

Fisheries



Gulf St Vincent Prawn, *Penaeus (Melicertus) latisulcatus*, Fishery 2010/11



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

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SARDI Aquatic Sciences
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Government
of South Australia

Fishery Assessment Report to PIRSA Fisheries and Aquaculture

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This report documents the 2010/11 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 2009/10 and analyses data from the 2010/11 season as part of SARDI Aquatic Sciences' ongoing assessment program for the Gulf St Vincent Prawn Fishery (GSVVPF). The aims are to: (1) synthesise information for the GSVVPF; (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 current biomass of prawns in GSV is significantly higher than it was in 2004/05 when regular fishery-independent surveys were first conducted but has declined since 2008/09.
3. Commercial catch increased from 187 t in 2005/06 to 288 t in 2008/09 but declined to 178 t in 2010/11. Commercial CPUE followed similar trends, reaching an historic high of 113.1 kg/h in 2008/09 then declined to 72.2 kg/h in 2010/11.
4. Standardised estimates of survey catch rate were similar to nominal estimates for all survey months and appear to be a robust measure of relative biomass for the fishery.
5. In recent years declining trends in mean prawn size were observed in both fishery independent survey data and commercial catches. During 2009/10, the relative biomass of large prawns was significantly lower than in 2004/05. With a substantial increase in the biomass of mixed prawns (10-15 and 16-20 prawn grades) in the population, harvest strategies developed during 2010/11 deliberately targeted this size class. While the catch rate of mixed prawns declined, there was no significant difference in the catch rate of small (20+ grade) or large (U10 and larger) prawns in 2010/11.
6. Two recent, significant management changes have been implemented for the fishery. Firstly, a "tradeable nights" system was introduced in December 2011 to facilitate increases in economic efficiency among the fleet. Secondly, T90 cod-ends with grids were introduced into commercial fishing operations in March 2012. These changes will result in a period of transition for the harvest strategy where a flexible management framework will be required.
7. Investment in fishery-independent surveys during the last seven fishing years has provided a reliable index of relative biomass for fishery assessment. Despite changes in the survey design beginning 2011/12, relative biomass estimates should remain as the primary source of information upon which to base future management decisions.
8. Although total biomass declined for the second consecutive season in 2010/11, the biomass of large and small prawns was stable between years which is important for future egg production and recruitment to the fishery, respectively. Given the declining trends in biomass, total catch in 2011/12 should be lower than the 178 t harvested in 2010/11.

1. GENERAL INTRODUCTION

1.1 Overview

This Fishery Assessment Report for the Gulf St Vincent Prawn Fishery (GSVVPF) 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 GSVVPF; (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. Since 2004/05, fishery-independent stock assessment surveys have been conducted prior to each fishing period and are the principal source of data for assessment and management. Measures of relative biomass from these surveys 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 GSVVPF (Dixon *et al.* 2011) with data from the fishing year: 2010/11. This improvement in the timing of reporting was deemed necessary following the identification of issues with the current stock status.

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 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.

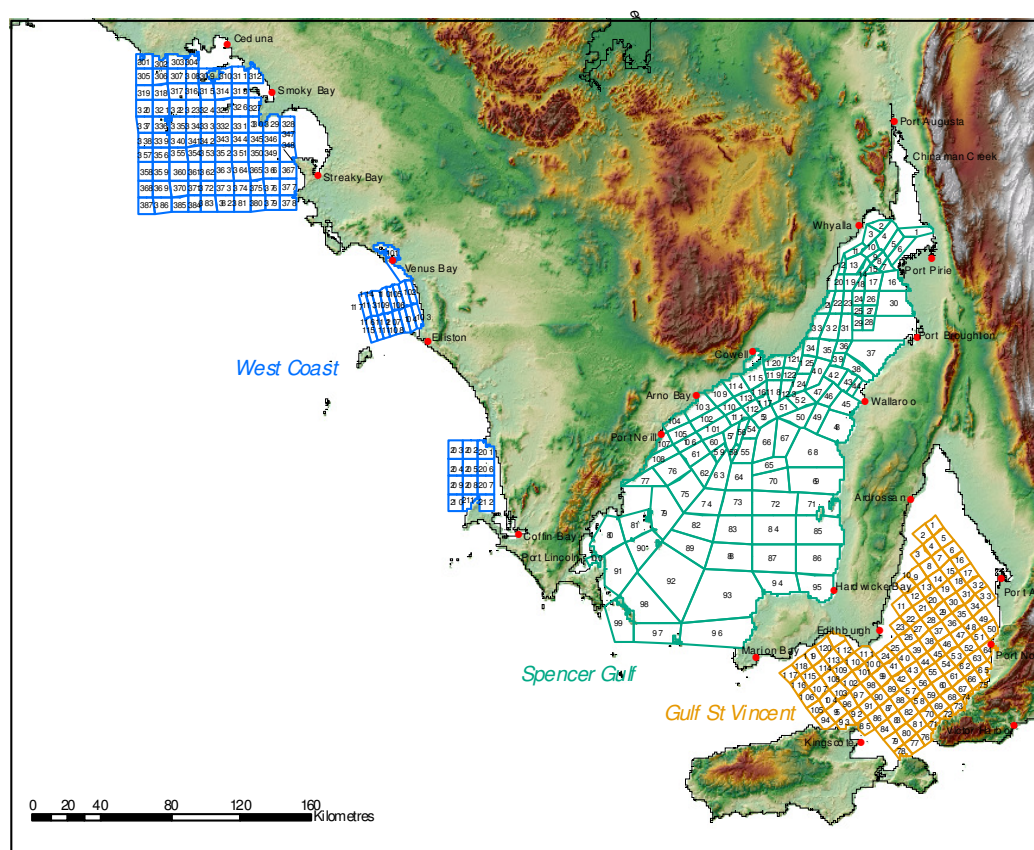


Figure 1.1 Location of South Australia's three western king prawn fisheries.

1.2.2 GSV environment

GSV is a large, relatively shallow embayment (generally <40m depth) that has 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 acting 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.

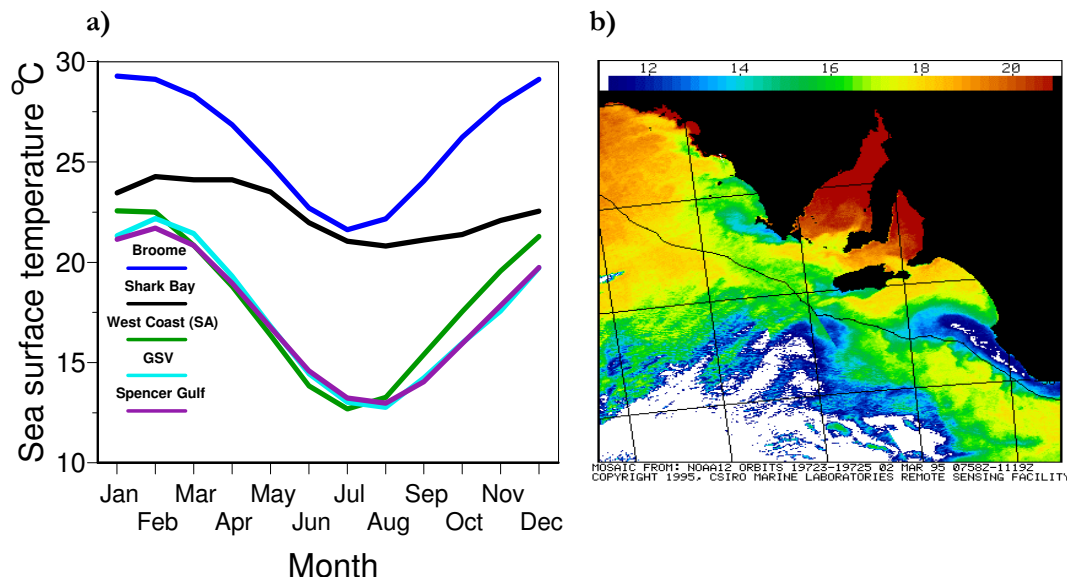


Figure 1.2 Comparison of mean monthly sea surface temperature (SST, °C) for the Australian prawn fisheries that target *P. latisulcatus*. Figure reproduced from Carrick 2003. **1.2b** Sea-surface temperatures over the continental shelf of South Australia during late summer/early autumn, 1995. A colour-coded 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).

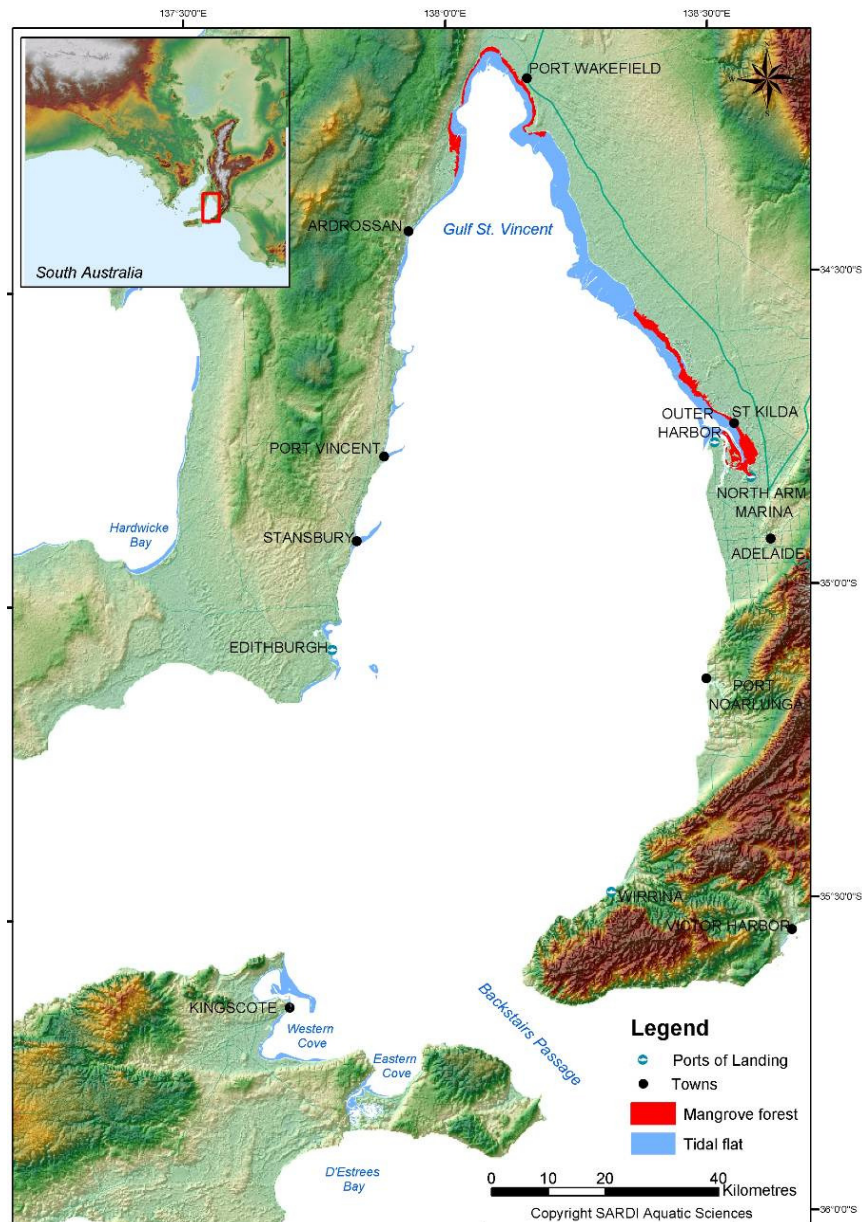


Figure 1.3 Important juvenile nursery habitat, mangrove forest and tidal flats, around coastal Gulf St Vincent. Reproduced from Bryars (2003).

1.2.4 Commercial fishery

The GSVPF is a single species fishery that targets the western king prawn, *Penaeus (Melicertus) latisulcatus*. 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).

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.

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 traditional aboriginal and illegal fishing are considered negligible (Anon 2003).

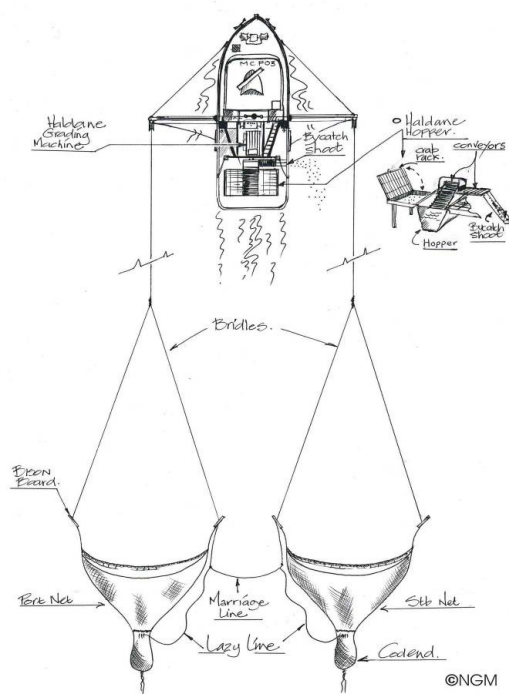


Figure 1.4 Double rig trawl gear and location of hopper sorting and prawn grading systems used in the Spencer Gulf Prawn Fishery. Figure from Carrick (2003).

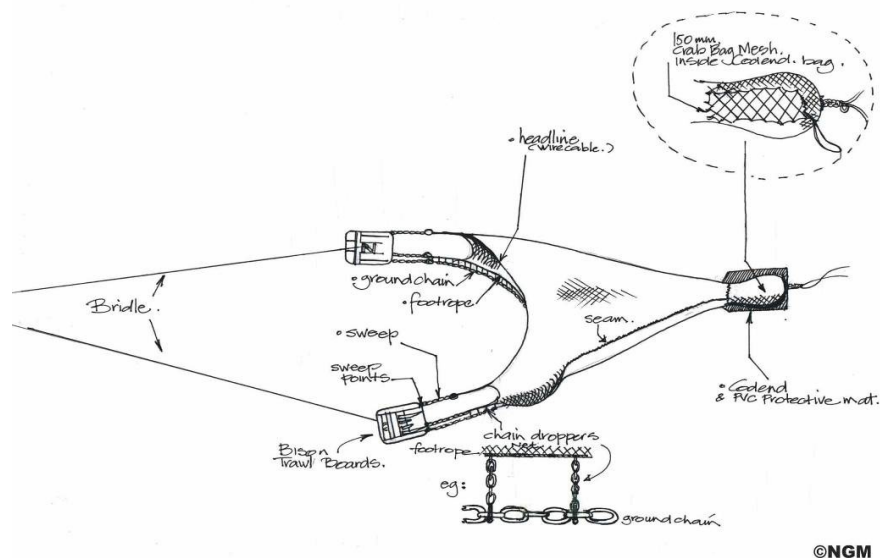


Figure 1.5 Trawl net configuration showing trawl boards, head rope, ground chain and cod end with crab bag. Figure from Carrick (2003).

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

Key management milestones are 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, following an independent survey that is 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.

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 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.

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 a 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).
2011	Review undertaken by Cobalt (Knuckey <i>et al.</i> 2011)

Table 1.5 Current management arrangements

Management tool	Current restriction
Permitted species	<i>Penaeus (Melicertus) latisulcatus</i> , <i>Ibacus</i> spp., <i>Sepioteuthis australis</i>
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

1.3.4 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 coordinator 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. 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*.

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.* 2012).

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 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 = $a \times \text{carapace length}^b$

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

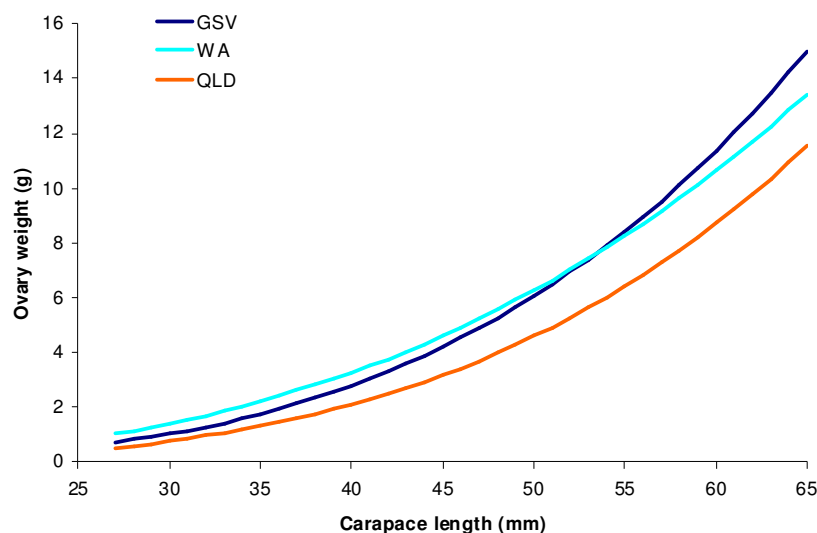


Figure 1.6 The relationship between fecundity (ovary weight) and carapace length (CL) for *P. latissulcatus* in GSV, Western Australia and Queensland, as determined from the fecundity relationships defined in Table 1.8.

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. latissulcatus* in South Australia, although at low prevalence (Roberts *et al.*, 2010). Viral infections have been demonstrated to affect moulting and reproduction of *Fenneropenaeus indicus* (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. latissulcatus* in South Australia.

1.4.3 Larval and juvenile phase

P. latissulcatus 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.* 2012). Roberts *et al.* (2012) found that the total larval period varies from 12.7 days (at 24.4°C) to 31.3 days (at 17.1°C) under constant laboratory conditions, while larval survival was greatest at 25°C (74%) and lowest at 17°C (36%). 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.

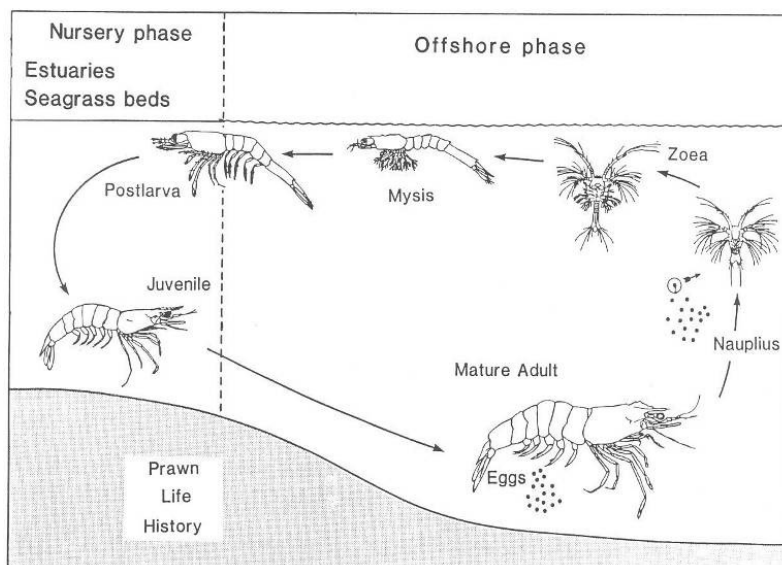
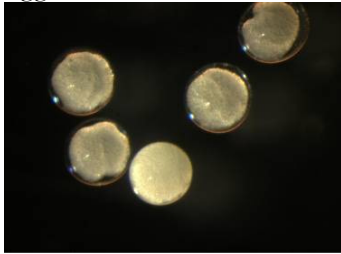


Figure 1.7 Life cycle of *P. latissulcatus* (Carrick 2003).

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. latissulcatus* are considerably lower than for other prawn species (Carrick 1996).

Eggs



Nauplius I



Nauplius II



Nauplius III



Zoea I



Zoea II



Zoea III



Mysis I



Mysis II



Mysis III



Post larvae



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

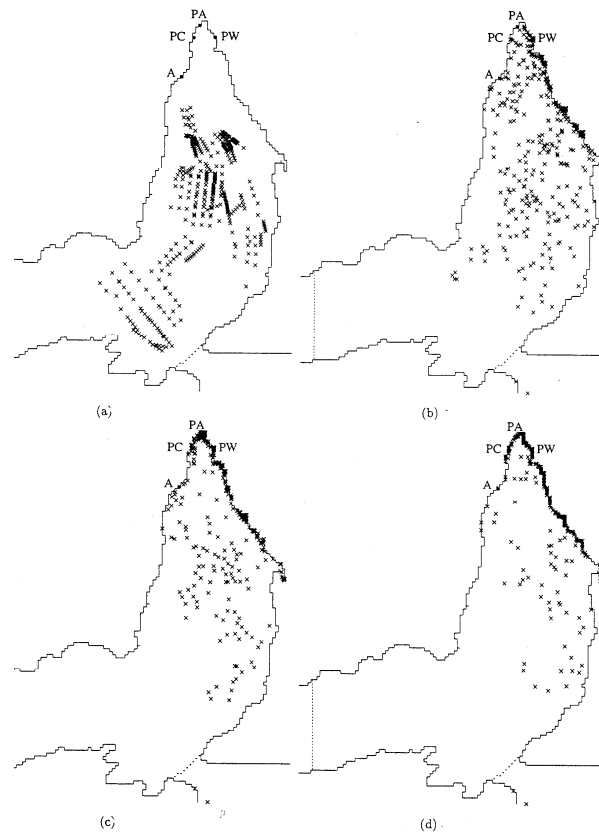


Figure 1.9 (a) Initial egg production of *P. latisulcatus* in GSV during November 1990 and (b) advection and diffusion of larvae at four, (c) six and (d) eight weeks after spawning as determined from a computer generated model (Kangas 1999). PW – Port Wakefield, PA – Port Arthur, PC – Port Clinton and 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 = $a \times \text{carapace length}^b$ ” varies between males ($a= 0.00124$, $b=2.76$) and females ($a= 0.00175$, $b=2.66$). Kangas (1999) determined the length weight relationship for juvenile prawns in GSV ($a= 0.00066$, $b=2.91$, $N=325$) (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).

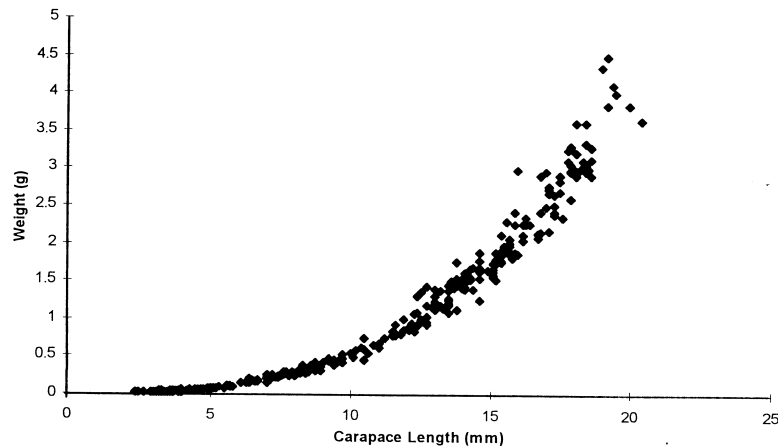


Figure 1.11 Length weight relationship for juvenile *P. latisulcatus* in GSV (Kangas 1999).

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 not 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. latissulcatus* 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: IHNV, 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). That assessment indicated 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 provided an appropriate precautionary approach. Recently, an independent review of the fishery assessment and harvest strategy was conducted (Knuckey *et al.* 2011). Of the 35 listed recommendations, the primary ones that relate to this assessment include (but are not limited to): maintain the use of fishery-independent surveys as a measure of relative biomass; conduct standardisations of CPUE data (survey and commercial); consider reducing the number of surveys from the four currently done, and; review performance measures and reference points. Other outcomes included a re-evaluation of the current harvest strategy, implementation of T90 cod-ends and the development of a bio-economic model for the fishery.

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; Dixon *et al.* 2011). 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. 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, these data will be required to underpin the bio-economic model that has been funded to begin in mid 2012.

The FRDC project (2009/069) aimed to identify new gear technologies to optimise prawn size and reduce by-catch. The success of this project has resulted in the adoption of “T90 cod-ends” in the fishery, beginning March 2012. Although only in its early phase of adoption, the potential benefits include: significant reduction in total by-catch for the fishery; improved prawn selectivity which increases the mean size of prawns harvested and enables larger areas to be fished within target size criteria; increases in efficiency including reduced fuel costs due to a reduction in drag from the nets, and longer trawling duration and handling time due to the reduced by-catch levels; improvement in product quality through a reduction in the proportion of damaged prawns in the catch, and; reduced risk of injury to crew, particularly due to the exclusion of stingrays. Assuming that T90 nets will continue to be used, future reports will need to consider the impact of the new gear type on fishery assessment.

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.*, 2012), 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 surveys conducted in 2009 and 2011 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 2010/11 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 2010/11. 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 being 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):

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

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:

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

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 catch in 2010/11 was 189 t, of which 11 t were harvested during fishery-independent and by-catch surveys. Total catch (fishing and survey) during 2010/11 decreased by 20% compared to 2009/10 (241 t). While this was the lowest catch harvested since 2005/06, it was 10% higher than the 172 t harvested 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 to a low of 172 t in 2003/04 and have since remained above 184 t. It is noteworthy that the four-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 2010/11 was 2,701 h. This was the highest effort observed for the last five years (range: 2,442–2,657 h) but it remains 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).

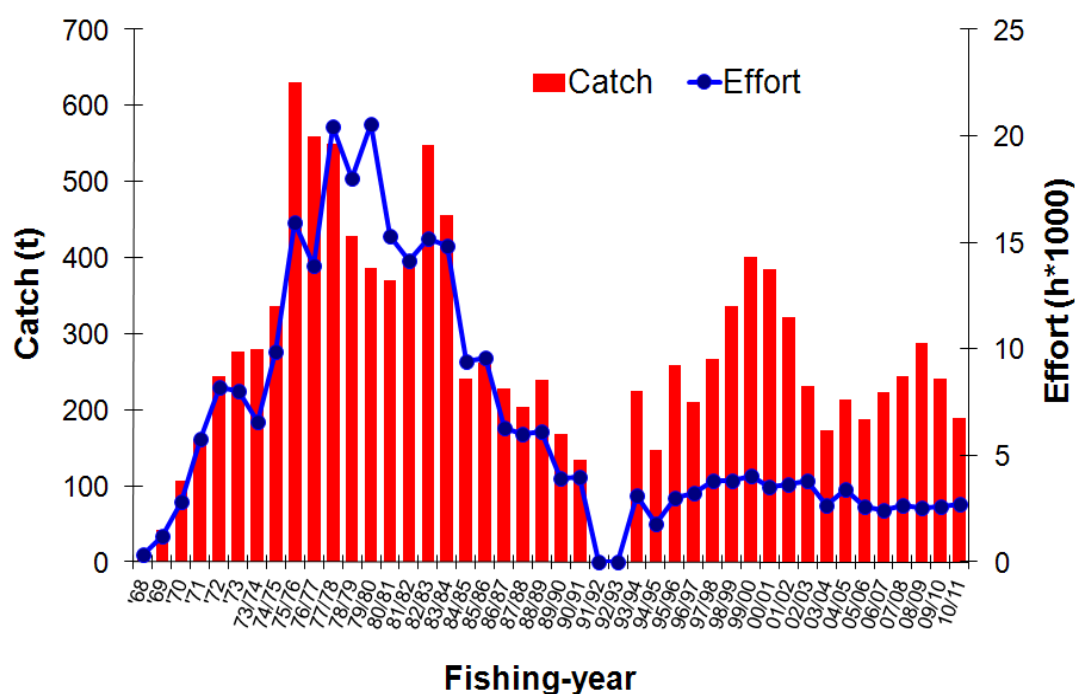


Figure 2.1 Total (fishing & survey) catch (t) and effort (h) for GSV from 1968 to current. Data for 1968–1973 are reported as calendar year. Data for 1973/74 are from January 1974 to October 1974. From 1974/75 data are reported in fishing years.

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).

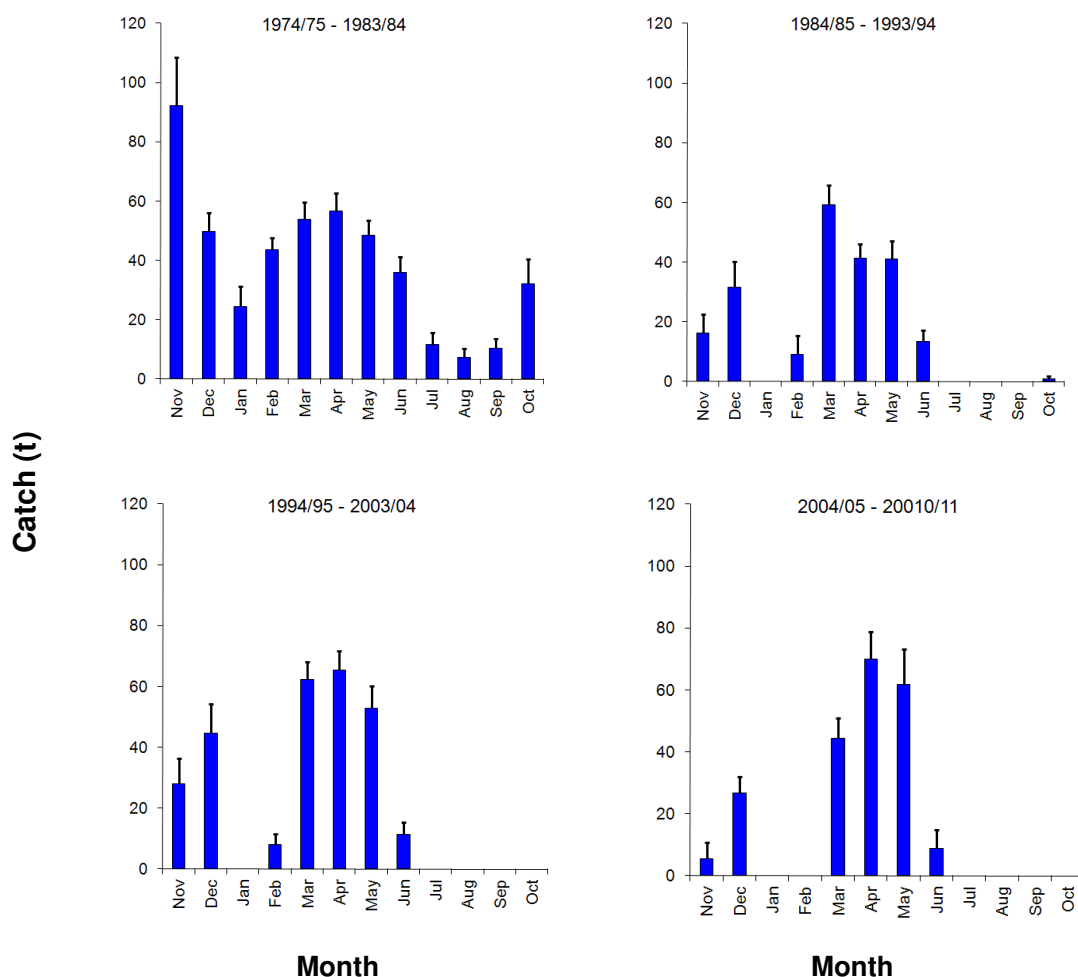


Figure 2.2 Average monthly catches from GSV for 10-year periods from 1974/75–2003/04 and for the seven fishing-years from 2004/05 to 2010/11. Note: 1984/85–1993/94 includes the 2-year closure period.

2.3.3 Catches during the spawning season

During 2010/11, 34.4 t (which includes 2.5 t of survey catch), were harvested during the early spawning period. This represents 18% of the annual catch. The total catch and proportion of prawns harvested during the early spawning period in 2010/11 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.

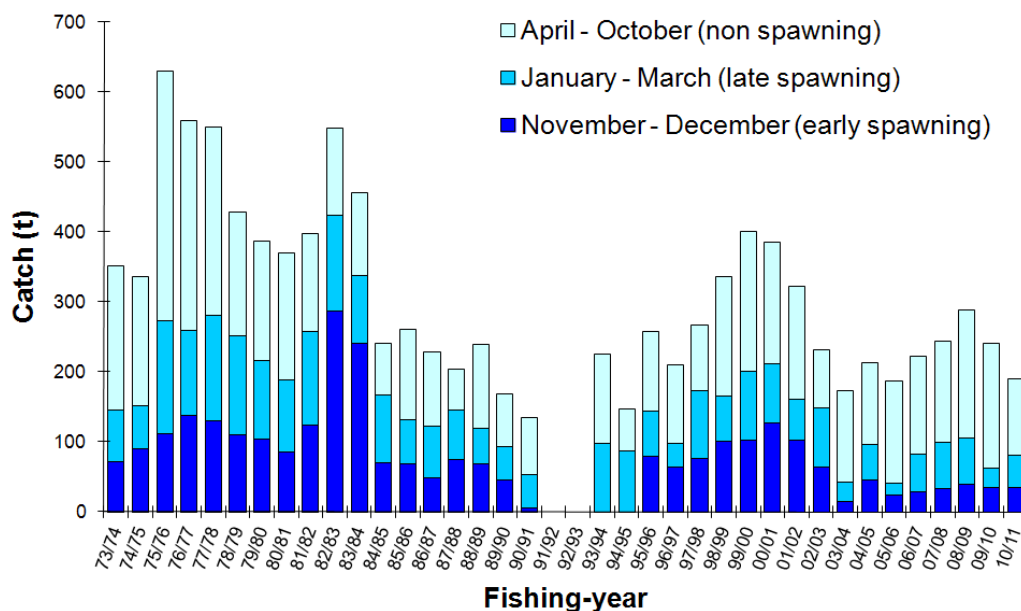


Figure 2.3 Catches (fishing & survey) from the early (November - December), late (January - March) and non-spawning (April - October) periods relative to the total annual catch from 1973/74 to 2010/11 in GSV.

2.3.4 Spatial distribution of effort from 1993/94 to 2010/11

From 1993/94 to 2003/04, trawl effort was distributed among more reporting blocks than for the subsequent period 2004/05 to 2010/11 (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).

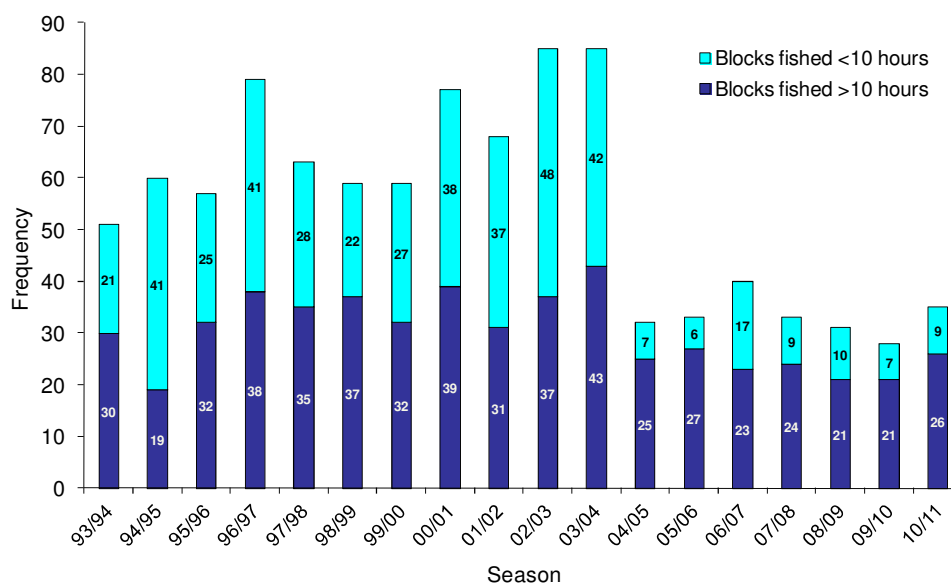


Figure 2.4 The number of reporting blocks fished from 1993/94–2010/11.

2.3.5 Seasonal distribution of effort from 1992/93 to 2010/11

The distribution of effort throughout the year was similar for the periods 1992/93–1997/98 and 1998/99–2003/04 (Figures 2.5, 2.6 and 2.7). During these periods effort was generally distributed in the north during November/December, mid gulf during February and March, and in the southern half of the gulf from April to June. Since 2004/05, effort has been predominantly distributed in mid GSV on the eastern side during November and December, been scattered throughout GSV during all other months.

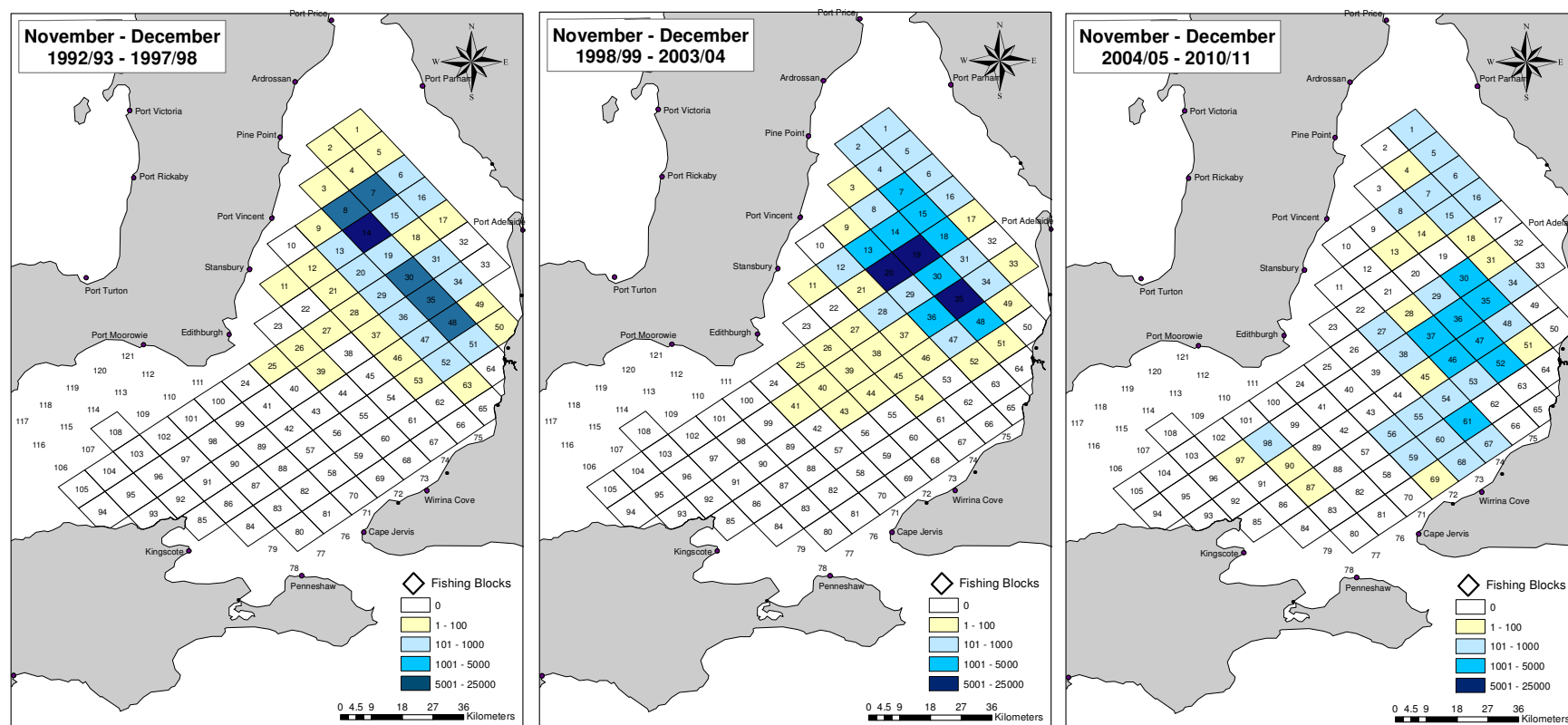


Figure 2.5 Fishing effort (average trawl minutes per block) for November and December fishing periods after the closure for six-year periods from 1992/93.

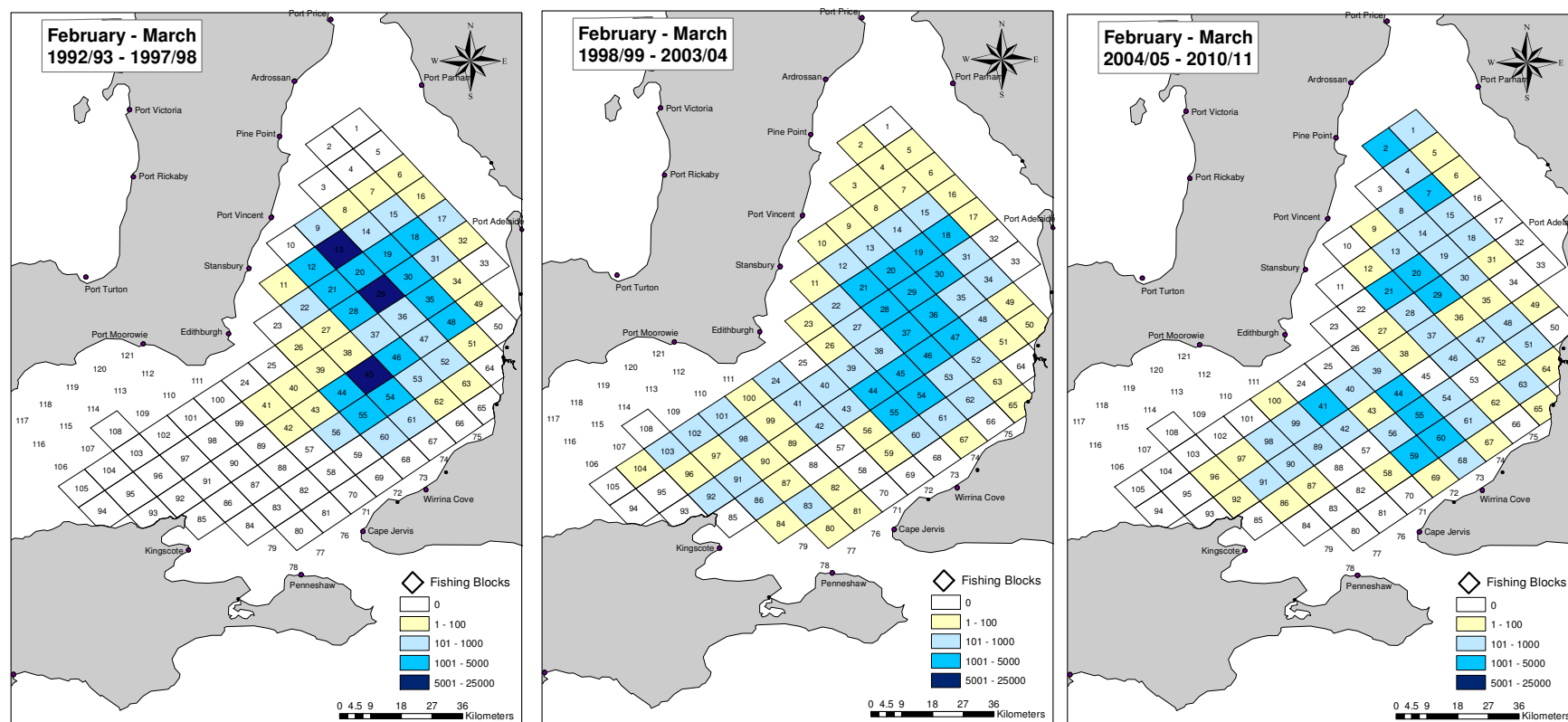


Figure 2.6 Fishing effort (average trawl minutes hours per block) for February and March fishing periods after the closure for six-year periods from 1992/93.

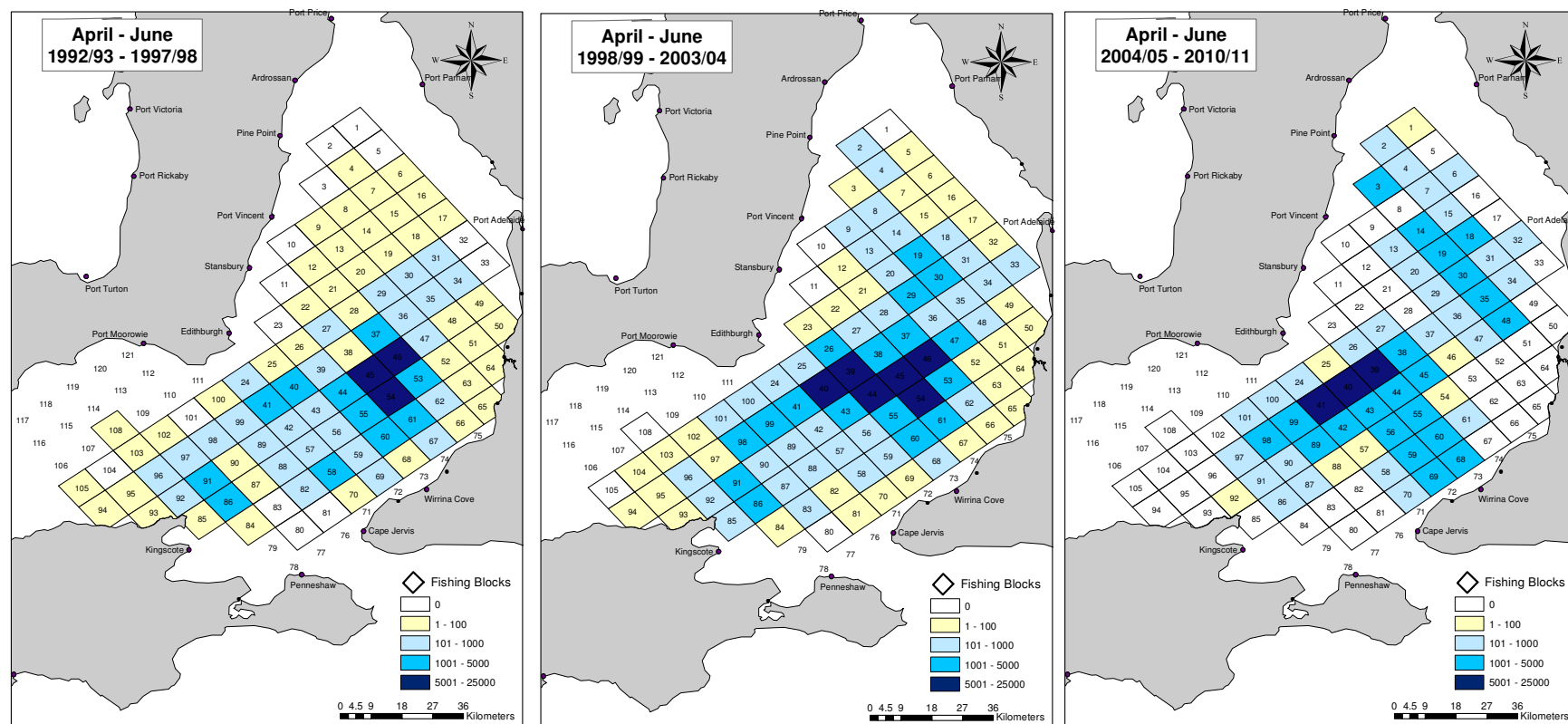


Figure 2.7 Fishing effort (average trawl minutes per block) for April to June fishing periods after the closure for six-year periods from 1992/93.

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

The annual estimate of CPUE in 2010/11 was 70.1 kg/h (Figure 2.8), a decrease of 24% from the previous season (93.2 kg/h). The large increase in CPUE observed from 2005/06 to 2008/09 and the substantial decrease in CPUE between 2008/09 and 2010/11 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.

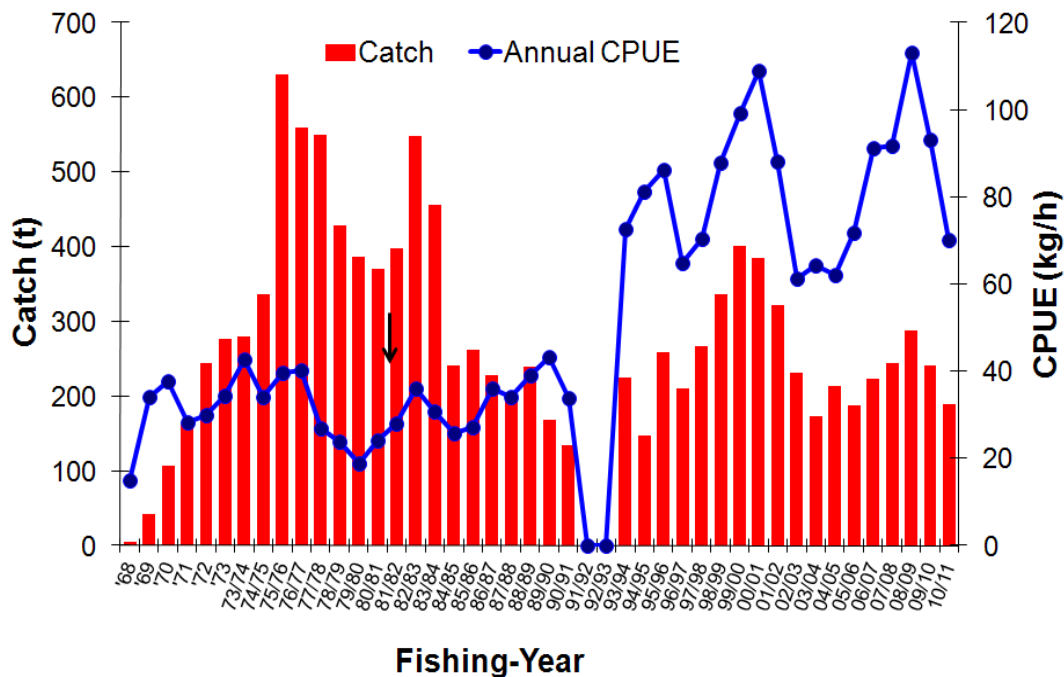


Figure 2.8 Annual catch and catch-per-unit-effort (CPUE) for GSV (fishing & survey) from 1968–2010/11. Data for 1968–1973 are reported as calendar year. Data for 1973/74 are from January 1974 to October 1974. From 1974/75 data are reported in fishing years. ↓ indicates introduction of triple-rig gear.

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 2010/11, searching effort was <8% (211 h) of total trawl hours, a similar proportion to that in 1999/00.

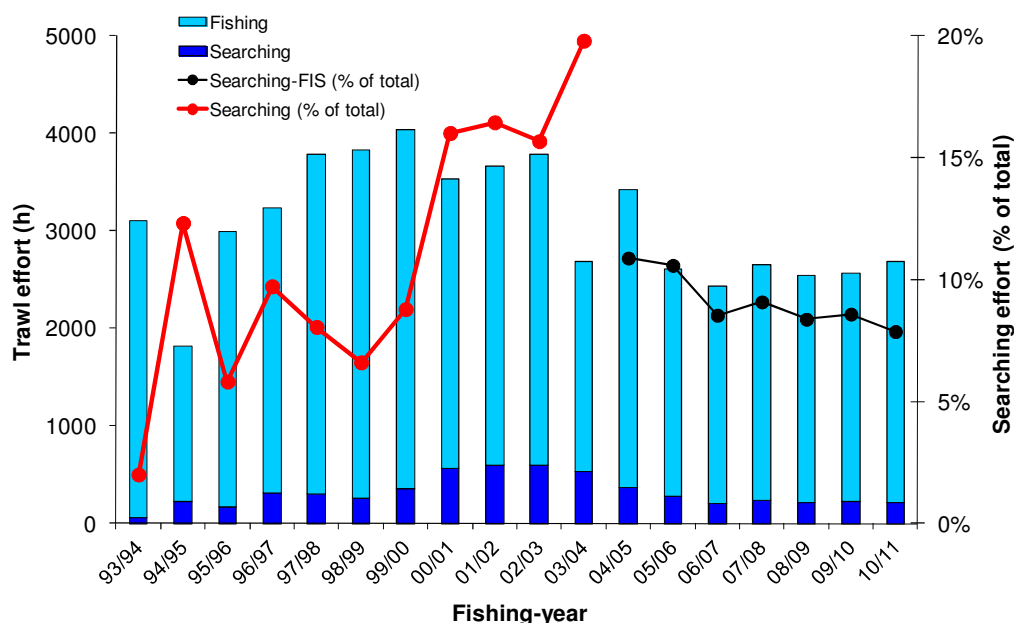


Figure 2.9 Fishing effort (light blue bars), searching effort (dark blue bars) and % of searching effort (line) from 1993/94 to 2010/11 in GSV. Note that searching effort from 2004/05 to 2010/11 represents effort done during fishery-independent surveys.

2.6 Prawn size

2.6.1 Inter-annual trends in prawn grades from 1993/94 to 2010/11

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 and 2010/11 seasons (Figure 2.10).

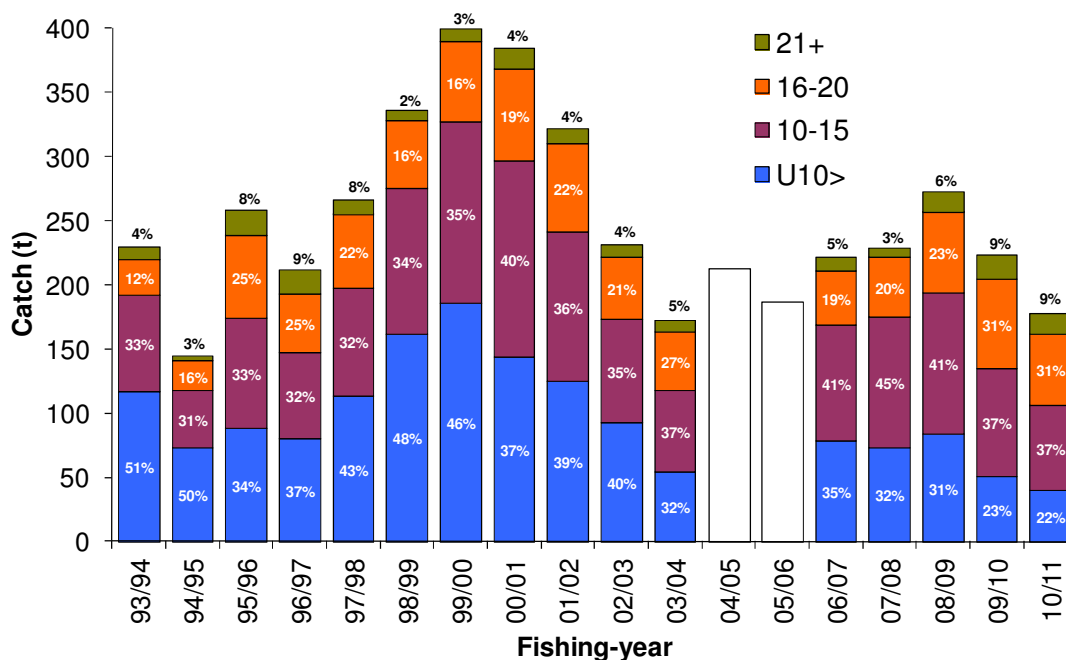


Figure 2.10 Estimated grade weights of the commercial catch from 1993/94 to 2010/11. Labels indicate the proportion by grade. Data were not available for 2004/05 and 2005/06.

2.6.2 Mean daily prawn size per vessel

The mean size of prawns generally became incrementally smaller (i.e. prawns/kg increased) from 2005/06 to 2010/11 in all months fished (Table 2.4). The greatest difference was observed in December (27.1 prawns/kg in 2006/07 to 37.1 prawns/kg in 2010/11) and March (26.1 prawns/kg in 2005/06 to 34.2 prawns/kg in 2010/11) and the smallest difference was observed in May (26.7 prawns/kg in 2005/06 to 30.0 prawns/kg in 2010/11). The monthly mean size of prawns harvested during 2010/11 ranged from 30.0–37.1 prawns/kg.

The change in mean size resulted in a general increase over time in the percentage of nights fished when target size criteria were not met (Table 2.4). Again, the greatest difference was observed during December, where the percentage of nights that target criteria were met fell from 100% in 2006/07 to 12% in 2010/11. During

2010/11, the percentage of nights that target criteria were met each month ranged from 7–36%.

Table 2.4 Mean daily prawn size per vessel and the percentage of nights when target size criteria were met for each month fished from 2005/06 to 2010/11.

Season	Mean daily prawn size (prawns/kg)				% of nights when target size was met			
	Dec	March	Apr	May	Dec	March	Apr	May
2005/06		26.1	26.2	26.7		83%	88%	71%
2006/07	27.1	29.9	27.7	26.8	100%	21%	48%	57%
2007/08	28.7	29.1	27.6	27.0	100%	31%	65%	66%
2008/09	30.6	28.0	31.1	28.3	92%	65%	17%	50%
2009/10	34.1	33.4	31.3	30.8	40%	0%	18%	20%
2010/11	37.1	34.2	30.3	30.0	12%	7%	36%	21%

2.7 Discussion

Commercial logbook data provide valuable information on catch, effort, CPUE and harvested prawn size to aid assessment. Data indicate that stocks improved from 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 since 2008/09.

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 and 2010/11 both commercial catch and CPUE consecutively decreased, approximating levels of catch and CPUE observed during 2007/08 and 2005/06, respectively. While CPUE data are affected by a number of factors including gear types, season, location and environmental conditions, the trends in CPUE observed since 2004/05 are considered indicative of changes in relative biomass because the magnitude of fluctuations were large relative to the differences in fishing practices during this period.

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 increase in pre-recruit abundance observed in recent years, particularly from 2005/06 to 2008/09 (Dixon *et al.* 2011). The limitation on effort during the pre-Christmas spawning period should be continued until alternative harvest strategies can be examined through the bio-economic model.

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 changed considerably in the last seven years under the current harvest strategy, with fishing areas being determined by targeting areas of high catch rate and target size during surveys. From 1992/93 to 2003/04, catches were generally distributed in the north pre-Christmas, in central GSV during February and March, and in southern GSV toward the end of the fishing year. Future harvest strategies may consider rules regarding the temporal and spatial distribution of fishing effort.

On-board observer (1993/94 to 2003/04) and commercial prawn grade data (2006/07 to 2010/11) 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%) and 2010/11 (22%). 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 and 2010/11, 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.

The size of prawns harvested has generally decreased each year since 2005/06 in all months fished. In turn, this affected the ability of the fleet to fish within target size criteria in recent years. During 2010/11, the monthly mean size of prawns harvested ranged from 30.0–37.1 prawns/kg, and the percentage of vessel nights that target criteria were met each month ranged from 7–36%.

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 2010/11. 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 within the Gulf St Vincent prior to the December, March, April and May harvest periods from 2004/05 to 2010/11. Surveys were typically done over two consecutive nights commencing on the second and third nights following 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). 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.

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 set direction for a specified period of time (usually 30 minutes). The total distance covered was dependent on trawl speed, which was influenced by vessel power, tide and weather conditions. The data collected during surveys included total catch, trawl duration and distance, catch weight by prawn grade, sex-specific length-frequency, sex ratio, prawns per kg from a bucket count and water temperature.

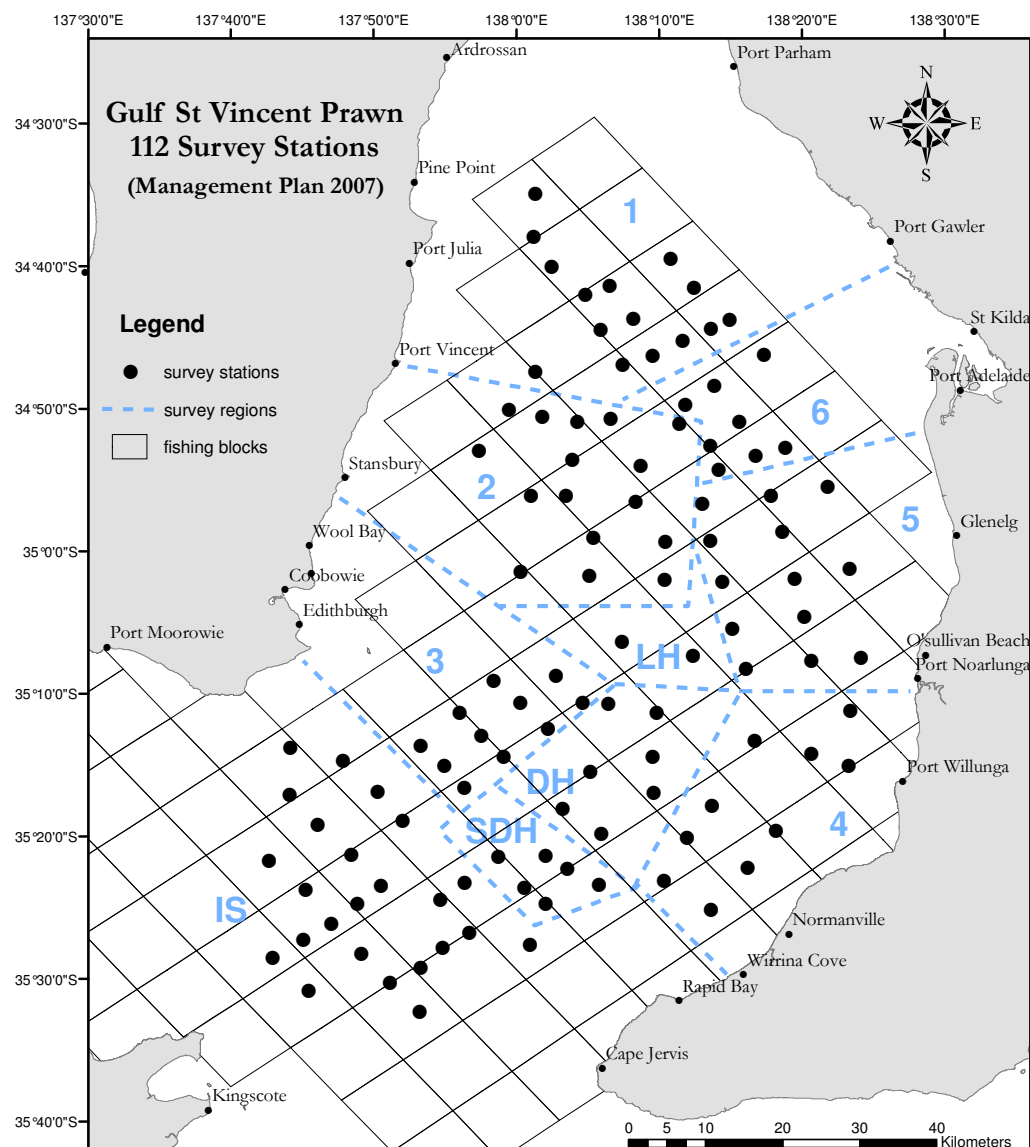


Figure 3.1 Survey stations, regions and fishing blocks of the GSV Prawn Fishery

Analysis of Variance (ANOVA) and Student-Newman-Keuls (SNK) tests were used to assess variation in catch rates at various temporal scales. Homoscedasticity and normality of the data were determined by Levene's test and visual assessments of residual plots. Where necessary, $\log_{10}(x + 10)$ 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 $\pm$ standard error (SE).

3.2.1 Standardised indices of relative biomass (survey CPUE)

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

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

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

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

Four seasonal surveys were examined: December, March, April and May. Unique vessel identifiers were obtained from commercial logbook data. Average SST for Gulf St Vincent was derived from satellite data for each survey night obtained from Physical Oceanography Distributed Active Archive Center (NASA 2011, Figure 3.2). Two measures were used to quantify the position of survey shots: Region (Figure 3.1) and; Latitude. For analyses, the Little Hole (LH), Deep Hole (DH) and Southern Deep Hole (SDH) regions were combined (Figure 3.1). Tide Speed (m/s) was determined as the daily average tidal volume at Port Adelaide from tide tables (Anon 2011) and Trawl Duration was obtained from survey skipper logs. The percentage of the moon illuminated (Moon Luminosity) at midnight for Guam (equivalent to

Australian Eastern Standard Time) was obtained for each survey night from the U.S. Naval Observatory (USNO 2011).

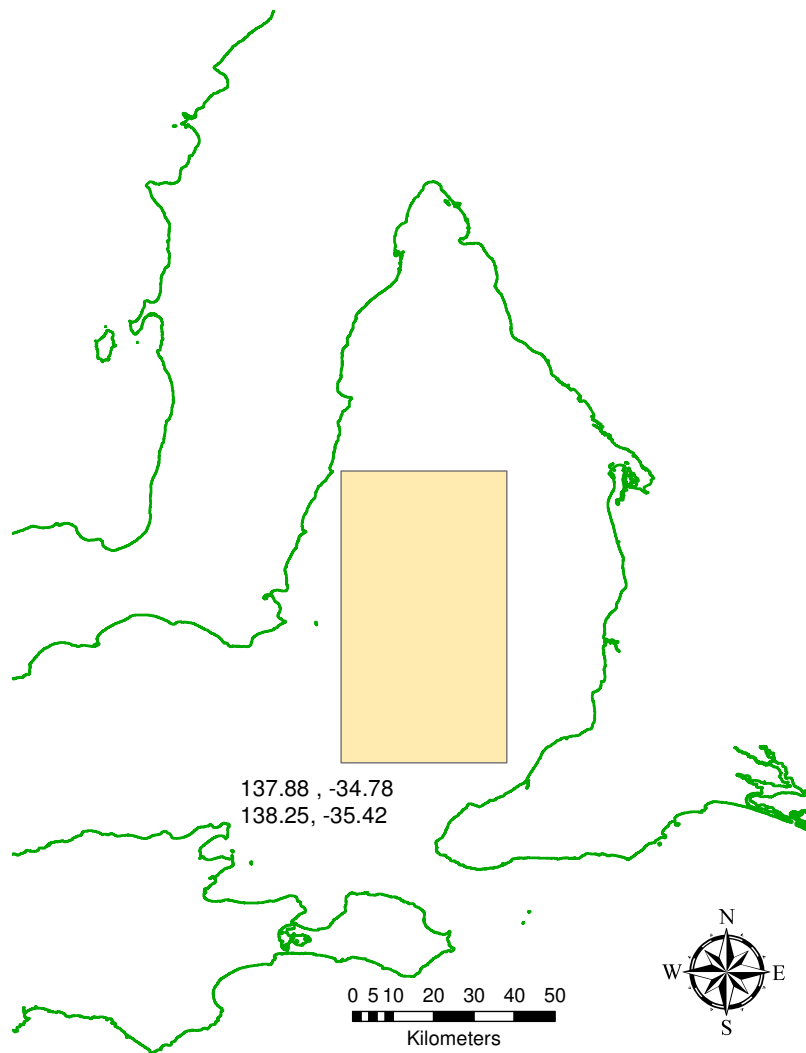


Figure 3.2 Area (shaded yellow) from which average SST was derived from satellite data from the Physical Oceanography Distributed Active Archive Center (NASA 2011)

To account for shots with zero survey CPUE under a log model, a small constant (0.01) was added to each record (shot) to permit the inclusion of zeroes in the dataset. Latitude, SST, Tide Strength, Trawl Duration and Moon Luminosity were included as continuous variables. The remaining explanatory variables (Survey Month, Vessel and Region) were included as categorical variables or factors.

Model selection was determined using the Bayesian Information Criteria (BIC; Burnham and Andersen 2002) with the model having the lowest BIC generally considered optimal. When two or more candidate models were within 2 BIC units of

each other the most parsimonious (simplest) model was chosen as the optimal model. Models were fitted using a stepwise forwards procedure, with terms added sequentially until the model was no longer statistically significant (Analysis of Deviance; $\alpha=0.05$). Only a single term was considered to represent the position of survey shots, thus once either Region or Latitude were included the other term was excluded. Interaction terms were not considered, the exception being the interaction of Season with Survey month which is required for the seasonal model.

In the annual analyses, standardised survey CPUE was obtained from the coefficients (β s) of the seasonal terms in the model. For the seasonal analyses, standardised survey CPUE was obtained from the coefficients of the season and survey month terms and the interaction between them for each survey. Because standardised estimates are determined relative to the first year of data, standardised annual estimates are provided for the period 2005/06 to 2010/11. For the seasonal model, standardised estimates are determined relative to the first survey conducted (December 2004). Thus, estimates are provided for the period 2005/06 to 2010/11 in December and 2004/05 to 2010/11 in all other months.

3.2.2 Relative biomass by size class (nominal)

To examine the size structure of the survey population, nominal (unstandardised) survey CPUE was broken into three 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 survey CPUE 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 CPUE.

3.2.3 Egg production

Egg production was estimated for each year from 2004 to 2010 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.

3.2.4 Recruitment index

A recruitment index was calculated for each survey, defined as male prawns <33 mm CL and female prawns <35 mm CL according to the Management Plan. Recruitment indices (recruits per hour trawl shot) were calculated for 96–105 consistent shots surveyed with available length-frequency data for each month from 2004/05–2010/11. 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.

3.2.5 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).

3.2.6 Water temperature data collected during surveys

Bottom water temperature (BT) was recorded consistently during surveys from 2006/07 to 2010/11 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 2011. 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 Standardised indices of relative biomass (survey CPUE)

Nominal survey CPUE increased consecutively from 2004/05 to 2008/09 and declined thereafter (Figure 3.3e). During 2010/11, nominal annual CPUE was 53.5 kg/h which was 24% higher than 2004/05. Although seasonal trends were more variable, each measure showed a trend of general increase followed by general decrease over time (Figure 3.3a-d).

Generally, trends in standardised estimates of survey CPUE were similar to but lower than nominal estimates for all measures (Figure 3.3a-e). However, the difference between measures generally increased over time so that by 2010/11, nominal CPUE was overestimating the standardised measure by 4% in December, 8% in March, 5% in April, 1% in May, and 5% for the overall measure.

Several significant factors were identified that influenced the annual and seasonal models (Tables 3.1 and 3.2). The optimal annual model included survey region only and was preferred as it was within 2 BIC units of model 2.3 and had the fewest number of terms (Table 3.1). Survey CPUE was highest at regions in the middle of Gulf St Vincent (2, 3, 5, 6, Hole) and lowest in the north (Region 1), southeast (Region 4) and south of the gulf (Region IS). The increasing difference observed between measures over time reflects the changing of the distribution of survey shots since 2004/05.

The optimal seasonal model included survey region (Table 3.2). Estimates of survey CPUE by region were very similar to those obtained from the annual model, with survey CPUE being highest at regions in the middle of the Gulf (2, 3, 5, 6, Hole) and lowest in the north (Region 1), southeast (Region 4) and south of the gulf (Region IS).

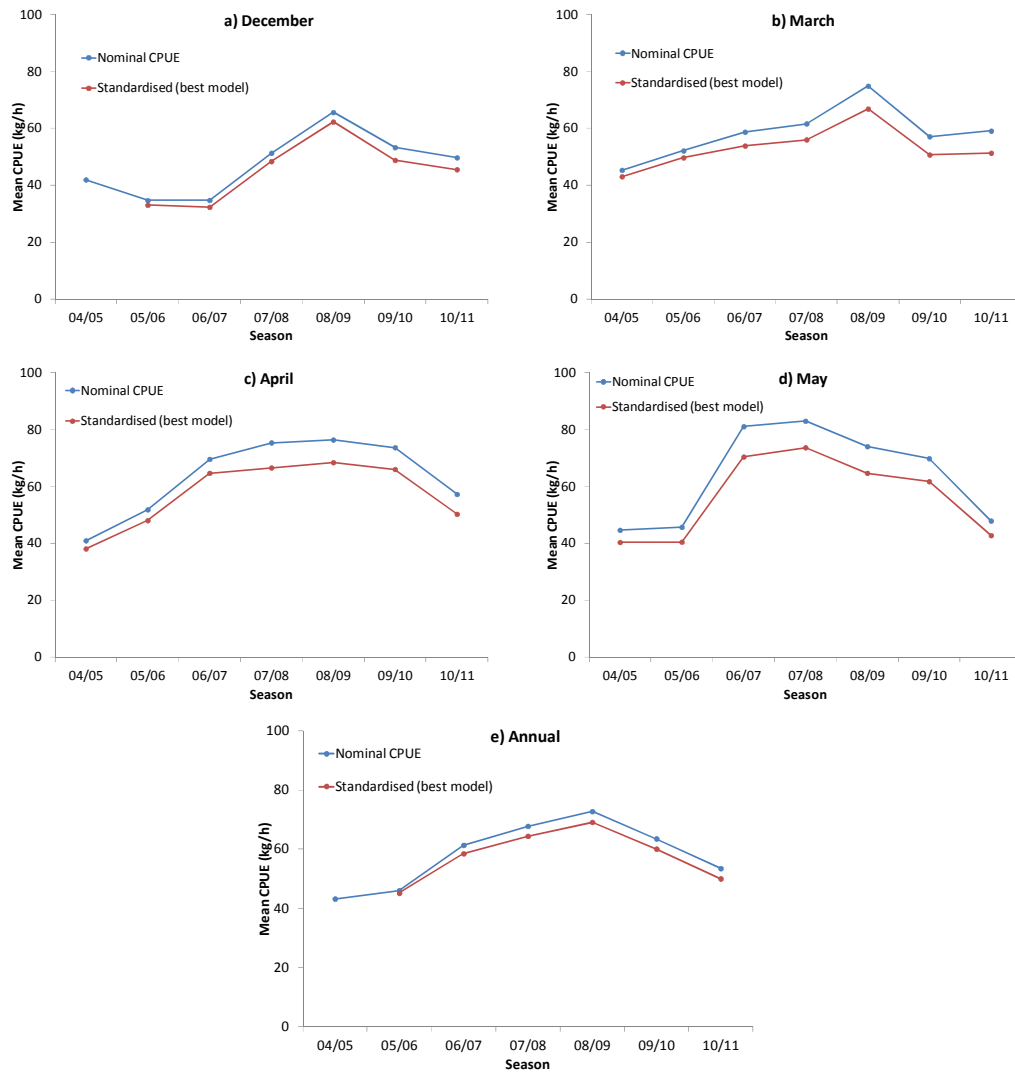


Figure 3.3 Nominal and standardised survey catch rate for a) December, b) March, c) April, d) May and e) all survey months combined (annual).

Table 3.1: Generalised linear model (GLM) results modelling the effect of environmental and fishery variables on annual survey CPUE. Explanatory variables include survey month (Survey), vessel, sea surface temperature (SST), region of survey shot, latitude of survey shot, tide strength (Strength), duration of survey shot (Minutes) and moon luminosity (Luminosity). Notation: Res. Dev = residual deviance; df = residual degrees of freedom; BIC = Bayesian information criterion; Δ BIC is the change in the Bayesian information criterion between the best (*) and candidate models. The null (Season only) model is also shown.

Model Formula		Res. Dev.	df	BIC	Δ BIC	p-value
Null	log CPUE ~ Season	3845.9	3095	31422.6	80.8	-
1.7*	log CPUE ~ Season + Region	3704.8	3088	31341.8	0.0	<0.001
2.3	log CPUE ~ Season + Region + Survey	3678.9	3085	31340.2	-1.6	<0.001
2.4	log CPUE ~ Season + Region + Strength	3700.5	3087	31345.5	1.2	0.021
2.5	log CPUE ~ Season + Region + Minutes	3704.8	3087	31349.8	54.6	0.807
2.6	log CPUE ~ Season + Region + Luminosity	3702.5	3087	31347.5	2.6	0.092
3.1	log CPUE ~ Season + Region + Survey + SST	3673.5	3084	31343	5.8	0.011
3.2	log CPUE ~ Season + Region + Survey + Vessel	3638.6	3073	31396.4	2.1	<0.001
3.3	log CPUE ~ Season + Region + Survey + Strength	3675.0	3084	31344.4	80.8	0.029

Table 3.2: Generalised linear model (GLM) results modelling the effect of environmental and fishery variables on seasonal survey CPUE. Explanatory variables include vessel, sea surface temperature (SST), region of survey shot, latitude of survey shot, tide strength (Strength), duration of survey shot (Minutes) and moon luminosity (Luminosity). Season*Survey represents an interaction term between the season and the survey month. Notation: Res. Dev = residual deviance; df = residual degrees of freedom; BIC = Bayesian information criterion; Δ BIC is the change in the Bayesian information criterion between the best (*) and candidate models. The null (Season*Survey only) model is also shown.

Model	Formula	Res. Dev.	df	BIC	Δ BIC	p-value
Null	log CPUE ~ Season*Survey	3765.4	3074	31513.8	71.3	-
1.6*	log CPUE ~ Season*Survey + Region	3636.4	3067	31442.5	0.0	<0.001
1.7	log CPUE ~ Season*Survey + Minutes	3764.3	3073	31520.8	78.3	0.27
1.8	log CPUE ~ Season*Survey + Luminosity	3764.9	3073	31521.3	78.8	0.44
2.1	log CPUE ~ Season*Survey + Region + SST	3632.8	3066	31447.0	4.5	0.04
2.2	log CPUE ~ Season*Survey + Region + Vessel	3597.7	3055	31499.9	57.4	<0.001
2.3	log CPUE ~ Season*Survey + Region + Strength	3636.3	3066	31450.5	8.0	0.72
2.4	log CPUE ~ Season*Survey + Region + Minutes	3635.6	3066	31449.8	7.3	0.32
2.5	log CPUE ~ Season*Survey + Region + Luminosity	3636.3	3066	31450.4	7.9	0.68

3.3.2 Relative biomass by size class (nominal)

Mean total survey catch rate differed significantly among seasons (ANOVA: $F_{6, 3103} = 17.74$, $P < 0.001$), with significant increases observed between 2005/06 (1.69 lb/min) and 2006/07 (2.25 lb/min) and again between 2006/07 and 2008/09 (2.49 lb/min); prior to decreases in 2009/10 (2.34 lb/min) and 2010/11 (1.96 lb/min) (Figure 3.2). Whilst the total catch rate declined significantly in the last two years, it remains significantly higher than it was during the 2004/05 and 2005/06 seasons.

The biomass of large (U10>) prawns increased slightly but not significantly from 2004/05 to 2008/09 and declined thereafter (ANOVA: $F_{6, 3103} = 12.58$, $P < 0.001$; SNK-tests: 2004/05-2008/09 > 2009/10 and 2010/11). Despite this, the biomass of large prawns in 2010/11 was not significantly less than that of 2009/10. Trends in the biomass of mixed (10/20) and small (20+) prawns were similar, with annual increases observed from 2004/05 to 2008/09 followed by declines in 2009/10 and 2010/11. 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 increases observed from 2004/05 up until respective peaks in 2008/09 (December, March and April) and 2007/08 for May (Figure 3.3). Whilst there have been general declines since these peak years, catch rates for the months December and March have remained constant for the last two years, whereas those of April and May have continued to decline. Some caution must be applied to comparisons between May 2007/08 and 2008/09 as the timing of surveys was shifted during 2008/09.

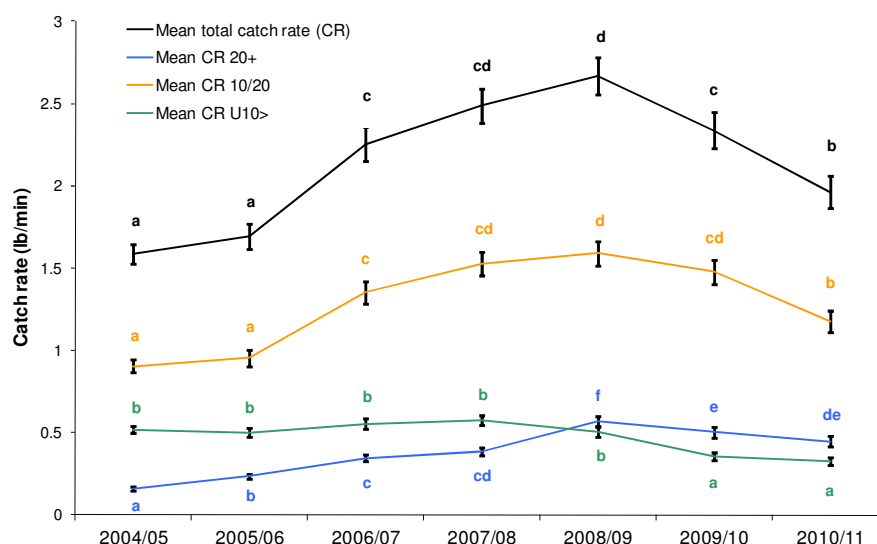


Figure 3.2 Mean total catch rate and mean catch rates of small (20+), mixed (10/20) and large (U10>) prawn grades, obtained from surveys conducted from 2004/05 to 2010/11. Letters identify significant differences among years.

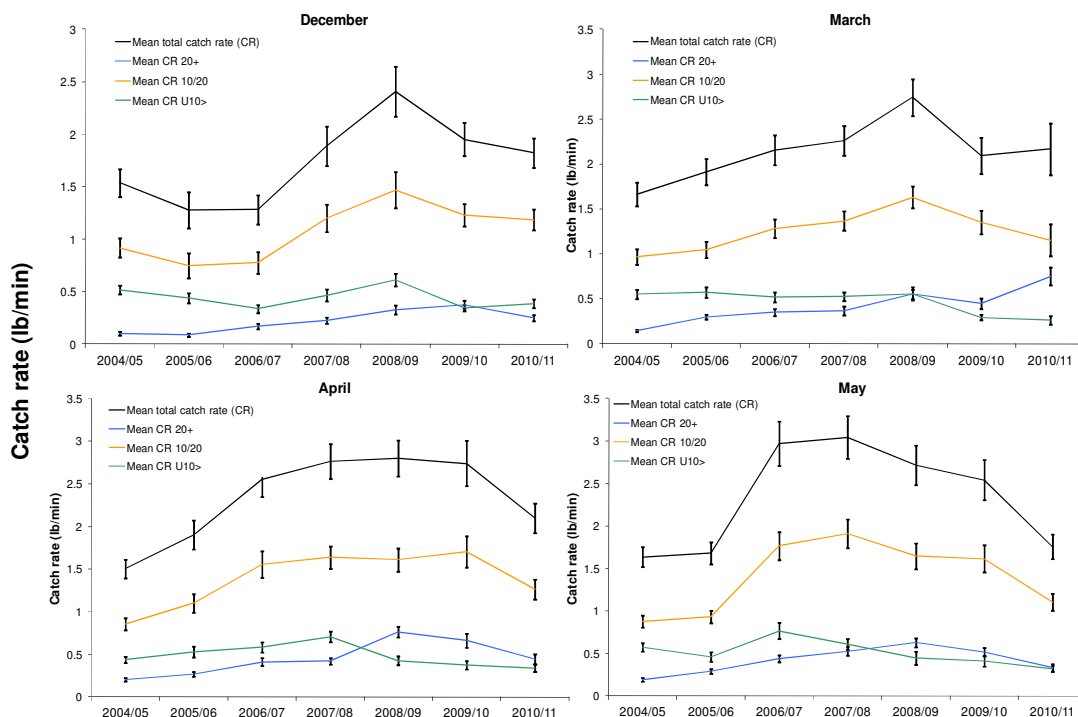


Figure 3.3 Mean total catch rate and mean catch rate of prawns grade 20+ and smaller, 10/20 and U10 and larger for each month surveyed from 2004/05 to 2010/11.

3.3.2 Estimates of egg production

From 2004 to 2008 estimates of egg production ranged from 423 to 717 million eggs per survey trawl hour (Figure 3.5). Egg production in 2009/10 and 2010/11 were the lowest observed at 388 and 393 million eggs per trawl hour, respectively.

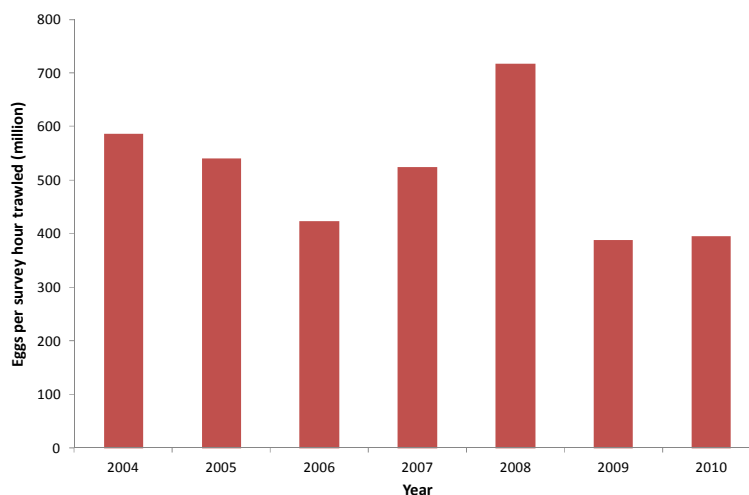


Figure 3.5 Mean (SE) number of fertilised eggs (million per survey trawl hour) produced by females captured during December surveys conducted from 2004 to 2010.

3.3.3 Trends in recruitment

Generally, recruitment patterns followed similar trends to total mean survey catch rates (section 3.3.1) with increases between 2004/05 and 2008/09 followed by a decline in 2009/10 and 2010/11, with the exception of March 2011 (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 2010/11 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.

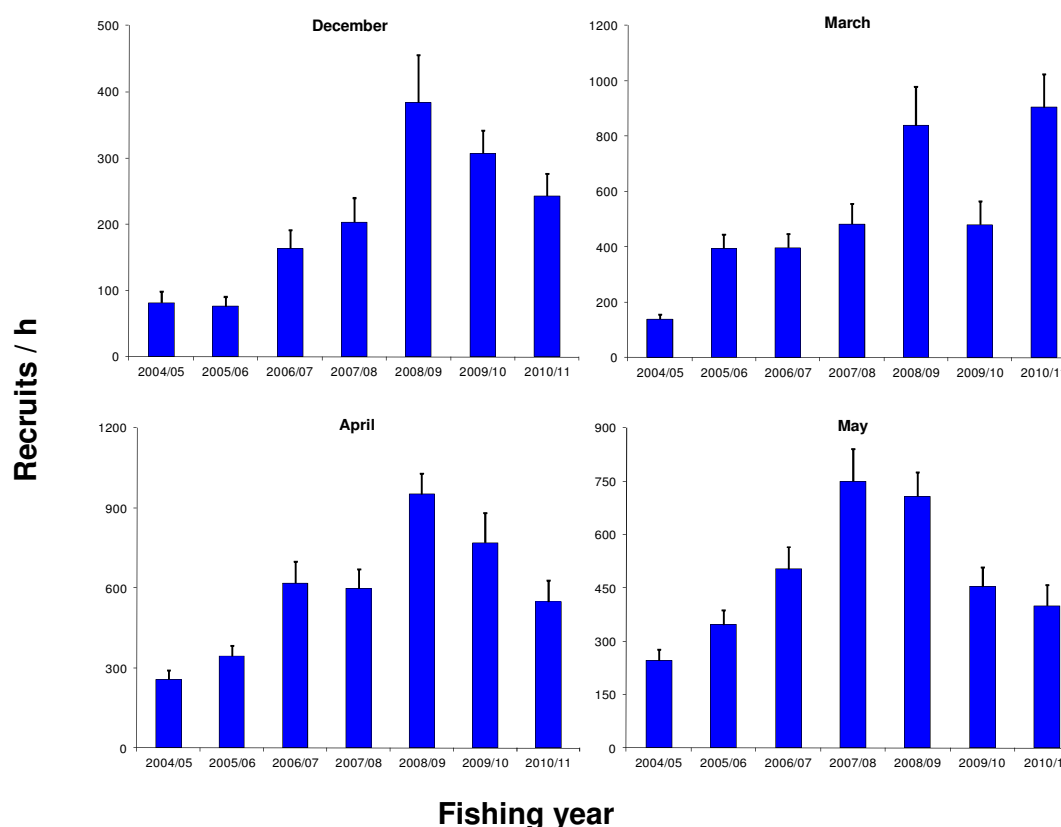


Figure 3.6 The mean (SE) number of recruits per trawl hour during surveys conducted between 2004/05 and 2010/11 during December and March to May. Note that May surveys were conducted on the dark of the moon from 2004/05 to 2007/08.

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.

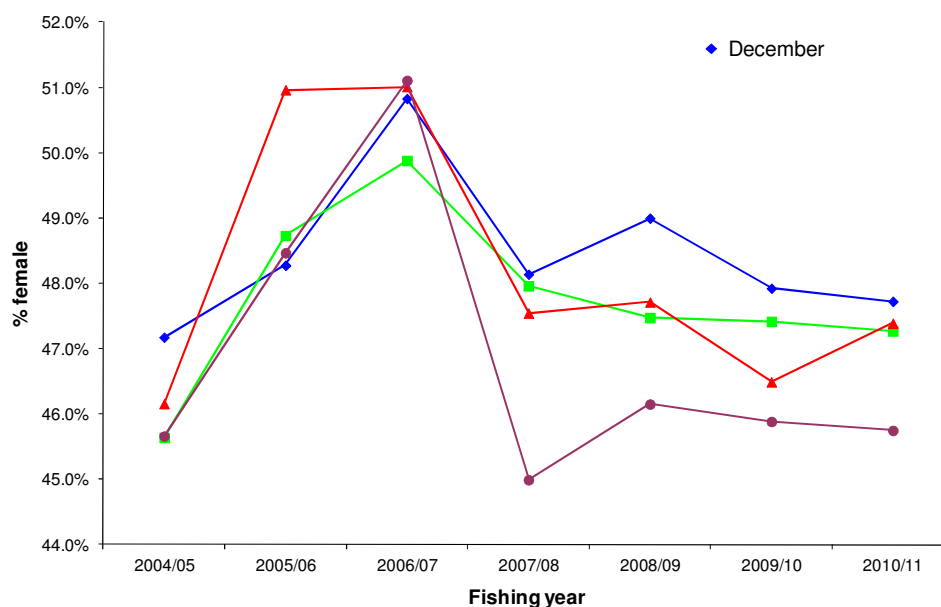


Figure 3.7 The proportion of females within the surveyed population for December, March, April and May 2004/05 to 2010/11.

3.3.5 Water temperature

Estimates of SST among years ranged from 17.3–18.8°C in November/December, 18.1–21.5°C in March, 17.7–20.5°C in April and 15.3–18.9°C in May (Table 3.1). While SST data were similar to BT data on most occasions, there were some notable exceptions (e.g. March 2010/11). BT data are a more reliable measure.

Table 3.1 Mean (SE) sea surface temperature (°C) (SST) and bottom water temperature (BT) during surveys conducted between 2004/05 and 2010/11.

Source	Year	Nov/Dec	March	April	May
SST	2004/05	18.8	20.1	17.7	18.2
SST	2005/06	17.3	21.1	17.9	15.3
SST	2006/07	18.2	21.5	20.4	17.9
SST	2007/08	18.4	20.5	19.1	17.8
SST	2008/09	17.4	20.4	19.4	17.6
SST	2009/10	18.8	20.6	20.5	18.9
SST	2010/11	18.1	18.1	19.0	16.1
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)
BT	2010/11	17.6 (0.1)	19.8 (0.1)	18.5 (0.0)	16.1 (0.0)

3.4 Discussion

Fishery-independent surveys conducted between 2004/05 and 2010/11 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, as noted in the previous report (Dixon *et al.* 2011). Importantly, although survey catch rates declined again between 2009/10 and 2010/11, there was no significant reduction in the catch rate of large or small prawns. This is important for the spawning biomass and recruitment to the fishery, respectively.

This report is the first to provide a standardised measure of biomass for the fishery. The most important factor for both the annual and seasonal models was region, with higher CPUE in the central parts of the gulf. The differences between standardised and nominal (unstandardised) estimates of survey CPUE were small for both seasonal and annual measures. This results from the consistent spatial and temporal survey design that minimises variability in these effects between years. Although small, there was an increasing divergence between measures over time (5% over six years). As region was the only significant factor in the optimal model, the increasing difference reflects the changing of the survey design over time as some shots of consistently low catch rate were dropped and replaced by shots with higher catch rates. Future comparisons using nominal surveys measures should ensure that these data are excluded from analyses to eliminate bias.

Beginning 2011/12, the number of stock assessment surveys will be reduced from four to two, with surveys to be conducted in April and May on the dark of the moon. The decision to reduce the number of surveys resulted from the consideration of two primary issues: costs associated with the conduct of surveys relative to income of the fishery, and; similarity in the trends among months, as discussed by Knuckey *et al.* 2011. The decision to maintain April and May surveys was based on judgement and logistic issues. December surveys were excluded for several reasons including: the trends in catch rate are relatively inconsistent in comparison to other months (this is similar in Spencer Gulf for pre-Christmas surveys and relates to spawning activity); the fishing strategy does not rely on survey results (a total catch cap is in place for

December), and; there appears to be a poor correlation between December survey catch rates and subsequent recruitment to the fishery. Two primary reasons to keep April and May surveys in preference to March are: recruitment generally peaks in April, and; surveys were conducted in May during 2003 and 2004 providing an extended dataset that can be used in the bio-economic model. Additionally, catch rates (and therefore survey catches) are highest during April and May which helps to offset the cost of surveys. Finally, the decision to conduct surveys on the dark of the moon rather than two nights after the last quarter (as done currently) was made on the basis that: May surveys were done on the dark phase of the moon up until 2007/08, and trends in mean catch rate did not appear to differ greatly; preliminary standardisations in this report did not highlight luminosity as a key factor influencing the model, and; industry generally had greater confidence in the interpretation of trends in catch rate if surveys were conducted on the dark of the moon.

The standardisations conducted for this report are preliminary analyses only. The recently funded bio-economic model provides opportunity to examine alternative models more thoroughly. Several models should be considered, particularly; examining the effect of reducing surveys to April and May only, and; examining the effect of changing to the dark of the moon. While the optimal model included only region as a significant factor, it should be noted that several other parameters gave similar model fits suggesting that additional modelling may improve the reliability of these estimates.

Nominal catch rate 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, declined significantly in 2009/10 and remained at similar levels in 2010/11. The biomass of small prawns has increased considerably since 2004/05 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 and March in 2010/11.

A primary concern regarding the interpretation of survey (and commercial fishing) 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. Further, modelling exercises (standardisation of catch rates and the bio-economic model) should consider explicit estimates of vessel power for the fishery.

There are several other sources of data for the fishery that augment the assessment. Recruitment indices estimated for each survey indicate that the timing of peak annual recruitment varies from March to May in GSV. In March 2010/11, a very high recruitment was observed. Closer investigation of the March survey data indicated a discrepancy between prawn grade data (20+ catch) and the proportion of recruits in length frequency samples for several shots that had very high catch rates. Despite this uncertainty, the very high levels of recruitment observed in March appear to at least offset the slight declines observed in April and May 2011.

Egg production estimates indicate that potential egg production, determined from the proportion and size of females in the December survey catch, was low during 2009/10 and 2010/11. The egg production model has not changed since it was first developed in 2007. The FRDC Project (2008/011), which will be completed within the next six months, provides a greater understanding of the reproductive and larval biology of western king prawns in South Australia. Until these results are obtained, annual comparisons of egg production from the current model should be interpreted cautiously. Finally, the proportion of females in the population has been seasonally stable for the last four years. The importance of sex ratio in the assessment of the fishery is poorly understood.

4. ASSESSMENT OF HARVEST STRATEGIES

4.1 Introduction

The harvest strategy developed each month for the fishery (designating spatial fishing areas) aims to maintain catches within the guidelines of the Management Plan with respect to prawn size and minimum catch per night. This is aided by real time management during commercial fishing by the “committee-at-sea”. Harvest strategy development 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). Real time management is guided by these same ‘at-sea’ decision rules of target prawn size and minimum catch. If prawns are harvested at sizes that do not reach target criteria during any night, the committee-at-sea notify PIRSA the following morning and the area is either closed or boundaries are adjusted. This section of the report aims to assess the effectiveness of harvest strategy development and management.

4.2 Methods

Fishery-independent surveys were conducted during December 2010 and March, April and May 2011 (see Section 3). Mean prawn size was 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.

Total catch and mean harvested size were summarised for each harvest period and assessed against the relevant criteria for minimum catch per vessel night and target harvested size. These same rules apply for ‘at-sea’ decision rules by the committee-at-sea. Decision rules for harvest period 1 (December) 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/June) 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). Detailed maps for each survey and harvest period are provided in Appendix 8.6.

Table 4.1. Statistics of fishing performance regarding catch and prawn size criteria as assessed against the Management Plan for four harvest periods in 2010/11. *Blocks and total catch outside of size criteria do not include confidential catches.

Harvest period	Decision rule (prawns/kg)	Blocks fished	Blocks outside size criteria	Blocks no size data	Total catch (t)	Total catch outside size criteria (t)	Nights fished	Nights below size criteria	Nights below catch criteria
1 (December)	27-33	12	9	3	31.8	30.4	5	5	0
2 (March)	< 28	11	11	0	43.6	43.6	6	6	1
3 (April)	< 28	10	8	0	59.4	53.8	8	6	0
4 (May)	< 28	12	9	1	43.2	40	7	7	0

4.3 Results: 2010/11

Between 10 and 12 blocks were fished during each of four harvest periods in 2010/11 (Table 4.1). Of the 26 nights fished in total, all but two nights had a mean size commercially harvested that was outside of the target size criteria of the Management Plan. In contrast, the fleet failed to achieve the minimum catch per night rule on only one night during the season (in March 2011).

4.4 Discussion

As identified in this and previous reports, the size structure of the prawn population in Gulf St Vincent has changed in recent years. This has resulted in an inability to maintain catches within the target size criteria established in the Management Plan during 2007. Although there were only 2 of 26 nights when the target size criteria were met in 2010/11, this was not surprising as on most occasions fishing areas were deliberately selected to target mixed sized prawns (outside of target criteria) to enable some fishing to occur while maintaining a population of large prawns within the gulf.

The previous fishery assessment report (Dixon *et al.* 2011) and the review of the fishery by Knuckey *et al.* (2011) identified the need to change the current harvest strategy approach. Following substantial consultation among industry, PIRSA and SARDI in 2011, significant changes in the harvest strategy were implemented starting from December 2011 with the introduction of tradeable fishing nights. Even more significantly, “T90” cod-ends with grids were introduced into the commercial fishery in March 2012. This gear is highly selective compared to standard diamond nets, significantly reducing the capture rates of small prawns. This has already resulted in a dramatic change in how harvest areas are designated and has improved the ability of fishers to maintain target size criteria during commercial fishing. Future reports will need to consider the effects of these changes on spatial and temporal harvest strategy assessment.

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– 2010/11 fishing years. Red shaded cells indicate PI triggered.

PI	LRP	'07/'08	'08/'09	'09/'10	'10/'11
Recruitment index (May: recr/h)	>250	693	707	454	399
Total commercial catch (t)*	Increasing each year of Plan	229	273	223	178
Mean commercial CPUE (kg/h)*	Increasing each year of Plan	93	113	93	72
Mean prawn size	Within target criteria each harvest period	No	No	No	No
Fishery independent surveys	4 surveys completed	Yes	Yes	Yes	Yes
Indices of current biomass	Decreases in 2 consecutive surveys	No	No	Yes	Yes
Indices of future biomass	Falls below limits in 2 consecutive surveys	No	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. Recruitment indices were above the Limit Reference Point (250 recr/h) in each of the last four fishing years.

5.2 Total commercial catch

Total commercial catch declined by 45 t in 2010/11 (178 t). This second consecutive decline triggers the Limit Reference Point in 2010/11.

5.3 Mean commercial CPUE

Mean commercial CPUE closely followed the trends in catch with a decline in 2010/11 (72 kg/h). Again, this second consecutive decline triggers the Limit Reference Point in 2010/11.

5.4 Mean prawn size

During 2010/11, mean prawn size was outside of the target range during each of the four harvest periods.

5.5 Fishery independent surveys

Four fishery independent surveys were conducted during 2010/11.

5.6 Indices of current biomass

The index of current biomass (mean survey catch rate) was lower than the previous year for surveys conducted in December 2010, April 2011 and May 2011 and thus the LRP was triggered for 2010/11.

5.7 Indices of future biomass

The mean catch rate of 20+ size prawns was above the reference level for all surveys during 2010/11. 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 the 2007/08 to 2010/11 fishing years for the Gulf St Vincent Prawn Fishery (Dixon and Sloan 2007).

Performance Measure	LRP	'07/'08	'08/'09	'09/'10	'10/'11
Recruit index December survey all shots	>100	191	363	314	243
Recruit index March survey all shots	>200	452	823	469	904
Recruit index April survey all shots	>250	570	947	737	548
Egg production (eggs $\times$ 10 ⁶ /h trawled)	>500	525	717	388	395
% of >U10 in the commercial catch – March to June	>25%	30.0	29.1	21.5	25.9
% of 20+ in the commercial catch – Dec	<7%	2.7	6.8	14.2	17.4
% of 20+ in the commercial catch – March to June	<5%	3.2	5.6	7.6	5.6

Recruitment index was determined for December, March and April from all survey stations conducted during 2010/11. Recruitment indices were all above the Limit Reference Point (LRP) in all months.

Egg production estimates were determined from the model presented in Appendix 8.5. Egg production was below the LRP in 2010/11 (395 million).

Data on prawn grades from the commercial catch were available for all months during 2010/11. The proportion of prawns between March and June of the >U10 prawn size grade category were within acceptable limits, however the proportion of 20+ prawns in December and March to June were above acceptable limits.

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.

With the exception of PIs based on the conduct of surveys and levels of recruitment (i.e. recruitment index and indices of future biomass) most PIs and additional performance measures triggered during 2009/10 and 2010/11. This reflects a recent decline in biomass and subsequent reductions in catch and CPUE, and a shift in the size structure of the population. As the harvest strategy for the fishery has changed, particularly with the introduction of T90 cod-ends and grids, a new suite of performance measures need to be considered.

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 (Dixon *et al.* 2011) indicated that although the biomass of prawns in GSV during 2009/10 was significantly larger than in 2004/05, highly effective targeting of the largest prawns likely contributed to a decline in the biomass of large prawns in recent years, with subsequent concerns for potential egg production. Consequently, fishing strategies developed during 2010/11 specifically targeted a higher proportion of “mixed” prawns in the catch to enable some fishing to occur while aiming to conserve the large prawns in the stock.

Although the biomass again declined significantly in 2010/11, there was no significant decrease in the catch rate of large prawns. Thus while the targeting of mixed prawns did not achieve an increase in the biomass of large prawns as hoped, it appears to have prevented another substantial reduction in potential egg production for the fishery under the assumption that large prawns are critical for spawning and recruitment success. Also, there was no significant decline in the catch rate of pre-recruits between years, with mean recruitment during 2010/11 being substantially and significantly higher than that observed in 2004/05. While these trends in biomass suggest that future egg production and recruitment are not in immediate danger, the decline in total biomass for the second consecutive year suggests that a sustainable catch for 2011/12 is likely to be lower than the 179 t obtained during 2010/11.

This report is the first to provide standardised estimates of relative biomass for the fishery. Although only preliminary modelling has been conducted, the high degree of correlation among standardised and nominal catch rates increase the certainty in the implied trends of population biomass. Although the optimal model included only region as a significantly influencing factor, a number of other variables had similarly good fits suggesting that additional modelling may further improve the reliability of these estimates.

Commercial catch and effort data support the implied trends in 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 and 2010/11 to the lowest levels observed since the closure. Despite uncertainties 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 target size criteria were rarely met during the 2010/11 fishing year. This was not unexpected given the increased focus on developing fishing strategies that targeted mixed rather than large size prawns. The introduction of the highly selective T90 cod-ends should dramatically improve the ability of the fleet to maintain catches within the target size of <28 prawns per kg.

A combination of factors including declining catches, smaller prawns harvested, increasing costs of fishing and declining prawn prices due to increased aquaculture production, has heightened the need for management change in the Gulf St Vincent Prawn Fishery. In response, PIRSA Fisheries and Aquaculture have facilitated the implementation of several new approaches for the fishery. Of primary importance, the introduction of tradeable nights in December 2011 enables individual operators to increase economic efficiency and paves the way for a more formal approach to transferability in the future. The introduction of T90 cod-ends and grids in March 2012 is also likely to have a dramatic effect on the future of the fishery. While the positives for the environment are clear (primarily reduced by-catch), there are many tangible benefits for the fishery as well including: improved size structure of the catch (higher value); improved quality (reduced proportions of damaged prawns); increases in trawling efficiency through reductions in fuel cost (less drag) and an increase in trawl duration (from 1 to 2 hours), and; improved Occupational Health and Safety through decreased sorting time and reduced interactions with stingrays.

While these management changes are positive and needed, they will have a considerable impact on the assessment of the fishery and will result in increased uncertainty in the status of the resource for at least the next two years. This will be further exacerbated by the cessation of December and March surveys and the possible shifting of April and May surveys to the dark of the moon. Although not ideal, it is appropriate to make these changes concurrently. Fortunately, funding for the development of a bio-economic model for the fishery was recently approved through the Seafood CRC. A primary role for the development of the GSV model will be to robustly determine appropriate approaches to deal with the current change management.

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 (currently planned to be revised by June 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. Standardised estimates would be the most appropriate measure.

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 interpretation of trends in commercial catch and CPUE and the development of LRPs will be substantially affected by the introduction of T90 cod-ends.

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, therefore it is suggested that the future annual recruitment index should reflect an average of recruitment across both the April and May surveys.

6.3 Harvest strategy

The use of the term “harvest strategy” in the Gulf St Vincent Prawn Fishery Management Plan (Dixon and Sloan 2007) and in this report differs to the definition and use of the term for most other Australian fisheries. Here, a harvest strategy

refers to the management of fishing effort for each harvest period through temporal and spatial closures, with several harvest strategies being developed and managed throughout each fishing year. The Commonwealth Fisheries Harvest Strategy Policy and Guidelines (Anon 2007) defines a harvest strategy as the framework that “sets out the management actions necessary to achieve defined biological and economic objectives in a given fishery.” As with most fisheries, the Gulf St Vincent Prawn Fishery is assessed against biological and economic objectives on an annual basis, and thus the current use of the term is inappropriate. A more appropriate term for the management of fishing effort throughout the year could be “fishing strategy”.

As a result of the recent change in management, the harvest strategy in the current Management Plan needs to be revised to ensure that it is an appropriate tool to manage and assess the fishery. Further, given the magnitude of the change it is unlikely that an appropriate framework will be developed within the next two years. During this period of transition, a flexible management framework will be required.

Despite this situation, the fishery and its assessment remain in a sound position. This is primarily due to the investment in fishery-independent surveys during the last seven fishing years which has provided a reliable index of relative biomass for the fishery. As long as the surveys conducted in the immediate future collect data from one diamond mesh net, this measure will continue to provide a sound basis for assessment and management. If an appropriate adjustment factor can be determined, particularly for indices of recruitment, a full conversion to T90 cod-ends for surveys will be possible in the near future.

The harvest strategy can be managed during the transitional period by adhering to guiding principles learnt from this and previous assessments. One of the weaknesses of the current harvest strategy was that it enabled overly effective targeting of large prawns. Transitional and future harvest strategies must ensure that an adequate biomass of large prawns remains at the end of each season to provide an adequate spawning biomass for the subsequent year. Also, 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. Finally, 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.

As part of the development of the next Management Plan, the current area based approach of linking total biomass with exploitation rate will need to be revised. Tradeable nights were recently introduced by PIRSA Fisheries and Aquaculture in acknowledgement of the urgent need for transferability to improve economic performance while the biomass is at historically low levels. In 2011/12 there will be an increased reliance on the results from the two surveys conducted in April and May for the assessment of the fishery. One suggested approach for managing fishing effort during this transitional period is to explicitly link changes between years in relative harvestable biomass (standardised catch rate) with the total allocation of tradeable nights. Thus, if the biomass declines/increases between years, the allocation of nights should reduce/increase in a proportion that ensures a sustainable harvest. Consideration may also be given to the changes in biomass of large and small prawns which reflect the spawning biomass and future recruitment, respectively. Such an approach may be needed until the outputs of the bio-economic model are realised (mid 2014).

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, economic outlook and change in management. This requires considerable reprioritising of research activity.

There is an urgent need to robustly evaluate the impact of the introduction of T90 cod-ends into the fishery. The tactical FRDC project that underpinned its development was aimed at rapid evolution of the technology with minimal evaluation. Understanding the differences between net types, particularly changes in selectivity is critical in assessing the Performance Indicators for the fishery. This can be achieved by comparing one diamond net against a T90 with grid during stock assessment surveys conducted in April and May 2012. Concurrently, additional quantitative information on bycatch could be collected.

The development of the bio-economic model will be a valuable tool for the determination of optimal fishing strategies. 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.

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.

7. REFERENCES

Anon (1991) Report of the select committee on the St Vincent Gulf prawn fishery. Third session, forty-seventh parliament, House of Assembly, South Australia.

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

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

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

Beverton, R.J.H. and Holt, S.J. (1957). On the dynamics of exploited fish populations. United Kingdom Ministry of Agriculture, Food, and Fisheries Investigations Series 2. No. 19. 533 pp.

Boxshall S. and Johnson J. (2001) Gulf St Vincent Prawn. SARDI Aquatic Sciences, South Australian Fisheries Assessment Series 01/05.

Boxshall S. and Williams H. (2000) Gulf St Vincent Prawn. SARDI Aquatic Sciences, South Australian Fisheries Assessment Series 00/05.

Boxshall S., Xiao Y. and Williams H. (1999) Gulf St Vincent Prawn. Fishery Assessment Report to PIRSA. SARDI Aquatic Sciences, South Australian Fisheries Assessment Series 99/05.

Broadhurst M.K., Larsen R.B., Kennelly S.J. and McShane P. (1999) Use and success of composite square-mesh codends in reducing bycatch and in improving size-selectivity of prawns in Gulf St Vincent, South Australia. *Fish. Bull.* 97: 434–448.

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

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

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

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

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

Copes P. (1986) Prawn fisheries management in South Australia, with specific reference to problems in Gulf St Vincent and Investigator Strait. Consultancy report to the Minister of Fisheries, South Australia.

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

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

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

Currie, D.R. and Sorokin, S.J. (2010) The distribution and trophodynamics of demersal fish from Spencer Gulf. *Trans. Royal. Soc. SA.* 134(2):198–227.

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

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

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

Dixon C.D., Roberts S.D. and Hooper, G.E. (2007) Spencer Gulf Prawn (*Melicertus latisulcatus*) Fishery 2005-06. Fishery Assessment report to PIRSA Fisheries. SARDI Aquatic Sciences Publication no. F2007/000770–1, SARDI Research Report Series No 237.

Dixon, C.D., Roberts S.D. & Hooper, G.E. (2011). Gulf St Vincent Prawn, *Penaeus (Melicertus) latisulcatus*, Fishery 2009/10. Fishery Assessment report to PIRSA Fisheries. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007/000782-4. SARDI Research Report Series No. 526. 121pp.

Dixon C.D. and Sloan S. (2007) Management Plan for the South Australian Gulf St Vincent Prawn Fishery. The South Australian Fisheries Management Series. Paper No. 53

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

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

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

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

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

Hill, B.J. (1985) Effect of temperature on duration of emergence, speed of movement, and catchability of the prawn *Penaeus esculentus*. In P.C. Rothlisberg, B.J. Hill and D.J. Staples (Eds). *Proceedings of the second Australian national prawn seminar*. Simpson Halligan, Brisbane, Australia. pp 77–83.

Hooper G.E., Roberts S.D. and Dixon C.D. (2009) Gulf St Vincent prawn (*Melicertus latisulcatus*) fishery 2007/08 status report. Fishery status report to PIRSA Fisheries. SARDI Aquatic Sciences Publication No. F2007/001074-2, Research Report Series No 328.

Hooper G.E., Dixon C.D. and Roberts S.D. (2010) Spencer Gulf prawn *Penaeus (Melicertus) latisulcatus* fishery status report 2009/10. Fishery status report to PIRSA Fisheries. SARDI Aquatic Sciences Publication No. F2007/001094-4, Research Report Series No 512.

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

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

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

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

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

Khoi L.V. and Fotedar R. (2010) Effects of stocking density on the nutrient budget and growth of western king prawn (*Penaeus latisulcatus* Kishinouye) in a recirculating aquaculture system. Aquaculture Research. 41. e624–e633.

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

Knight M. and Tsohos A. (2011) South Australian Wild Fisheries Information and Statistics report 2009/10. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 60p. SARDI Publication No F2009/000804-3 SARDI Research Report Series No.521.

Knuckey I., Kompas T., and Bodsworth, A. 2011. Review of the Gulf St Vincent Prawn Fishery. Report for PIRSA Fisheries and Aquaculture and the Gulf St Vincent prawn fishers.

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

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

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

Middleton J.F. and Bye J.A.T. (2007) A review of the shelf slope circulation along Australia's southern shelves: Cape Leeuwin to Portland. Prog. Oceanogr. 75: 1-41.

Morgan, G. (1995) Assessment, management and research support for the Gulf St Vincent Prawn Fishery. South Australian Fish. Man. Series 12.

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

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

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

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

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

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

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

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

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

Primavera J.H. and Leбата M.J.H.L. (2000) Size and diel differences in activity patterns of *Metapenaeus ensis*, *Penaeus latisulcatus* and *P. merguensis*. Mar. Freshwater Behav. Physiol. 33: 173–185.

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

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

Roberts S.D., Dixon C.D. and Hooper G.E. (2007a) Gulf St Vincent Prawn (*Melicertus latisulcatus*) Fishery 2005/06. Fishery Assessment report to PIRSA Fisheries. SARDI Aquatic Sciences Publication No. F2007/000782-1, Research Report Series No 253.

Roberts S.D., Dixon C.D. and Hooper G.E. (2007b) Gulf St Vincent Prawn (*Melicertus latisulcatus*) Fishery 2006/07 Status Report. Fishery status report to PIRSA Fisheries. SARDI Aquatic Sciences Publication No. F2007/001074-1, Research Report Series No 254.

Roberts S.D., Dixon C.D. and Hooper G.E. (2008) Gulf St Vincent Prawn (*Melicertus latisulcatus*) Fishery 2006/07. Fishery Assessment report to PIRSA Fisheries. SARDI Aquatic Sciences Publication No. F2007/000782-2, Research Report Series No 300.

Roberts S.D., Dixon C.D. and Hooper G.E. (2009) Gulf St Vincent Prawn, *Penaeus (Melicertus) latisulcatus*, Fishery 2007/08. Fishery Assessment report to PIRSA Fisheries. SARDI Aquatic Sciences Publication No. F2007/000782-3, Research Report Series No 382.

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

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

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

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

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

Svane I. and Johnson J. (2003) Gulf St Vincent Prawn (*Melicertus latisulcatus*) Fishery. Fishery assessment report to PIRSA. SARDI Aquatic Sciences RD03/0063.

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

Tanner J.E. (2003) The influence of prawn trawling on sessile benthic assemblages in Gulf St Vincent, South Australia. Can. J. Fish. Aquat. Sci. 60: 517–526.

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

Vijayan K.K., Balasubramanian C.P., Jithendran K.P., Alavandi S.V. and Santiago T.C. (2003) Histopathology of Y-organ in Indian white shrimp *Fenneropenaeus*

indicus, experimentally infected with white spot syndrome virus. *Aquaculture* 221: 97–106.

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

Wassenberg T.J. and Hill B.J. (1994) Laboratory study of the effects of light on the emergence behaviour of eight species of commercially important adult Penaeid prawns. *Aust. J. Mar. Freshwater Res.* 45: 43–50.

Waters C. (1976) Sedimentation in Gulf St Vincent. PhD thesis, Flinders University of South Australia, Adelaide.

Xiao Y. and McShane P. (1998) Gulf St Vincent Prawn Fishery. SARDI South Australian Fishery Assessment Series 98/05.

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

Xiao Y. (2004) Use of generalized linear models in analyzing the catch and effort data on the western king prawn *Penaeus latisulcatus* Kishinouye in the Gulf St Vincent, Australia. *Fisheries Research* 68: 67-82.

Zacharin, W. (1997) Management plan for the South Australian Gulf St Vincent prawn fishery. South Australian Fishery Management Series. Paper no. 30.

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 subsections, 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.

[illegible]

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.

		Year and month																																															
Block	Shot	1984			1985			1986			1987			1988			1989			1990			1991			1992			1993			1994			1995														
		4	6	11	1	4	2	3	4	3	5	2	4	6	11	3	4	5	11	12	2	4	6	11	12	3	4	6	11	6	11	4	6	11	2	4	6	2											
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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																							
																						13	11		
1990	February																								
	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.

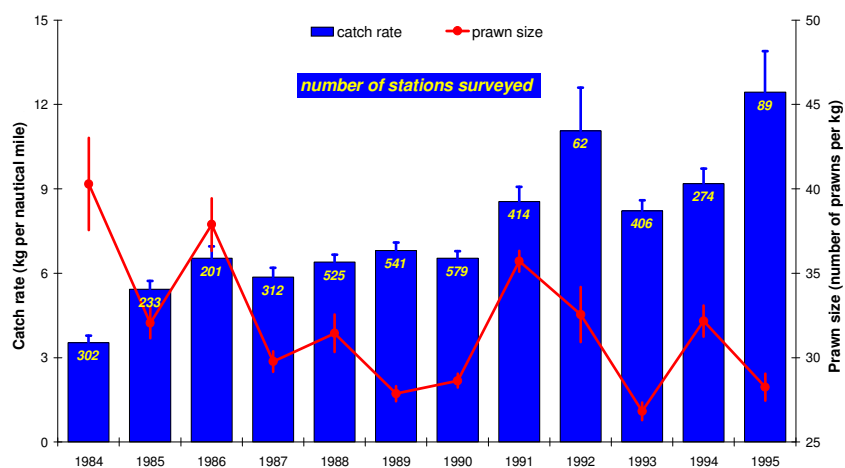


Figure 8.1 Mean (SE) catch rate (kg/nm) and the mean (SE) number of prawns/kg across months and blocks surveyed from 1984 to 1995 in GSV.

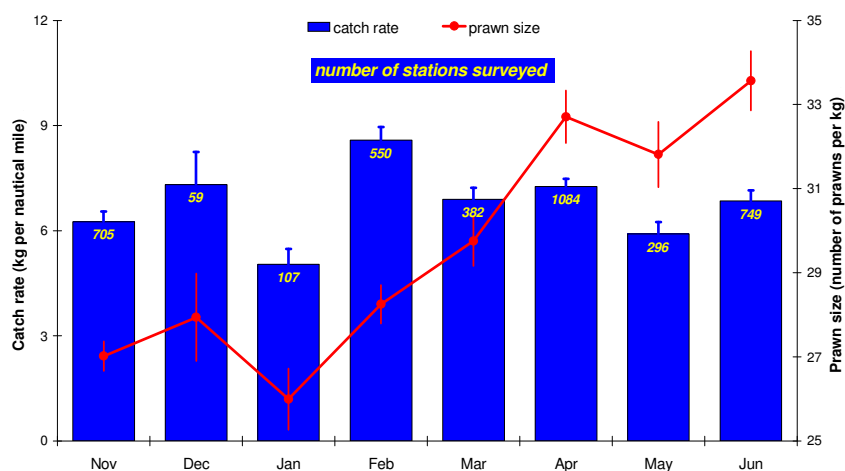


Figure 8.2 Mean (SE) monthly catch rate (kg/nm) and the mean (SE) monthly number of prawns/kg across years and blocks surveyed from 1984 to 1995 in GSV.

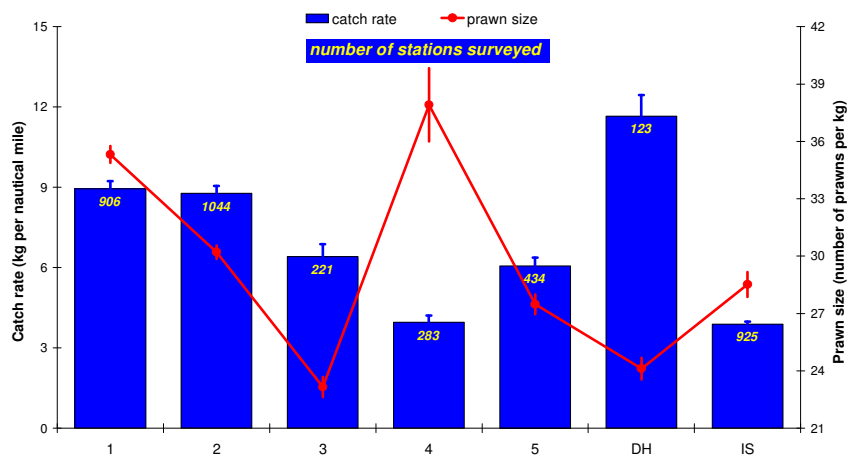


Figure 8.3 Mean (SE) regional catch rate (kg/nm) and the mean (SE) regional number of prawns/kg across years and months surveyed from 1984 to 1995 in GSV.

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.

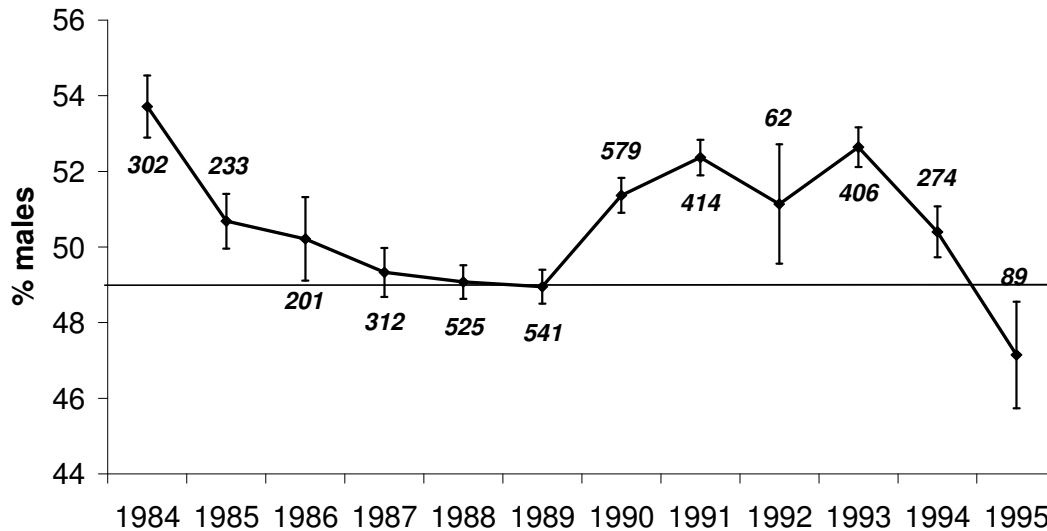


Figure 8.4 Mean (SE) annual % of males in the sampled population from GSV surveys done during 1984–1995. Numbers indicate the numbers of shots done.

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).

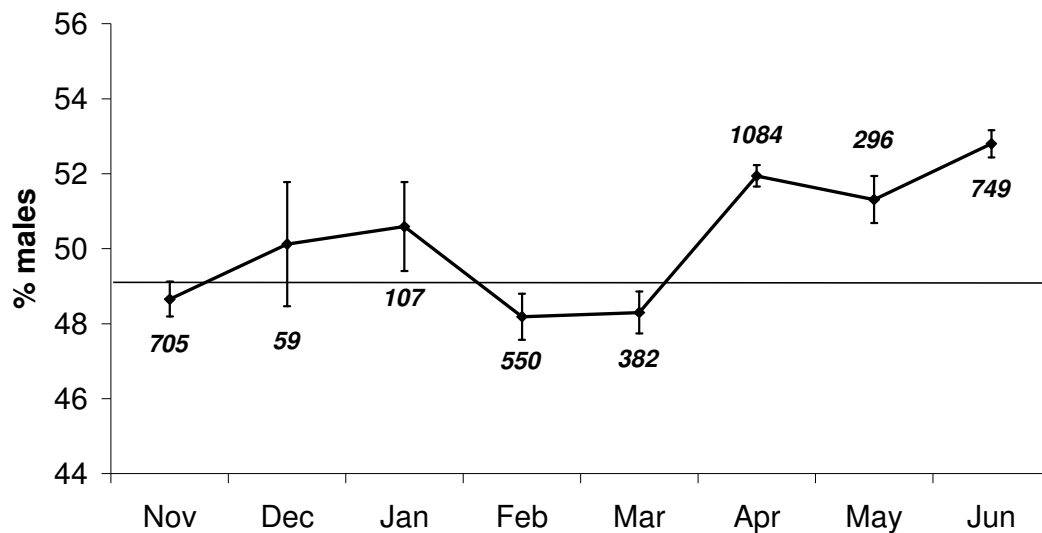


Figure 8.5 Mean (SE) monthly % of males in the sampled population from GSV surveys done during 1984–1995. Numbers indicate the numbers of shots done.

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.

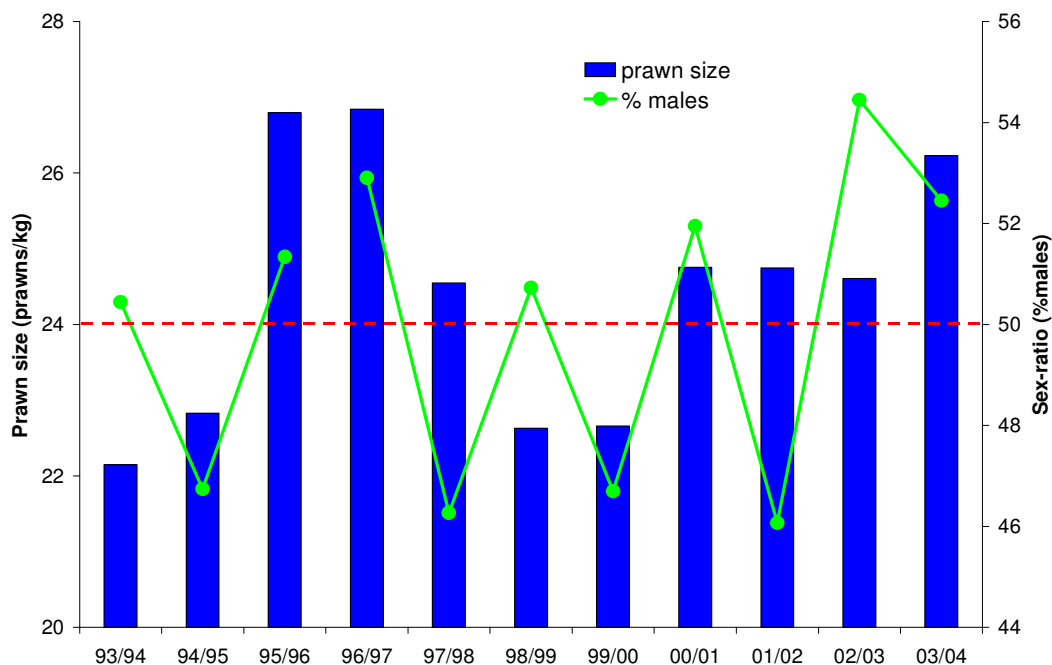


Figure 8.6 Sex-ratio (% males) and prawn size (prawns/kg) from data collected during commercial fishing operations in GSV from 1993/94 to 2003/04. The dotted red line indicates the target-size of 24 prawns/kg and an equal sex-ratio.

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).

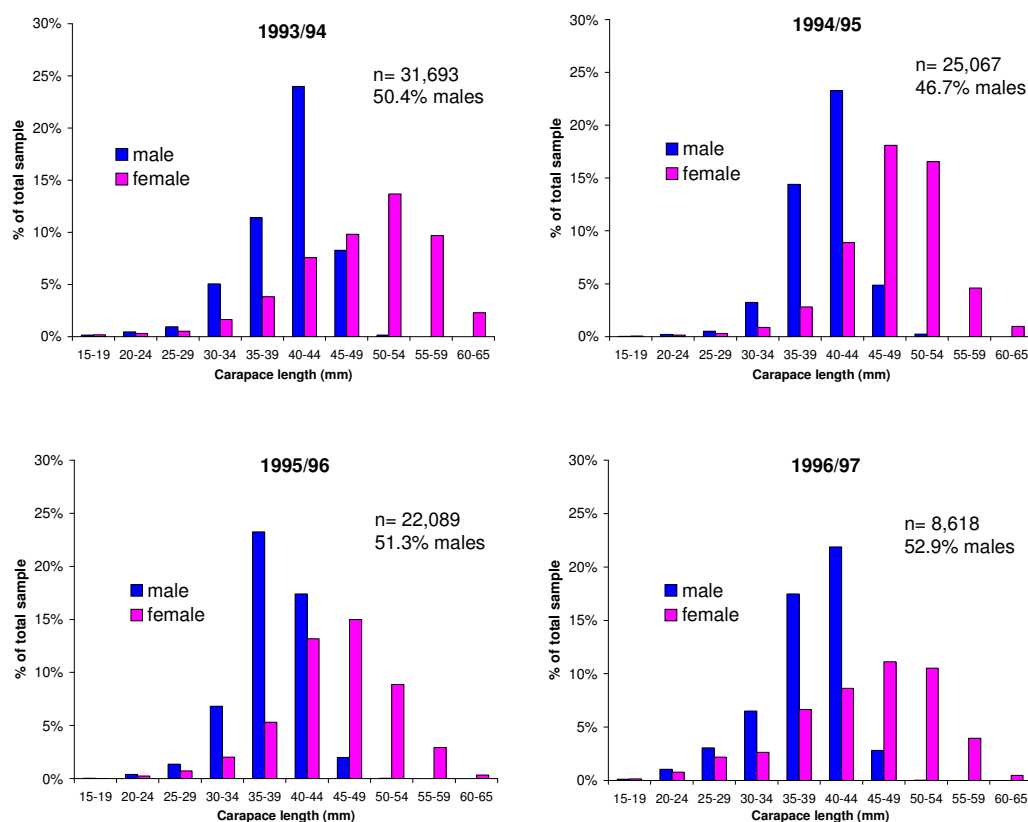


Figure 8.7a Size-frequency distributions from data collected during commercial fishing operations in GSV from 1993/94 to 1996/97.

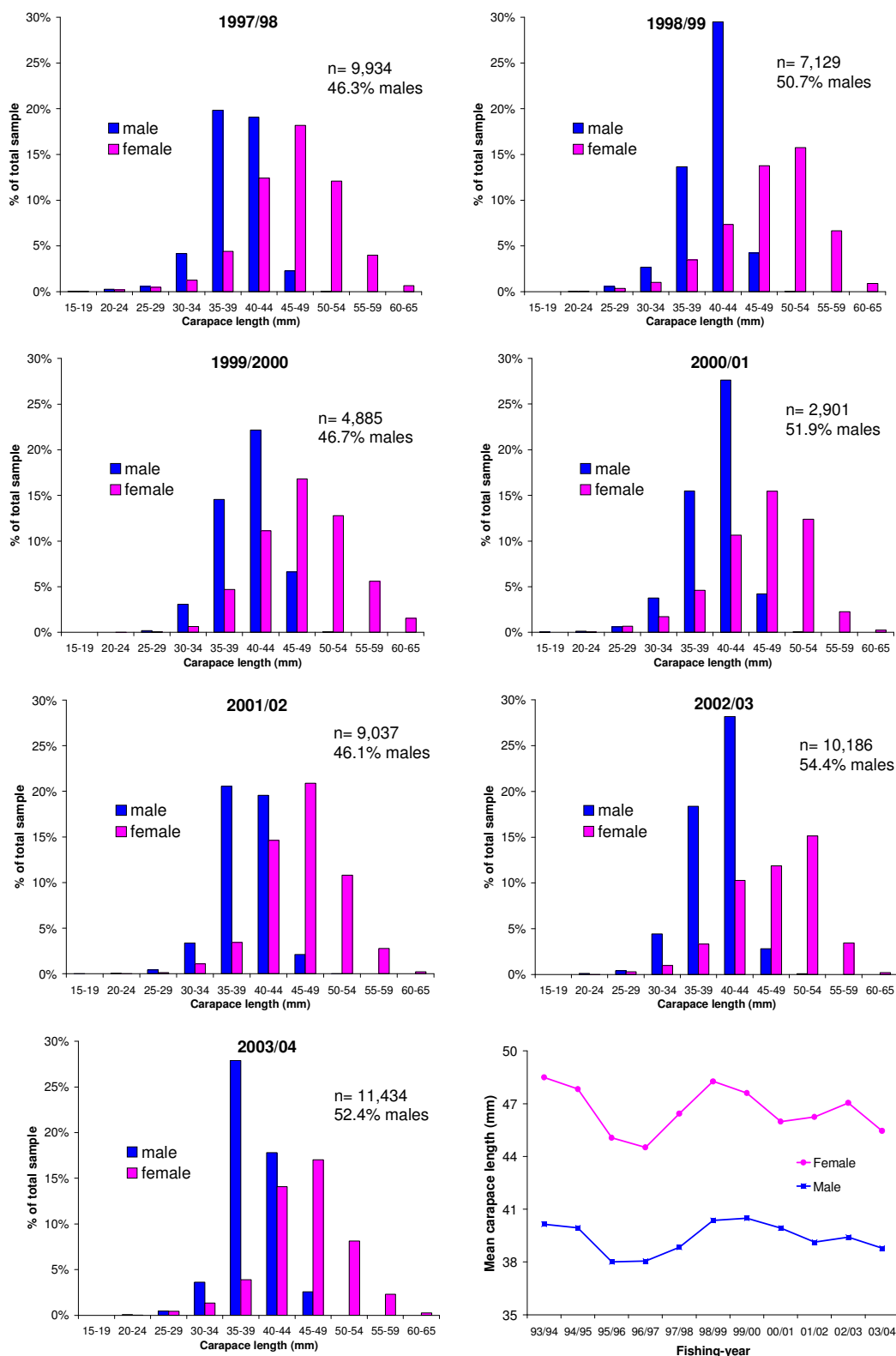


Figure 8.7b Size-frequency distributions from data collected during commercial fishing operations in GSV from 1997/1998 to 2003/04, and mean size (mm CL) of male and female prawns measured from 1993/94 to 2003/04.

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).

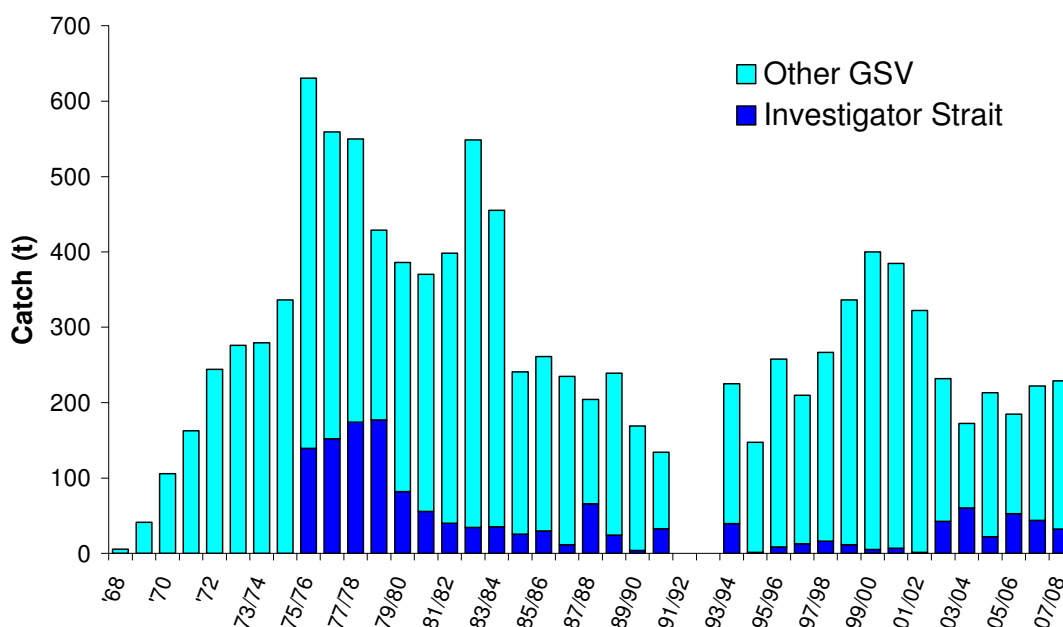


Figure 8.8 Total catch (t) from Investigator Strait and all other regions of GSV from 1968 to 2007/08. Data for 1968–1973 are reported as calendar year. Data for 1973/74 are from January to October 1974. From 1974/75 data are reported in fishing years.

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.

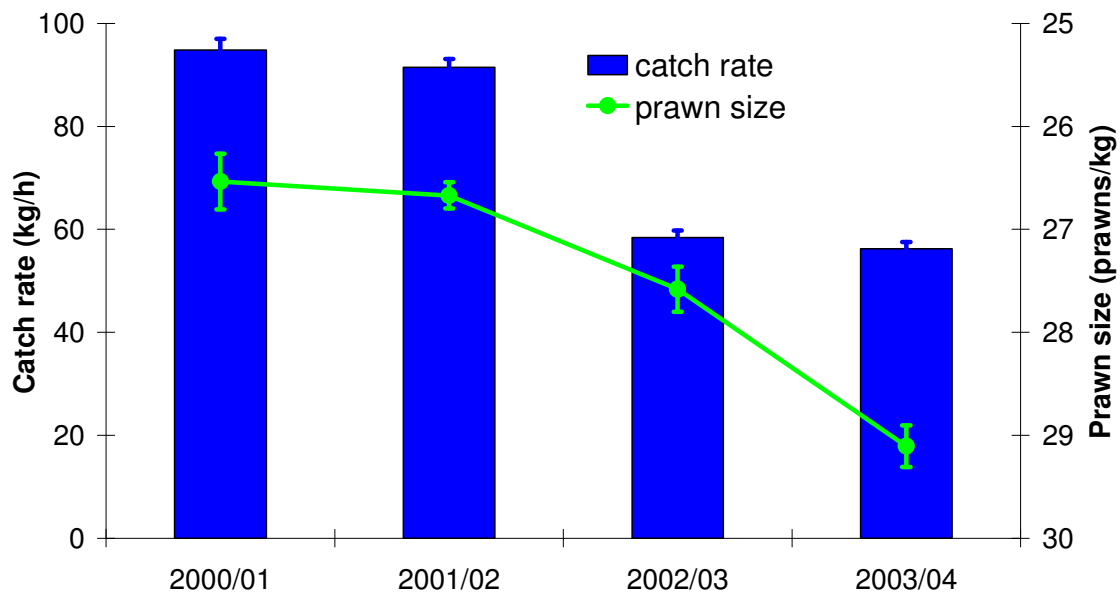


Figure 8.9 Mean (SE) catch rate (kg/h) and mean (SE) prawn size (prawns/kg) from searching shots conducted between 2000/01 and 2003/04.

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 ($F_{5,398}=1.53$, $P>0.05$).

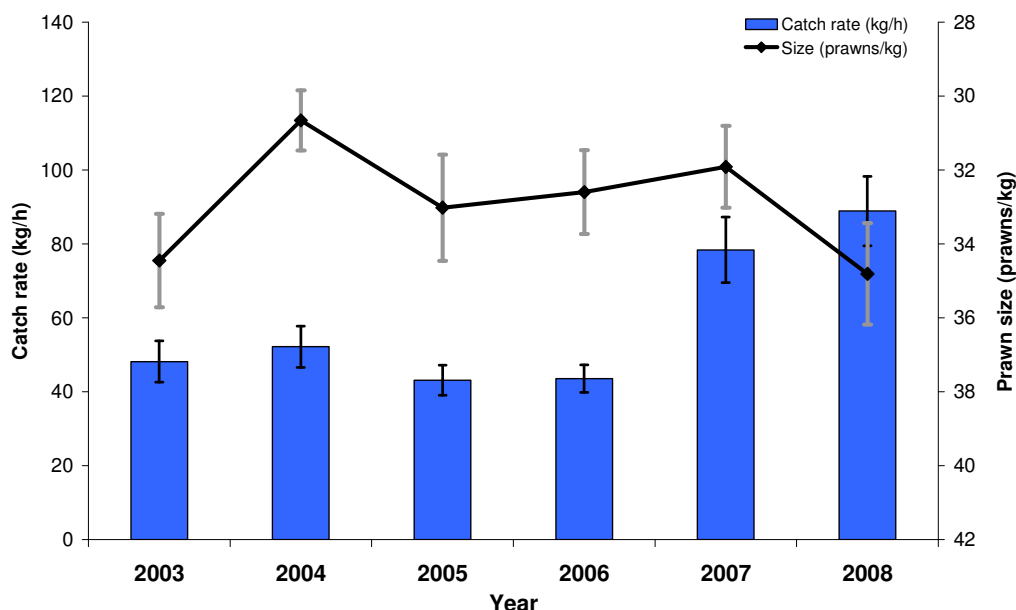


Figure 8.10 Mean (SE) catch rate (kg/h) and mean (SE) prawn size (prawns/kg) from May surveys between 2003 and 2008. Estimates compared from up to 71 trawl shots each year.

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).

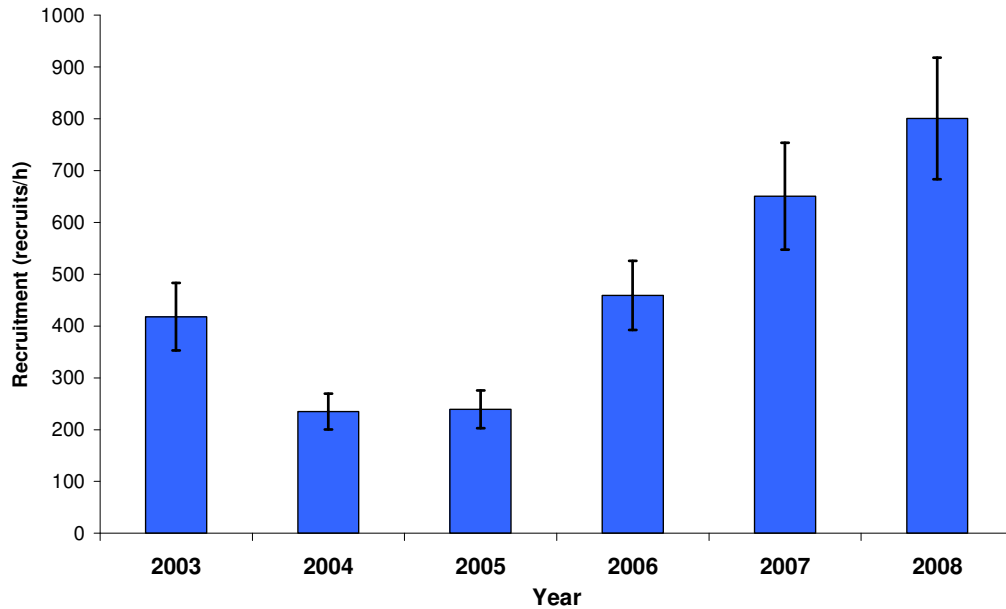


Figure 8.11 Mean (SE) number of recruits per trawl hour from May surveys between 2003 and 2008. Estimates compared from up to 56 trawl shots each year.

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)

8.5 Spatial and temporal assessment of survey results and commercial fishing

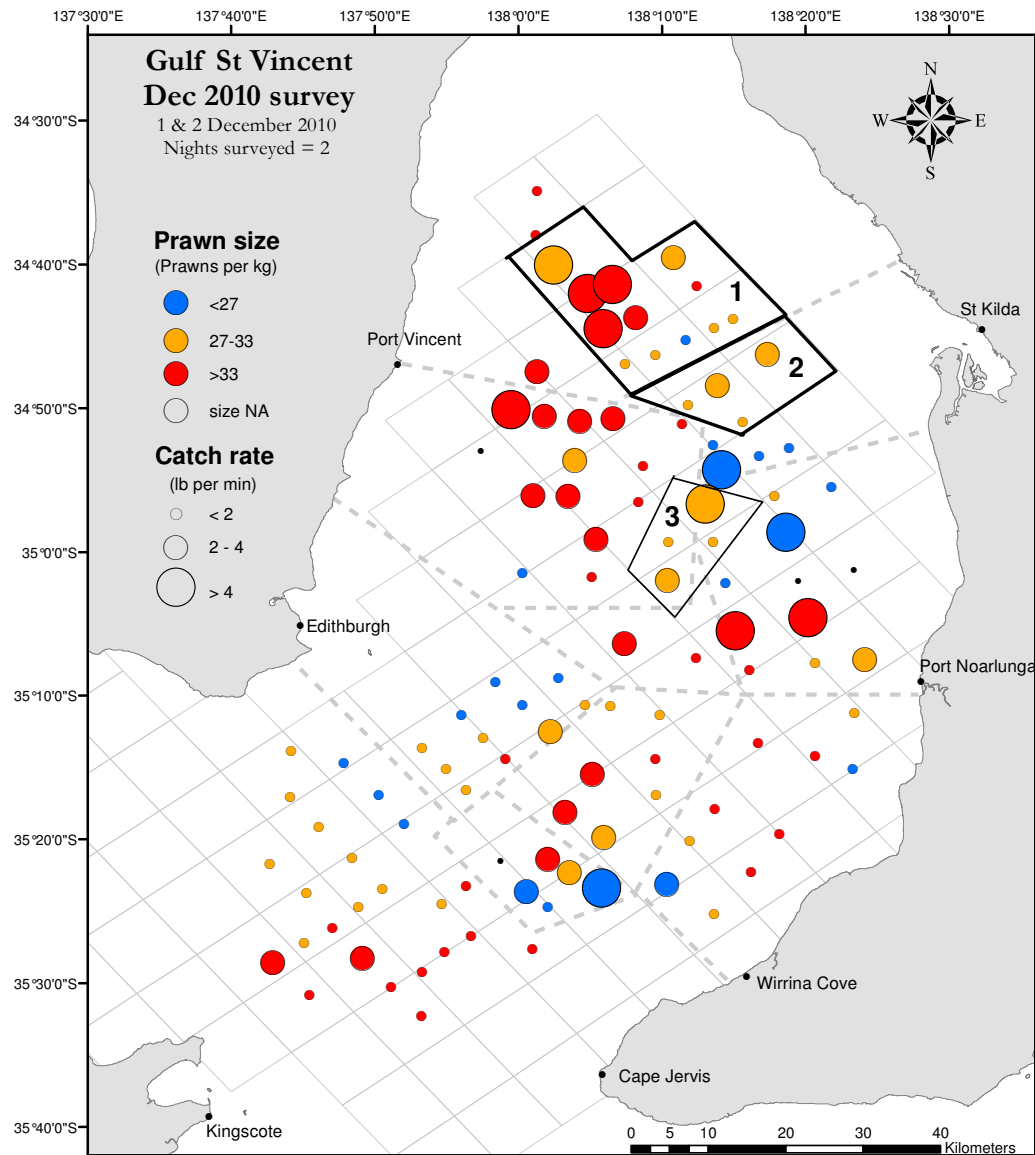


Figure 8.12 Catch rate and mean size during the December 2010 stock assessment survey, prior to harvest period 1. The polygon (black line) represents the maximum area opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented.

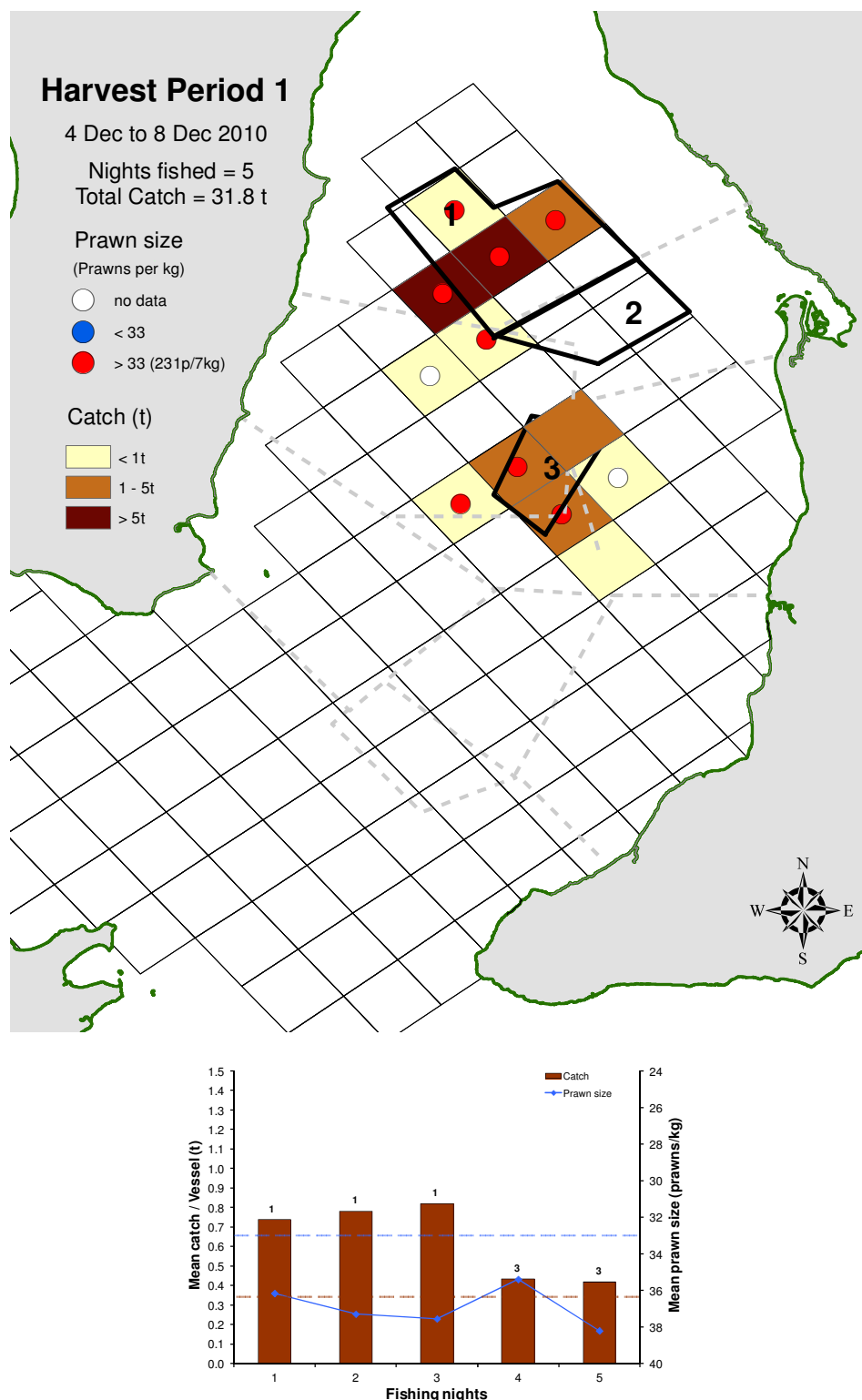


Figure 8.13 Map: Commercial catch (t) and prawn size (prawns/kg) from blocks fished during harvest period 1. The polygon (black line) represents the maximum area opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented. **Graph:** Mean daily 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.

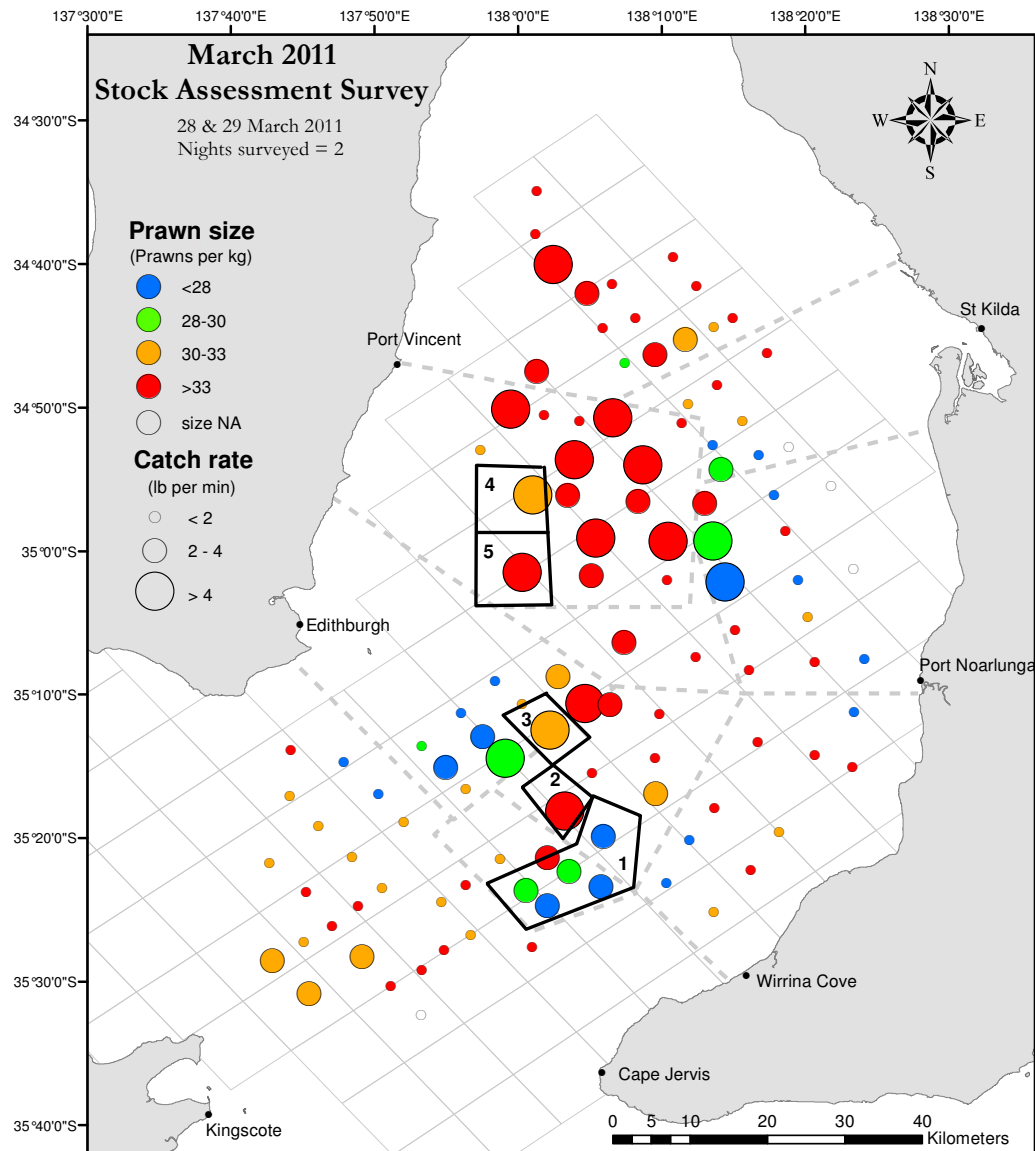


Figure 8.14 Catch rate and mean size during the March 2011 stock assessment survey, prior to harvest period 2. Polygons (black line) and west of the black line in the Investigator Strait represents the maximum areas opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented.

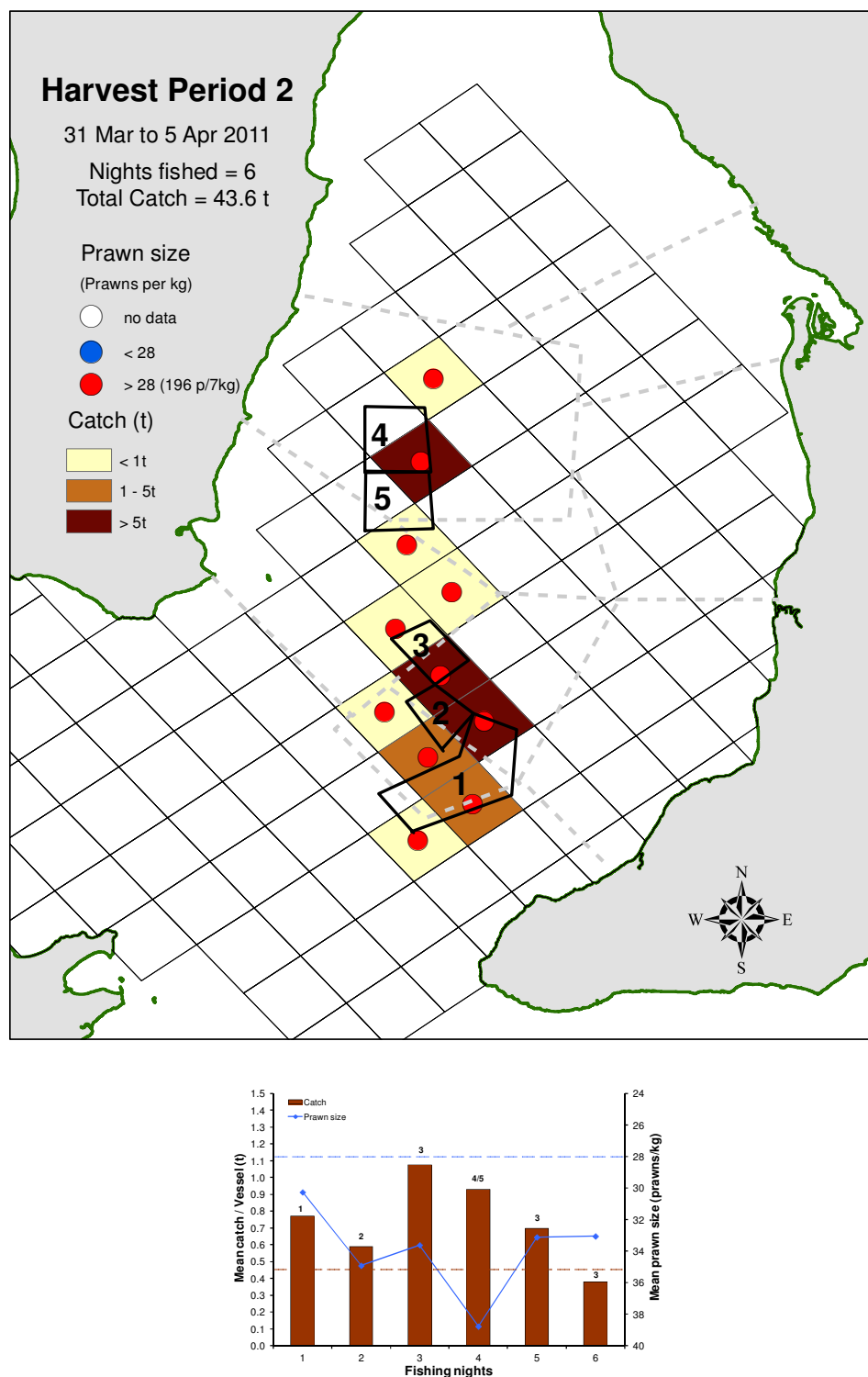


Figure 8.15 Map: Commercial catch (t) and prawn size (prawns/kg) by blocks fished during harvest period 2. Numbered polygons (black line) represent the maximum areas opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented. **Graph:** Mean 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. Numbers indicate harvest strategy areas fished.

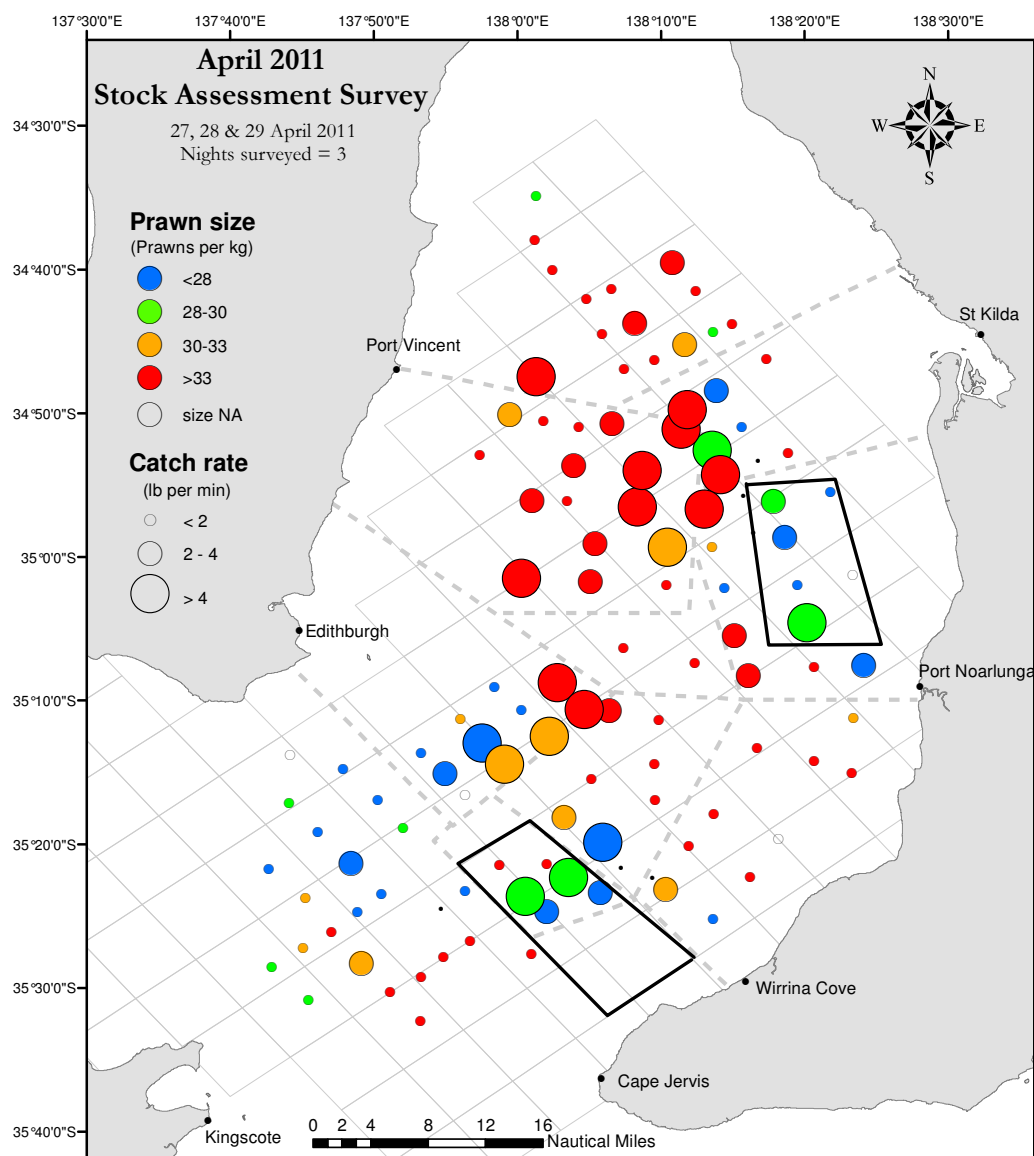


Figure 8.16 Catch rate and mean size during the April 2011 stock assessment survey, prior to harvest period 3. Polygons (black line) represent the maximum areas opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented.

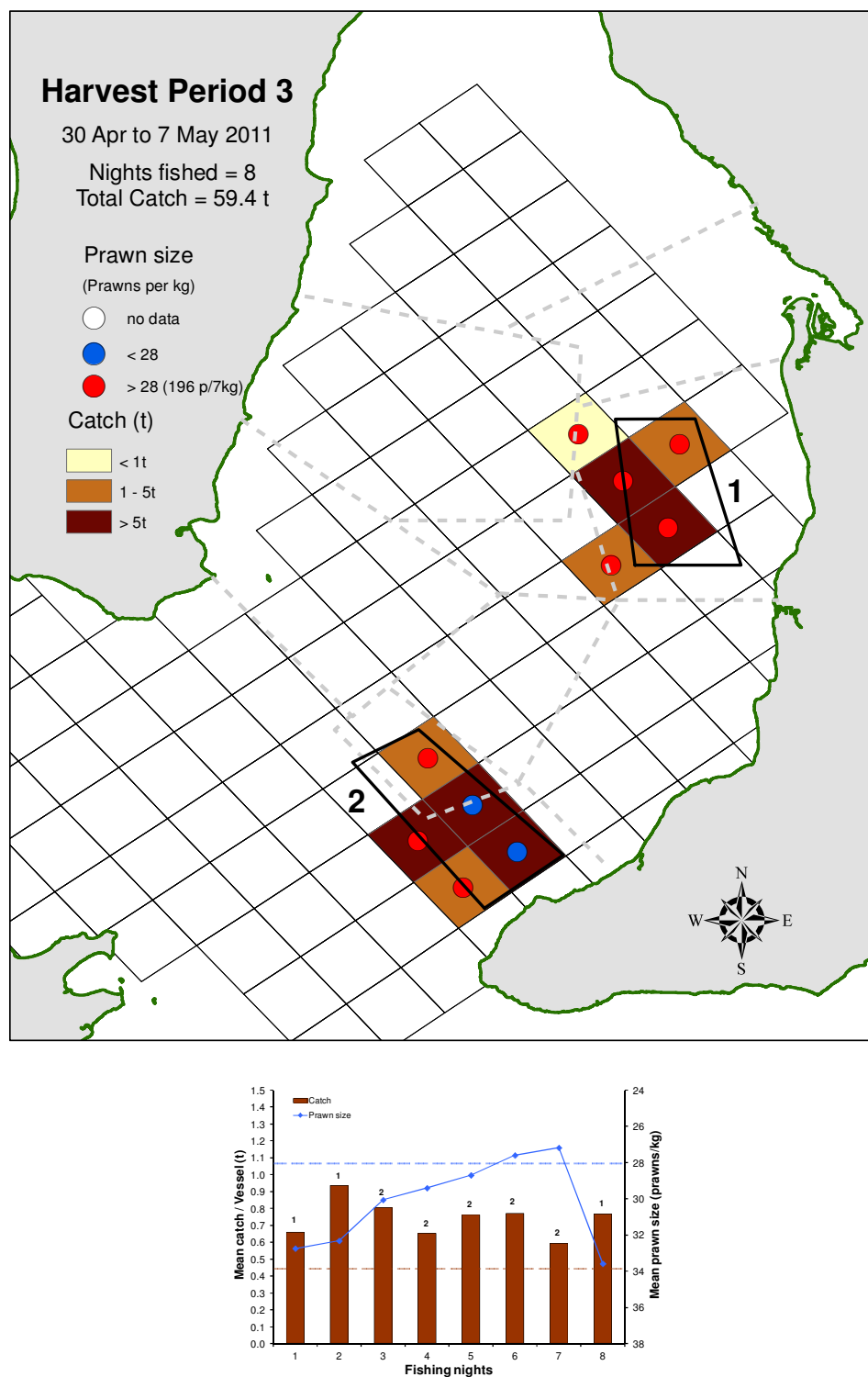


Figure 8.17 Map: Commercial catch (t) and prawn size (prawns/kg) from blocks fished during harvest period 3. Polygons (black line) represent the maximum areas opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented. **Graph:** Mean daily commercial 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 3. Numbers indicate harvest strategy areas fished.

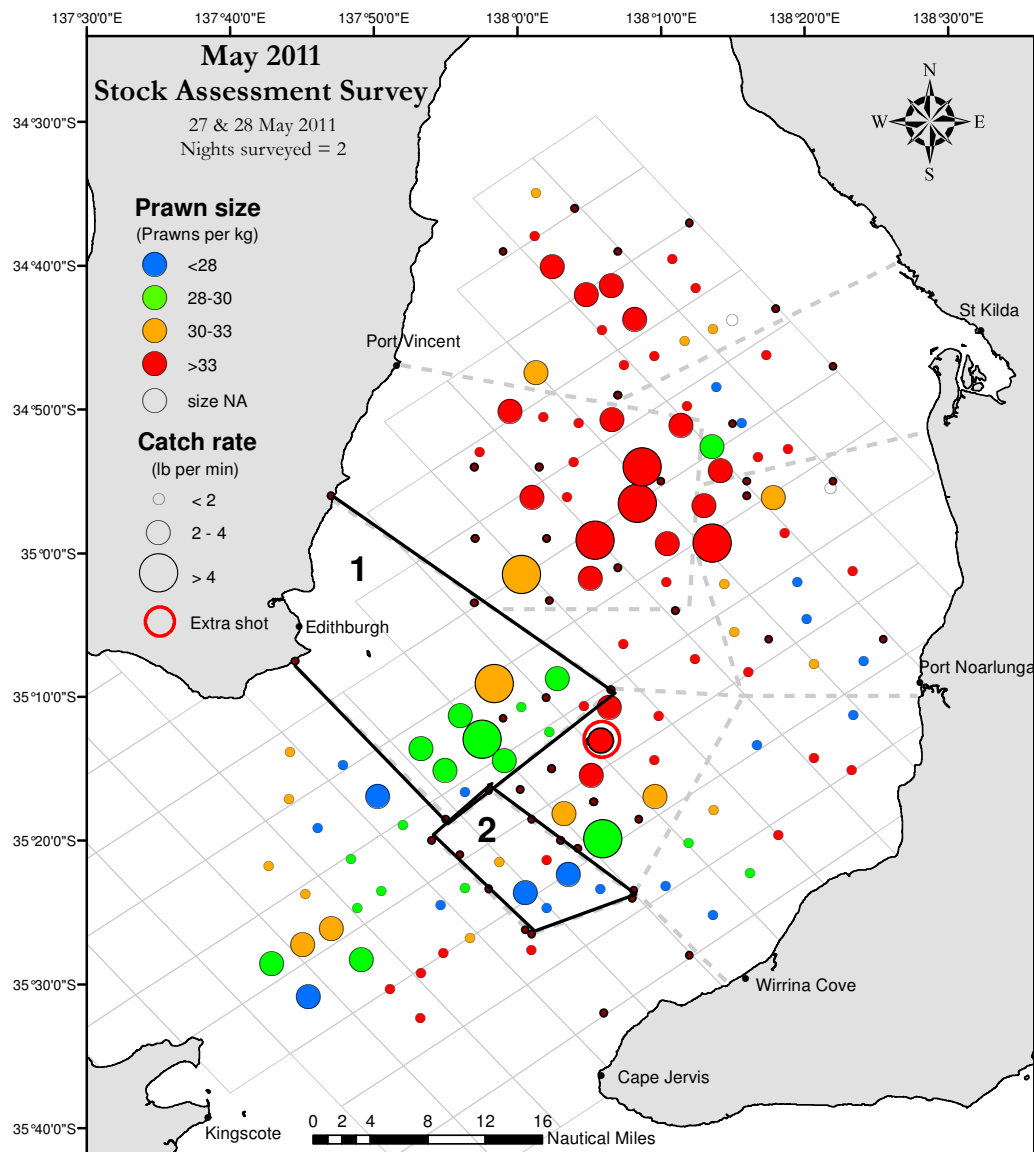


Figure 8.18 Catch rate and mean size during the May 2011 Stock Assessment survey, prior to harvest period 4. Polygons (black line) represent the maximum areas opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented.

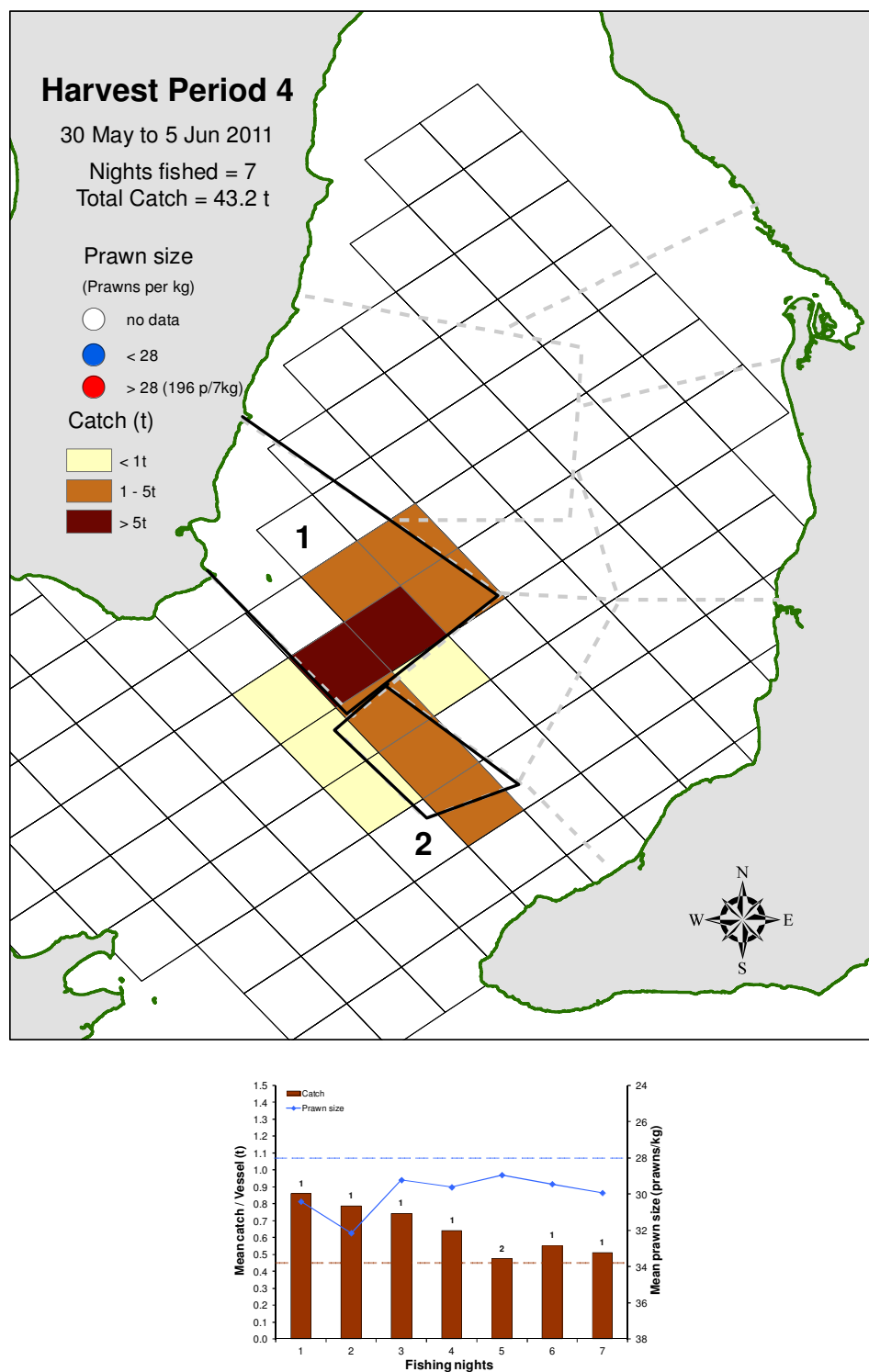


Figure 8.19 Map: Commercial catch (t) and prawn size (prawns/kg) from blocks fished during harvest period 4. Polygons (black line) represent the maximum areas opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented. **Graph:** Mean daily commercial 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 4. Numbers indicate harvest strategy areas fished.

8.6 Satellite imagery of monthly average SST (C)

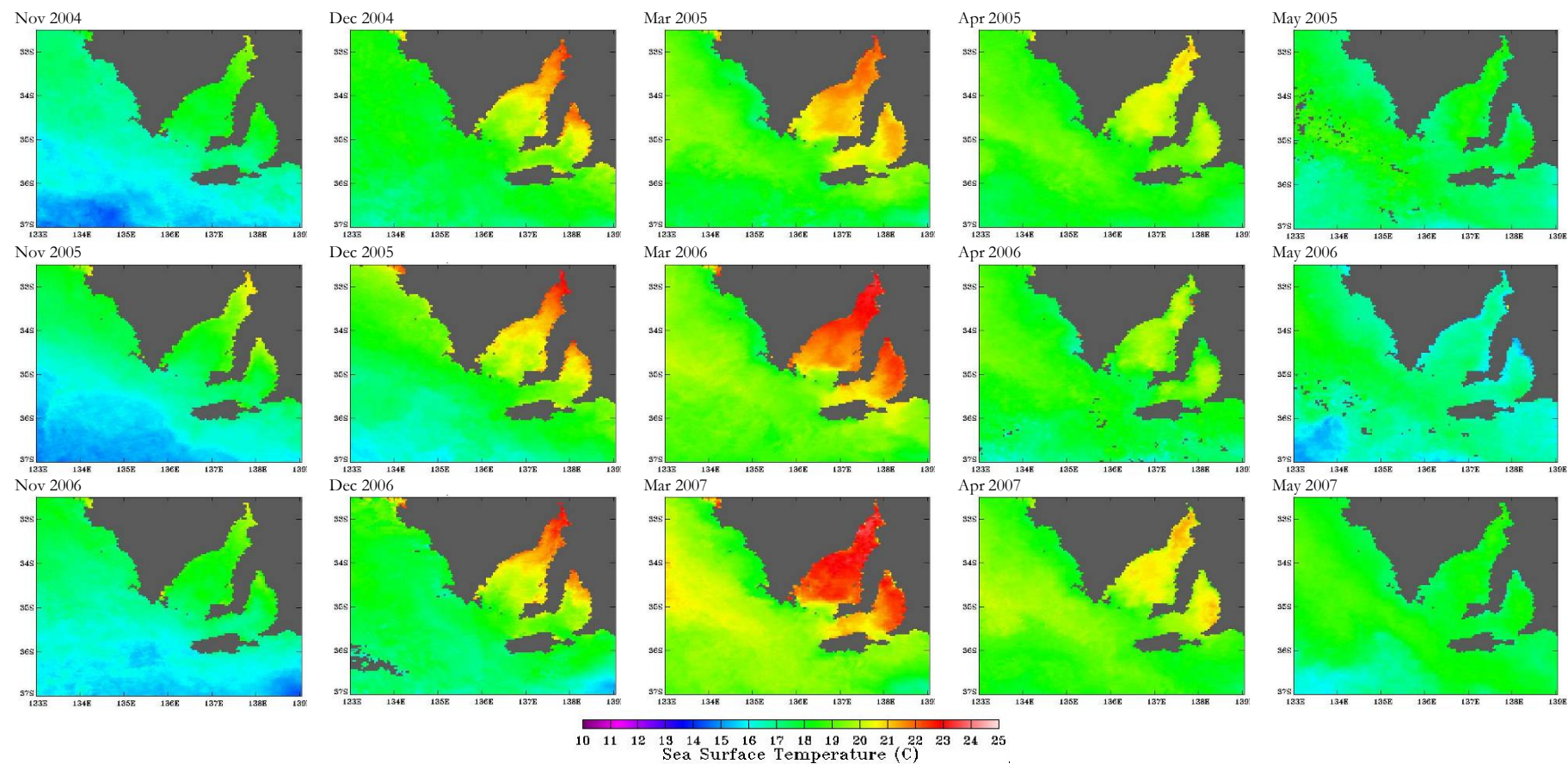


Figure 8.20 Satellite imagery of monthly average SST (C) for South Australia's gulf regions during November, December and March–May between 2004/05 and 2006/07. Maps were obtained from the PODAAC website (<http://poet.jpl.nasa.gov>).

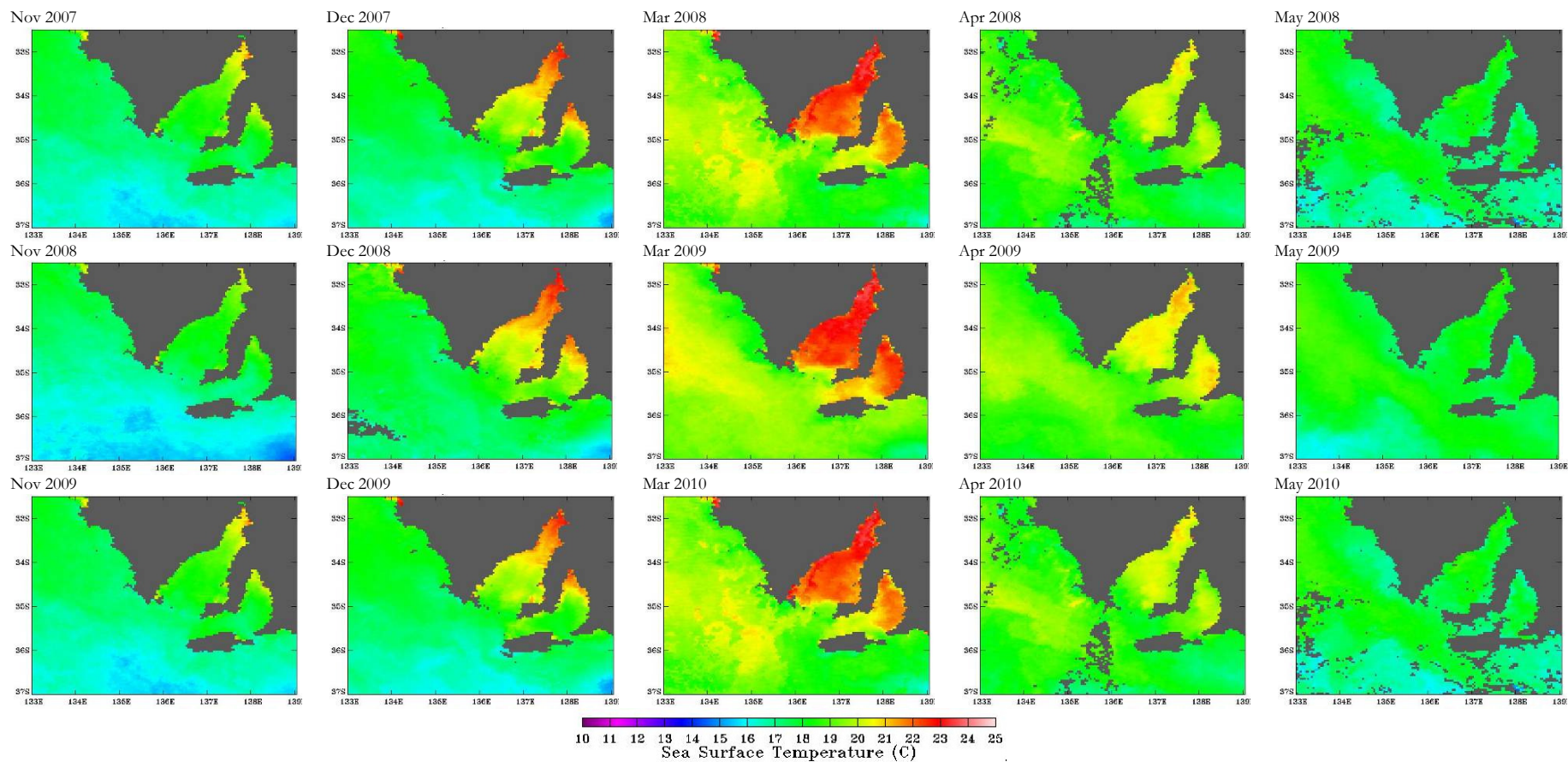


Figure 8.21 Satellite imagery of monthly average SST (°C) for South Australia's gulf regions during November, December and March–May between 2007/08 and 2009/10. Maps were obtained from the PODAAC website (<http://poet.jpl.nasa.gov>).

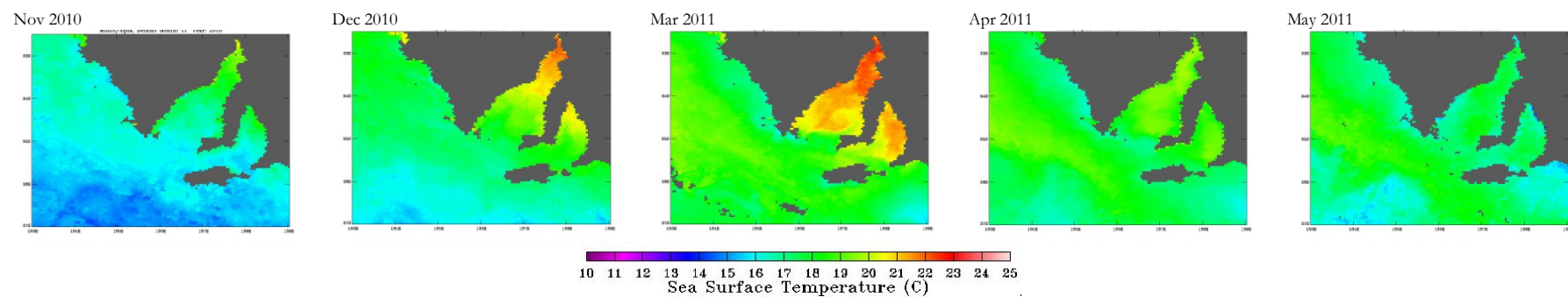


Figure 8.22 Satellite imagery of monthly average SST (°C) for South Australia's gulf regions during November, December and March–May between 2010/11. Maps were obtained from the PODAAC website (<http://poet.jpl.nasa.gov>).