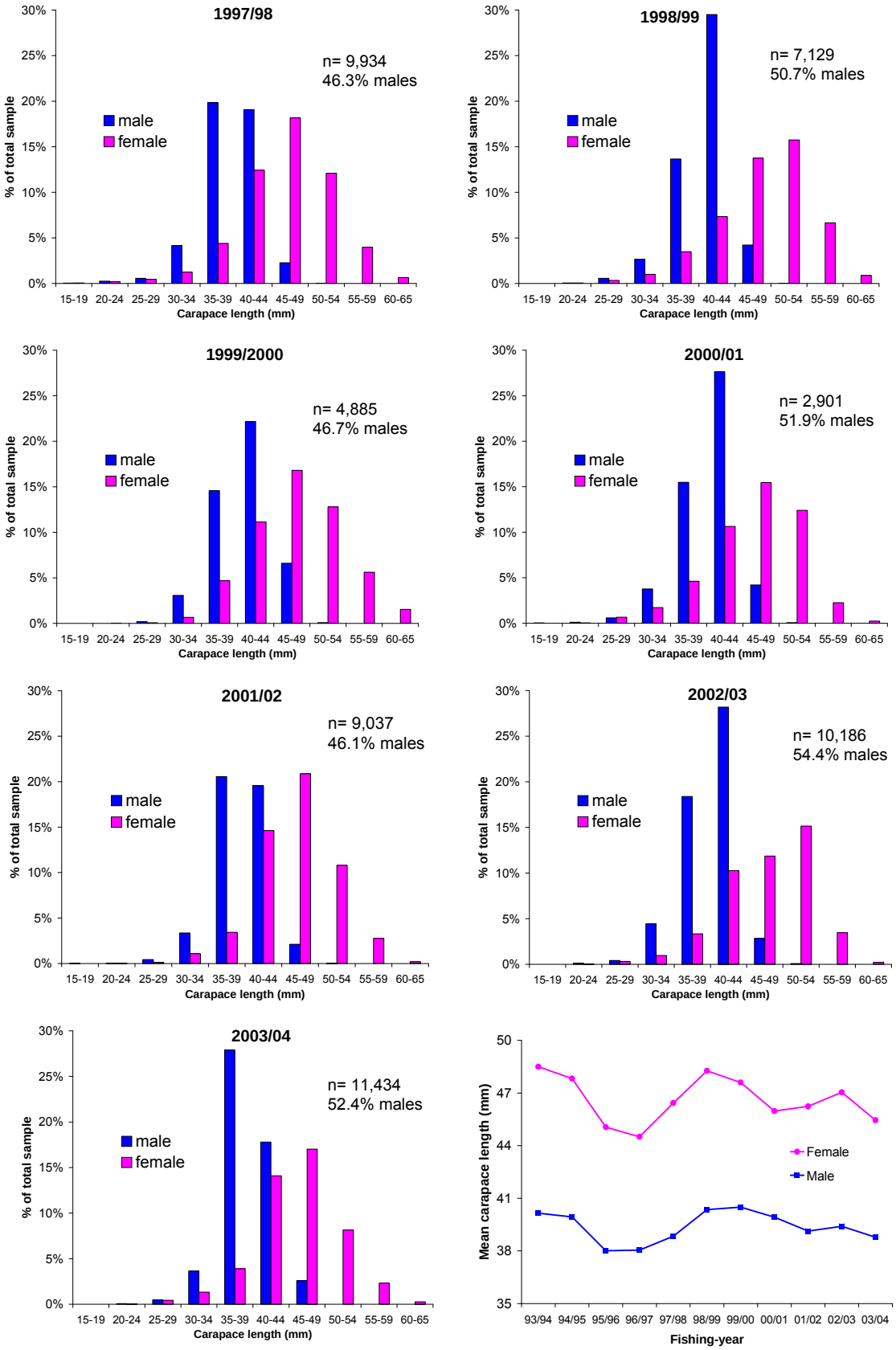

Figure 8.7b Size-frequency distributions from data collected during commercial fishing operations in GSV from 1997/1998 to 2003/04, and mean size (mm CL) of male and female prawns measured from 1993/94 to 2003/04.

8.3 Historical fishery-dependent catch and effort data

8.3.1 Regional catch in Investigator Strait

Investigator Strait (IS) is the most southern region in the current GSVPF (see Figure 3.1), which was separately managed between 1975 and 1986/87. Prawn catches were first recorded from IS in 1975/76 (139 t, Figure 8.8). Catches steadily increased until a peak catch of 177 t was harvested from IS in 1978/79. The first three years of harvest in IS coincided with the years of peak total catches for the fishery. Catches in IS reduced by ~50% between 1978/79 and 1979/80 (82 t), and continued to fall steadily thereafter. In 1986/87, only 12 t were harvested from IS and the separate management arrangements were removed. From 1993/94 to 2001/02, catches in IS ranged from 1–40 t (0.4–17% of total catch), while in more recent years from 2002/03 to 2007/08, catches have ranged from 22–61 t (10–35% of total catch).

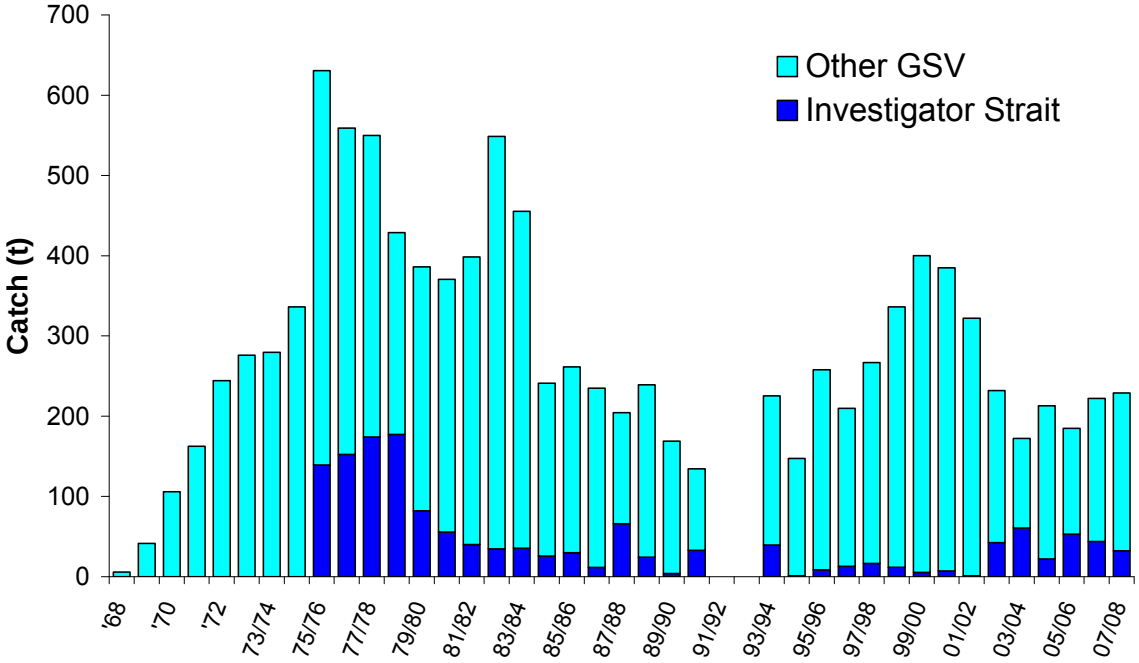

Figure 8.8 Total catch (t) from Investigator Strait and all other regions of GSV from 1968 to 2007/08. Data for 1968–1973 are reported as calendar year. Data for 1973/74 are from January to October 1974. From 1974/75 data are reported in fishing years.

8.3.2 Inter-annual trends in CPUE and mean prawn size

Between February 2000 and March 2004 only, industry vessels recorded data (additional to compulsory logbook information) from 6,282 searching shots. Data collected by fishers during these surveys included date, vessel, shot number, prawn size (number of prawns in a standard bucket, ~7 kg), catch rate (1 net) and some location information. Survey dates were not provided for 350 survey shots (6%) and these data were discarded. Data on catch rate were available for all survey shots, whereas prawn size data were only available for 69% of survey shots. Catch rate data were scaled up (scaling factor dependent on the use of double or triple-rig trawl gear) to be comparable with commercial CPUE.

CPUE was similar during 2000/01 and 2001/02 and similar but substantially lower in 2002/03 and 2003/04 (Figure 8.9). The number of prawns/kg was similar during 2000/01 and 2001/02, increased during 2002/03 and further increased during 2003/04. This reflects decreasing mean prawn size over this period.

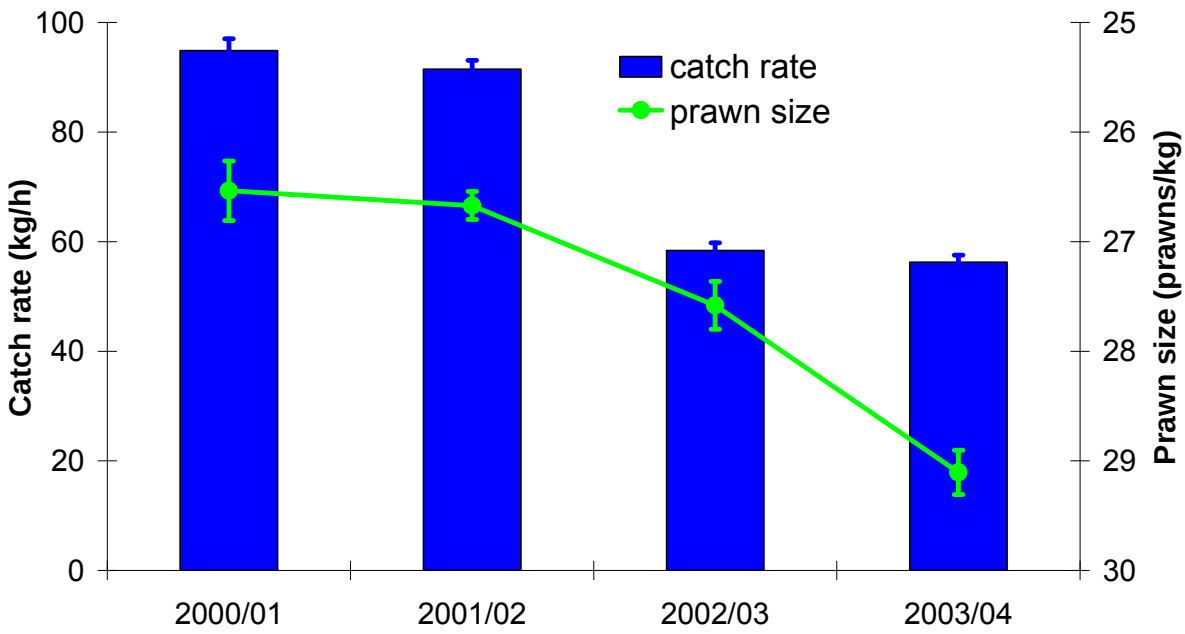

Figure 8.9 Mean (SE) catch rate (kg/h) and mean (SE) prawn size (prawns/kg) from searching shots conducted between 2000/01 and 2003/04.

8.4 Surveys conducted during May from 2003 to 2008

Surveys conducted on the dark of the moon in May from 2003 to 2008 provide a longer time series of May data than the current survey structure which commenced in December 2004. Data are presented here for a subset of 71 common shots surveyed in May each year for total catch rate and 56 common shots for recruitment data.

8.4.1 Inter-annual trends in total catch rate and mean prawn size

Mean total catch rate (kg/h) during May 2003–2008 ranged from 43.1 kg/h (2005) to 88.9 kg/h (2008) (Figure 8.10). Mean catch rate was significantly greater in 2008 compared to 2003–2006 ($F_{5,415}$=5.03, P<0.001). Mean prawn size (prawns/kg) was smallest during 2008 (34.8 prawns/kg) and largest during 2004 (30.7 prawns/kg). However, differences in prawn size among years were not statistically significant ($F_{5,398}$=1.53, P>0.05).

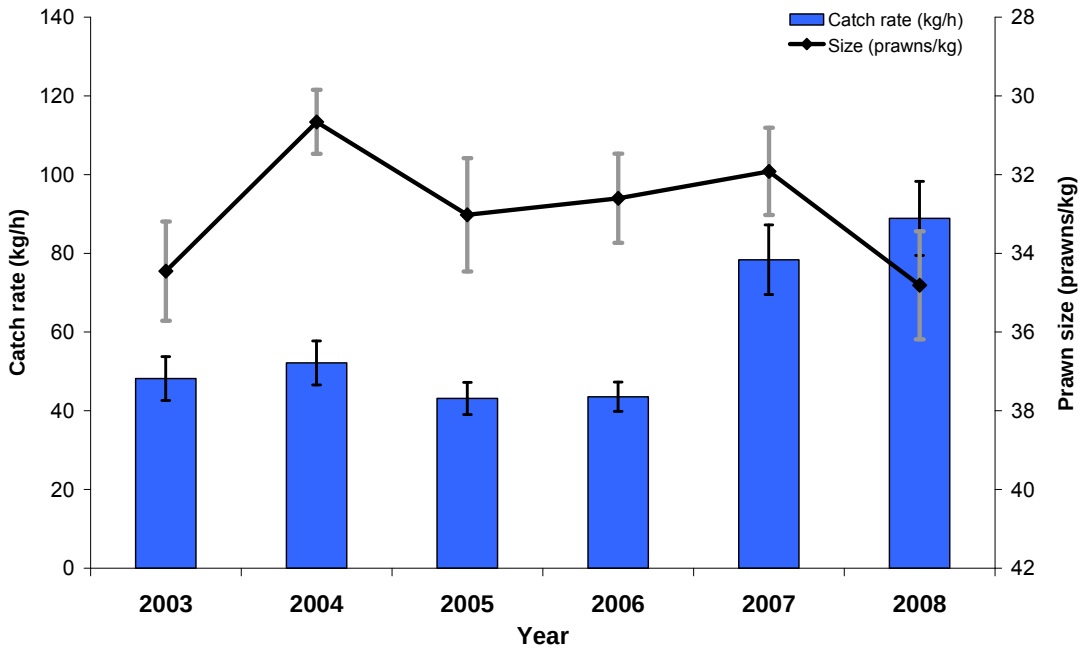

Figure 8.10 Mean (SE) catch rate (kg/h) and mean (SE) prawn size (prawns/kg) from May surveys between 2003 and 2008. Estimates compared from up to 71 trawl shots each year.

8.4.2 Inter-annual trends in recruits

Recruits are defined as male prawns < 33 mm CL and female prawns < 35 mm CL. Mean catch rate of recruits during May between 2003 and 2008 significantly varied among years ($F_{5,320}$=4.67, P<0.001) (Figure 8.11). Recruitment increased

substantially and consecutively from 2004 (235 recruits/h) to 2008 (800 recruits/h). Uncertainty in the estimates of recruitment include: insufficient sample sizes for length frequency data; insufficient number of survey shots; or, errors associated with differences in gear types (e.g. square mesh cod-ends).

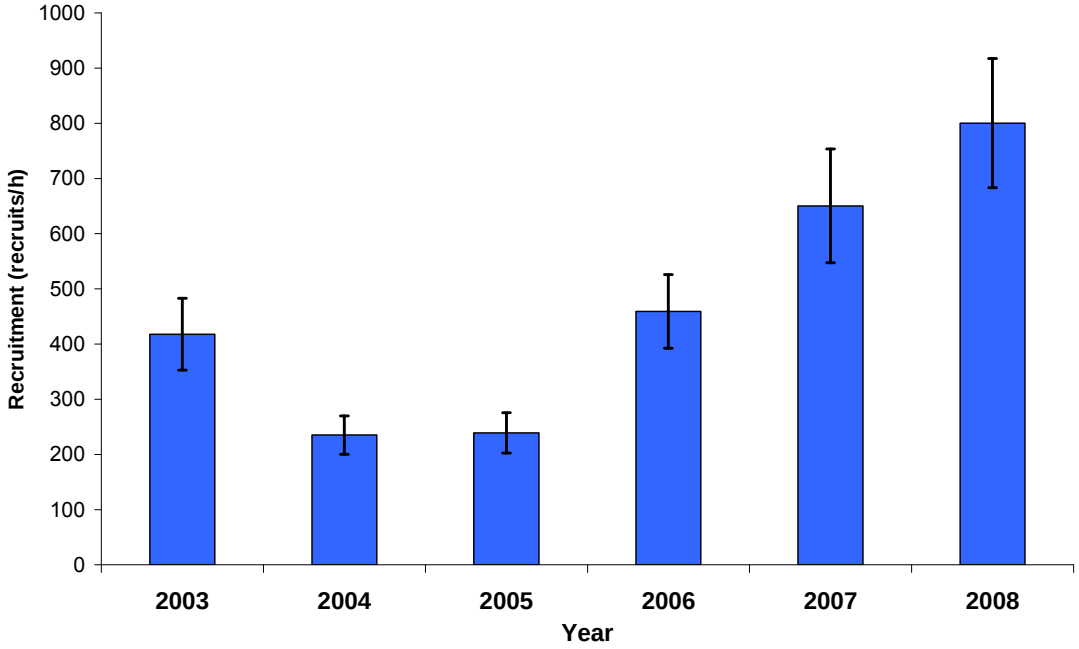

Figure 8.11 Mean (SE) number of recruits per trawl hour from May surveys between 2003 and 2008. Estimates compared from up to 56 trawl shots each year.

8.5 Egg production model

The egg production model is used to assess potential egg production between years, and is an additional performance measure in the Management Plan. Current assumptions of the model include:

- 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,
- 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 (see Sections 1.4.2 and 1.4.6) and on prawn grades obtained from commercial processors were used in the model. Also, fertilisation success for each size grade was determined visually from figures presented by Courtney & Dredge (1988). The following steps (1–11) describe the estimation of egg production and Table 3.3 presents the associated values:

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 hour was calculated directly from prawn grade weight data collected during each December survey.
8. Data from 7) and 1) were used to calculate the mean (SE) number of prawns captured per shot.
9. The proportion of female prawns in each prawn grade was calculated from sex-specific length-frequency data collected during December surveys in 2004 and 2005.

10. Data from 8) and 9) were used to calculate the mean (SE) number of female prawns captured per hour.
11. Data from 3), 4), 5) and 10) were used to calculate the number of potential fertilized eggs (million) per hour that captured females could have contributed to egg production.

Table 8.4 Model parameters and an example of the egg production estimate determined from the December 2007 survey.

Prawn grade	21+	16-20	10-15	U10	U8
Mean individual weight (g)	16.7	26.3	37.0	50.0	62.5
Mean CL (mm)	31.3	37.2	42.3	47.3	51.5
Eggs per female	119745	216987	338534	500303	668900
% mature	23.7%	57.5%	84.9%	95.3%	98.1%
Spawning frequency	3	3	3	3	3
Fertilisation success	40.0%	85.0%	90.0%	98.0%	99.0%
Mean catch rate (kg/h)	3.8 (0.5)	18.0 (2.0)	18.3 (2.2)	7.2 (0.9)	3.4 (0.5)
Prawns per hour	230.6 (31.9)	683.9 (74.6)	494.5 (58.1)	143.2 (18.2)	53.9 (8.3)
% females	18.85%	29.93%	43.78%	92.62%	99.08%
Females per hour	43.5 (6.0)	204.7 (22.3)	216.5 (25.4)	132.6 (16.8)	53.4 (8.2)
Eggs (million per hour)	1.5 (0.2)	65.2 (7.1)	168.0 (19.7)	185.9 (23.6)	104.0 (16.1)

8.6 Satellite imagery of monthly average SST (°C)

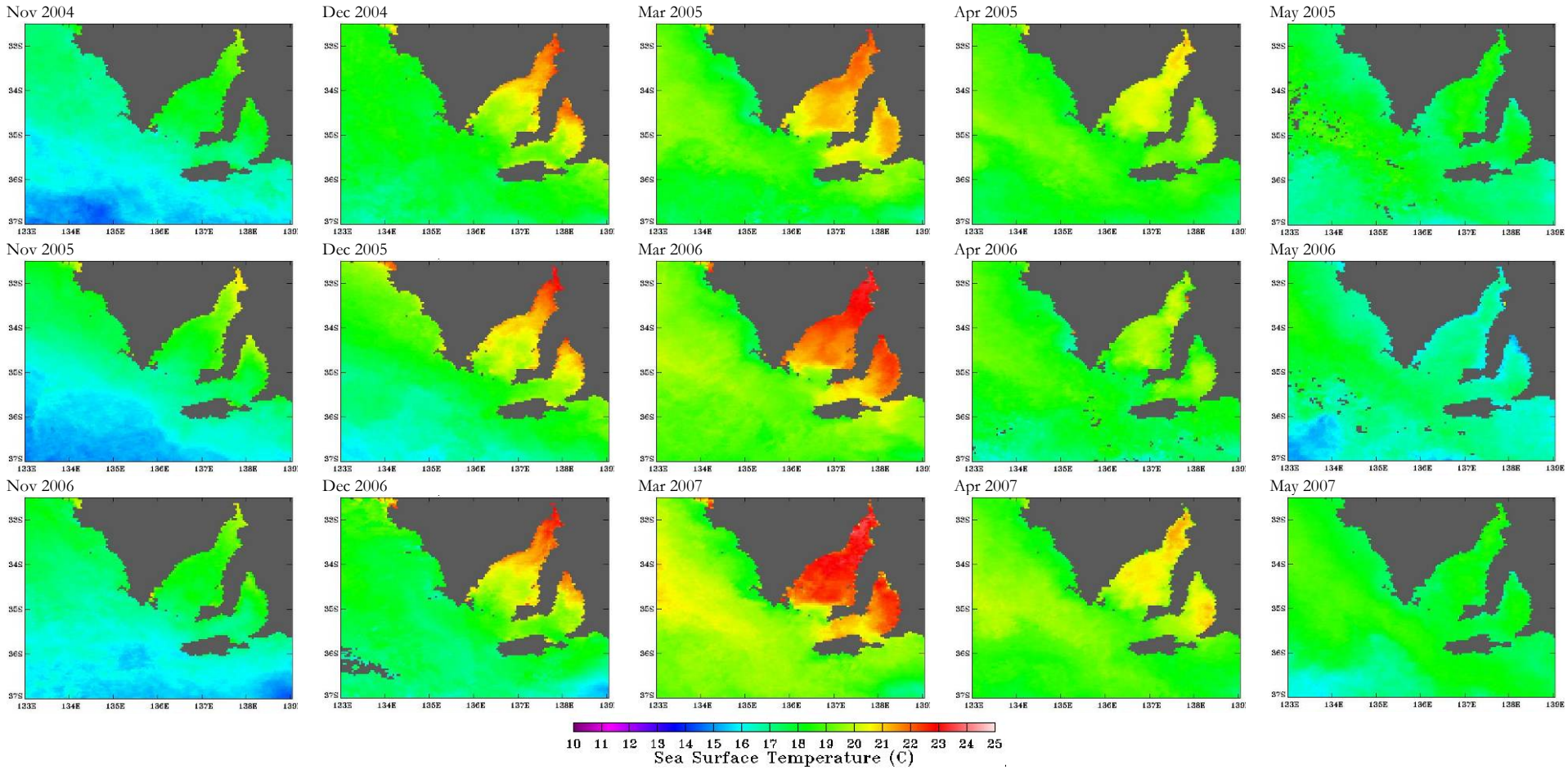

Figure 8.12 Satellite imagery of monthly average SST (°C) for South Australia's gulf regions during November, December and March–May between 2004/05 and 2006/07. Maps were obtained from the PODAAC website (http://poet.jpl.nasa.gov).

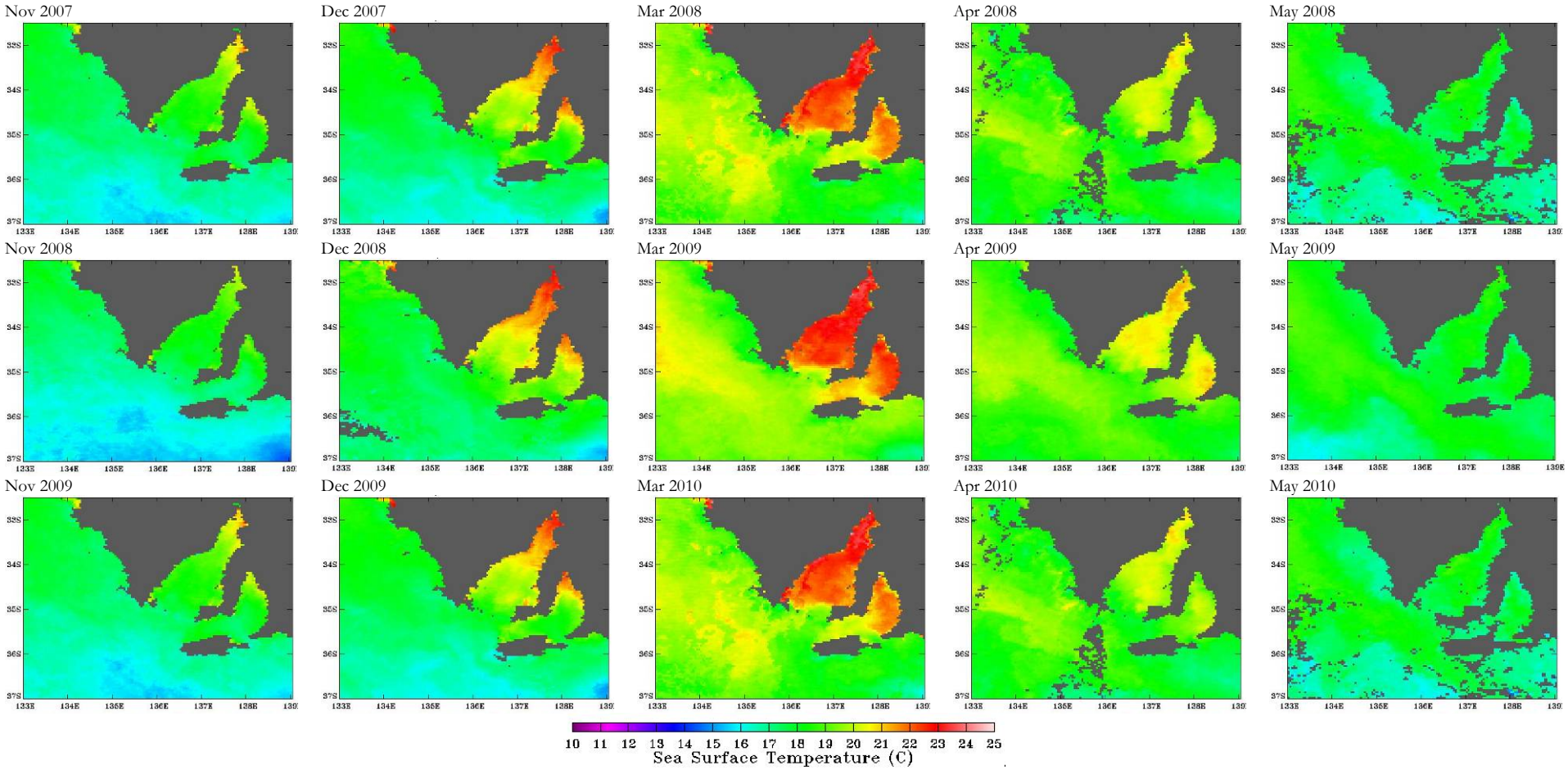

Figure 8.13 Satellite imagery of monthly average SST (°C) for South Australia's gulf regions during November, December and March–May between 2007/08 and 2009/10. Maps were obtained from the PODAAC website (http://poet.jpl.nasa.gov).