Fishery Assessment Report to PIRSA Fisheries

Gulf St Vincent Prawn (*Melicertus latisulcatus*) Fishery 2006/07

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This report updates the December 2007 Fishery Assessment Report for the Gulf St Vincent Prawn Fishery (2005/06 season) 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 2005/06 with data from the 2006/07 season, and is part of SARDI Aquatic Sciences' ongoing assessment program for the Gulf St Vincent Prawn Fishery (GSVPF). The aims are to: (1) synthesise information for the GSVPF; (2) assess the current status of the resource and consider the uncertainty associated with the assessment; (3) comment on the current Performance Indicators and Reference Points; and (4) identify future research needs for the fishery.

2. The current Management Plan for the GSVPF identifies stock recovery as the key objective of the fishery for the next five years (2007 – 2011). The Plan outlines decision rules for conservative harvest strategies aimed at: 1) limiting fishing effort during the early spawning period (pre-Christmas); and 2) linking exploitation with indices of biomass (survey catch rates). Key biological Performance Indicators are based on indices of catch, biomass, prawn size and recruitment, calculated from both commercial and fishery-independent survey data.

3. Available data indicates stock recovery (increasing biomass) during the last two seasons. There are several lines of evidence to support this, including:
   i. Increases in mean survey catch rates in consecutive years between 2004/05 and 2006/07;
   ii. Increases in recruitment indices in consecutive years between 2004/05 and 2006/07;
   iii. Significantly greater abundances during May 2007 survey for all size classes compared to previous years;
   iv. Increases in commercial CPUE of ~50% between 2004/05 and 2006/07; and
   v. A 19% increase in total catch between 2005/06 and 2006/07

4. During the 2006/07 fishing season, mean prawn sizes harvested during December, April and May were within target size ranges. However, mean prawn size harvested during March (29.9 prawns/kg) was smaller than the target size (<28 prawns/kg). The harvest of small prawns may be reduced in the future by: 1) improving harvest strategy management at sea; and 2) applying spatial guidelines to improve harvest strategy development.

5. Data were available to assess the fishery against all 7 key biological Performance Indicators. Six of these measures were within the reference limits, while mean size was triggered due to prawns smaller than target size harvested during March 2007.

6. The substantial increase in recruitment observed during 2007, along with continued conservative harvest strategies as outlined in the Management Plan, are conducive to further stock recovery during 2007/08.

1. GENERAL INTRODUCTION

1.1 Overview

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

This report updates the previous GSVPF 2005/06 stock assessment report (Roberts *et. al.* 2007a), which concluded that the biomass upon which the fishery is based has revealed signs of modest stock recovery. It also: (1) provides a more comprehensive assessment of the fishery than the 2006/07 status report (Roberts *et. al.* 2007b), (2) documents inter-annual trends in the stock from consistent (temporal and spatial) fishery-independent surveys, and (3) addresses the performance of the fishery under the revised management plan, which is underpinned by the principal objective of stock recovery.

The report is divided into six sections. Section One is the General Introduction, which: (1) outlines the aims and structure of the report; (2) describes the GSV fishery; (3) outlines current management arrangements and identifies the Performance Indicators and Reference Points; (4) summarises the biological knowledge of GSV prawns; (5) provides a synopsis of previous stock assessment reports for the fishery; and (6) outlines the current research program.

Section Two presents the analyses and interpretation of fishery-dependent logbook data from 1968–2007, documenting trends in catch, effort and CPUE. Analyses of fishery-independent survey data are presented in Section Three. Section Four provides spatial comparisons of fishery-independent survey data with commercial logbook data for catch rate and prawn size to enable an assessment of harvest strategies developed throughout the 2006/07 season.

Section Five provides assessment of the fishery against the Performance Indicators identified in the Management Plan. The final section, Section Six, (1) summarises the information available for stock assessment of the GSVPF, (2) assesses the status of the resource and comments on the uncertainty associated with that assessment, (3) assesses the effectiveness of harvest strategies and identifies ways to improve and refine harvest strategies where appropriate, (4) identifies the limitations of the current Performance Indicators and (5) outlines future research needs to improve stock assessment for this fishery.

1.2 Description of the fishery

1.2.1 Fishery location

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

The waters of the GSVPF are bound between a line from the southern shore of Yorke Peninsula, east of the meridian of longitude 137°, down to the northern shore of Kangaroo Island on the same meridian, and a line from Cape St Alban, Kangaroo Island (Latitude 35° 48.7' south, longitude 138° 07.4' east) to Porpoise Head on the southern shore of Fleurieu Peninsula (latitude 35° 39.6' south, longitude 138° 13.6' east).

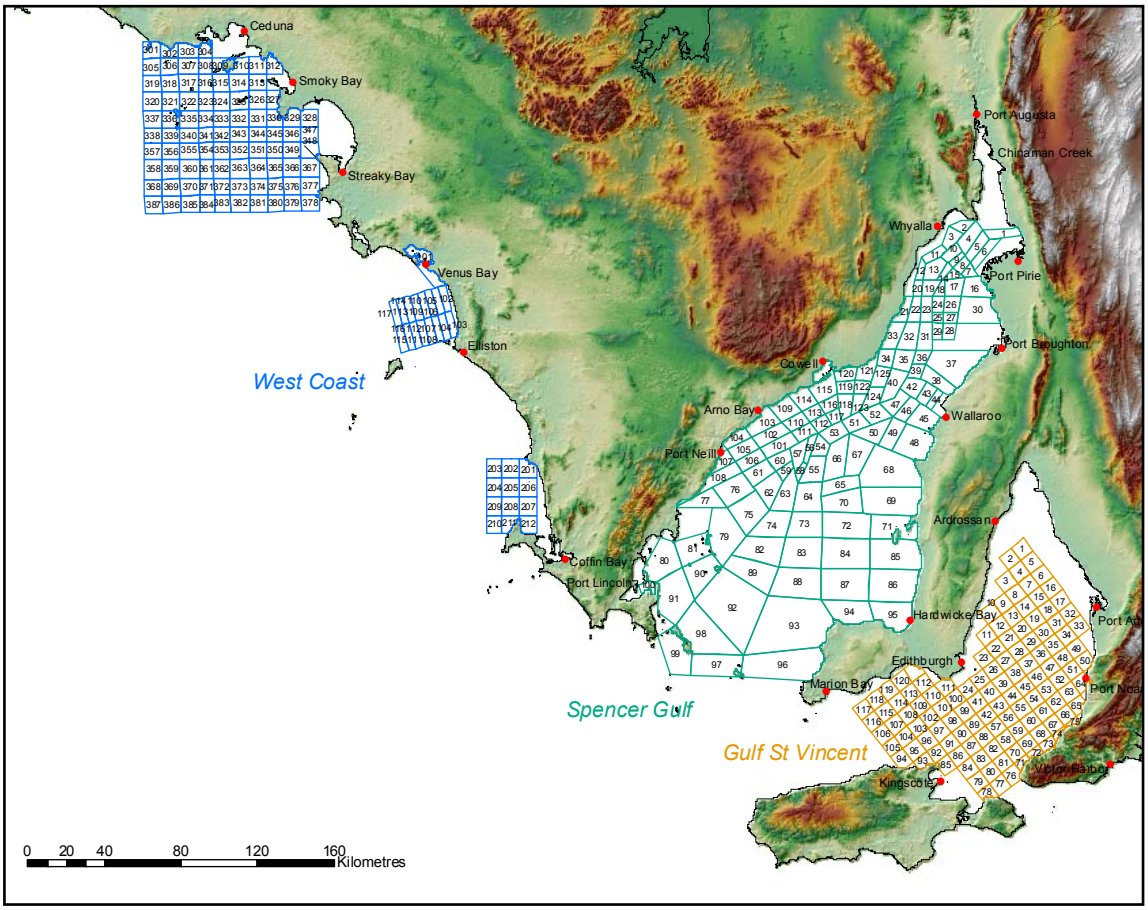

Figure 1.1 Location of South Australia's three western king prawn fisheries.

1.2.2 The GSV environment

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

Sea surface temperatures (SSTs) in South Australia are lower and more variable than in other northern fisheries that target *Melicertus latisulcatus* (e.g. Broome and Shark Bay, Figure 1.2). Figure 1.3 illustrates the warmer waters of both gulfs relative to other South Australian coastal waters, particularly in the northern regions of each gulf.

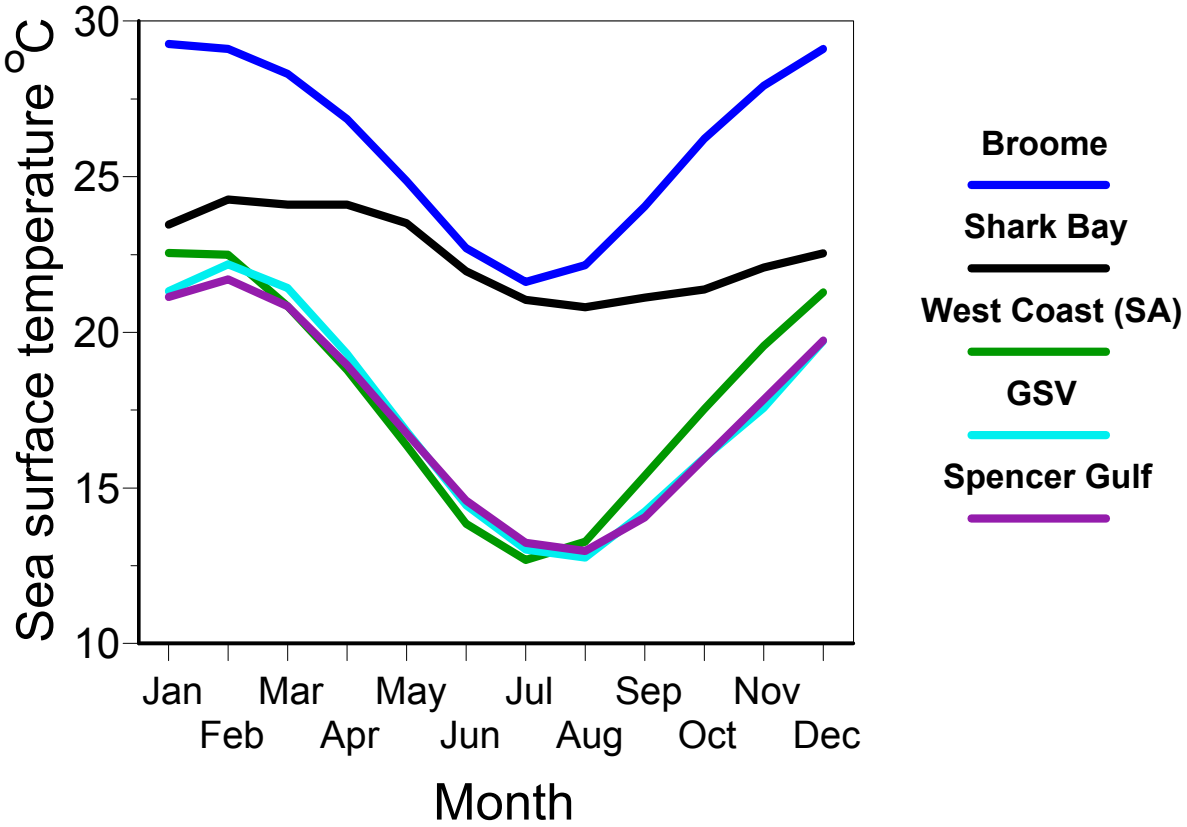

Figure 1.2 Comparison of mean monthly sea surface temperature (SST, ºC) for the Australian prawn fisheries that target *Melicertus latisulcatus*. Figure reproduced from Carrick 2003.

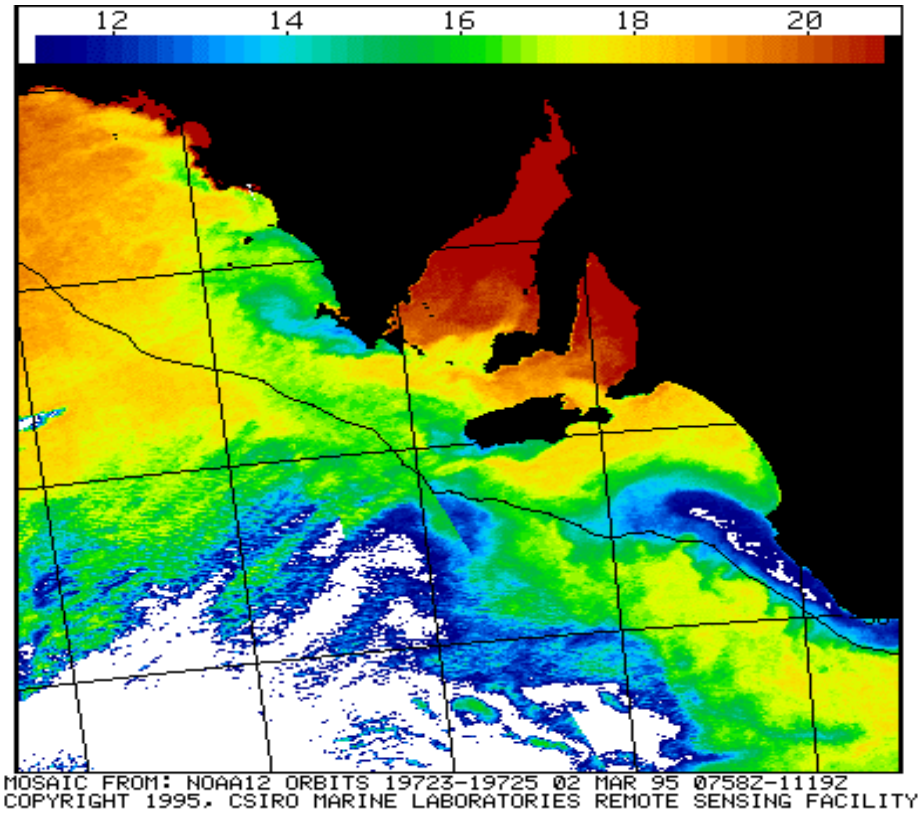

Figure 1.3 Sea-surface temperatures over the continental shelf of South Australia during late summer/early autumn, 1995. A colour-coded key in degree Celsius is situated at the top of the map. Figure from Middleton & Bye (2007), sourced from CSIRO.

1.2.3 Nursery Areas

In South Australia, juvenile *M. 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 shown to be similar across the intertidal zone (Kangas and Jackson 1998), while in Spencer Gulf abundances were significantly greater 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. The entire South Australian coastline was divided into a number of Fisheries Habitat Areas (FHA) that corresponded to each of the three South Australian prawn fisheries as follows:

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 has a comprehensive description, including colour-coded maps of up to 12 habitat types. Of these, the habitat types 'tidal flats' and 'mangrove forests' were determined as

appropriate juvenile prawn habitat. 'Tidal flats' included mud flats, sand flats and intertidal unvegetated soft sediments. However, 'tidal flat' habitat also included intertidal seagrass meadows and intertidal macroalgal environments, unsuitable habitat for juvenile prawn settlement (and therefore these are a potential source of error in calculations). 'Mangrove forest' were characterised by a soft sediment substrate in the upper intertidal zone dominated by a vegetative cover of the grey mangrove (*Avicennia marina*). Mangrove forest always overlapped with tidal flat habitat (see Figure 1.4) and was thus labelled mangrove forest (+ tidal flat) for this report. 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 provides summary 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 Port Adelaide (~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 1.4). These areas corresponded with sites in GSV that were previously found to contain the greatest abundances of juvenile prawns (see Section 1.4.3).

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

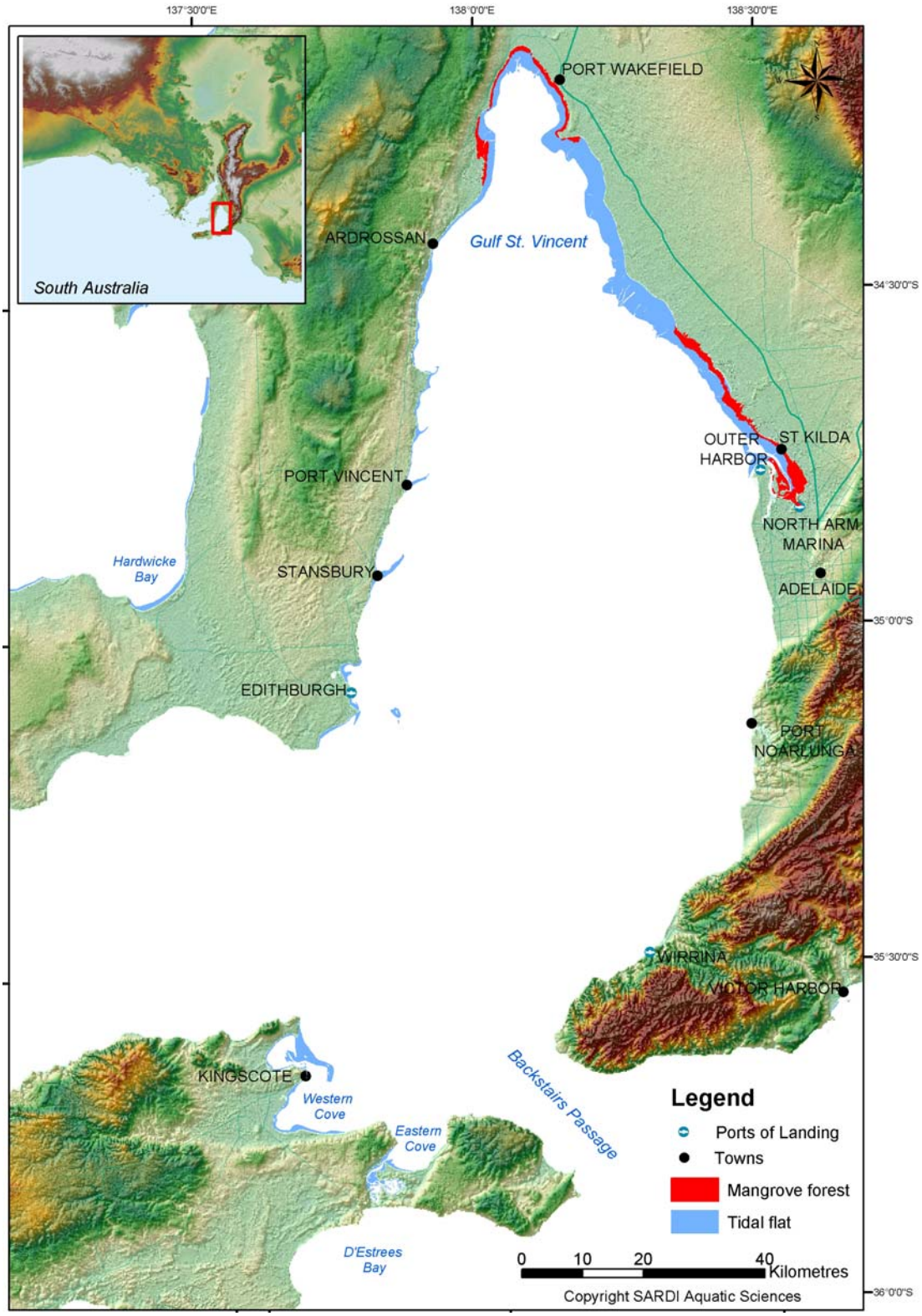

Figure 1.4 Important juvenile nursery habitat, mangrove forest and tidal flats, around coastal Gulf St Vincent. Reproduced from Bryars (2003).

1.2.4 Commercial fishery

The GSVPF is a single species fishery that targets the western king prawn, *Melicertus latisulcatus*, previously known as *Penaeus latisulcatus* (see Perez Farfante & Kensley 1997). 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 fishery in terms of production, value and number of licensed fishers. Production per vessel from the GSVPF is ~40% of that from Spencer Gulf Prawn Fishery (Table 1.2).

Table 1.2 Production figures and species harvested in major Australian prawn fisheries. * includes by-product

Fishery	Year	Production (t) (% *W. king*)	Value $000,000	Vessels	Prawn sp. harvested
Northern	2004–05	5,035 (<1.5%)	65	95	banana, tiger, endeavour, king
North Qld	2003	9,348*	110*	630	banana, tiger, endeavour, king, bay
NSW	2000–01	3,411*	32*	238	eastern king, school
Shark Bay	2001	1,696 (78%)	25.2	27	western king, tiger, endeavour, coral
Broome	2001	142 (44%)	1	5	western king, coral
Spencer Gulf	2005–06	1,870 (100%)	33.3	39	western king
GSV	2005–06	179 (100%)	3.2	10	western king
West Coast	2005–06	21 (100%)	0.4	3	western king

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 in June 1991 for two years until February 1994 following a parliamentary review (Anon 1991). Table 1.3 documents the history of licence limitation in the fishery. Since the closure, six vessels have been upgraded to larger vessels that are similar to those operating in Spencer Gulf (see Dixon *et al.* 2007).

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. The six large GSV vessels are restricted to double-rigged gear (Figure 1.5), whereas the four smaller GSV vessels 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 1.6). Large vessels use "hoppers" for efficient sorting of the catch and rapid return of by-catch (Figure 1.5) and "graders" to sort the prawns into marketable size categories (Figure 1.5).

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. Exacerbating the increase in catch, a 250% increase in the catch of prawns during the early spawning season during these two years likely resulted in recruitment over-fishing.

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. Following, catch, effort, CPUE and mean prawn size declined from 1999/00 to 2003/04. 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 in November 2004.

1.2.5 Recreational, indigenous and illegal catch

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

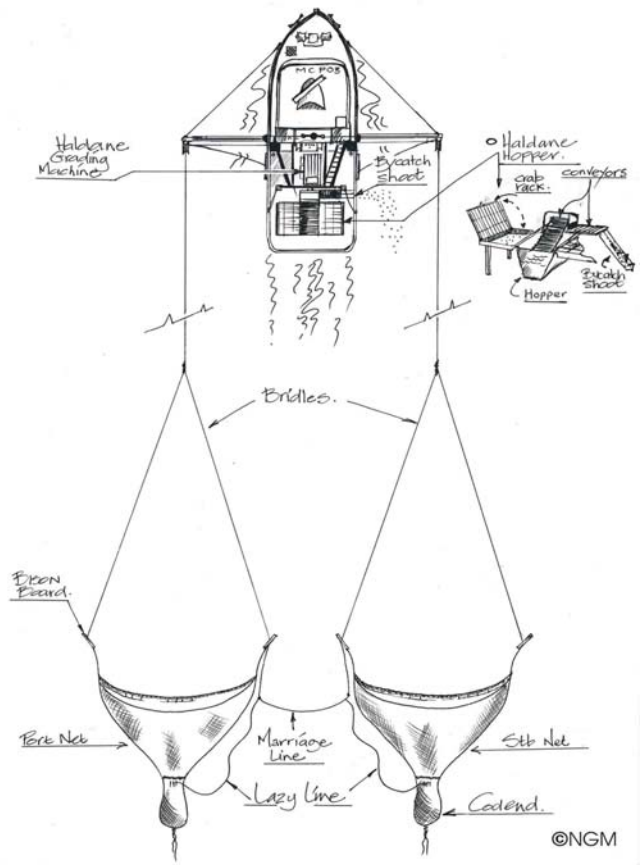

Figure 1.5 Double rig trawl gear and location of hopper sorting and prawn grading systems used in the Spencer Gulf Prawn Fishery. Figure from Carrick (2003).

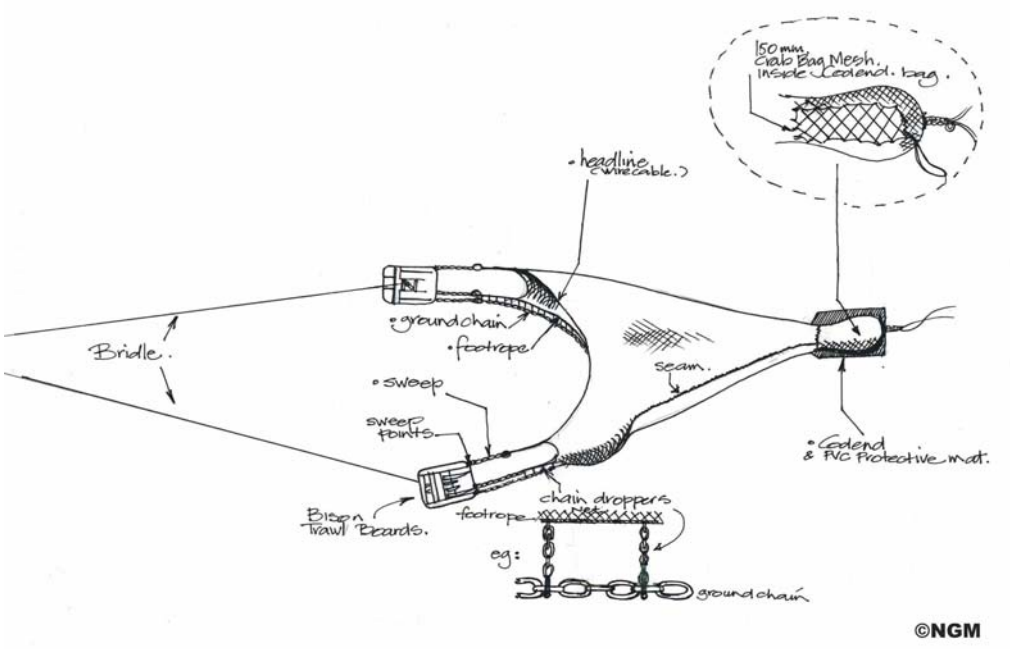

Figure 1.6 Trawl net configuration showing trawl boards, head rope, ground chain and cod end with crab bag. Figure from Carrick (2003).

1.3 Management of the fishery

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

1.3.1 Management history

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

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

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

1.3.2 Current fishery management

The GSVPF is a limited entry input controlled fishery with 10 licensed operators. Trawling activities are prohibited during daylight hours and must be conducted in waters >10m depth. Effort is restricted both spatially and temporally throughout the fishing year by fishery closures. Effective effort (fishing power) is controlled by gear restrictions including 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, from the last quarter of the moon through to the first quarter, generally in the months of November, December, March, April, May and June. Current management arrangements are summarised in Table 1.5.

Table 1.5 Current management arrangements

Management tool	Current restriction
Permitted species	*Melicertus latisulcatus*, *Ibacus* spp., *Sepioteuthis australis*
Limited entry	10 licences
Licence transferability	Permitted
Corporate ownership	Permitted
Spatial and 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
Maximum headline length – large	29.26 m
Maximum headline length – small	27.43 m
Maximum vessel length – large	15.2 – 22 m
Maximum vessel length – small	<15.2 m
Maximum vessel power – large	272 kW
Maximum vessel power – small	224 kW
Minimum mesh size	4.5 cm
Catch and effort data	Daily and monthly logbook submitted monthly

1.3.3 Prawn Fishery Management Plan

Zacharin (1997) developed the first Gulf St Vincent Prawn Fishery Management Plan, documenting the management history, policy framework and Performance Indicators for the fishery. Recently, a review and update of the Management Plan was undertaken (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. The Plan also aims to identify an appropriate balance between long term ecological sustainability and the optimum utilisation and equitable distribution of resources between all stakeholder groups and future generations, however this can only be considered within the constraints of 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 specific guidelines for the development of harvest strategies for the fishery. Harvest strategies are the mechanism for managing fishing effort using spatial and

temporal closures, the aim of which is for the fleet to target limited areas of appropriately sized prawns, ensuring protection of a sufficient proportion of the stock to enable stock recovery. The Plan provides details on the data required for harvest strategy development and the decision rules for harvest strategy determination.

1.3.4 Performance Indicators

The extent to which the Plan is achieving the range of 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 (refer below)
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

The recruitment index is calculated as the mean number of juvenile prawns (males <33 and females <35 mm CL) captured per trawl hour from all shots surveyed during May. Previously, recruitment in GSV was calculated as either: 1) male prawns ≤ 33 mm CL and female prawns ≤ 35 mm CL following Morgan (1995); or 2) prawns < 36 mm CL following Zacharin (1997). This current definition of recruits (males <33 and females <35 mm CL) as defined in the new Management Plan is in line with that used in the Spencer Gulf Prawn Fishery (Dixon *et al.*, 2007).

Total commercial catch and mean commercial CPUE are calculated from commercial logbook catch and effort data for the fishing season from December to June inclusive. Data on mean prawn size (weighted by catch) are obtained from commercial logbook size grade data. Indices of current and future biomass are based on the catch rates obtained during each of the four fishery independent surveys conducted annually. Indices of current biomass are based on comparisons of the mean survey catch rate for the current month and the mean survey catch rate for the same month in the previous year. Stock recovery is considered to have occurred if the mean survey catch rate in the current month is higher. The limit reference point for current biomass is failure to achieve stock recovery in two consecutive surveys. The limit for future biomass is a mean

survey catch rate for the 21+ prawn grade of 3.0, 3.0 and 4.6 kg/h during March, April and May surveys, respectively. Note that size grade categories have been inconsistently reported in the past. The Management Plan refers to the small size grade as 20+, although for this report it is referred to as 21+ (see Table 2.1).

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 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 survey catch – March to June	>25%
% of 21+ in the catch – Dec	<7%
% of 21+ in the catch – March to June	<5%

Additional performance measures include recruitment indices for each stock assessment survey, calculated as with the Recruitment index in Table 1.6. Egg production is calculated following Section 3.2.6 of this report. The percentage of U10 and 21+ grade prawns in the catch is calculated from commercial logbook data following Section 2.5 of this report.

1.4 Biology of the western king prawn

1.4.1 Distribution and taxonomy

The western king prawn, *M. 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.

M. 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 catchability) is greater during the dark phase of the lunar cycle and during warmer months (Penn, 1976; Penn *et. al.* 1988).

The distribution and abundance of *M. latisulcatus* within gulfs and estuaries is affected by salinity and the presence of sandy substrate (Potter *et. al.* 1991). Higher abundances are associated with salinities above 30‰ (Potter *et al.* 1991). In physiological studies on *M. latisulcatus*, optimal salinity ranged from 22–34‰, and 100% mortality occurred at salinities below 10‰ (Sang and Fotedar 2004). Juvenile *M. 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). During mating the male transfers a sperm capsule (spermatophore) to the female reproductive organ (thelycum). The success of this insemination depends on the female prawn having recently moulted. Ovary development followed by spawning of fertile eggs occurs during a single intermoult period (Penn 1980), where fertilisation presumably occurs immediately prior to or on release of the eggs by the female

During the peak spawning period, the sex ratio of *M. latisulcatus* harvested in WA was typically female biased. This was attributed to higher catchability of females due to increased foraging-feeding activity necessitated by food requirements during ovary development (Penn 1976; Penn 1980). During November and December, harvested populations of *M. latisulcatus* were found to be female biased in GSV (Svane 2003; Svane & Roberts 2005).

Spawning and fecundity are affected by water temperature, with the minimum temperature for spawning being 17°C for *M. latisulcatus* in WA (Penn 1980). The peak reproductive period in Queensland (QLD) populations of *M. latisulcatus* was between June and July when water temperature dropped below 25°C (Courtney & Dredge 1988). Thus, the ideal temperature range for spawning in *M. latisulcatus* appears to be 17–25°C.

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

$$\text{Proportion mature} \quad = 8.3\times10^{-6} + \left[\frac{1}{1+e^{-(0.277(CL-36.45))}}\right]$$

While females can mature at a small size, differences between tropical and temperate populations 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 female observed was 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 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 *M. latisulcatus*.

Table 1.8 and Figure 1.7 presents the results of fecundity studies for *M. 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 1.7). Thus larger prawns make a greater contribution to total egg production due to both greater insemination rates and higher fecundity (Penn 1980; Courtney & Dredge 1988; Carrick 1996).

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

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

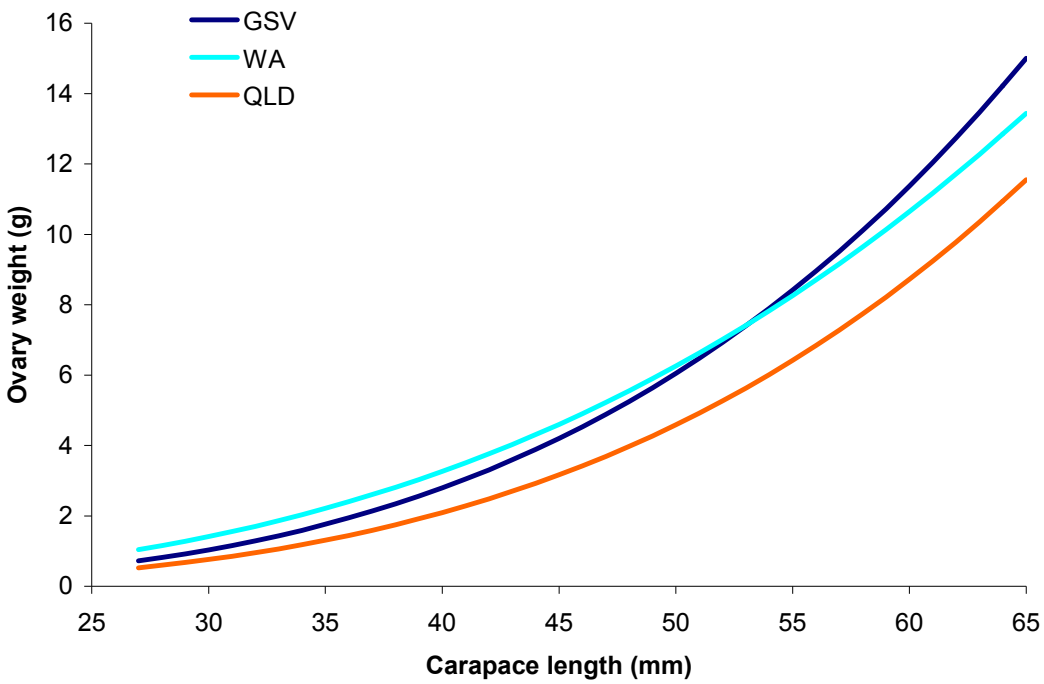

Figure 1.7 The relationship between fecundity (ovary weight) and carapace length (CL) for *M. latisulcatus* in GSV, Western Australia and Queensland, as determined from the fecundity relationships defined in Table 1.8.

In the eastern king prawn (*P. plebejus*) a reproductive index indicated that females greater than 50 mm CL contributed little to egg production, while the bulk of the eggs were produced by prawns in the middle to upper size range of 35–48 mm CL (Courtney *et al.* 1995). Such ovarian senescence in old female *M. latisulcatus* has not been documented.

Spawning frequency of *M. latisulcatus* was related to moulting frequency in several previous studies. This was concluded because: no recently moulted female was found with well-developed (stage 3 or 4) ovaries (Penn 1980; Courtney and Dredge 1988); females lost the spermatophores with the exuvae at moult (Penn 1980) and; the average interval for both moulting and spawning was the same in tagging experiments (Penn 1980). The average moult interval, and hence spawning interval, for mature untagged females in WA populations during the spawning season was estimated at 30–40 days (Penn 1980).

Multiple spawning events can occur in *M. latisulcatus* as spawning frequency is related to moulting frequency. There are three lines of evidence supporting this concept: (1) spent ovaries are difficult to identify since immediate ovary development occurs after spawning (Penn 1980; Courtney & Dredge 1988); (2) in an experiment where ripe females were tagged and released, 15 re-captured individuals were found to have spawned and moulted, and had ovaries at an early stage of development during the same season (Penn 1980) and; (3) artificial spawning of *P.*

orientalis in aquaria, using eyestalk ablation, provided direct evidence for the multiple spawning capacity of Penaeids (Arnstein & Beard 1975). In addition to multiple spawning within a season, females may repeat the process in subsequent years. This was determined by the large proportion of females in different size cohorts being reproductively active during the spawning season (Penn 1980).

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 *P. plebejus*. Bopyrid isopods have been observed to parasitise *M. latisulcatus* in South Australia, although at low prevalence (S. Roberts, personal observation). In *F. indicus*, it was shown that viral infections affected moulting and reproduction in Penaeid shrimp (Vijayan *et. al.* 2003). In addition, environmental pollution from coastal industries can increase the susceptibility of prawns to disease and reduce reproductive output (Nash *et. al.* 1988). These issues are poorly understood for *M. latisulcatus* in South Australia.

1.4.3 Larval and juvenile phase

M. latisulcatus has an offshore adult life and an inshore juvenile phase (Figure 1.8). Prawn larvae undergo metamorphosis through four main larval stages: nauplii, zoea, mysis and post-larvae. The length of the larval stage depends on water temperature, with faster development in warmer water (Hudinaga 1942). It has previously been suggested that the larval period of *M. latisulcatus* in Spencer Gulf could exceed 40 days, where water temperatures over the main spawning and larval period range from 19–25° C (after Shokita 1984, cited in Carrick 2003). Kangas (1999) agreed with this conclusion, suggesting that the larval period was between 4–8 weeks in GSV.

Prawn larvae are generally dispersed by wind-driven and tidal currents. Latitude, water temperature and salinity influenced the distribution and abundance of larvae in Spencer Gulf (Carrick 2003). 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 events 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.

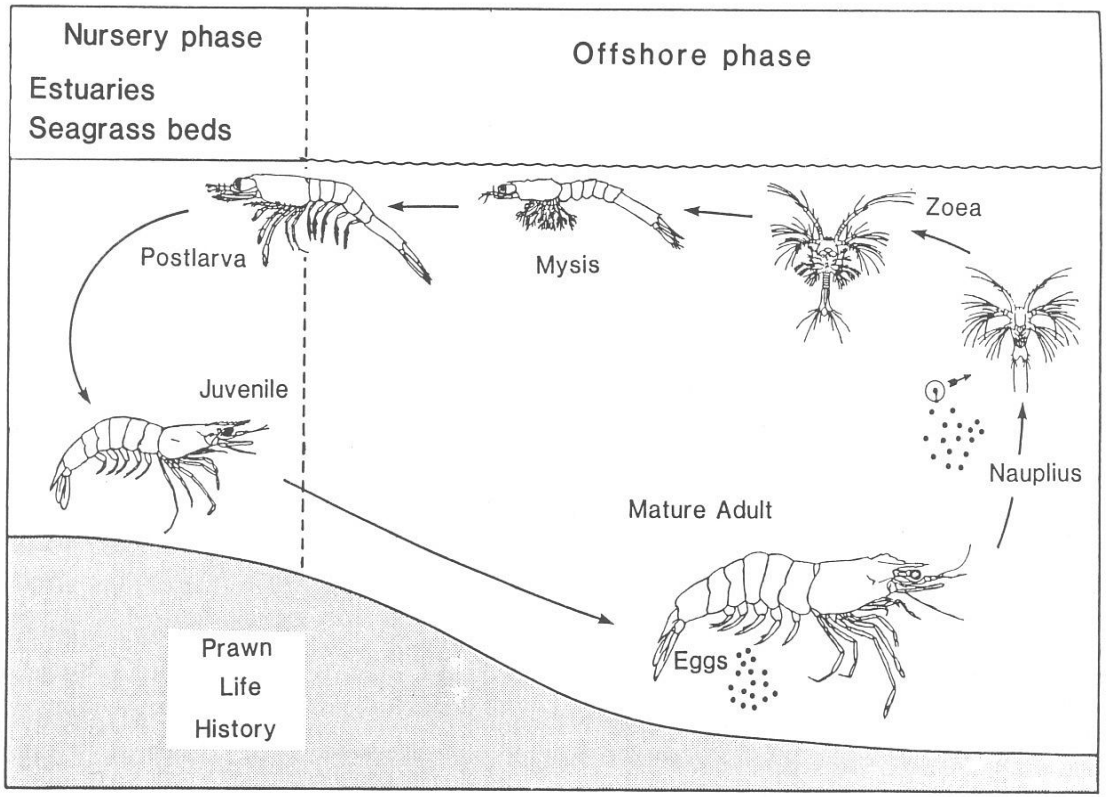

Figure 1.8 Life cycle of *M. latisulcatus* (Carrick 2003).

In GSV, Kangas (1999) showed that post-larvae settled in inshore nursery areas at 1 mm CL, with juveniles 2–7 mm CL comprising 90% of the surveyed population. Mean growth rates in nurseries varied from 0.53–0.65 mm CL per week in winter to 0.71–1.28 mm CL per week in summer (Kangas 1999). 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, 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 *M. latisulcatus* are considerably lower than for other prawn species (Carrick 1996).

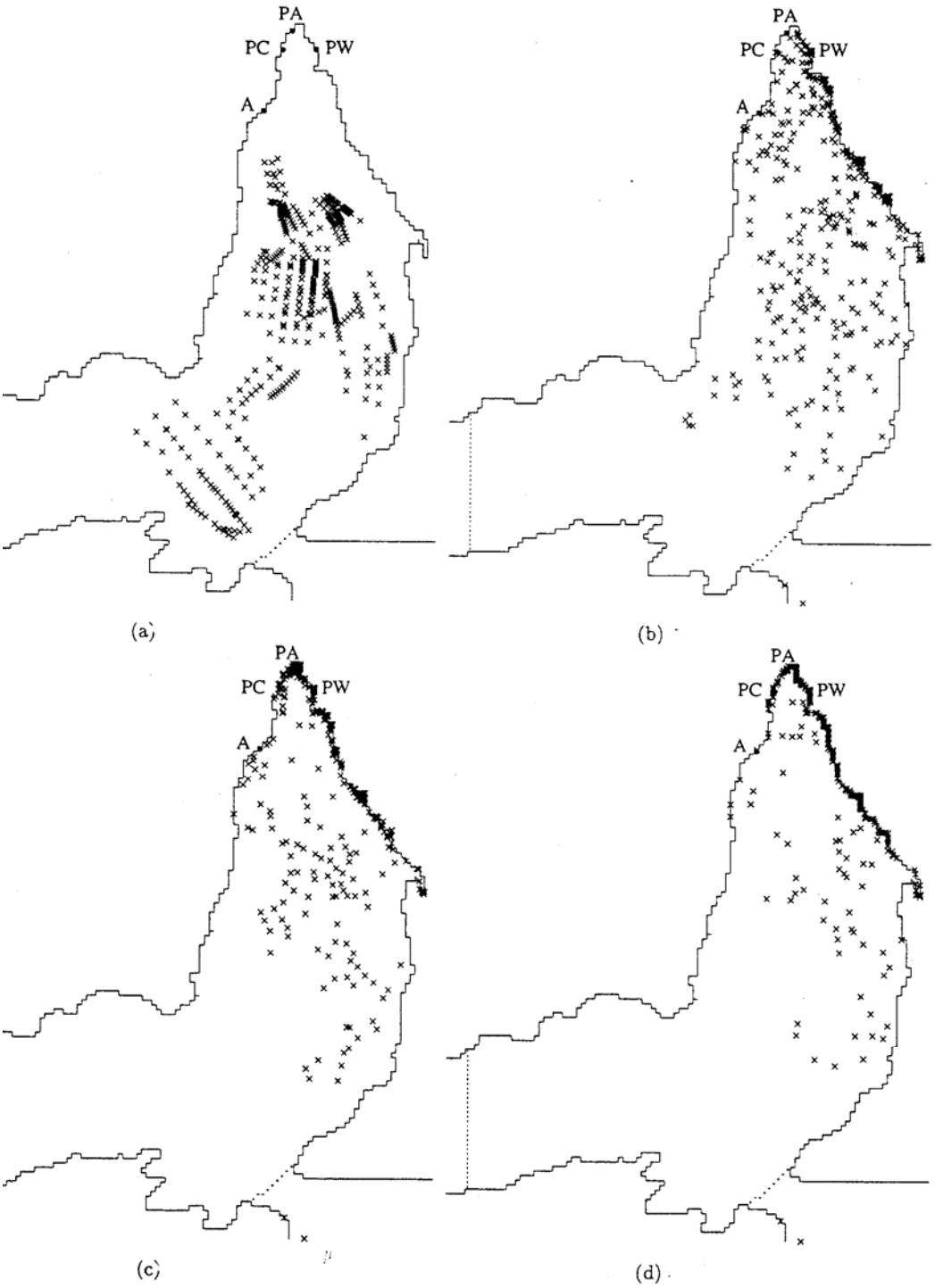

Figure 1.9 (a) Initial egg production of *M. latisulcatus* in GSV during November 1990 and (b) advection and diffusion of larvae at four, (c) six and (d) eight weeks after spawning as determined from a computer generated model (Kangas 1999). PW – Port Wakefield, PA – Port Arthur, PC – Port Clinton and 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 *M. latisulcatus* between South Australia and Western Australia (Carrick 2003). However, an analysis of the genetic structure of *M latisulcatus* within South Australia using electrophoresis suggests a homogenous stock (Carrick 2003).

1.4.5 Growth

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

Uncertainties associated with each method of growth estimation include:

- growth suppression by the tagging process (Penn 1975; Menz & Blake 1980);
- short time at liberty for tag-recaptures influenced by seasonal growth;
- bias in size at release and time at liberty during tag-recapture experiments;
- 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 1.7). The von Bertalanffy limited growth model is $dL/dt = k(L_\infty - L)$, where k is a function of temperature. The formula for growth is usually re-written as $L(t) = L_\infty (1-e^{r(t-t_0)})$, where r is the specific growth rate, t is time, and k=r. The constant, r, is species (and gender) dependent and determines the rate of growth.

The longest time at liberty recorded from tag-recapture data in the GSV was 3.05 years for a female released at 30.3 mm CL and recaptured at 58.5 mm CL. This is in accordance with an estimated lifespan of 3–4 years. 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.

Growth estimates for prawns from GSV are compared to those estimated from Spencer Gulf and the West Coast Fishery in Table 1.9 and Figure 1.11. Carrick (2003) estimated growth rates from >9,000 tag-recaptures in Spencer Gulf while in the West Coast Prawn Fishery growth was estimated from 510 tag-recaptures and from length-frequency cohort analysis (Wallner 1985).

Seasonal growth and differences between genders were evident in each fishery. Prawns in GSV attained a similar size to those in Spencer Gulf, although a slower growth rate was evident for males from GSV (Figure 1.11). Furthermore, prawns in both Gulfs attained a greater size and growth rate than their West Coast counterparts. Whilst this may be an artefact of the uncertainty associated with the West Coast growth estimates (see Dixon and Roberts 2006), growth may be slower due to cooler summer water temperatures of the West Coast's oceanic environment.

Table 1.9 Sex-specific growth parameters for *M. 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 (Kangas & Jackson 1997).

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

1.4.6 Length weight relationship

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 × 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 1.12). 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).

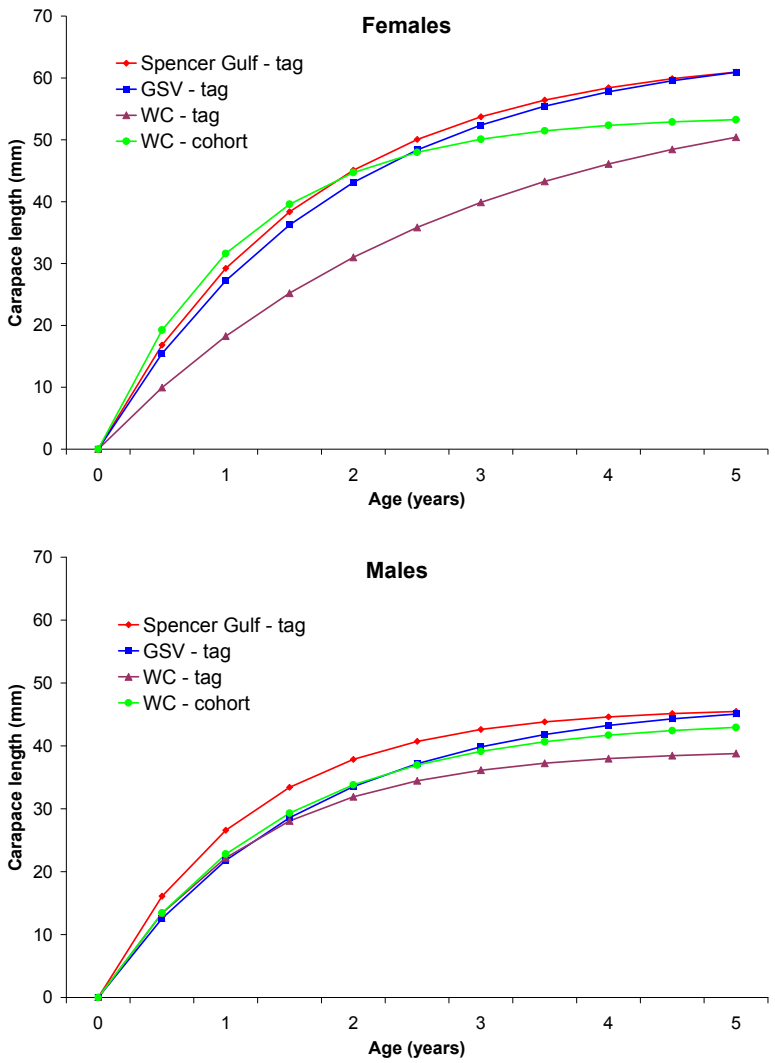

Figure 1.11 Sex-specific growth curves for M. latisulcatus estimated from tag-recapture and cohort analysis in the West Coast (Wallner 1985) and from tag-recapture in Spencer Gulf (Carrick 2003) and Gulf St Vincent (Kangas & Jackson 1997). See Table 1.9.

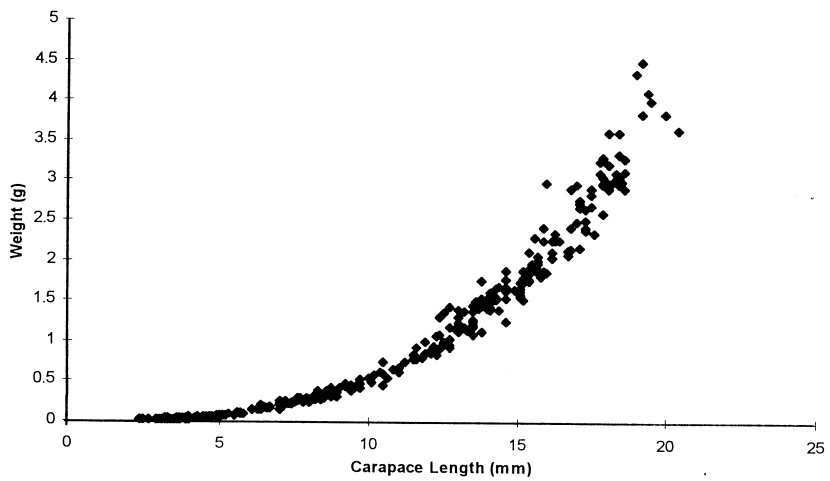

Figure 1.12 Length weight relationship for juvenile M. latisulcatus in GSV (Kangas 1999).

1.4.8 Natural mortality

Previous estimates of daily instantaneous rate of natural mortality was determined as 0.003 for GSV prawns (Kangas & Jackson 1997). Xiao and McShane (2000) determined sex differences in GSV prawns as 0.0031 for females and 0.0034 for males. These values were similar to that estimated for *M. 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).

1.4.9 Prawn health

The health of South Australian populations of *M. latisulcatus* and the potential effects of coastal pollutants, parasites and disease on growth, survival and reproduction is poorly understood. In Spencer Gulf, juvenile habitats appear to have been influenced by oil spills (Roberts *et al.* 2005) and industrial effluent (Carrick, 2003). In GSV, anecdotal evidence suggests that juvenile prawn abundances at Barker Inlet have declined substantially since the early 1970's, probably due to human induced factors including increased nutrient loading (Kangas 1999). The disturbance of acid sulfate soils as a result of coastal development were recently identified as a major cause of habitat degradation in GSV, including mangrove dieback at St Kilda and contaminated tidal flats in the Barker Inlet (SA Coast Protection Board, 2003). Common marine pollutants in South Australia include heavy metals, high nutrient loads from coastal industries and petroleum (hydrocarbon) discharges (Edyvane 1999). Although these sources of pollution are common, and potentially directly affect juvenile prawn nurseries, little research has been conducted to address these issues.

Bopyrid isopods affect reproductive output in penaeid prawns (Courtney *et al.* 1995) and have been noted to parasitise *M. latisulcatus* in South Australia (S. Roberts, personal observation), although the effects of these and other parasites and diseases on the status of this resource are unknown.

1.5 Stock Assessment

1.5.1 Reports and publications

Kangas and Jackson (1997) produced the first comprehensive stock assessment report for the GSVPF. The report provided relevant biological information, analyses of commercial catch and effort data and an assessment of fishing power of the GSV fleet. Stock assessment reports have since been published documenting annual fishing seasons (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). In addition, stock status reports have recently become a component of the assessment program, which aim to provide a brief end-of-season update as to the status of the stock (Roberts *et al.* 2007b). Furthermore, Xiao (2004) documented catch and effort data from the GSVPF (1980-1998) in an attempt to standardise CPUE to reflect temporal changes in biomass. Of note, the most recent stock assessment report for the fishery (Roberts *et al.* 2007a) indicated that the biomass upon which the fishery is based has revealed signs of modest stock recovery since the lowest CPUE in 2002/03.

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 is available since 1968. Annual data (1968–1972) and monthly data (January 1973 to June 1987) were obtained from 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 from data sources that include fishery-independent surveys and on-board observers. These provide five separate datasets for assessment:

1. Surveys conducted in consecutive fishing periods (December, March, April and May) between 2004/05 and 2006/07 (Section 3.2 of this report);
2. Surveys conducted during May between 2003 and 2007 (Section 3.3 of this report);
3. Surveys conducted from April 1984 to February 1995 (Appendix 8.1) ;
4. Observer data collected during fishing between 1993/94 and 2003/04 (Appendix 8.2); and
5. Small vessel surveys conducted during 2004/05 and 2005/06.

The first two datasets (2004/05–2006/07; May 2003–2007) are currently an ongoing component of stock assessment for the GSVPF. Since December 2004, a rigorous survey design was implemented to aid stock assessment and to inform harvest strategy decisions for the GSVPF. These surveys have been conducted prior to each fishing period from December 2004 to May 2007 by the large vessels of the fishery (except during May when small boats participate). Furthermore, survey data collected during May are also available for 2003 and 2004 using the same methodology (large and small vessels), which allows for the second dataset (May 2003–2007), although only a subset of survey shots are consistent between all years. The May survey dataset provides useful trends in catch rate, prawn size and recruitment since 2003.

Data from surveys conducted between 1984 and 1995 were 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. Detailed analyses of trends in catch rate, prawns size and sex-ratio at various temporal and spatial scales between 1984 and 1995 are documented in Appendix 8.1.

Data from fishery-independent on-board observations were collected during fishing operations on commercial vessels in the GSVPF between 1993/94 and 2003/04. Trends in annual prawn size (CL and grades) and sex-ratio of commercial catches during this period were informative and are documented in Appendix 8.2. In general, the sampling design was rigorous and representative of the fishery: sampling occurred across all fished months from at least six of the ten licensed vessels. Observer data indicated that high catches of large prawns were harvested prior to the most recent decline of the fishery (since 2000/01), including high catches of large prawns during the early spawning season. Currently, the Management Plan (Dixon and Sloan 2007) limits the total catch during the early spawning season to less than 30 t, and encourages the harvest of medium sized prawns to protect large spawning females.

Small vessel surveys were conducted during 2004/05 and 2005/06 to supplement fixed stock assessment surveys. However, analyses of these data demonstrated it was not useful for determining trends in prawn abundance or biomass (Roberts *et al.*, 2007a). Assessment of small

vessel survey data was limited by: 1) inconsistent spatial and temporal replication, 2) inconsistent and inaccurate methods for obtaining catch weights, which were estimated by either visual assessment by the crew or with the use of Salta scales, 3) the quality and accuracy of data collected in the absence of an on-board observer, and 4) the absence of grade data (small vessels do not have prawn grading machines) per shot for calculating the Future Biomass measure of recruitment (21+, kg/h), as outlined in the Management Plan. In addition, the difference in current fishing power between large and small vessels, particularly regarding engine power and number of nets used (2 nets versus 3 nets), is unkown. Differences in fishing power may effect catch rates (O'Neill and Leigh, 2007), and so the use of small vessels during fishery-independent surveys may unpredictably effect survey results.

1.6 Current Research and Monitoring Program

The current research program conducted by SARDI Aquatic Sciences in support of the GSVPF comprises five components. These are: (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, juvenile sampling and tagging 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.

The primary objective of the current research program is to facilitate stock recovery by gathering data to inform sustainable harvest strategies, enable monitoring of prawn biomass and allow a robust assessment of fishery performance against the Performance Indicators in the revised Management Plan.

1.7 Discussion

Generally, aspects of the biology of *M. latisulcatus*, the environment in which they are distributed and the management of the commercial fisheries that harvest them within South Australia are well documented. However, several key elements of the Gulf St Vincent Prawn Fishery are poorly understood, particularly regarding prawn health, spawning and recruitment success.

Recently, there has been a greater awareness and need for understanding the effects of coastal pollutants, parasites and disease on growth, survival and reproduction of prawns in South Australia. This is largely due to issues regarding the potential risks of disease introduction associated with the use of imported prawns for bait, dredging of the Port River and effects from coastal development.

Currently, there are no data available on the frequency of individual spawning events and the influence of temperature during the spawning season. Similarly, no data are available on fertilization success of *M. latisulcatus* in temperate South Australian waters. Further, an improved understanding of larval behaviour and the influence of water temperature on the duration of the larval phase is needed. Once these data are obtained, a model that combines hydrodynamic processes with spawning and larval dispersal can be developed to track egg production through to post-larval settlement. Such a model would 1) provide an improved understanding of recruitment to the fishery, 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 minimise the effect of pre-Christmas fishing on future recruitment to the fishery.

Fishery statistics (catch and nominal effort) are available since 1968 and fishery-independent data are available since 1984, while comprehensive stock assessment reports for the GSVPF have been produced since 1997. Fishery-independent surveys conducted since May 2003, and prior to each harvest period since 2004/05, are an ongoing component of stock assessment for the GSVPF. While current surveys are rigorous in their design and provide valuable information to assess the status of the stock, the greatest uncertainty lies with May survey data. This is due to the use of small vessels without prawn size graders and inaccurate methods for collecting catch weights. May surveys could be improved in the future with the use of large vessels only.

2. FISHERY STATISTICS

2.1 Introduction

This section presents analyses of fishery-dependent (catch and nominal effort) data for the GSVPF since 1968. In this report, a "fishing year" is defined as the period from November to October. Currently, most fishing is done from December to June, in "harvest periods" of varying length between the last and first quarter of the moon (maximum length 18 days). "Historical catch periods" refer to two periods of increasing annual catches followed by substantial declines (1968–1991/92 and 1993/94–current).

2.2 Catch and effort

2.2.1 Inter-annual catch and effort

While 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. Catches declined to <400 t in 1981/82 and again increased to >500 t in 1982/83. Whilst catches exceeded 400 t in 1983/84, they reduced 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. From 1993/94 to 1999/2000 catches generally increased, reaching a contemporary peak of 400 t. Catches subsequently declined annually to 172 t in 2003/04 and have since remained above 184 t. Total catch in 2006/07 was 222.7 t, of which ~12.7 t was harvested during fishery-independent surveys and ~0.7 t was harvested during a 1-night, fishery-dependent, spot survey during May 2007. This represented an increase of 19% from 2005/06 (total catch: 187 t).

From 1968–1976/77 trends in commercial effort generally reflected trends in catch. From 1977/78–1979/80 commercial effort peaked (range: 18,035–20,569 hours) despite decreasing catches during this period. Effort stabilized from 1980/81–1983/84 (range: 14,174–15,329 hours) before declining sharply, again reflecting trends in catch. Since 1993/94, effort has been generally stable (range: 1,815–4038 hours, mean: 3,210 hours), and much lower than mean effort prior to the closure in 1991/92 (9,856 hours). Total effort in 2006/07 was 2,442 h, which was a decrease of 6% from 2005/06 (2,599 h).

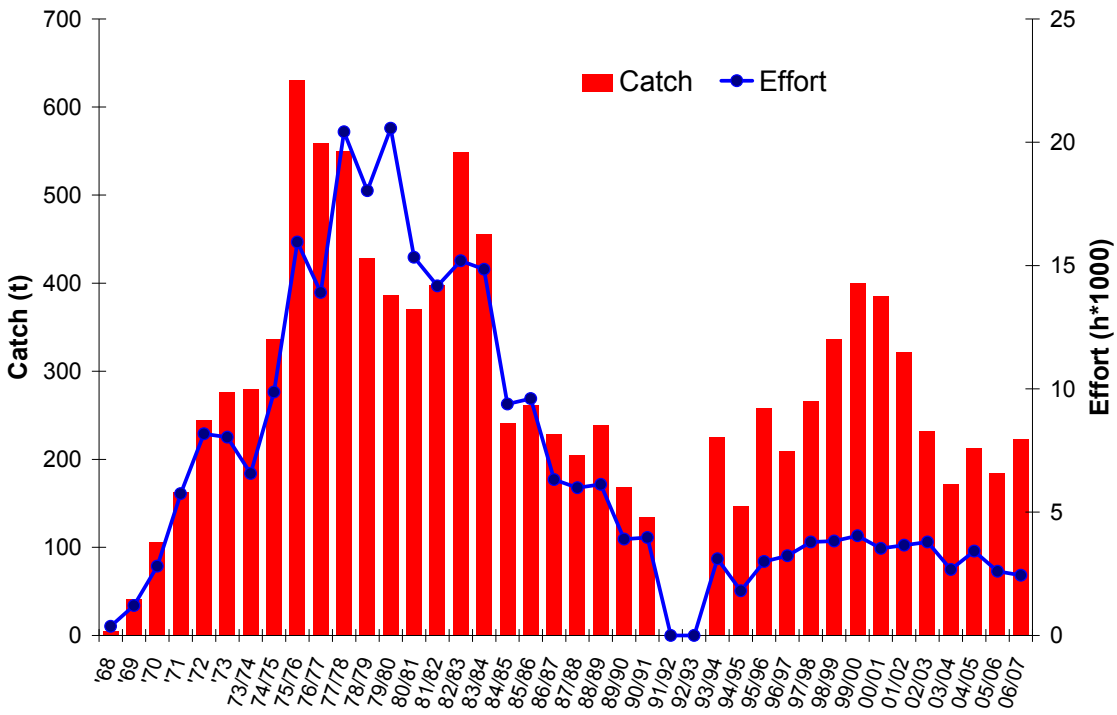

Figure 2.1 Total catch (t) and effort (h) for GSV from 1968 to 2006/07. Data for 1968–1973 are reported as calendar year. Data for 1973/74 are from January 1974 to October 1974. From 1974/75 data are reported in fishing years.

2.2.2 Intra-annual catch

The seasonal patterns in monthly catches have changed over the last 30 years (Figure 2.2). Note that monthly trends disregard harvest periods during a fishing year, which may extend between two months. Monthly trends allow comparisons with historical catches when harvesting was not conducted during set harvest periods. Between 1975/76 and 1979/80, some prawns were captured in all months with peaks in November and April. Temporal closures were introduced in August 1979. From 1980/81 to 1984/85, mean catches during November (108 t) were more than twice that recorded for most other months. Since 1985/86 most of the catch has been taken during December, March, April and May. During the past two years the majority of catch was harvested in April, reaching 90 t in 2006/07.

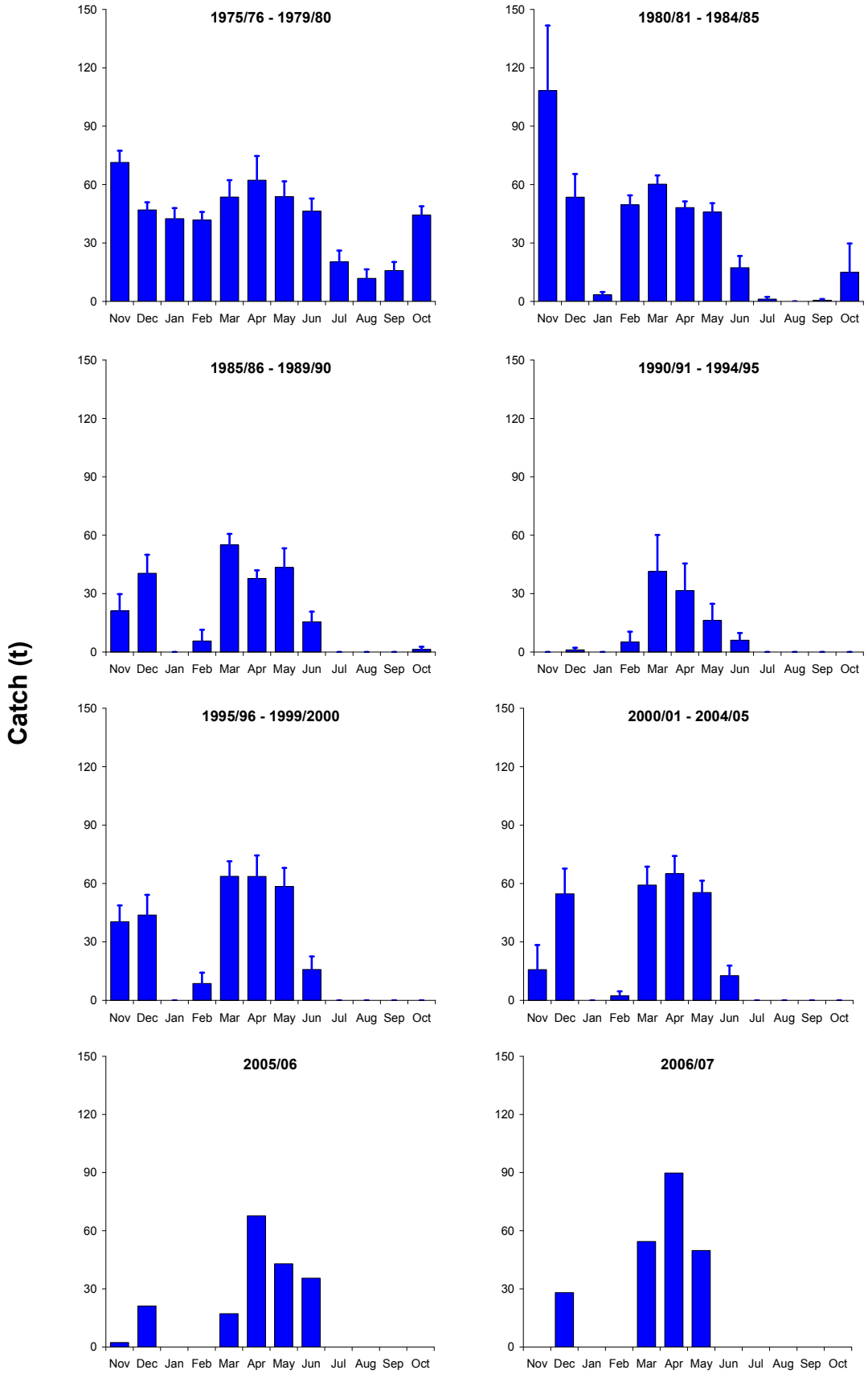

Figure 2.2 Average monthly catches from GSV for 5-year periods from 1975/76–2004/05, and for 2005/06 and 2006/07. Note: 1990/91–1994/95 includes the 2-year closure period.

2.2.3 Catches during the spawning season

The main spawning period for *M. latisulcatus* in GSV extends from November to March. Hence, effective management supported by robust monitoring of catches during these months is important for the sustainability of the fishery. Figure 2.3 shows catches from the early (November and December), late (January to March) and non-spawning (April to October) periods.

From 1973/74 to 1981/82 catches from the early spawning period ranged between 72 and 138 t. During 1982/83 and 1983/84, a total of 287 and 241 t, respectively, was 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. Following the closure, catches during the early spawning period rapidly increased. From 1998/99 to 2001/02 catches during this period were >100 t each year, peaking at 126 t in 2000/01. Catches during this period have not exceeded 65 t since (mean 41 t). Since 2003/04, catches during the early spawning period have ranged between 14 and 45 t (mean 27 t). During 2006/07, 28 t (13% of total catch) was harvested during the early spawning period. Importantly, the total and proportion of prawns harvested during the early spawning period in 2006/07 was much lower than the historic average since 1973/74 (81 t, 25% of total catch).

There were no obvious trends in catches taken during the late spawning period. Of note, since 1986/87 there have been no substantial catches obtained in January or February during the late spawning period.

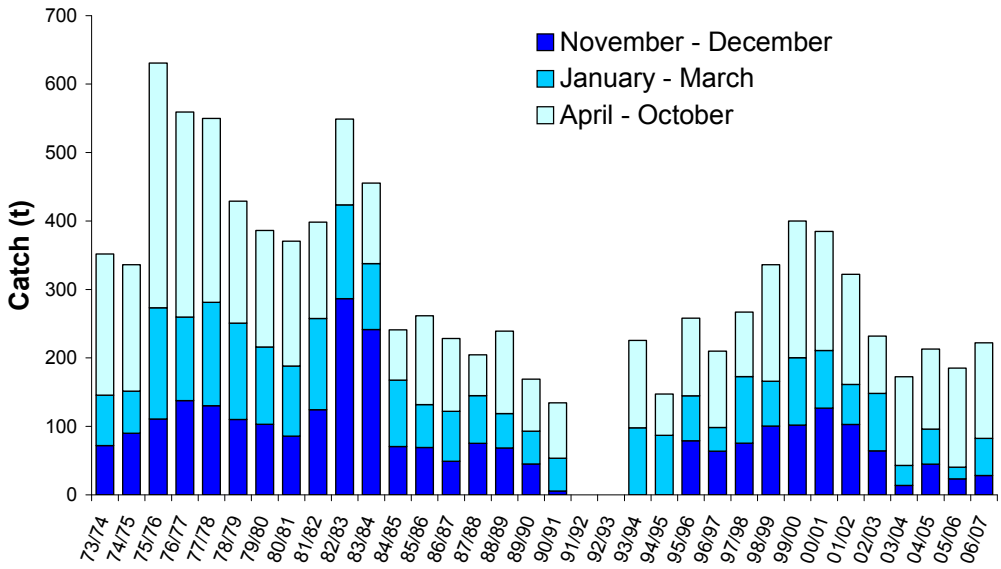

Figure 2.3 Catches from the early (November – December), late (January – March) and non-spawning (April – October) periods relative to the total annual catch from 1973/74 to 2006/07 in GSV.

2.2.4 Regional catch

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 2.4). 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 2006/07, catches have ranged from 22–61 t (10–35% of total catch).

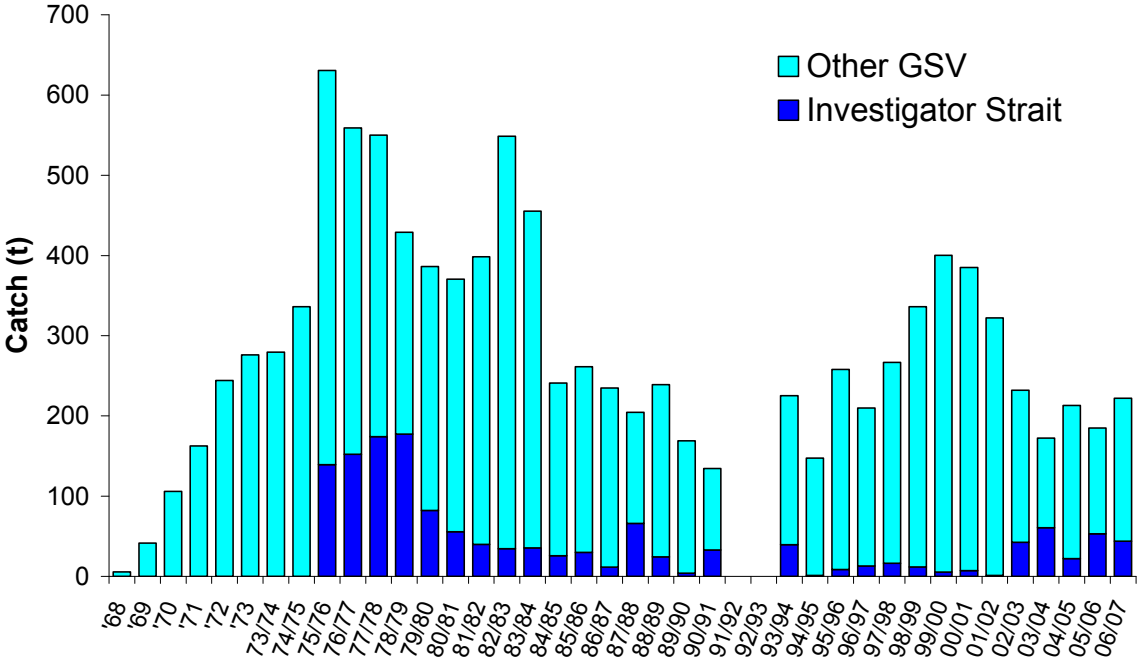

Figure 2.4 Total catch (t) from Investigator Strait and all other regions of GSV from 1968 to 2006/07. Data for 1968–1973 are reported as calendar year. Data for 1973/74 are from January to October 1974. From 1974/75 data are reported in fishing years.

Since 1987/88 daily catch data have been obtained from 10 regions (Figures 2.5a,b). Regions are illustrated in Figure 3.1. During this period, most of the catch was harvested from Region 3 (24% of the total catch), followed by Region 2 (21%), Region 5 (13%), the IS region (11%), the Deep Hole region (DH, 10%), and the Little Hole region (LH, 7%). All other regions have each contributed <6% of the total catch.

Catches from Region 3 ranged between 14 and 68 t from 1987/88–1998/99 (mean 31 t). Catches have increased substantially since, ranging between 60 and 109 t in the last eight years (mean 81 t). Catches from Region 2 ranged between 0 and 91 t from 1987/88–2000/01 (mean 44 t). Catch peaked in this region during 2001/02 (179 t) and has not exceeded 44 t since. Trends in catch

from Region 5 were similar to those of total catch (Figure 2.1). Catches from DH were high in the year immediately prior to and after the closure, steadily decreased between 1998/99 (50 t) and 2003/04 (10 t), and have been <1.5 t since 2005/06, the lowest since 1987/88. Highly variable catches have been obtained from Regions 1, 4, 6, LH, and IS. Annual catch from SDH has never exceeded 5 t.

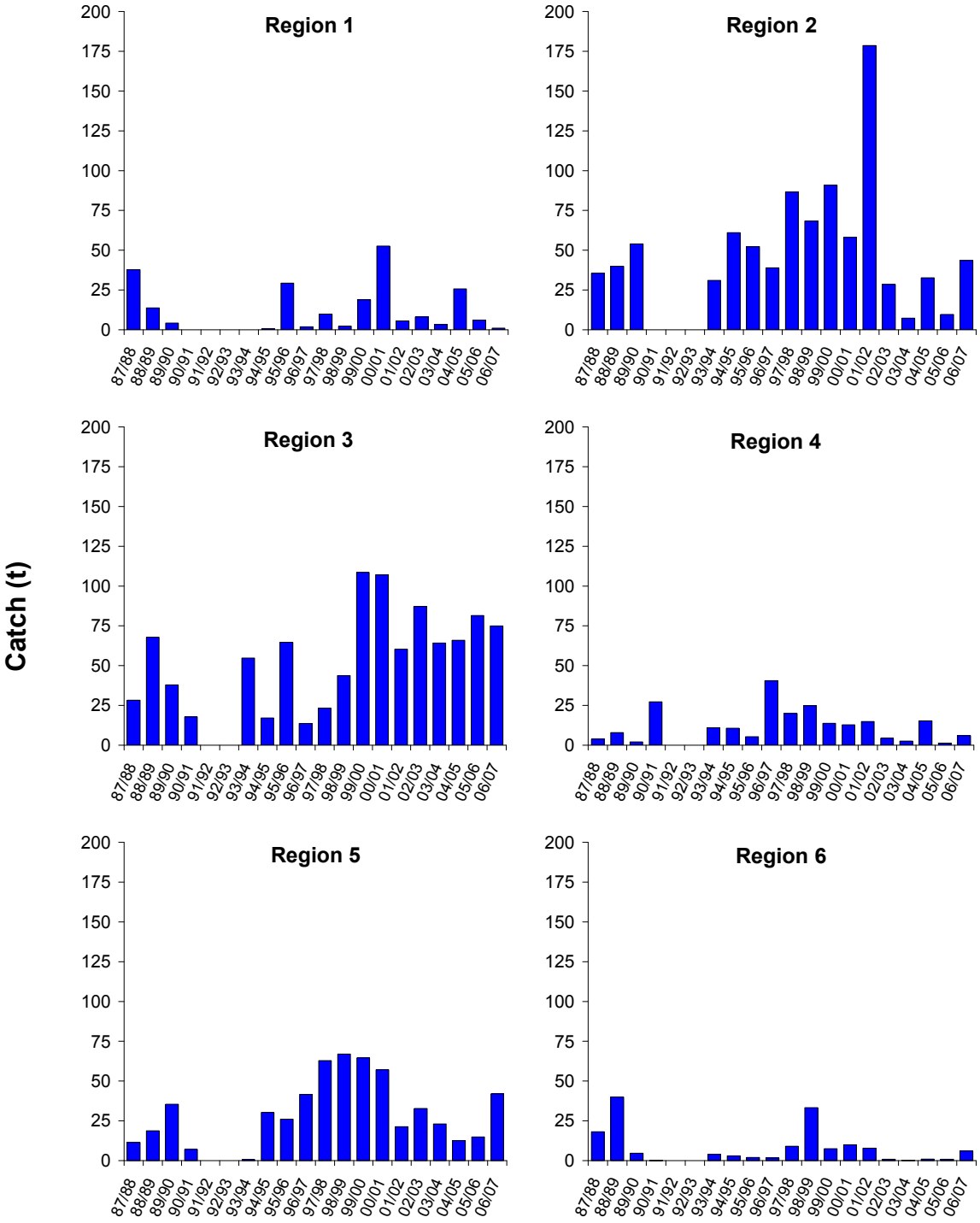

Figure 2.5a Total catch (t) from Regions 1–6 in GSV from 1987/88–2006/07.

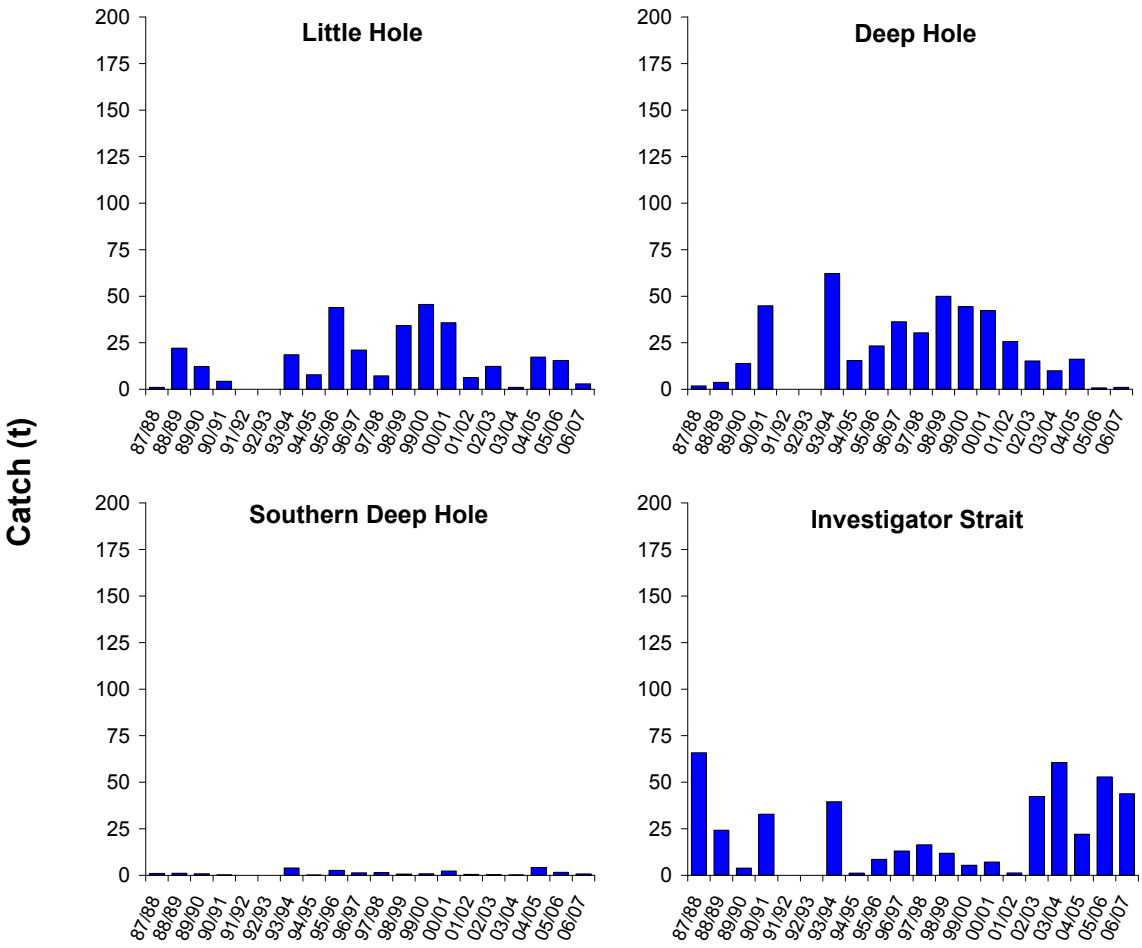

Figure 2.5b Total catch (t) from the Little Hole, Deep Hole, Southern Deep Hole and Investigator Strait regions from 1987/88–2006/07.

2.3 Catch-per-unit-effort (CPUE)

Commercial catch-per-unit-effort (CPUE) data are affected by gear types, season, location and environmental conditions. Therefore, CPUE data are an unreliable index of prawn abundance and trends in CPUE must be interpreted cautiously. Long-term trends are most affected and thus comparison of CPUE data between historical catch periods (i.e. pre and post-closure) is uninformative. Large differences in CPUE over short time scales (i.e. between years or several consecutive years) may be indicative of changes in biomass if differences in gear types, harvest strategies and environmental conditions are minimal.

During 2006/07, the GSV fleet consisted of six large and four small vessels, using double and triple-rig trawl gear, respectively. The differences in CPUE between vessel types are not examined in this report. However, anecdotal evidence suggests that they are not substantial. In the following sections, trends in CPUE are examined between years, within years and among regions.

2.3.1 Inter-annual CPUE

Annual (nominal) CPUE has varied since the inception of the fishery (Figure 2.6). During the first historical 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 historical catch period (1993/94–2006/07), CPUE has been higher, ranging from 61.2 to 109.0 kg/h (mean 79.2 kg/h). From 1996/97 to 2000/01, CPUE increased from 64.9 to 109.0 kg/h. This substantial and sequential increase is likely to be indicative of an increasing biomass after the fishery closure. From the peak of 109.0 kg/h in 2000/01, CPUE declined to 61.2 kg/h in two years. Such a substantial and rapid decline is likely to be indicative of a decreasing biomass during this period. During 2004/05, CPUE remained low (64.6 kg/h) despite a substantial decrease in the proportion of searching time with the introduction of harvest strategies informed by fishery-independent surveys (see Section 2.4). CPUE in 2006/07 was 91.3 kg/h, an increase of 41% from 2004/05, and the highest since the historic peak in 2000/01.

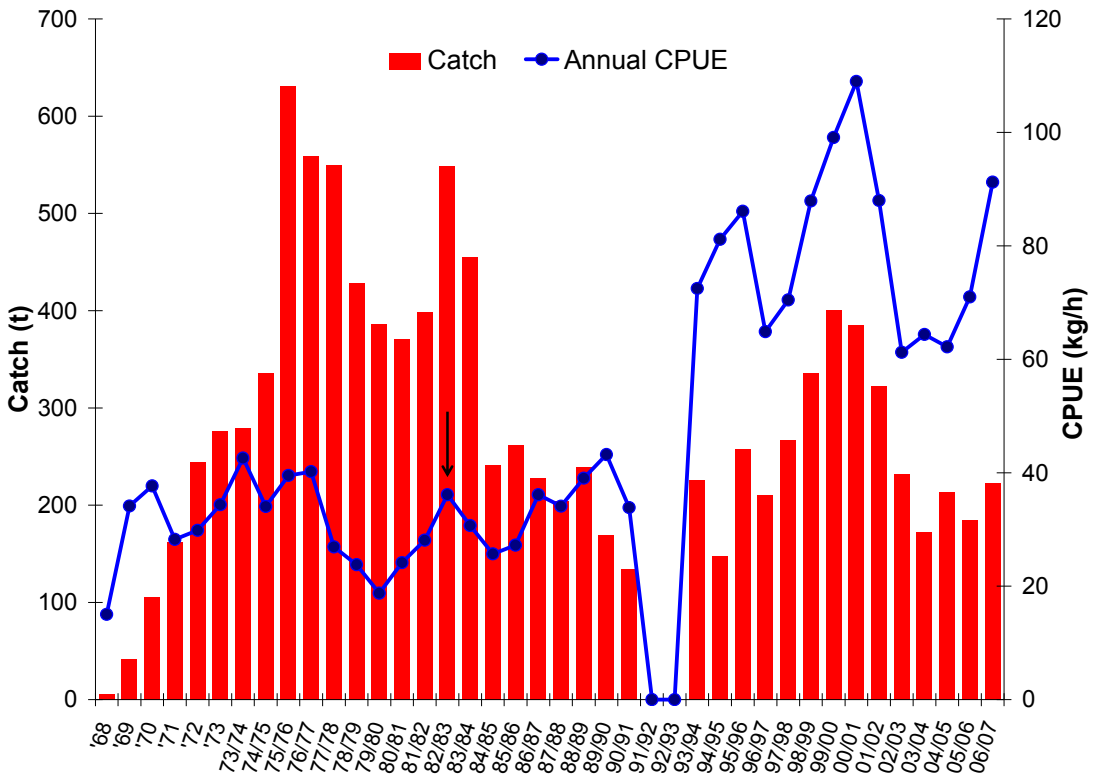

Figure 2.6 Annual catch and catch-per-unit-effort (CPUE) for GSV from 1968 to 2006/07. Data for 1968–1973 are reported as calendar year. Data for 1973/74 are from January 1974 to October 1974. From 1974/75 data are reported in fishing years. ↓ indicates introduction of triple-rig gear.

2.3.2 Intra-annual CPUE

Intra-annual trends in mean CPUE were examined only for months fished in at least 2 years, and when >10 t was harvested over the 5-year period, to exclude variable results from low sample sizes (Figure 2.7). Since 1975/76, within-year trends in mean monthly CPUE have been highly variable. During the period 1975/76 to 1979/80, CPUE was highest in November (38 kg/h) and ranged from 29 to 36 kg/h between December and June. CPUE was lowest from July to October (20–25 kg/h). From 1980/81 to 1984/85, when total catches >10 t were harvested during only nine months of the year, CPUE was also highest in November (36 kg/h) and ranged from 18–31 kg/h in other fished months. From 1985/86 to 1989/90, CPUE ranged from 30–43 kg/h, again peaking in November. During the period 1990/91 to 1994/95, harvesting was conducted between March-June, with CPUE peaking in April (71 kg/h) and at its lowest in June (43 kg/h). Over the 10-year period between 1995/96 and 2004/05, CPUE was generally highest prior to Christmas (range: 82–108 kg/h), and lowest in June(range: 57–66 kg/h). CPUE was also highest prior to Christmas in 2005/06, however during 2006/07 very high catch rates were obtained during May (133 kg/h).

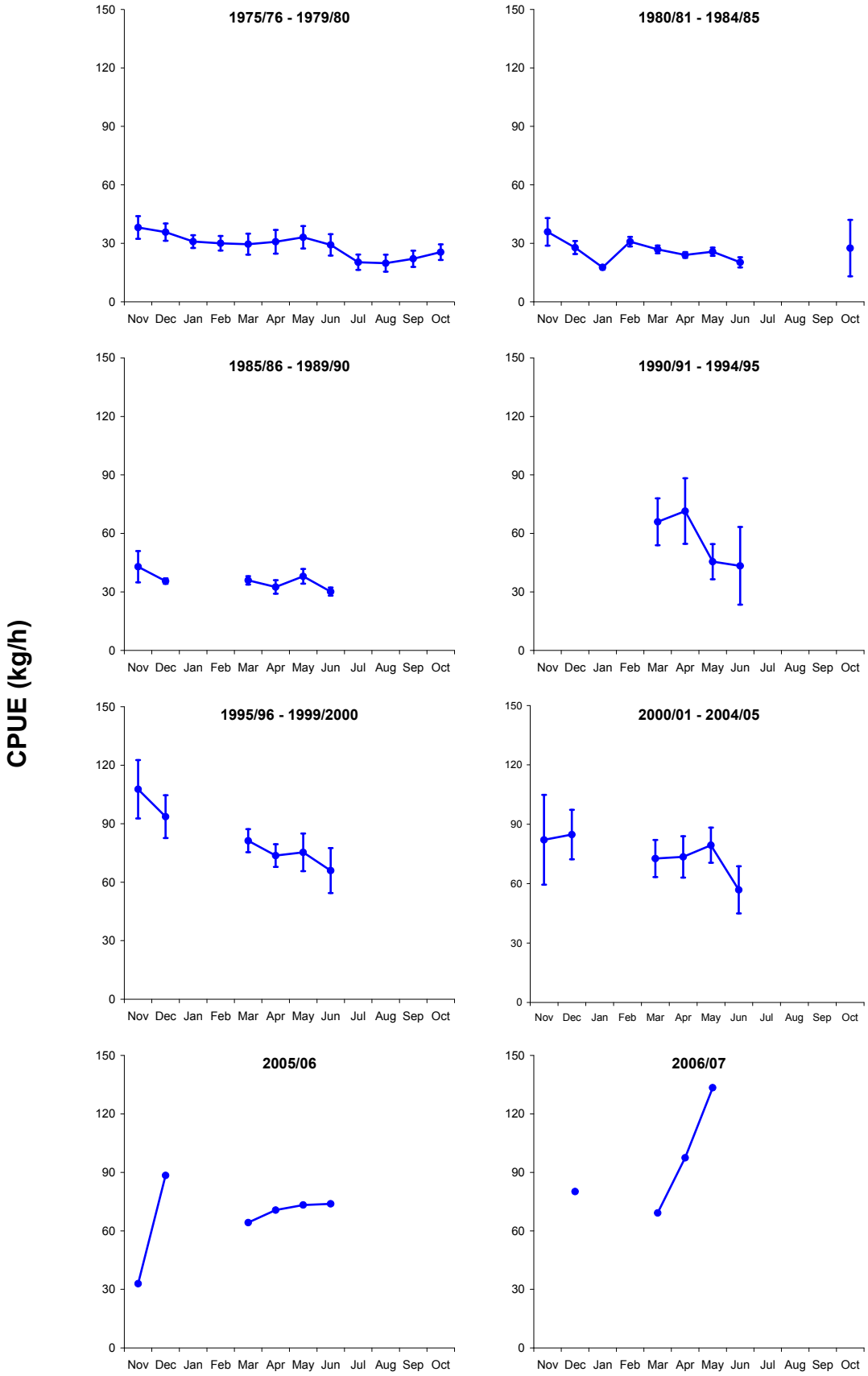

Figure 2.7 Mean monthly CPUE (SE) for 5-year periods from 1975/76–2004/05, and for 2005/06 and 2006/07. The period 1990/91–1994/95 includes the two-year closure period.

2.3.3 Regional CPUE

During the last 5-year period (2002/03 to 2006/07), mean annual CPUE has varied among regions (Figure 2.8). Mean annual CPUE was highest in Region 2 (88.5 kg/h) and lowest in the SDH region (59.4 kg/h). Mean annual CPUE in all other regions ranged from 62.5 to 88.3 kg/h. Uncertainty in the interpretation of these results during this period arises from: high spatial variability of fishing effort; variable inter-annual trends in CPUE, and; the effect of harvest strategies on annual CPUE.

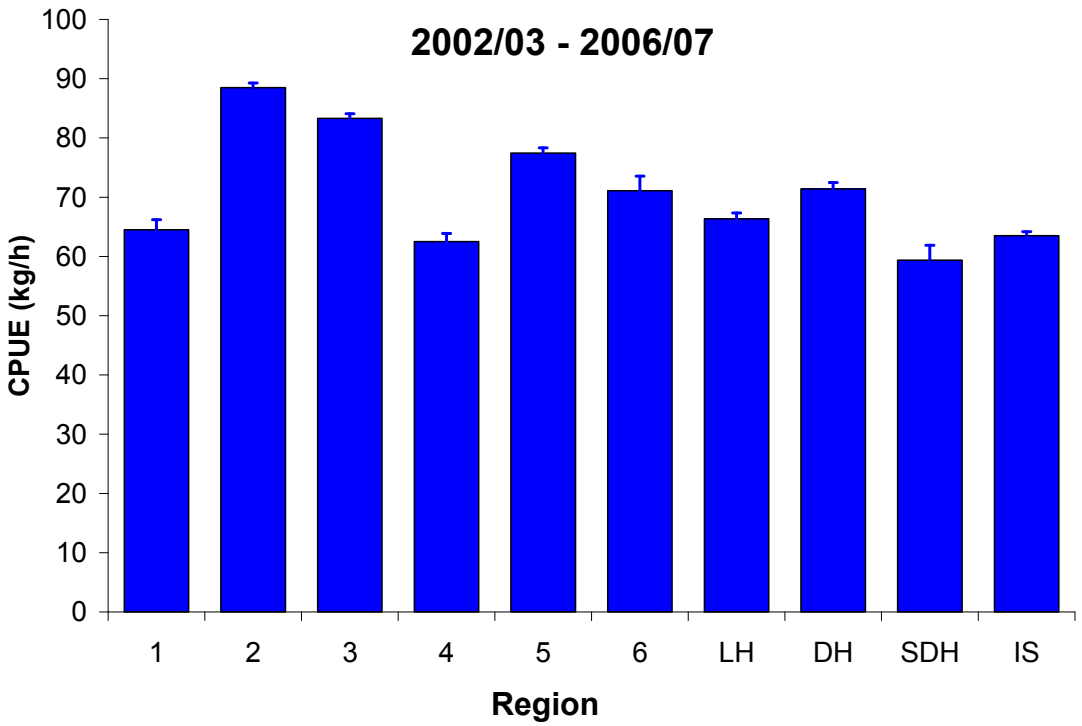

Figure 2.8 Mean (SE) annual CPUE for the 10 fishing regions within GSV from 2002/03 to 2006/07.

2.4 Searching effort

After the closure period, industry vessels developed a surveying strategy to locate areas of prawns of target size and target catch rate. These "searching" shots were generally 20 minutes or less in duration and were conducted with the cod-end of only one net tied. Generally, all ten commercial vessels would "line up" and sweep areas of GSV in a single direction. Surveyed areas were determined by fishers on an ad-hoc basis that was influenced by expectation of the location of target-sized prawns. When quantities of target-sized prawns were encountered, commercial fishing operations would commence. During 2004/05 harvest strategies were modified, with the introduction of fishery-independent surveys throughout GSV (30 minute shots), replacing previous searching methods. For analyses, these survey shots were classed as "searching" in addition to fishing shots of ≤ 20 minutes. Prior to 2004/05 changes in the pattern of searching effort, relative to fishing effort, likely reflect changes in the abundance of target-sized prawns.

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% 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. During 2006/07, searching effort was 9% of total trawl hours, the lowest proportion of total effort since 1998/99.

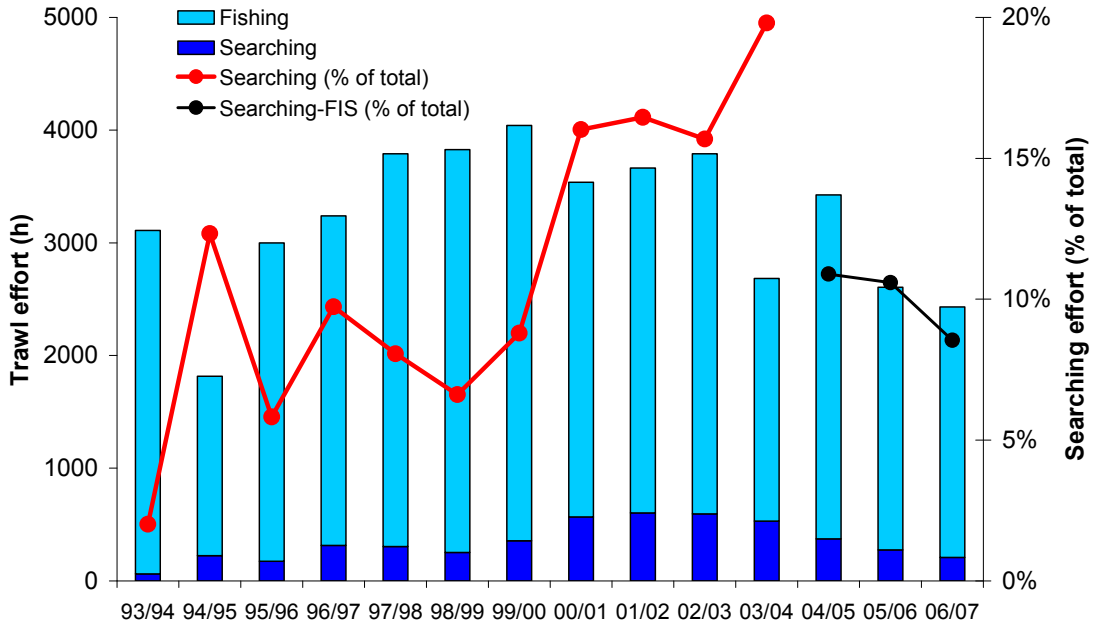

Figure 2.9 Fishing effort (light blue bars), searching effort (dark blue bars) and % of searching effort (line) from 1993/94 to 2006/07 in GSV. Note that the majority of searching effort from 2004/05 to 2006/07 represents effort done during fishery-independent surveys (FIS).

2.4.1 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 2.10). 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.

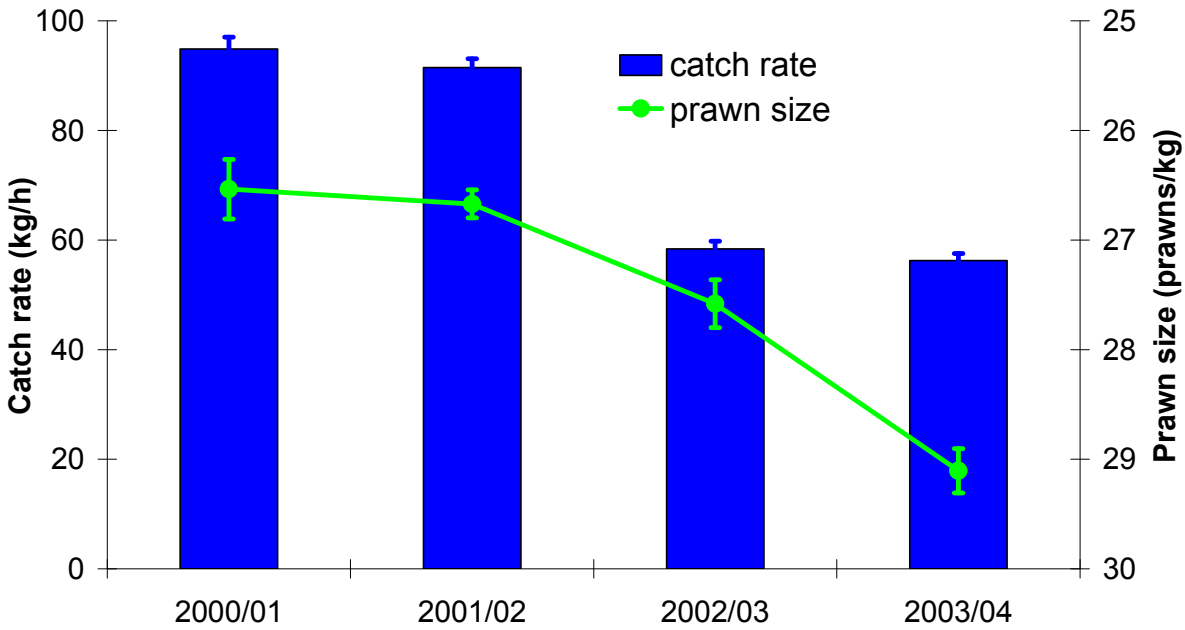

Figure 2.10 Mean (SE) catch rate (kg/h) and mean (SE) prawn size (prawns/kg) from searching shots conducted between 2000/01 and 2003/04.

2.5 Prawn size

Mean commercial prawn size is a biological Performance Indicator in the Management Plan (Dixon & Sloan, 2007). Reference points include target size criteria for each harvest period. Information on prawn size was obtained from fishery dependent prawn-grade data. Mandatory reporting of grade data in daily logbooks was introduced during the 2005/06 fishing year in GSV. During 2005/06, five large vessels with prawn grading equipment reported grade data during three harvest periods; March (29 March – 4 April), April (26 April – 5 May) and May (29 May – 5 June). During 2006/07, five large vessels with prawn grading equipment reported grade data during the December harvest period (18 – 21 December), while six large vessels reported grade data during the remaining harvest periods; March (17 – 26 March), April (16 – 24 April) and May (19 – 23 May). 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 29 size classes (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 prawns that could not be graded.

Considerable uncertainty associated with the calculation of prawn size data arises from: the number of vessels from which data were available (5–6 of 10); 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 Analytical categories assigned to reported prawn grades from the 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

2.5.1 Inter-annual and monthly trends in prawn grades

During 2006/07 the size composition of harvested prawns did not significantly vary among months (χ^2 = 6.22, d.f. = 15, P>0.05) (Figure 2.11). However, of note, during March 2007, catches were skewed towards smaller size prawns. During 2006/07, medium-large prawns dominated catches (mean = 37.6 % of the total catch), followed by large (mean = 20.1 %) then medium prawns (mean = 17.5 %). For comparisons among seasons, catches between March and

May were considered only. The greatest differences in the proportion of size grades between 2005/06 and 2006/07 were observed for medium (mean = 11.4 % and 18.5 % respectively) and XL size prawns (mean = 17.2 % and 12.5 %, respectively). This suggested that smaller size prawns were harvested during 2006/07 compared to 2005/06.

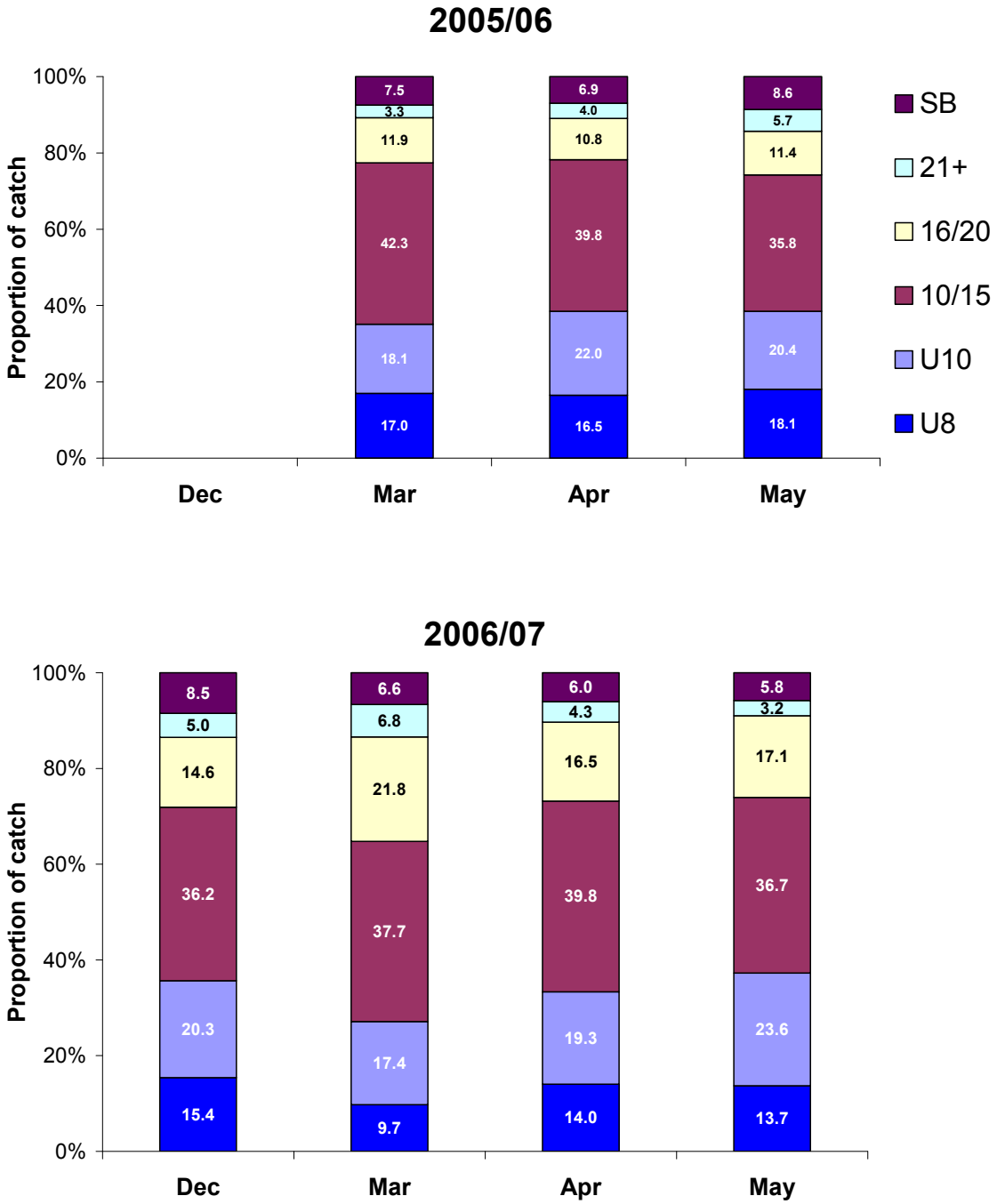

Figure 2.11 Size composition of prawns during each reported month fished in 2005/06 and 2006/07.

2.5.2 Inter-annual daily prawn size

The number of prawns per kilogram for each of the 23 prawn grades was estimated from the prawn grade name (i.e. prawn grade 10–15 was estimated as 12.5 prawns per pound equalling 27.5 prawns per kg) and are presented in Table 2.2.

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

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

The average number of prawns 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; Figure 2.12):

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

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

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

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

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

Daily prawn size data is comparable among years for the March, April and May harvest periods only, when prawn size is targeted at <28 prawns/kg as outlined in the Management Plan for GSV (Dixon & Sloan, 2007). For the March–May harvest periods combined, it was evident that a greater proportion of fishing effort (nights) occurred when harvested prawns were smaller than the target size during 2006/07 (76 %) compared to 2005/06 (33 %) (Figure 2.12). Subsequently, average prawn size during 2006/07 (28.1 prawns/kg) was smaller compared to 2005/06 (26.3

prawns/kg). Similarly, modal prawn size during 2006/07 (29 prawns/kg) was also smaller compared to 2005/06 (27 prawns/kg).

Daily mean prawn size during each harvest period is shown in Table 2.3. During the December fishing period (4-nights), mean prawn size was 27.2 prawns/kg, and 75 % of fishing effort (15 of 20 vessel-nights) was within the target criteria as defined in the Management Plan (27–33 prawns/kg). During the March harvest period (9-nights), mean daily prawn size was 29.9 prawns/kg, which was less than the target size (<28 prawns/kg), while only 6% of fishing effort (3 of 53 vessel-nights) resulted in harvested prawns within target size. During the April harvest period (9-nights), mean daily prawn size was 27.5 prawns/kg, and 35% of fishing effort (19 of 54 vessel-nights) was within target criteria for prawn size. During the May harvest period (3-nights), mean daily prawn size was 26.9 prawns/kg, and 44% of fishing effort (8 of 18 vessel-nights) was within target size.

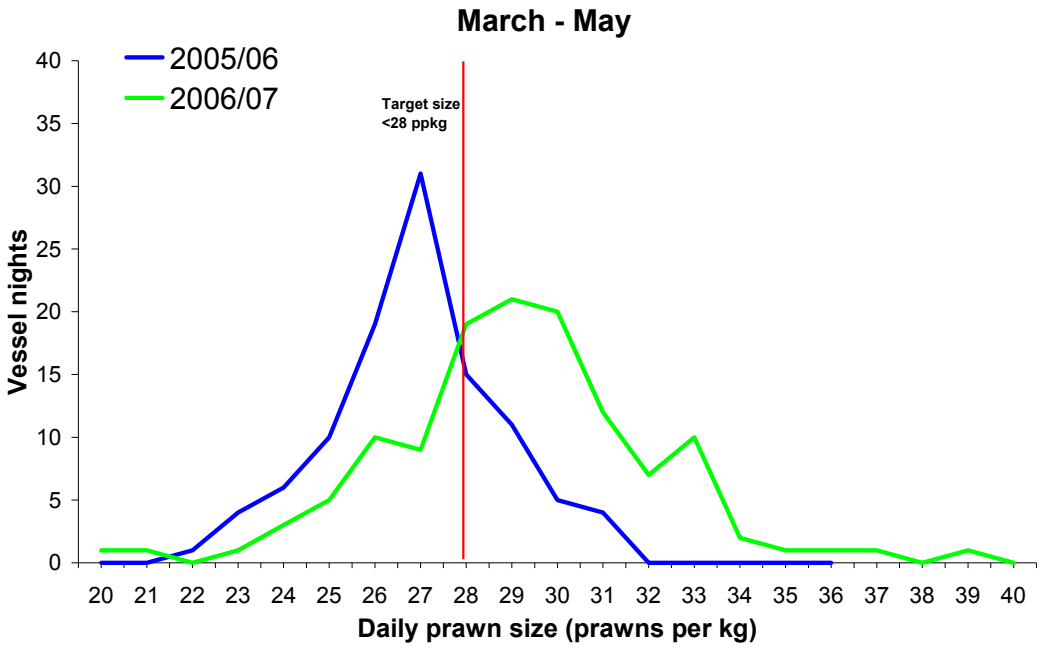

Figure 2.12 Mean daily prawn size estimated from prawn grade data provided in commercial logbooks during the March–May harvest periods combined in 2005/06 and 2006/07.

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

Year	Harvest Period	Target size (ppkg)	Mean (ppkg)	Fishing nights	Vessel nights measured	# vessel nights within target size
2006/07	December	27-33	27.2	4	20	15
2006/07	March	<28	29.9	9	53	3
2006/07	April	<28	27.5	9	54	19
2006/07	May	<28	26.9	3	18	8

2.6 Discussion

Annual catch and effort information are available since 1968 and validated daily logbook data are available since 1988. The catch history of the fishery is punctuated by two periods of increasing catch followed by decline: 1968–1990/91 and 1993/94–current.

During the first period catch peaked at 631 t during 1976/77. Catch exceeded 500 t annually during the next two fishing years before declining to around 400 t for the next four fishing years. During 1981/82, the introduction of triple-rig gear saw catches again exceed 500 t, but then rapidly decline thereafter, generally not exceeding 250 t from 1984/85 through to the closure.

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 seasons (1993/94 & 1994/95). However, catches increased rapidly from 1996/97 (210 t) to peak at 400 t during 1999/2000. It is noteworthy that the 4 –year period of peak catches following the closure (>300 t caught from 1998/99 – 2001/02) was approximately 200 t lower than the period of peak catches in the late 1970's.

Whilst catch during 2006/07 was low in an historical context, the rapid decline in catch observed prior to 2004/05 has ceased, with catches since fluctuating between 185 and 222 t. Since 1973/74 the average catch of prawns harvested during the early spawning period (November and December) was 81 t, representing 27% of the mean annual catch for this period. Importantly, since 2005/06, catches from the early spawning period (December only) were restricted to less than 30 t, representing between 11% and 13% of the total annual catch in the last 2-years.

Another difference between the periods of harvest pre and post closure is observed in commercial CPUE trends. Historically, commercial catch rates were low, averaging around 40 kg/h between 1968 and 1991/92. Trends in catch rate did not appear to reflect changes in abundance, particularly over longer time periods. Since the closure, CPUE has approximately doubled and prior to the introduction of spatial harvest strategies in 2004/05, trends in CPUE tended to reflect changes in catch. Notably, in the last two years CPUE has begun to increase again toward the levels achieved prior to the most recent collapse of the fishery. This is indicative of 1) a recovering biomass, 2) a more efficient harvest strategy or 3) a combination of both.

Whilst it is uncertain whether the current harvest strategy approach has resulted in more efficient commercial fishing, the conduct of structured fishery independent surveys has unequivocally 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 effort for the fishery, resulting in a substantial increase in efficiency for the fleet.

Mandatory reporting of grade data in daily logbooks was introduced during 2005/06 in GSV, and has allowed an assessment of prawn size during commercial fishing. Grade data indicated that smaller size prawns were harvested during 2006/07 (estimated mean: 28.1 prawns/kg) compared to 2005/06 (26.3 prawns/kg). The greatest differences between years were observed for medium and extra-large size prawns. During the March 2007 harvest period, mean prawn size was less than the target size (<28 prawns/kg) as outlined in the Management Plan. As the new Management Plan was not implemented until September 2007, management responses are not required for this breach of a Performance Indicator (see Section 5), however presenting these analyses here is an informative tool for stock assessment. A detailed spatial analysis of daily commercial prawn size is presented in Section 4, enabling effective assessment of harvest strategies at finer temporal scales.

3. FISHERY-INDEPENDENT SURVEYS

3.1 Introduction

Fishery-independent surveys utilising a consistent and rigorous methodology have been conducted since May 2003, providing two ongoing datasets for assessing the status of the GSVPF (2004/05–2006/07; May 2003–2007). This chapter provides separate analyses of both datasets with the aim to document trends in catch rate, prawn size, abundance, recruitment, reproductive activity, egg production and water temperature among years. Statistical analyses primarily aim to determine whether 2006/07 was significantly different from previous years.

Surveys, using large commercial vessels with fishery-independent observers on-board, were conducted in GSV prior to the December, March, April and May harvest periods during 2004/05, 2005/06 and 2006/07 (Table 3.1). December, March and April surveys generally took two nights to complete and were conducted on the second and third nights after the last quarter of the moon. May surveys were conducted from 2003 to 2007, during one night on the dark of the moon and are included in both datasets. The effect of the difference in lunar phase between May surveys and other months was ignored in analyses and thus results pertaining to May should be interpreted cautiously. Up to 112 common stations were surveyed between 2004/05 and 2006/07 and used for data analyses, while a subset of these stations (up to 71) surveyed during May were compared between 2003–2007. The consistent spatial and temporal replication enabled valid comparison among months and regions. To ensure statistically meaningful sample sizes for regional analyses, the LH, DH and SDH regions were combined and are referred to as the "Hole" region.

Survey shots were done at semi-fixed sites (Figure 3.1). Each survey shot began close to a known location (later fixed by Global Positioning System, GPS) and then continued in a particular direction for a specified period of time (usually 30 minutes). The distance trawled depended on trawl speed, which was influenced by vessel power, tide and weather conditions.

The data collected during surveys included total catch, trawl time and distance, sex-specific length-frequency, sex ratio, prawns/kg and sea surface water temperature. From May 2003, data on reproductive status of females and GPS data were collected and from December 2004 data on prawn grade weight were also collected. Catch rate data (kg/h) are analysed and presented for comparison to performance indicators set out in the Management Plan (Dixon & Sloan, 2007). As with CPUE data, there are several sources of uncertainty in the interpretation of survey catch rates including: differences in gear efficiency such as vessel power and gear configuration; the

effect of the environment on catchability (e.g. water temperature); and, the assumption that surveyed sites are representative of the population.

The use of large vessels with electronic "at sea" scales ensured accurate determination of the mean weight of prawns. Graders on large vessels also enabled the collection of weight data by prawn grade, from which egg production was determined. A random sample of 100 prawns was measured at sea from each shot to determine sex-specific length frequency and sex-ratio. The reproductive status of females was estimated macroscopically following King (1977) during December, March and April.

Length frequency data were also used to determine a recruitment index. Recruits were defined as male prawns < 33 mm CL and female prawns < 35 mm CL following the Management Plan (Dixon & Sloan, 2007). Recruitment index (recruits per hour trawl shot) was calculated for 88 and 56 common shots with available length-frequency data for the 2004/05–2006/07 and May 2003–2007 datasets, respectively. Roberts *et al.* (2007) demonstrated that between 2004/05 and 2005/06 the distribution, extent and timing of recruitment was highly variable. Thus, in this report recruitment is not assessed at the regional level, but is assessed for each harvest period among years. 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 mesh types may vary among vessels, there have been few changes in cod-end mesh type for individual vessels during the survey period.

The 2004/05 stock assessment report (Dixon *et. al.* 2006) presented catch rate data per nautical mile. In the following section, catch rate data are presented per trawl hour to conform to the requirements of the Management Plan. Comparison of the two measures from survey data obtained during 2004/05 determined that there was a highly significant correlation between trawl distance and time ($F_{1,489}$=9972.98, P<0.001), suggesting that either measure is suitable.

Where statistical analyses were appropriate, analysis of variance (ANOVA) and Tukey post-hoc tests were used to determine significant differences at various spatial and temporal scales. Homoscedasticity and normality of the data were determined by Levene's test and visually assessing residual plots. Where necessary, $\log_{10}$ (n + 10) transformations of data were employed to ensure homogeneity of variances. In all cases, significance was accepted at P<0.05. Data analyses were performed using SPSS software (SPSS, version 16.0) and values are presented as mean ± standard error (SE).

Table 3.1 Calendar dates of surveys and subsequent harvest periods between 2004/05 and 2006/07.

Harvest period	2004/05		2005/06		2006/07	
	survey	fishing	survey	fishing	survey	fishing
December	9-10 Dec	12-19 Dec	27-28 Nov	3-8 Dec	15-17 Dec	18-21 Dec
March	6-7 Mar	9-18 Mar	25,26,28 Mar	29 Mar - 4 Apr	14-16 Mar	17-26 Mar
April	4-5 Apr	7-16 Apr	23-24 Apr	26 Apr - 5 May	13-14 Apr	16-24 Apr
May	8 May	10-16 May	27 May	29 May - 5 Jun	17 May	19-23 May
June	1 Jun	4-7 Jun	-	-	-	-

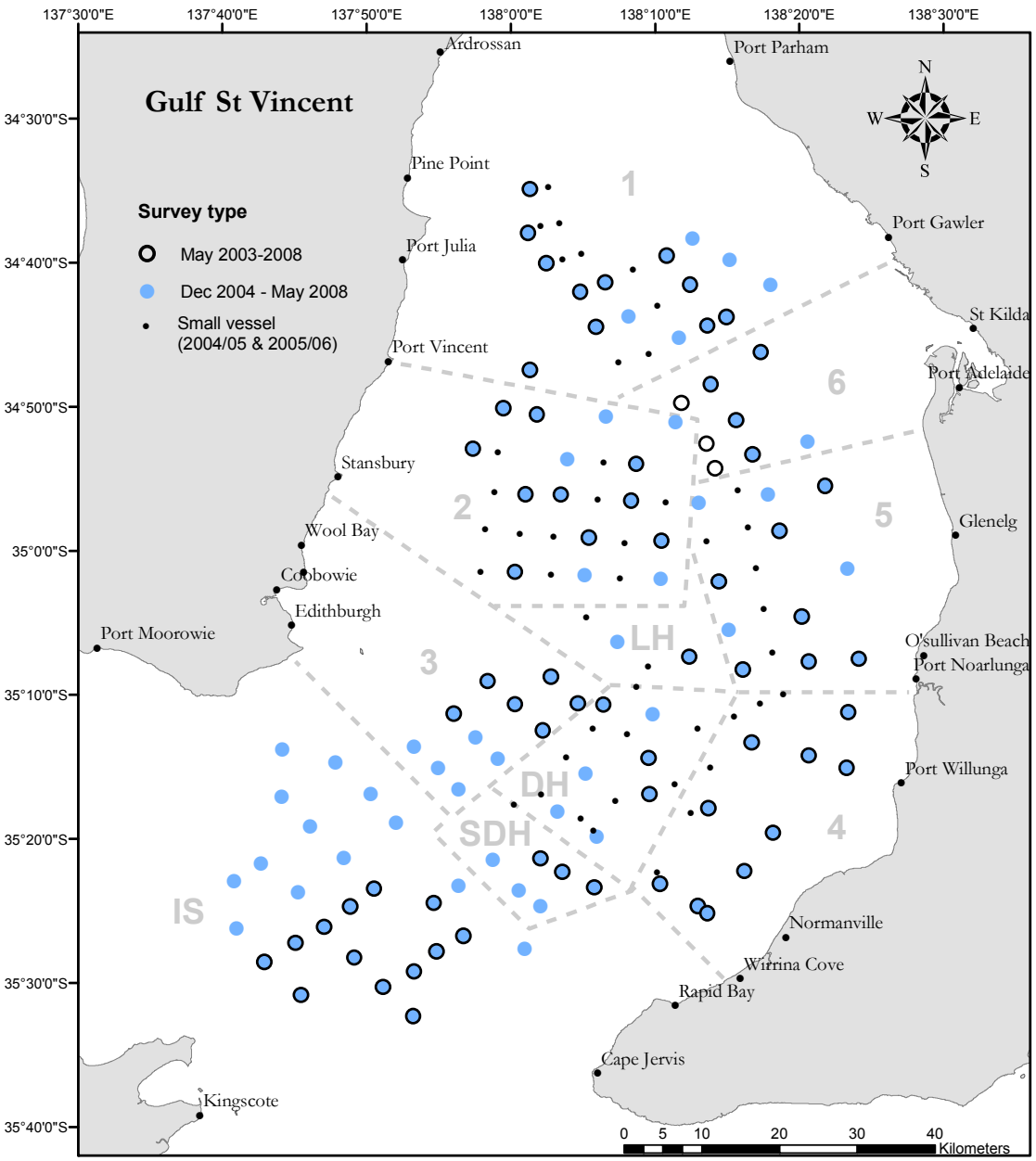

Figure 3.1 Stations and surveyed regions (defined by dashed lines) included in analysis of data from surveys conducted between May 2003-2007, December 2004 and May 2007, and by small vessels during 2004/05 & 2005/06.

3.2 Surveys conducted between 2004/05 and 2006/07

3.2.1 Catch rate

Annual mean catch rate in 2006/07 (61.4 ± 2.8 kg/h) was significantly higher (~32%) than in 2005/06 (46.6 ± 2.1 kg/h), and significantly higher (~45%) than in 2004/05 (42.5 ± 1.7 kg/h) ($F_{2,1352}$=11.07, P<0.001). During March, April and May, mean catch rates have increased consecutively each fishing year since 2004/05 (Figure 3.2). During April and May in 2006/07, mean catch rates were significantly higher compared to previous years (post-hoc test: P<0.01). In 2006/07, increases of 13%, 34% and 76% were observed for March, April and May respectively compared to catch rates obtained in 2005/06. In 2006/07, catch rates were 37%, 72%, and 82% higher than those observed in 2004/05 during March, April and May, respectively. It should be noted that water temperature during May 2005/06 was substantially lower than both 2004/05 and 2006/07 and thus catch rates in May 2005/06 were likely to be a conservative indication of relative biomass (see section 3.2.7). Unlike other months, there was no significant difference in catch rate over time for December surveys.

Regional trends in mean catch rates significantly differed between 2004/05, 2005/06 and 2006/07 ($F_{2,1341}$=16.25, P<0.001) (Figure 3.3). During 2006/07 the highest mean catch rates were observed in region 3 (98.7 kg/h) and region 6 (81.0 kg/h), while the lowest mean catch rate was observed in region 1 (37.8 kg/h). During 2004/05 and 2005/06 the highest mean catch rate was observed in region 5 (64.9 kg/h) and region 6 (60.6 kg/h) respectively, while the lowest mean catch rate was observed in region 4 (<27 kg/h) during both fishing years.

3.2.2 Mean prawn size

Mean weighted annual prawn size decreased significantly among years ($F_{2,1270}$=12.18, P<0.001) from 27.4 ± 0.5 prawns/kg (2004/05) to 29.6 ± 0.4 prawns/kg (2005/06) and again in 2006/07 to 31.1 ± 0.5 prawns/kg. During December surveys, mean prawn size was smaller in 2006/07 (31.1 prawns/kg) compared to the previous 2-years (2004/05: 27.7, 2005/06: 26.1 prawns/kg) (Figure 3.2). During March surveys, mean prawn size was smaller in 2005/06 and 2006/07 (30.9 and 32.1 prawns/kg, respectively) compared to 2004/05 (27.1 prawns/kg). During April surveys, mean prawn size was smaller in 2006/07 (32.7 prawns/kg) compared to the previous 2-years (30.0–30.4 prawns/kg), while during May surveys mean prawn size was smaller during 2005/06 and 2006/07 (30.4 and 29.0 prawns/kg, respectively) compared to 2004/05 (24.8 prawns/kg). Reduced mean prawn size, combined with increased total catch rates likely reflects strong recruitment of small prawns to the fishery.

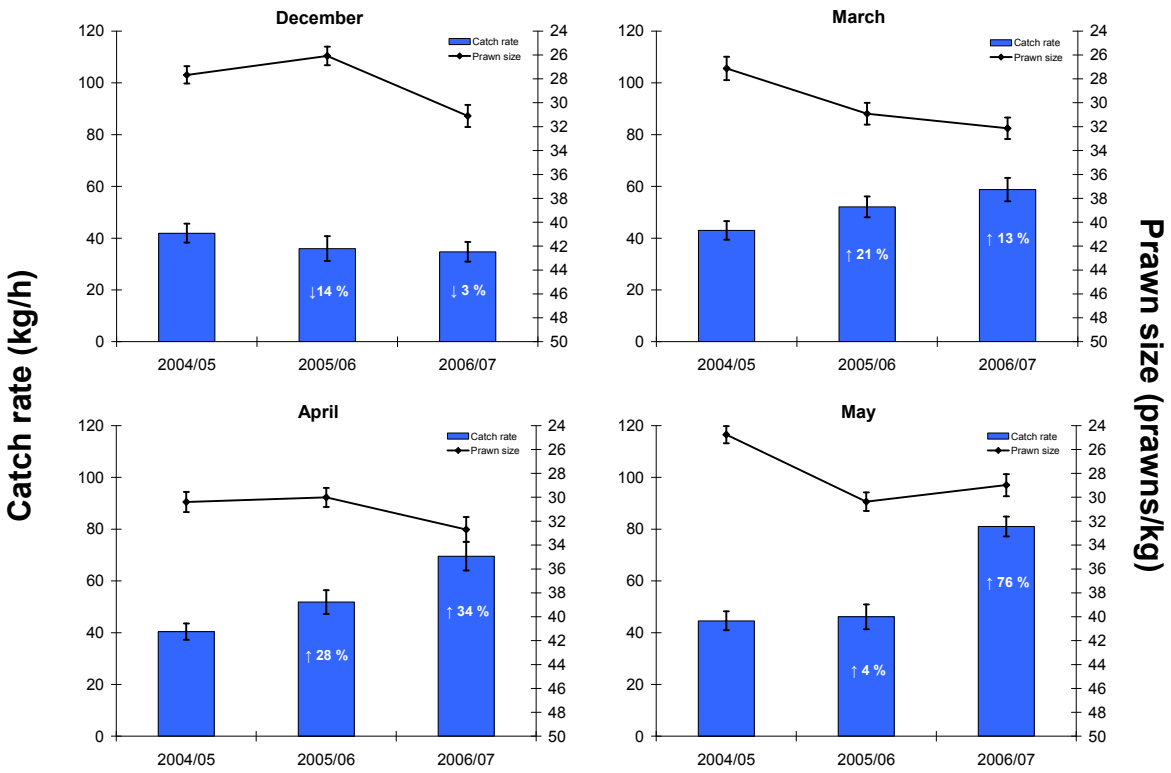

Figure 3.2 Survey mean catch rates (kg/h) and prawn size (prawns/kg) between 2004/05 and 2006/07 conducted prior to the December, March–May harvest periods. May surveys were conducted on a different lunar phase. Numbers indicate the percent increase from the previous year.

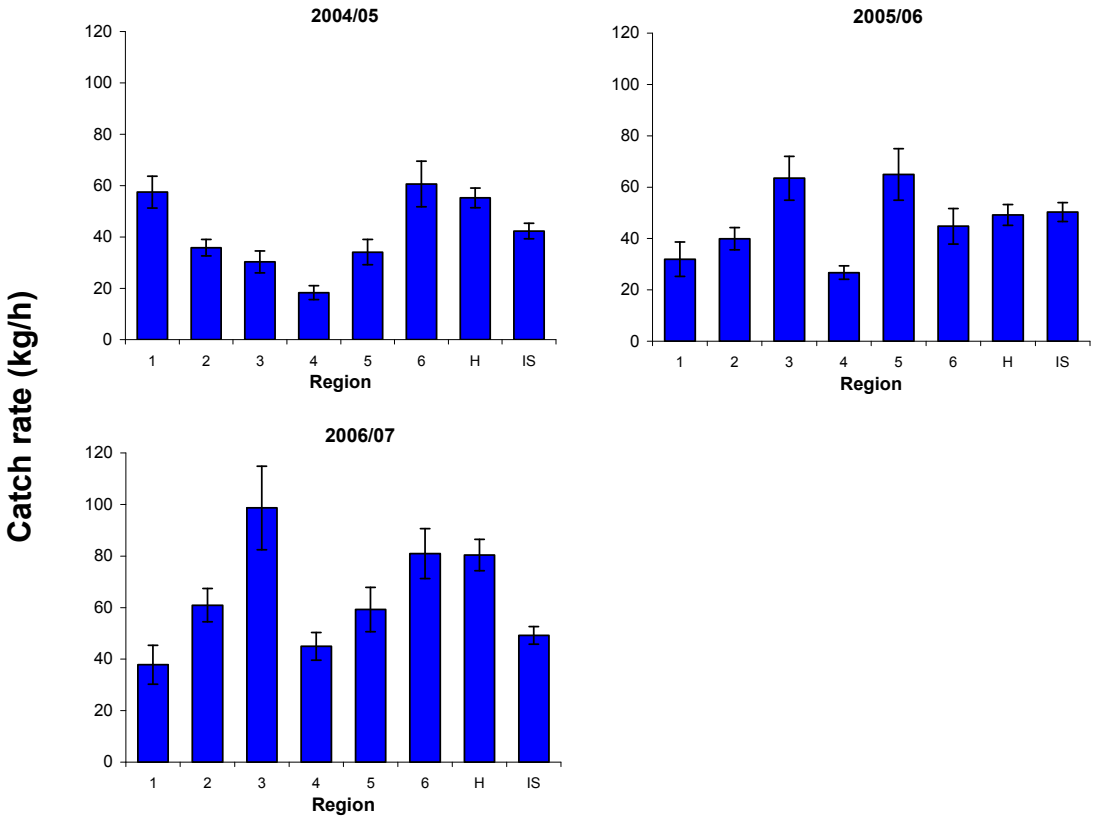

Figure 3.3 Regional mean (SE) catch rate (kg/h) from surveys conducted during 2004/05, 2005/06 and 2006/07. Number labels indicate the number of stations surveyed. May surveys were conducted on a different lunar phase.

3.2.3 Length frequency

Prawn length (mm, CL) frequency data (n≈100 per shot) collected during surveys between 2004/05 and 2006/07 were scaled up to prawn abundance per 30 minute shot. Length frequency data were separated into commercial grades, based on length-weight relationships (see Section 1.4.6 and Table 2.2), to determine whether abundances during 2006/07 were significantly different compared to previous years for individual size classes. Four size classes were assessed; 1) 'small', <36 mm CL (grade 21+), 2) 'medium', 36–39 mm CL (grade 16-20), 3) 'medium-large', 40–45 mm CL (grade 10-15) and 4) 'large' >45 mm CL (grade U10).

The abundance of prawns in each size class was determined for each survey shot by summing across the scaled up length frequency within each grade. The Management Plan identifies stock recovery as annual increases in abundance for each survey month. To assess whether abundance was significantly higher in 2006/07 than previous years, ANOVA was used for each month and size class. Table 3.2 summarises the results of these tests, highlighting in green the months and size classes with significantly greater abundances in 2006/07. Note that no statistically significant decreases in abundance were observed in 2006/07 compared to previous years. Abundance data (by size class) are displayed in Figure 3.4, while length-frequency data (1 mm CL bins) are displayed in Figure 3.5.

Table 3.2 ANOVA of changes in mean prawn abundance (per 30 minute survey shot) among years for each of four size classes. Green-shaded cells indicate a significantly greater mean prawn abundance in 2006/07 compared to previous years. No shading indicates no significant difference.

Size class	Dec	March	April	May
Small (21+)	$F_{2,306}$=3.54, P<0.05	$F_{2,309}$=15.97, P<0.01	$F_{2,319}$=12.16, P<0.01	$F_{2,308}$=11.11, P<0.01
Medium (16-20)	$F_{2,306}$=0.44, P=0.642	$F_{2,309}$=9.73, P<0.01	$F_{2,319}$=9.71, P<0.01	$F_{2,308}$=21.07, P<0.01
Medium-large (10-15)	$F_{2,306}$=0.68, P=0.509	$F_{2,309}$=0.37, P=0.69	$F_{2,319}$=6.19, P<0.01	$F_{2,308}$=11.01, P<0.01
Large (U10)	$F_{2,306}$=2.28, P=0.104	$F_{2,309}$=0.22, P=0.806	$F_{2,319}$=2.86, P=0.059	$F_{2,308}$=4.24, P<0.05

Temporal trends in size abundance

Small prawns were significantly greater in abundance in 2006/07 for each surveyed month compared to previous years (Table 3.2, Figure 3.4). The greatest difference in abundance was a ~3-fold increase observed during March surveys from 126 (2005) to 352 prawns/shot (2007). The highest abundance of small prawns was observed during April 2007 (421 prawns/shot) and the lowest abundance was observed during December 2005 (93 prawns/ shot).

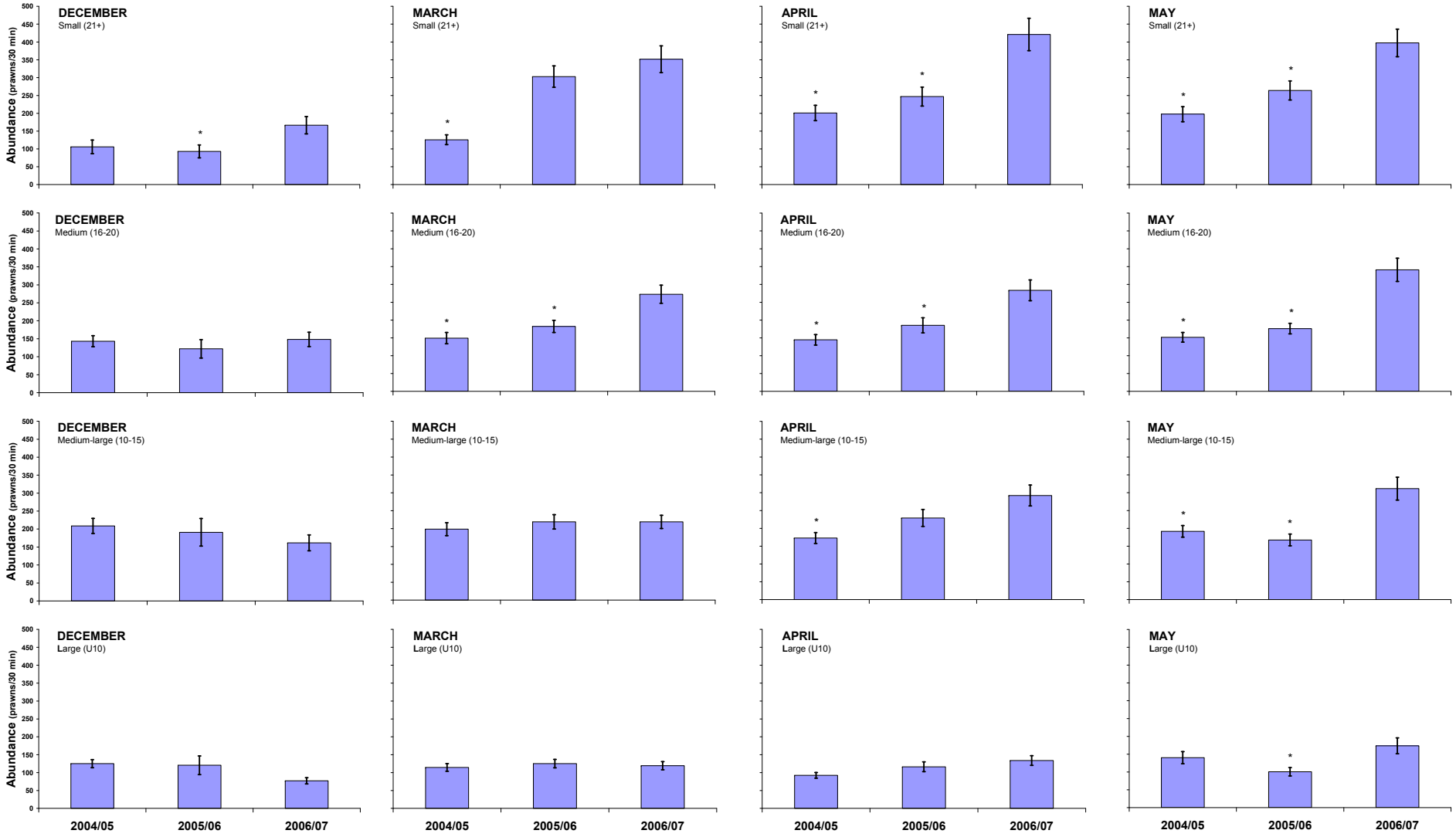

Figure 3.4 Mean (SE) prawn abundance (prawns / 30 minute survey shot) among years for each of four size classes. Abundance was calculated from length frequency survey data collected prior to December, March–May harvest periods. Asterisks indicate significant difference (P<0.05) from 2006/07.

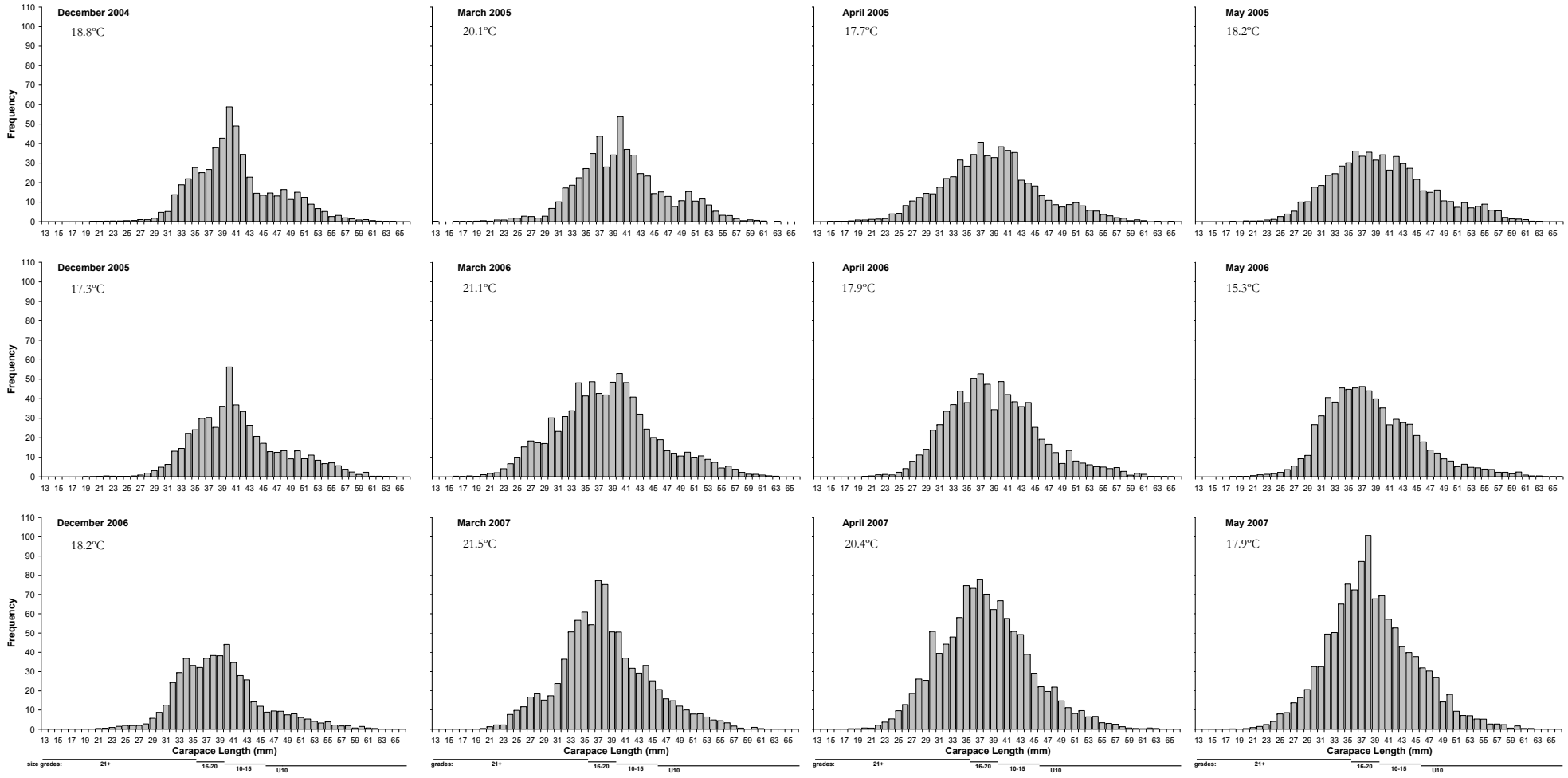

Figure 3.5 Prawn length frequency data, mm CL, (mean abundance of prawns from adjusted 30 minute survey shots) from surveys conducted prior to the December, March–May harvest periods between 2004/05 and 2006/07. Commercial prawn size grades (21+ to U10 prawns/lb) are also displayed, based on L/W relationships, for reference. Mean SST (ºC) collected during surveys is also displayed for reference.

Medium prawns were significantly greater in abundance in 2006/07 compared to previous years during March, April and May, but not in December (Table 3.2, Figure 3.4). The greatest difference in abundance of medium prawns was a ~2-fold increase observed during May surveys from 152 (2005) to 341 prawns/shot (2007). The highest abundance of medium prawns was observed during May 2007 (341 prawns/shot) and the lowest abundance was observed during December 2005 (122 prawns per shot).

Medium-large prawns were significantly greater in abundance in 2006/07 compared to previous years during April and May but not in March and December (Table 3.2, Figure 3.4). The greatest increase in abundance was a ~2-fold increase observed during April (173 in 2005 to 292 prawns/shot in 2007). In contrast, the abundance of medium-large prawns during December surveys decreased from 209 in 2004 to 162 prawns/shot in 2006, however these differences were not significant (Table 3.2). The highest abundance of medium-large prawns was observed during May 2007 (311) and the lowest abundance was observed during December 2006 (162 prawns/shot).

The abundance of large prawns was significantly greater in 2006/07 compared to previous years during May but not during December, March or April (Table 3.2, Figure 3.4). Whilst the difference in abundance observed during April surveys was not significant, it is noteworthy that abundance did increase over time (Table 3.2, Figure 3.4). In contrast, the abundance of large prawns during December surveys decreased over time, although again these differences were not significant (Table 3.2, Figure 3.4). The abundance of large prawns was highest during May 2007 (174 prawns/shot) and lowest during December 2006 (77 prawns/shot).

There were clear trends evident from statistical analyses of differences in abundance by size class for each survey period (Table 3.2). Significantly greater abundance during 2006/07 compared to previous years were more frequently detected 1) with decreasing size and 2) as the fishing year progressed, such that during May surveys significant increases in abundance were detected for all size classes. The increase in abundance of small prawns correlates with the increases in recruitment trends observed in the last two years (see Figure 3.7 and Section 3.2.4 following). The pattern of increased detection of significant changes in abundance throughout the season is likely explained by patterns in growth. Despite the fact that fishing throughout the year targets large and medium-large prawns, it is encouraging to note that significant increases in annual abundance are detected later in the season as rapid growth results in smaller prawns growing into these larger size categories.

Apparent decreases in abundance of large and medium-large prawns were observed between May 2005 and May 2006. This may have been caused by lower water temperature affecting catchability during May 2006 (Figure 3.5). The abundance of these size categories increased substantially

during 2007 when water temperatures were again close to those observed in 2005. Whilst it is difficult to calculate the effect of water temperature on estimates of abundance, comparison of water temperature data is useful to assist in the explanation of observed trends.

Sex-specific length frequency

Sex-specific length frequency data from surveys conducted during 2006/07 are presented in Figure 3.6. Commercial prawn grades are shown as determined from the length-weight relationship (see Section 1.4.6 and Table 2.2).

The size structure of male and female prawns differs substantially in all months due to the differences in growth rate between sexes (see Section 1.4.5). Female prawns grow faster than males and therefore their modal and maximum size is larger. Also, the distribution of females has a larger spread, and thus the modal frequency of males is always higher. As a consequence of the differential growth, females prawns dominate the larger size classes (U10 grade and to a lesser extent 10–15 grade; Figure 3.6).

Male and female recruit-sized prawns (male prawns <33 mm CL and female prawns <35 mm CL; Dixon & Sloan, 2007) begin entering the fishery in March. At this size and time of year growth is rapid, so the similar abundances of recruit sized prawns observed in April and May likely indicates that new recruits continue to enter the fishery during these periods.

The ratio of female to male prawns was similar in all survey months during 2006/07. This was a similar pattern to that observed during 2005/06 (Roberts *et al.* 2007).

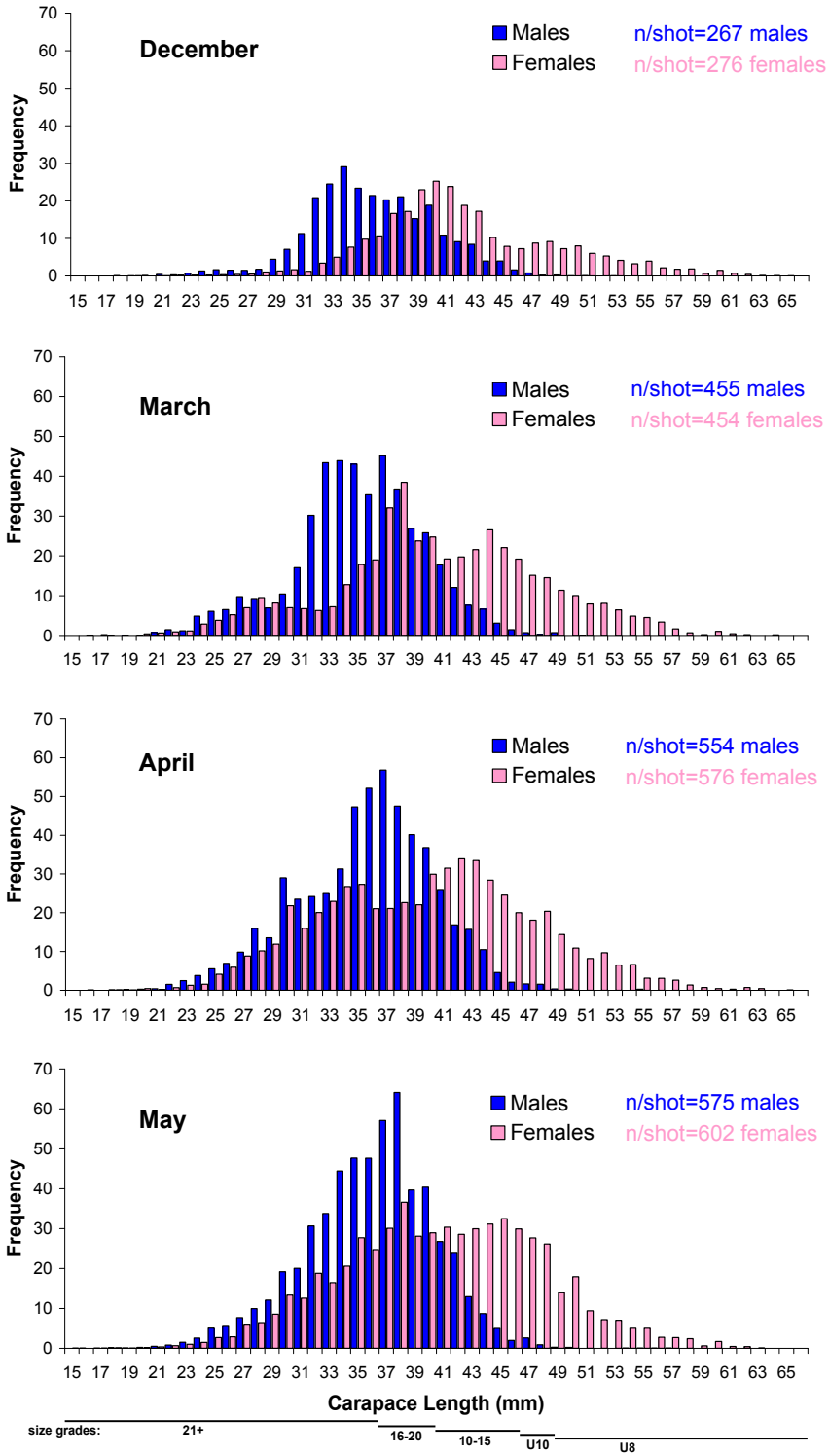

Figure 3.6 Sex-specific length frequency data, mm CL, (mean abundance of prawns from adjusted 30 minute survey shots) from surveys conducted prior to the December, March–May harvest periods during 2006/07. Commercial prawn size grades (21+, 16–20, 10–15 and U10 prawns/lb) are displayed.

3.2.4 Trends in recruitment

Mean annual mean recruitment significantly differed among years ($F_{2,1268}$=8.62, P<0.001), increasing from 175 ± 14 recruits/h in 2004/05 to 285 ± 20 recruits/h in 2005/06, and increasing again to 391 ± 29 recruits/h in 2006/07. Recruitment significantly differed among months ($F_{3,1268}$=47.74, P<0.001), with peak recruitment being between March and April each year (Figure 3.7). During December surveys over the last 3-years, recruitment was greatest in 2006/07. During March surveys, recruitment was over 2-fold greater in 2005/06 and 2006/07 compared to 2004/05. During April and May surveys, recruitment increased consecutively from 2004/05 to 2006/07.

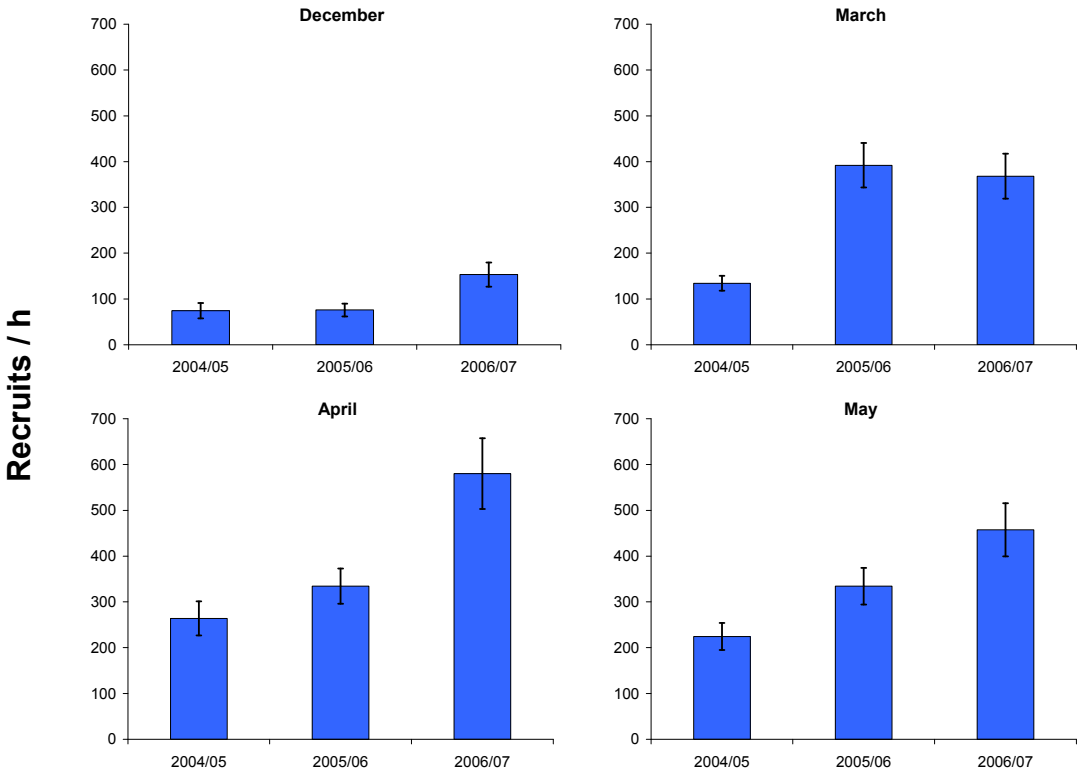

Figure 3.7 The mean (SE) number of recruits per trawl hour during surveys conducted between 2004/05 and 2006/07 prior to the December, March–May harvest periods. May surveys were conducted on a different lunar phase.

3.2.5 Female reproductive status

Macroscopic reproductive staging of female prawns, following King (1977), was done during surveys conducted prior to the December, March and April harvest periods during 2004/05, 2005/06 and 2006/07. Briefly, stage 0 indicates no reproductively active ovary development, stages 1 and 2 indicate reproductively active ovary development, and stages 3 and 4 indicate mature ovaries. A significant difference in monthly reproductive activity (% mature females) occurred among years (interaction: $F_{3,787}$=56.55, P<0.001; Figure 3.8). Peak reproductive activity occurred during December and March (stage 3+4 range: 21–48%) in 2004/05 and 2006/07. During 2005/06, reproductive activity mainly occurred during December only. Note that due to negligible reproductive activity during April between 2004/05 and 2005/06, reproductive data was not collected during April 2007.

During 2005/06 only, female prawns were staged according to their reproductive development during size frequency measurements during the December, March and April surveys. This enabled the analyses of mature females across sizes (mm, CL) and among months (Figure 3.9). During the December, March and April surveys, female prawns with mature ovaries (stage 3 and 4) ranged from 25–64 mm CL, 34–64 mm CL and 41 – 65 mm CL, respectively. This indicates that larger size female prawns undergo a protracted spawning season. Further, this may also indicate that larger females are more likely to spawn on multiple occasions within the one spawning season compared to smaller females.

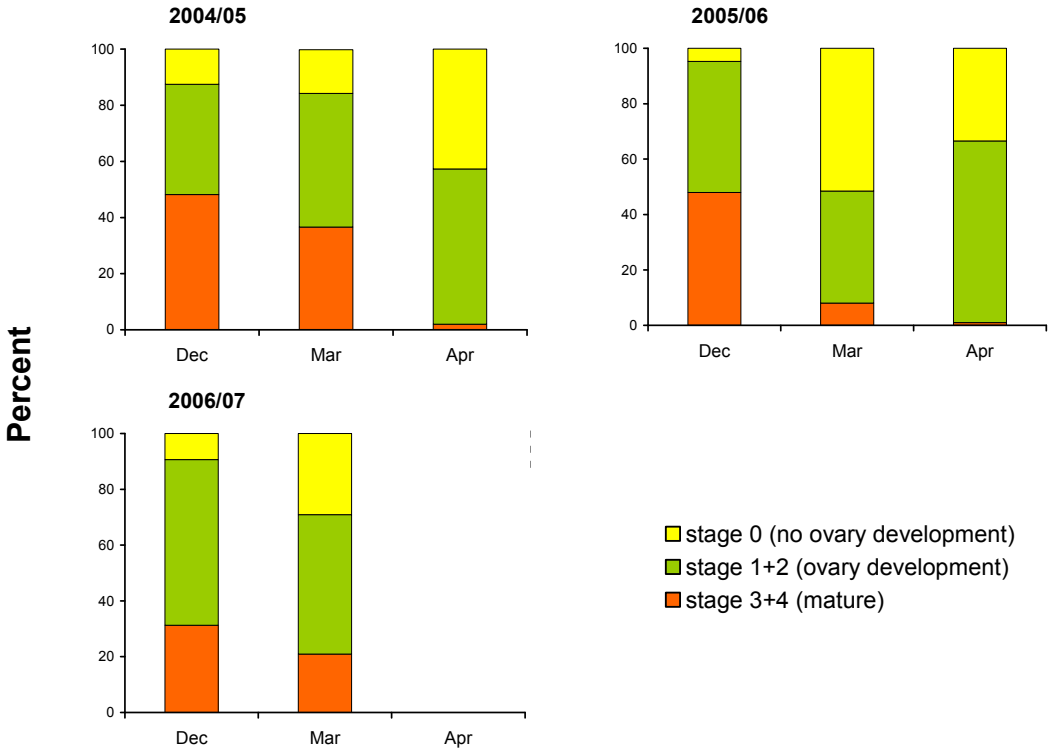

Figure 3.8 Reproductive development of female prawns during 2004/05, 2005/06 and 2006/07. Note that female prawns were not staged in April during 2006/07.

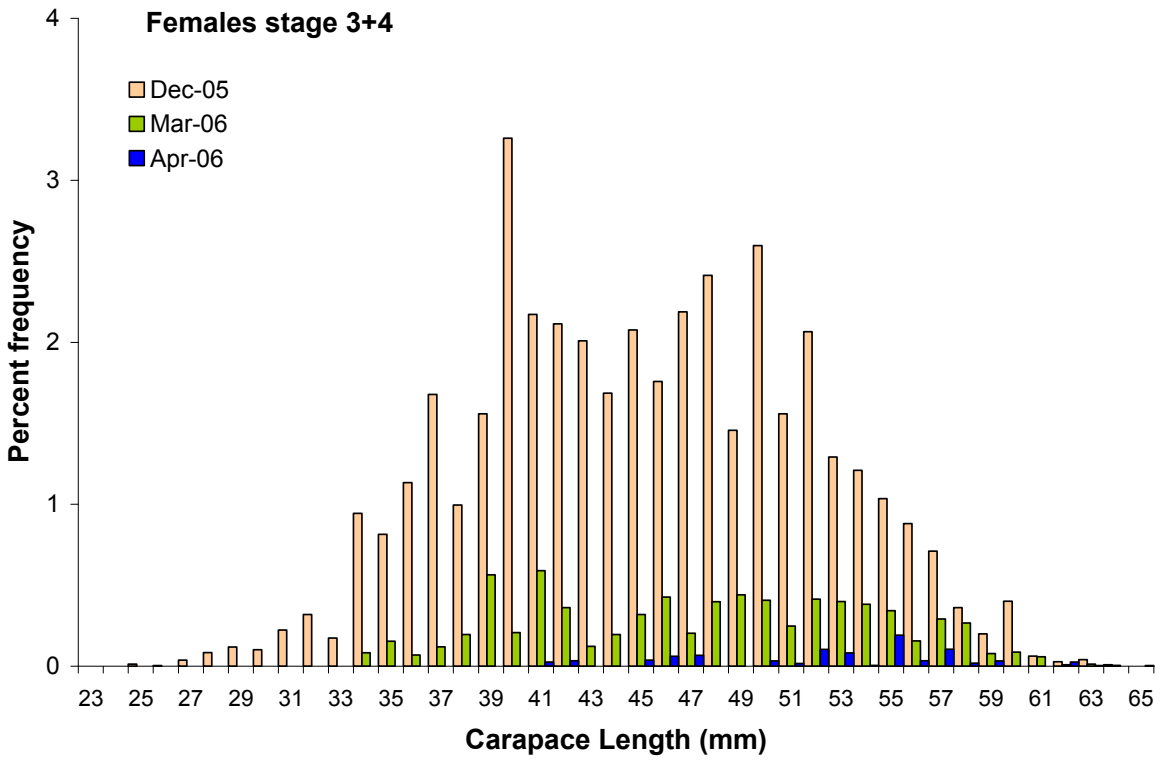

Figure 3.9 Size-frequency (mm, CL) of female prawns with mature ovaries (stage 3+4) (percent of total females) during 2005/06 when reproductive staging of sizes was documented during December, March and April surveys.

3.2.6 Estimates of egg production

Egg production was estimated for 2004, 2005 and 2006 from December survey data that included catch rate, weight of prawn grades and the proportion of females in the catch. These estimates reflect the potential egg production of female prawns captured during surveys. They are useful to assess the relative contribution toward egg production from female prawns of various size grades and to compare potential egg production between years.

The model utilises much of the current knowledge of the biology of *M. latisulcatus* (see Section 1.4). An FRDC project has recently begun that aims to improve the understanding of the biology that underpins the egg production model. As such, it should be noted that there is considerable uncertainty associated with the current outputs of the model. Current assumptions 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,
- natural mortality was zero,
- the % of females within each grade does not vary during the spawning season,
- the size at maturity doesn't vary with time, and
- sex-specific length frequency data from surveys were representative of the population.

Data on the biology of prawns (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 3.3 Model parameters and the egg production estimate for 2006/07 determined from the December 2006 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)	3.7 (0.5)	4.7 (0.9)	17.7 (2.6)	5.9 (0.9)	6.5 (0.7)
Prawns per hour	219.3 (29.3)	178.3 (34.4)	479.2 (69.2)	118.7 (18.9)	103.8 (11.7)
% females	18.85%	29.93%	43.78%	92.62%	99.08%
Females per hour	41.3 (5.5)	53.3 (10.3)	209.8 (30.3)	110.0 (17.5)	102.8 (11.5)
Eggs (million per hour)	1.5 (0.2)	26.7 (3.0)	131.3 (17.5)	160.2 (21.1)	103.5 (13.9)

Egg production per trawl hour in December 2006 (423 million/h) was lower than the previous two years (Figure 3.10). During 2006, U10 followed by 10/15 grade prawns contributed the greatest to egg production, while U8 followed by 10/15 grade prawns contributed the greatest during 2005. These differences were largely due to differences in mean catch rates among size grades between years (Figure 3.11).

While the greatest catch rates in each of the last three fishing years were for the 10/15 size grade, prawns in this size grade do not contribute the greatest to egg production. Prawns in the U8 and U10 size grades contribute the greatest number of fertilized eggs. During 2006, catch rates were greater for the U10 compared to U8 grade prawns, while the catch rate of U8 grade prawns during 2006 was lower than the previous two years. These trends in catch rates of the larger size prawns reflect trends in their associated egg production estimates.

These results were due to a) the proportion of female prawns in each size grade (10–15=43.8%, U10=92.6%, U8=99.1%), b) greater maturity of larger females, c) higher fecundity of larger females, and d) increased insemination rates of larger females. These results have substantial implications for the development of harvest strategies during the spawning season. Whilst the capture of smaller prawns during the early spawning period would clearly reduce the immediate impact on egg production, the effect on future recruitment by removing smaller individuals is unknown, and is a major source of uncertainty in these analyses. More complex analyses that incorporate natural and fishing mortality rates may improve this understanding.

There is considerable uncertainty in the current assumptions of this model. In particular, reproductive studies have demonstrated that the spawning season extends into March and April, particularly for large and highly fecund females. Thus, current outputs based only on December survey results are likely to be highly biased. Also, the protracted spawning season for large females may suggest that the assumption of spawning frequency being equal across all size classes is invalid. As such, the results presented here should be interpreted cautiously. The current studies on reproductive biology should considerably improve this model in coming years.

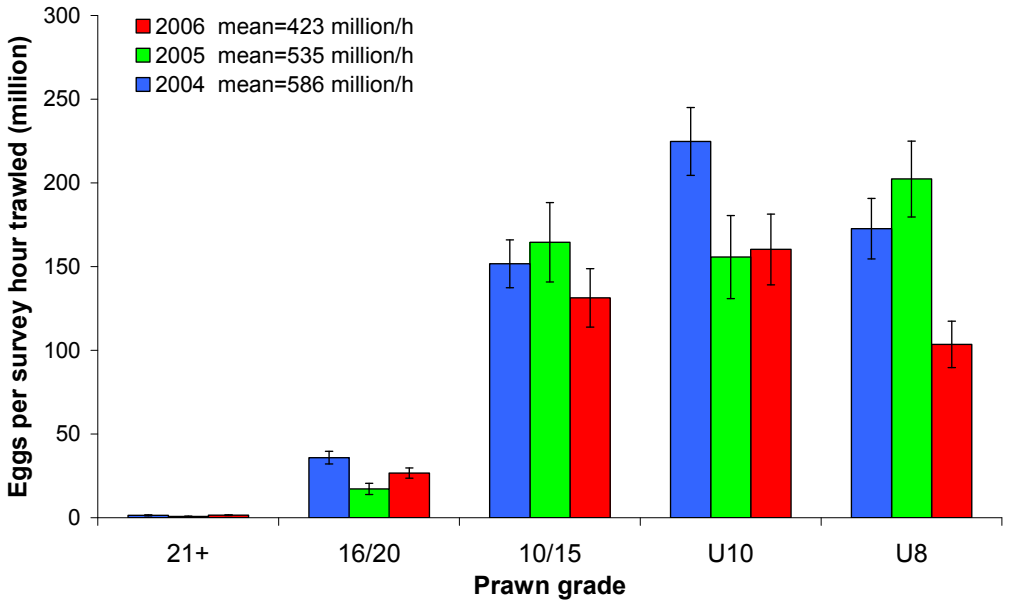

Figure 3.10 Mean (SE) number of fertilised eggs (million per trawl hour) produced by females captured during December surveys conducted in 2004, 2005 and 2006.

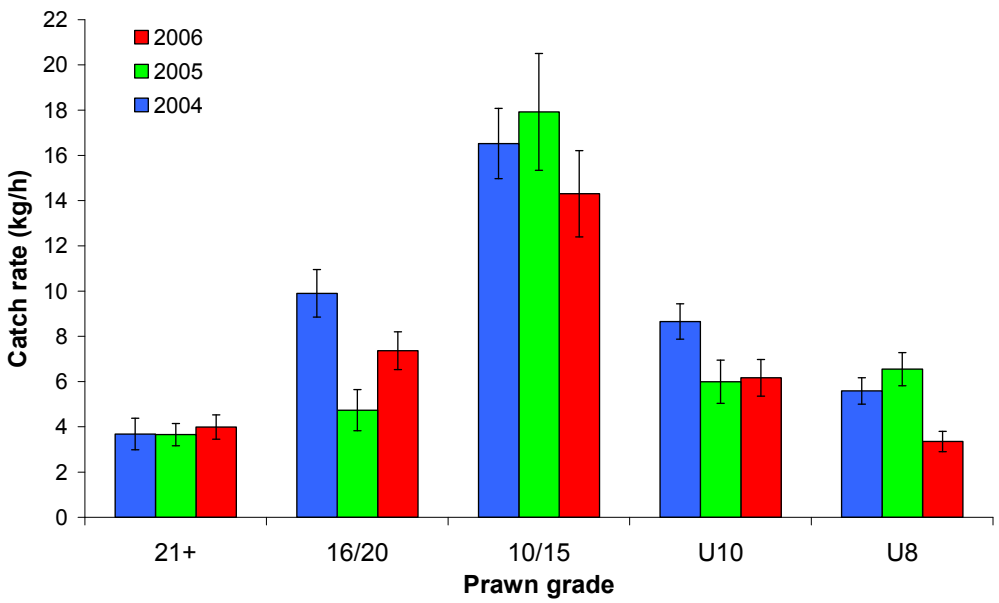

Figure 3.11 Mean (SE) graded catch (kg) per hour (males and females) during December surveys conducted in 2004, 2005 and 2006.

3.2.7 Water temperature

The catch rate of prawns is affected by abiotic factors that include season, moon phase and water temperature (Penn, 1976; Hill, 1985; Penn *et. al.*, 1988). Contemporary surveys aim to remove the effects of season and moon phase by conducting surveys that fix these parameters each year. It has previously been suggested that water temperature affects catchability in *M. latisulcatus* tropical fisheries (Penn, 1976; Penn *et. al.*, 1988), where catch rates generally increase with increasing water temperature.

GSV is a relatively shallow embayment where waters are well mixed (Middleton & Bye, 2007). Bottom water temperature is indicative of the benthic gulf environment that prawns inhabit, and has been collected since 2006/07 by attaching data loggers (Sensus Ultra, by Reefnet ®) to the otterboard of each survey vessel. Preliminary analyses indicated no statistically significant difference between mean annual bottom water temperature and SST in GSV ($F_{1,610}$=2.41, P>0.05), although moderate differences between these variables were evident during some months of the year. It should be noted that a poor relationship existed between SST and bottom water temperature on a shot by shot basis (R^2 = 0.32), largely due to greater variations and inconsistency in SST data. Thus, trends in SST data from historical surveys are only indicative of trends in bottom water temperature when compared over large temporal scales, as analysed in this report. For this report, only SST data are presented since trends extend over the 3-year period of consistent monthly surveys.

Water temperature data analysed for this section was obtained from two sources: 1) fishery-independent surveys in GSV (SST), and 2) the Physical Oceanography Distributed Active Archive Center (PODAAC) website (http://poet.jpl.nasa.gov). Fishery-independent SST data were collected on most large vessels during surveys in GSV conducted between December 2004 and May 2007. SST data were averaged for all vessels, and analyses excluded June 2005. It should be noted that during May surveys SST data were largely collected from south GSV only. Data obtained from PODAAC was satellite SST data in the form of spatial maps of South Australia's gulf regions for the months November, December, March–May between 2004/05 and 2006/07.

Mean SST was significantly different among years ($F_{2,70}$=7.56, P<0.01), with 2006/07 (19.9 ± 0.3 °C) warmer compared to 2004/05 (18.8 ± 0.5 °C) and 2005/06 (18.0 ± 0.4 °C) (Table 3.4). Mean SST differed significantly among months ($F_{4,70}$=22.73, P<0.001), with monthly trends also significantly different among seasons ($F_{6,70}$=4.04, P<0.01). Mean SST during 2006/07 peaked in March (21.5 ± 0.3°C) and remained above 17 °C through to May. Note that during May 2007,

only one vessel provided SST data. During 2004/05, mean SST also remained above 17 °C through to May, which was in contrast to the substantial decrease in mean SST in May during 2005/06 (15.3 ± 0.3°C). Uncertainty in analyses of SST data includes variations among the thermometers used, the method of measurement, and the regional consistency of SST data collected.

Table 3.4 Mean (SE) SST (°C) during surveys conducted in 2004/05, 2005/06 and 2006/07

Year	Nov/Dec	March	April	May	June
2004/05	18.8 (0.5)	20.1 (0.3)	17.7 (1.0)	18.2 (0.4)	16.4 (0.1)
2005/06	17.3 (0.2)	21.1 (0.3)	17.9 (0.3)	15.3 (0.3)	-
2006/07	18.2 (0.2)	21.5 (0.3)	20.4 (0.3)	17.9 (-)	-

Satellite SST maps visually demonstrate temporal and spatial differences in GSV, Investigator Straits (IS) and adjacent waters during the months November, December, March–May since 2004/05 (Figure 3.12). Between November and May, SST in GSV and IS are generally >17°C, with the exception of cooler waters evident during May 2006. SST peaks during the month of March in each year, while 2006/07 was the warmest year with >21°C extending through GSV and IS. During the months December and March, warmer waters are generally observed in the north-eastern part of GSV compared to cooler waters in southern GSV and IS. During the months April and May, warmer waters are generally observed in the middle of GSV.

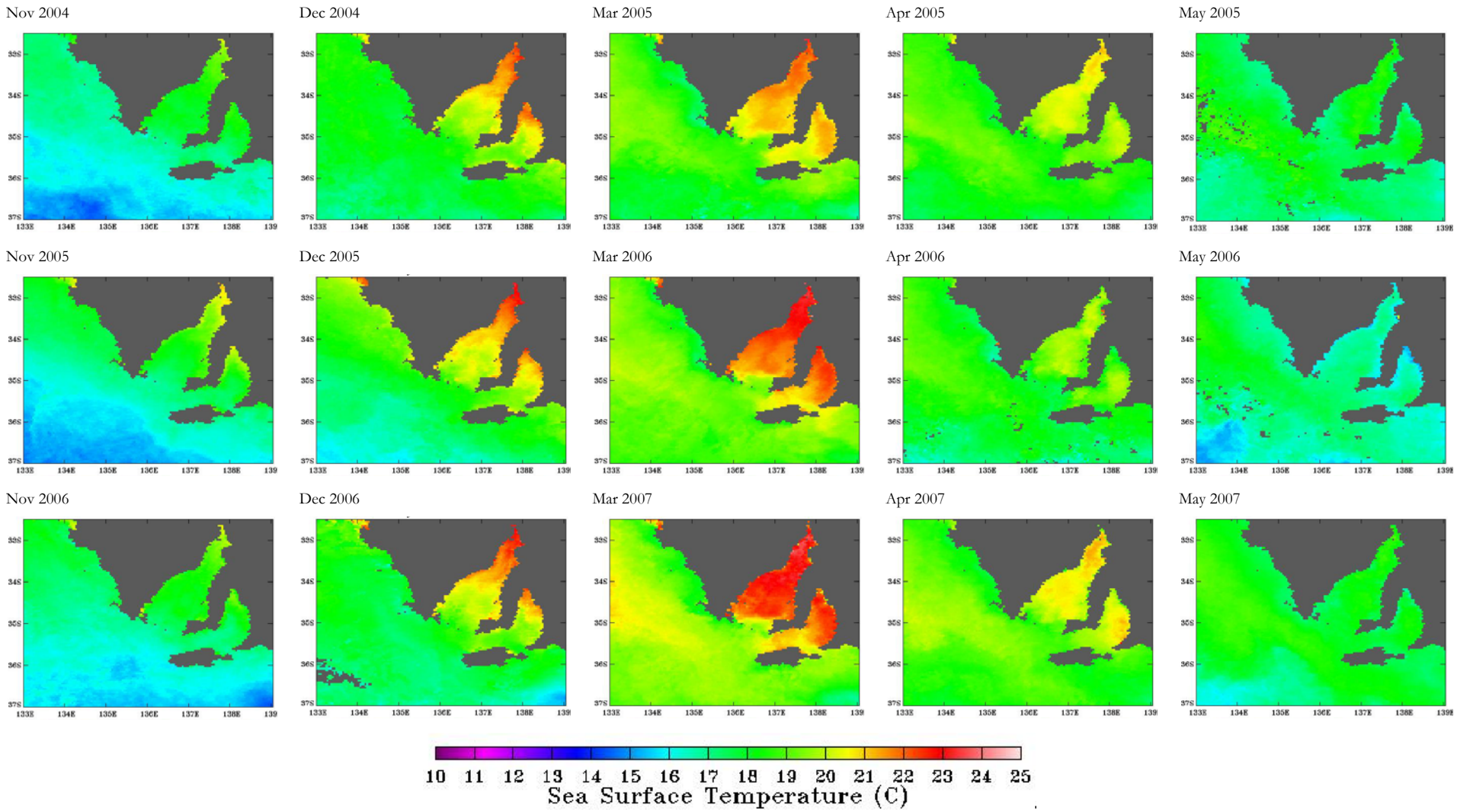

Figure 3.12 Satellite imagery of monthly average SST (°C) for South Australia's gulf regions during November, December and March–May between 2004/05 and 2006/07. Maps were obtained from the PODAAC website (http://poet.jpl.nasa.gov).

3.3 Surveys conducted during May between 2003 and 2007

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

Mean total catch rate (kg/h) from 71 shots surveyed during May 2003–2007 ranged from 43.1 kg/h (2005) to 78.4 kg/h (2007) (Figure 3.13). Mean catch rate was significantly greater in 2007 compared to 2003, 2005 and 2006 ($F_{4,349}$=3.11, P<0.05). Mean prawn size (prawns/kg) was smallest during 2003 (34.5 prawns/kg) and largest during 2004 (30.7 prawns/kg). However, differences in prawn size among years were not statistically significant ($F_{4,332}$=1.25, P>0.05).

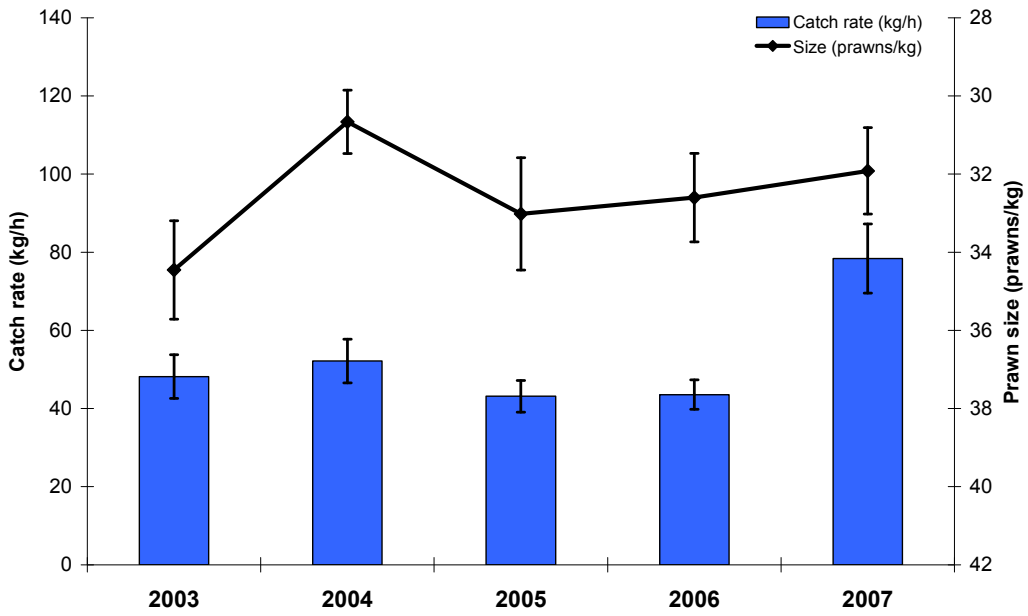

Figure 3.13 Mean (SE) catch rate (kg/h) and mean (SE) prawn size (prawns/kg) from May surveys between 2003 and 2007. Estimates compared from up to 71 trawl shots each year.

3.3.2 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 from up to 56 common shots surveyed during May between 2003 and 2007 significantly varied among years ($F_{4,267}$=3.37, P<0.05) (Figure 3.14). Recruitment increased substantially and consecutively from 2004 (235 recruits/h) to 2007 (650 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).

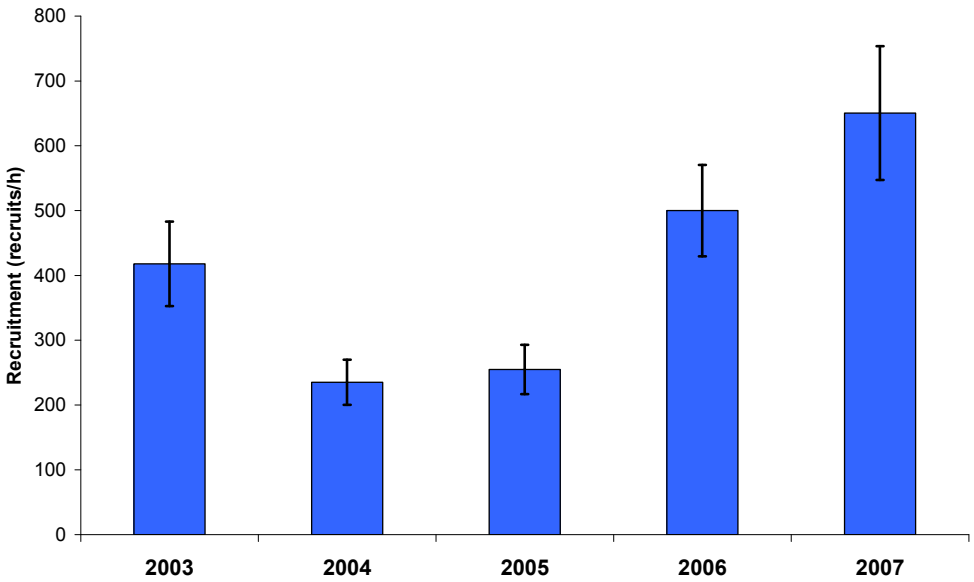

Figure 3.14 Mean (SE) number of recruits per trawl hour from May surveys between 2003 and 2007. Estimates compared from up to 56 trawl shots each year.

3.4 Discussion

Fishery-independent surveys conducted between 2003 and 2007 provide useful data for assessment of the current status of the prawn resource in GSV.

Fishery-independent surveys conducted between 2004/05 and 2006/07 at up to 112 stations (identified in the new Management Plan) provide a robust platform from which to assess spatial and temporal changes in the GSV prawn stock. Currently, data are available for three fishing-years, enabling inter-annual comparisons for each survey month between 2004/05 and 2006/07. Mean survey catch rates have increased each year during March, April and May surveys. In contrast, during December surveys catch rates decreased slightly over the same period. In 2006/07, increases from the previous year were 13% during March, 34% during April, and 76% during May. The large annual increase in catch rate during May 2007 (76%) was likely a combination of an increase in biomass, and a lower catchability of prawns during May 2006 due to cooler water temperatures. Of note, mean annual SST during 2006/07 was warmer (19.9 ± 0.3 °C) compared to both 2004/05 (18.8 ± 0.5 °C) and 2005/06 (18.0 ± 0.4 °C) (Section 3.2.7). While prawn activity (and catchability) is affected by water temperature (Penn *et. al.* 1988), the substantial increases in survey catch rates between 2004/05 and 2006/07 likely reflect an increasing biomass.

Statistical analyses of changes in abundance by size class for each survey period showed that significant increases in abundance were more frequently detected 1) with decreasing size and 2) as the fishing year progressed. This was demonstrated by significant increases in small size prawns in all months and significant increases in all size classes during May. This latter result is particularly important in assessment of the current harvest strategy which aims to target the upper end of the size distribution during March, April and May.

Annual trends in catch rate during December surveys do not follow trends observed in other months, and may be an unreliable indication of the status of the stock at the beginning of the fishing year. Whilst total abundance has generally increased consecutively in each year for each month surveyed between March and May, abundance during December surveys has varied by <4% between years. Further, abundance by size class in December was also highly variable between years. Whilst it is possible that these unexpected results may reflect true abundance, it is more likely that results are influenced by seasonal effects on catchability during the reproductive season. Catchability of female prawns is positively correlated to reproductive activity (Penn 1976; Penn 1980). Also, during peak reproductive activity, prawns aggregate to a greater extent, which would impact on the spatial variability in catch rates between survey shots. It is noteworthy that

both water temperature and reproductive activity during December surveys between 2004/05 and 2006/07 were variable.

Whilst December surveys are pivotal to understanding stock dynamics (particularly reproductive activity) and for harvest strategy development during this critical time of year, these patterns suggest that determination of annual trends in biomass would be best assessed from catch rates during March, April and May surveys only. This also indicates that the current harvest strategy approach of fixed catches during December and varying harvest areas with survey catch rates in all other months is an appropriate framework for determining sustainable annual harvest.

Mean annual recruitment increased substantially between 2004/05 (175 recruits/h) and 2006/07 (~391 recruits/h). The increases were observed each month and in consecutive years. During the last three years recruitment was lowest during December and highest during either March or April. The increases in recruitment, along with continued conservative harvest strategies as outlined in the Management Plan, are conducive to further stock recovery during 2007/08.

Data from May surveys conducted between 2003 and 2007 indicate that total mean catch rate was significantly greater in 2007 compared to 2003, 2005 and 2006. Importantly, the catch rate of recruit sized prawns increased significantly and consecutively from 2004 (235 recruits/h) to 2007 (650 recruits/h). No significant trends in prawn size were observed. There is substantial uncertainty associated with May survey data, which mainly arises from the use of small vessels (see Section 1.5.3). In addition, trends between May surveys can only be compared for 71 common stations surveyed in each year, as opposed to 112 stations for contemporary surveys. May surveys conducted since 2005 were done using the same methods as 2003 and 2004 (i.e. large and small vessels all survey on one night on the dark of the moon). This was done to ensure the collection of a comparable time series of survey data in the formative years of the more robust survey design. Now that several years of these improved data have been collected, standardising the survey methodology in May (i.e. two nights with large vessels) may further reduce the uncertainty in assessment.

Whilst estimates of egg production from December survey catch rates decreased between 2004/05 and 2006/07, there is considerable uncertainty associated with these estimates. Primarily, estimates based on December survey results may not provide estimates of egg production that are reflective of the population at that time. SARDI has recently engaged a PhD student to assess the reproductive dynamics of the western king prawn in South Australia. In addition, an FRDC project has just commenced, which explicitly aims to improve the egg-production model. The outcomes of these projects will enable refinement of the existing model and enhance the certainty of the egg production estimates in the future.

Despite the uncertainty in December survey catch rates and subsequent estimates of egg production, it is highly likely that favourable environmental conditions have contributed substantially to the magnitude of the observed increases in recruitment, particularly during 2006/07. Understanding the dynamics that result in favourable recruitment to the fishery is of significant importance for the ongoing sustainability of the GSVPF, particularly in regard to determining the carrying capacity of the resource.

4. SURVEYS, CATCH AND PRAWN SIZE FOR 2006/07 HARVEST PERIODS

4.1 Introduction

There were four harvest periods for the GSVPF during 2006/07. Each harvest period was preceded by a fishery-independent survey. Survey results were used to develop harvest strategies for the following harvest period. In this report, harvest periods were defined as all fishing activities conducted between surveys.

The following section details fishery-independent and fishery dependent data summarised in eight figures: two for each harvest period. The first figure for each harvest period presents survey information on catch rate and mean size prior to commercial fishing. The second figure for each harvest period presents; 1) commercial catch and mean size data by fishing block (map) and 2) nightly commercial catch per vessel and nightly mean size (graph). Both figures contain the harvest strategy closure lines for the maximum area opened to fishing during the fishing period. Comparison of these figures enables assessment of the effectiveness of the harvest strategy developed, as well as harvest strategy adjustment, particularly with respect to harvested prawn size. Figures are presented alternately as survey results, followed by commercial catch and mean size, sequentially for each harvest period.

Fishery-independent surveys were conducted during December 2006 and March to May 2007 (see Section 3). Data on catch rate and mean sizes are presented for each station surveyed prior to each harvest period. The start and end dates of the survey and the number of nights surveyed, are also presented.

Fishery-dependent data on mean size were determined from commercial logbooks (see Section 2.5). Only nine of ten licence holders agreed to provide access to confidential catch and effort information. Confidential data are defined as blocks where less than 5 fishers provided catch and effort information. For the 2006/07 fishing year, all catch by block data was non-confidential, and is thus presented in its entirety. However, prawn size data by block was confidential in some cases, which meant that calculations for mean size in those blocks excluded data for one vessel. The start and end dates of the harvest period and the number of nights fished are also presented. Please note that commercial catch and size data are presented on occasion for blocks that appear outside the harvest strategy region. This has likely resulted from: 1) minor discrepancies between the GPS systems used at sea and the software used to present these data, and/or 2) misreporting of blocks by fishers.

Accompanying the maps of commercial catch and mean prawn size by fishing block for each harvest period are graphs of nightly catch and prawn size for the purpose of assessing harvest strategy adjustment. Both nightly catch and prawn size are used as 'at-sea' decision rules for harvest strategy adjustment during commercial fishing, while mean prawn size is also used for harvest strategy development and is a Performance Indicator, as outlined in the Management Plan (Dixon & Sloan, 2007). Decision rules for harvest period 1 are: 1) a maximum total catch of 30 t, 2) minimum average catch per vessel night of 350 kg over 2 consecutive nights and 3) target prawn size of 27–33 prawns/kg. Decision rules for harvest periods 2–4 are: 1) minimum average catch per vessel night of 450 kg over 2 consecutive nights, and 2) target prawn size of <28 prawns/kg. The minimum average catch per vessel night is a decision rule to end fishing in that block.

All results in the following section are discussed in terms of the regions defined in Figure 3.1. In the following section, catch rates <2 lb/min are referred to as "low", 2–4 lb/min as "medium", and >4 lb/min as "high". Also, mean size <26 prawns per kg are referred to as "extra-large", 26-28 prawns per kg as "large", 28–33 prawns per kg as "medium" and >33 prawns per kg as "small". Note that for the first harvest period, large and medium prawns were of the ranges <27 and 27–33 prawns per kg, respectively. Commercial catches are reported in ranges that vary with respect to the total catch for that period, with the upper range of each "high" category being just greater than the highest catch per block for that period.

While this section is structured to provide useful assessment of the effectiveness of harvest strategy development, as well as adjustment during the harvest period, particularly with respect to harvested prawn size, it should be noted that the new Management Plan (Dixon & Sloan, 2007) was not implemented until after the 2006/07 fishing year (September 2007). As such, management responses would not be required for the following assessment. This section aims to assess the effectiveness of harvest strategies, and identify ways to improve and refine harvest strategies where appropriate.

4.2 Survey and Catch Data by Harvest Period

4.2.1 Harvest Period 1

During the December stock assessment survey, data were available for 105 stations. High catch rates were observed for 5 stations while medium catch rates were observed for 15 stations (Figure 4.1). Small prawns were observed for 33 stations generally scattered throughout northern GSV and IS. Large size prawns (41 stations) were generally aggregated throughout the mid gulf regions (Regions 3, 4 and Deep Hole) and extending up the Eastern side of GSV (Regions 5 and 6). One fishing area was opened for fishing encompassing 6 surveyed stations of medium to large size prawns ranging from low to high catch rates.

During harvest period 1, 26.5 t of prawns was commercially harvested (excluding survey) during 4 fishing nights. Catches were harvested from 7 fishing blocks, 3 of which the commercial catch was < 1 t (Figure 4.2, map). Commercial catches > 5t were harvested from 2 fishing blocks, both with medium size prawns harvested. Harvested prawn size by block for the period was within or greater than target size (medium to large size prawns).

'At sea' decision rules for both nightly catch and mean prawn size during harvest period 1 were generally not breached during fishing, the exception being during the first fishing night when mean harvested prawn size (26.9 prawns/kg) exceeded the target size (Figure 4.2, graph). No adjustment to the harvest strategy during period 1 was made.

4.2.2 Harvest Period 2

During the March stock assessment survey, data were available for 108 stations. High catch rates were observed for 16 stations while medium catch rates were observed for 35 stations (Figure 4.3). Small prawns were observed for 39 stations generally scattered throughout GSV. Extra-large and large size prawns were also observed throughout the gulf, although at low-medium catch rates. Three fishing areas were opened for fishing. Area 1 (Region 2) encompassed 5 surveyed stations, 4 of which were observed to have extra-large and large prawns at low to medium catch rates, while 1 station was observed to have medium size prawns (28 prawns/kg) at a high catch rate. Of note, stations immediately adjacent to this area were observed to have small to medium size prawns at medium to high catch rates. Area 2 was a large area of western IS encompassing 12 surveyed stations observed to have medium to extra-large size prawns, with most stations having low to medium catch rates. Of note, 1 station was observed with a high catch rate, but of medium size prawns (29 prawns/kg), while stations immediately adjacent to this area included 3 stations with medium catch rates of medium size prawns. Area 3 included 2 surveyed stations on the eastern side of GSV, both of which were observed to have medium catch rates of extra-large

size prawns. Of note, stations immediately adjacent to this area were observed to have small to medium size prawns at low to high catch rates.

During harvest period 2, 51.5 t of prawns was commercially harvested (excluding survey) during 9 fishing nights. Catches were harvested from 25 fishing blocks, 16 of which the commercial catch was < 1 t (Figure 4.4, map). Commercial catches > 5 t were harvested from 2 fishing blocks, both with medium size prawns harvested. Harvested prawn size by block for the period ranged from small to large size prawns, and did not reflect prawn sizes observed during survey. Of note, medium size prawns were harvested from 2 fishing blocks that were observed to have large catch rates of medium size prawns. It is noteworthy that: 1) all stations observed during survey with extra-large and large size prawns, and included in harvest areas, were of low to medium catch rates, and 2) all 3 harvest areas had stations immediately adjacent with generally small to medium size prawns at medium to high catch rates.

The 'At sea' decision rule for minimum average catch per vessel night is a decision rule to end fishing, and was not breached during harvest period 2. However, the decision rule for prawn size was breached during each of 9 fishing nights, which required implementation of harvest strategy adjustments (Figure 4.4, graph). The first harvest strategy adjustment was made on fishing night 5 (change of area), while further adjustments were made on fishing night 7 (amendment to area) and 9 (change of area). None of these harvest strategy adjustments resulted in a nightly target prawn size being achieved.

4.2.3 Harvest Period 3

During the April stock assessment survey, data were available for 110 stations. High catch rates were observed for 19 stations while medium catch rates were observed for 39 stations (Figure 4.5). Small prawns were observed for 40 stations generally aggregated through the mid-gulf (LH, DH, SDH) and south-eastern Investigator Strait and eastern Region 4. Extra-large and large size prawns were observed throughout northern GSV extending into Region 3 and western Investigator Strait. Two fishing areas were opened for fishing. Area 1 (Regions 5&6) encompassed 6 surveyed stations observed to have extra-large to large size prawns at low to high catch rates. One station was observed to have a high catch rate of large prawns, although immediately adjacent to this, and outside the harvest area, was 3 stations observed to have medium to high catch rates of medium size prawns. Area 2 encompassed 5 surveyed stations, all observed to have extra-large prawns, 3 of which had high catch rates.

During harvest period 3, 86.0 t of prawns was commercially harvested (excluding survey) during 9 fishing nights. Catches were harvested from 13 fishing blocks, 6 of which the commercial catch was < 1 t (Figure 4.6, map). Commercial catches > 5 t were harvested from 3 fishing blocks, with mean prawn size harvested ranging from medium to extra-large size prawns. Harvested prawn

size by block for the period ranged from medium to extra-large size prawns. Commercial catches in harvest area 2 were within target size, while catches from harvest area 1 included 3 fishing blocks with medium size prawns. Again note that immediately adjacent to this area were 3 stations observed to have medium to high catch rates of medium size prawns.

The 'At sea' decision rule for minimum average catch per vessel night was not breached during harvest period 3. However, the decision rule for prawn size was breached during 5 of 9 fishing nights, which all occurred in harvest area 1, and necessitates harvest strategy adjustment (Figure 4.6, graph). The first harvest strategy adjustment was made on fishing night 3 (change of area), when the fleet were moved from harvest area 1 to harvest area 2. During 4-nights fishing in area 2, mean nightly prawn size was subsequently within target range. However, the fleet then moved back to harvest area 1, resulting in mean nightly prawn size below target range during the last 3 fishing nights.

4.2.4 Harvest Period 4

During the May stock assessment survey, data were available for 112 stations. High catch rates were observed for 34 stations while medium catch rates were observed for 23 stations (Figure 4.7). Small prawns were observed for 33 stations generally aggregated through the mid-gulf, south-eastern Investigator Strait and eastern Region 4. Extra-large and large size prawns were observed throughout northern GSV extending into Region 3. Two fishing areas were opened for fishing. Area 1 (Regions 2) encompassed 2 surveyed stations observed to have extra-large size prawns at high catch rates. Stations immediately adjacent this area included 3 stations observed with high catch rates of extra-large and large size prawns, as well as 2 stations with medium to high catch rates of small to medium size prawns. Area 2 encompassed 4 surveyed stations with high catches rates of extra-large size prawns.

During harvest period 4, 45.3 t of prawns was commercially harvested (excluding spot and stock assessment surveys) during 3 fishing nights. Catches were harvested from 5 fishing blocks, all of which the commercial catch was > 1t (Figure 4.8, map). Commercial catches > 5t were harvested from 1 fishing block, with harvested prawns being of extra-large size. Commercial catches in harvest area 2 were within target size, while catches from harvest area 1 included 3 fishing blocks with medium size prawns.

The 'At sea' decision rules for minimum average catch per vessel night was not breached during harvest period 4. The decision rule for mean nightly prawn size was breached on the first of 3 fishing nights (Figure 4.8, graph). In response to this, harvest strategy adjustment was made on the second fishing night (change of area), resulting in target size prawns being harvested during the last 2 nights of fishing.

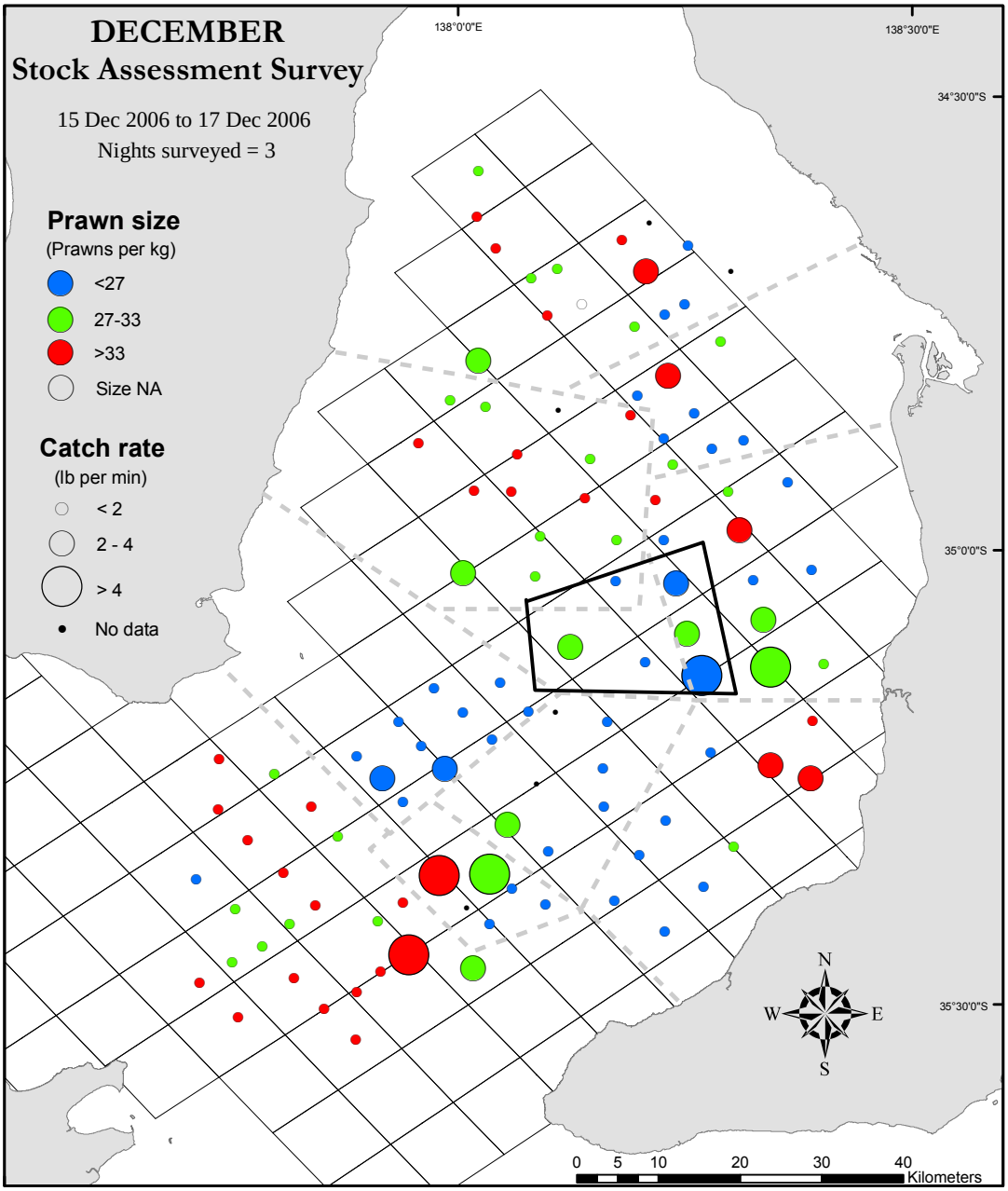

Figure 4.1 Catch rate and mean size during the December 2006 Stock Assessment survey, prior to harvest period 1. The polygon (black line) represents the maximum area opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented.

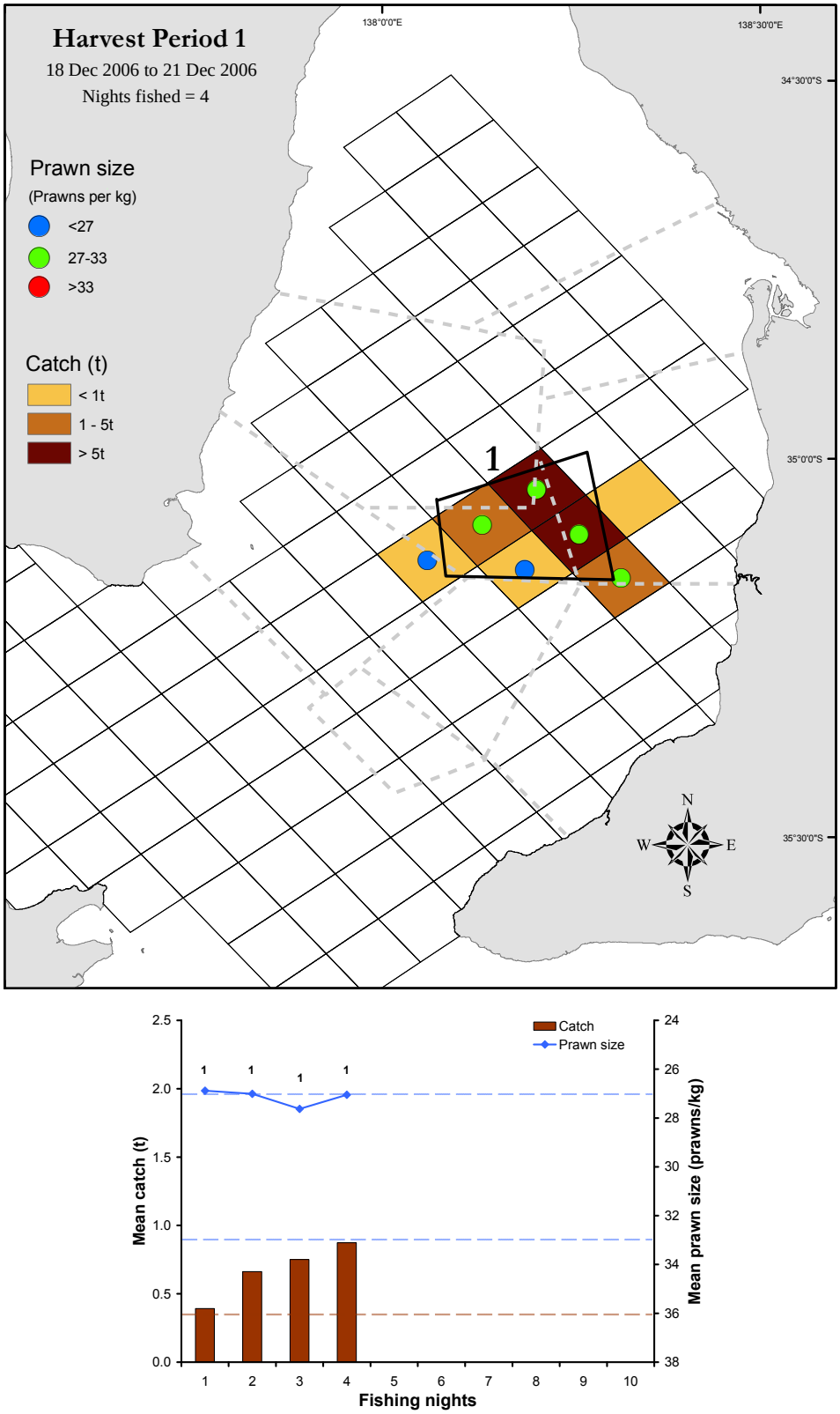

Figure 4.2 Map: Commercial catch (t) and prawn size (prawns/kg) from fishing blocks fished during harvest period 1. The polygon (black line) represents the maximum area opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented. **Graph:** Mean nightly commercial catch (t) per vessel and mean prawn size (prawns/kg) during harvest period 1. Orange dashed line represents the minimum nightly catch per vessel (350 kg), while the blue dashed lines represent target size range (27–33 prawns/kg) for harvest period 1 (Dixon & Sloan, 2007). Numbers indicate harvest strategy area's that were fished.

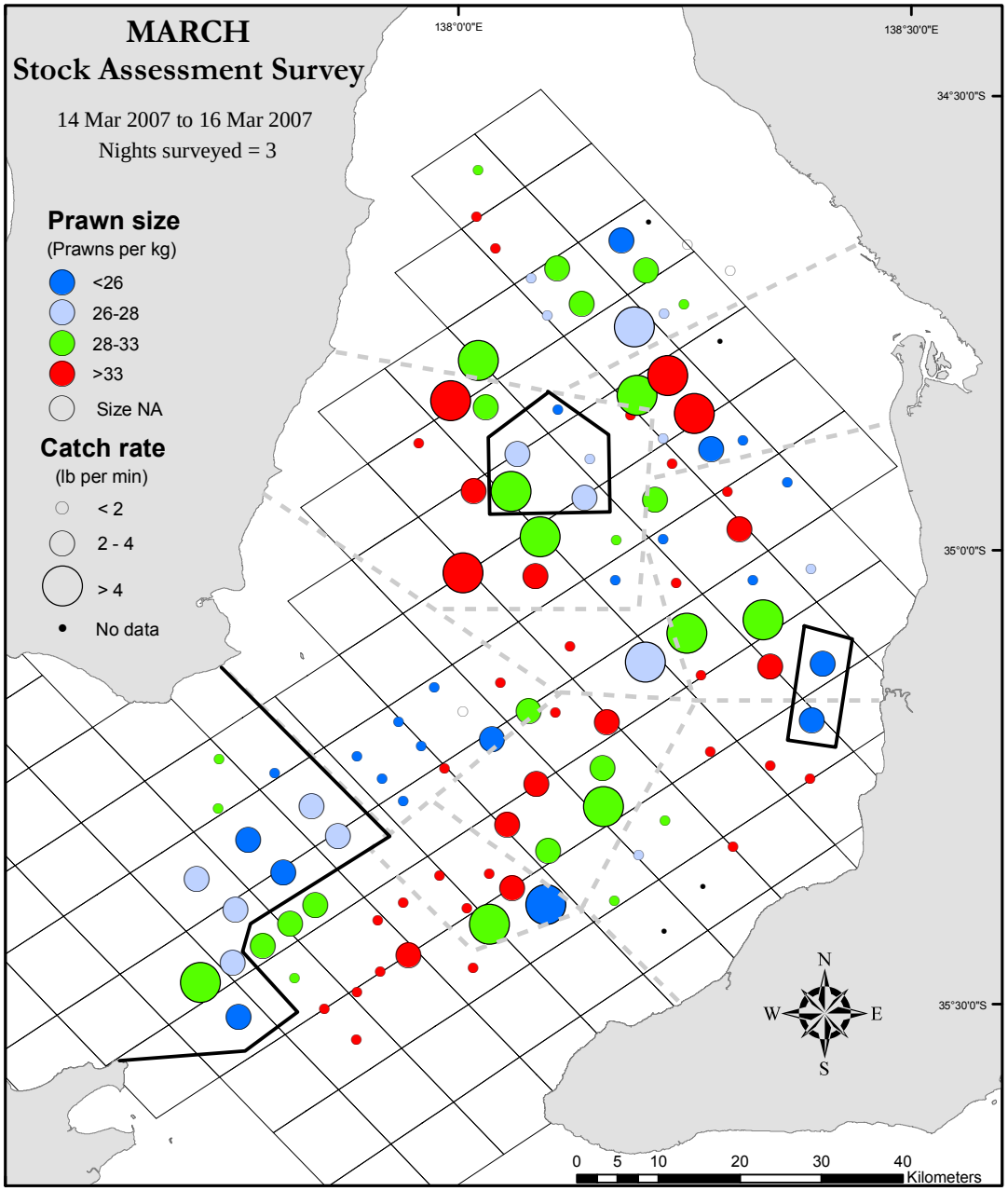

Figure 4.3 Catch rate and mean size during the March 2007 Stock Assessment survey, prior to harvest period 2. Polygons (black line) and west of the black line in the Investigator Strait represents the maximum areas opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented.

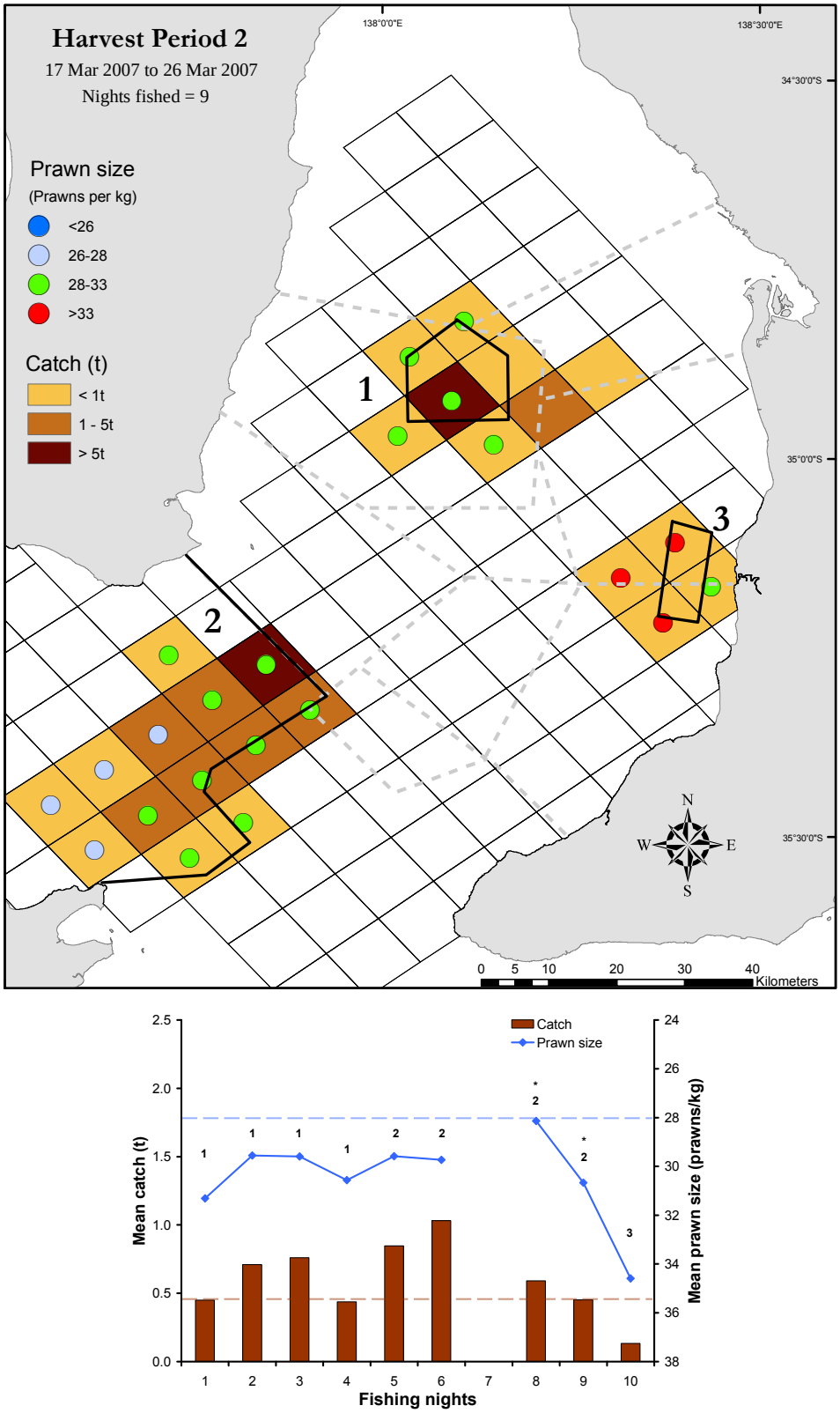

Figure 4.4 Map: Commercial catch (t) and prawn size (prawns/kg) by fishing blocks fished during harvest period 2. Numbered polygons (black line) and west of the black line in the Investigator Strait represents the maximum areas opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented. **Graph:** Mean nightly commercial catch (t) per vessel and mean prawn size (prawns/kg) during harvest period 2. Orange dashed line represents the minimum nightly catch per vessel (450 kg), while the blue dashed line represents target size (<28 prawns/kg) for harvest periods 2-4 (Dixon & Sloan, 2007). Numbers indicate harvest strategy area's that were fished, while an asterisk indicates that an amendment was made to a harvest strategy area.

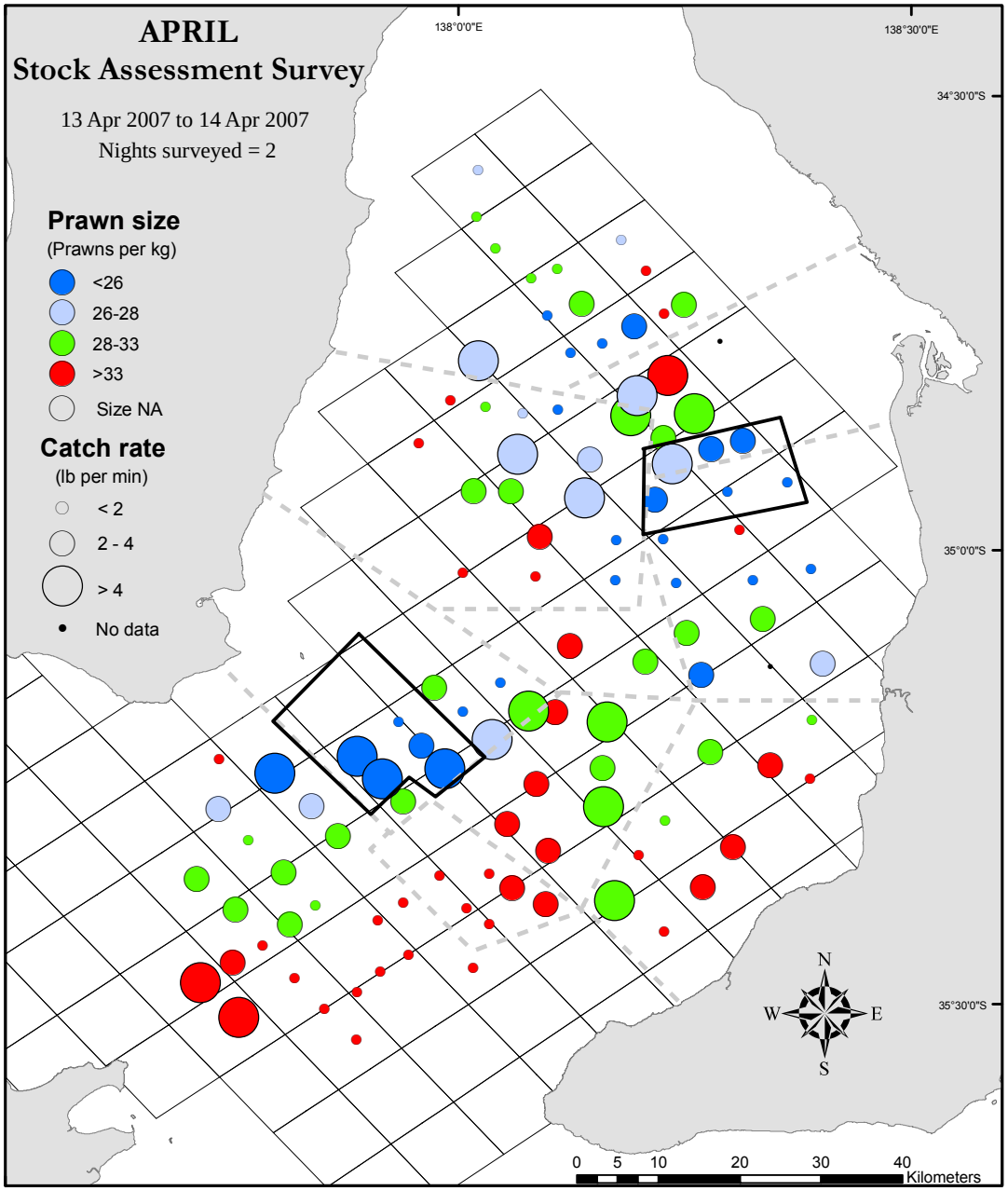

Figure 4.5 Catch rate and mean size during the April 2007 Stock Assessment survey, prior to harvest period 3. Polygons (black line) represent the maximum areas opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented.

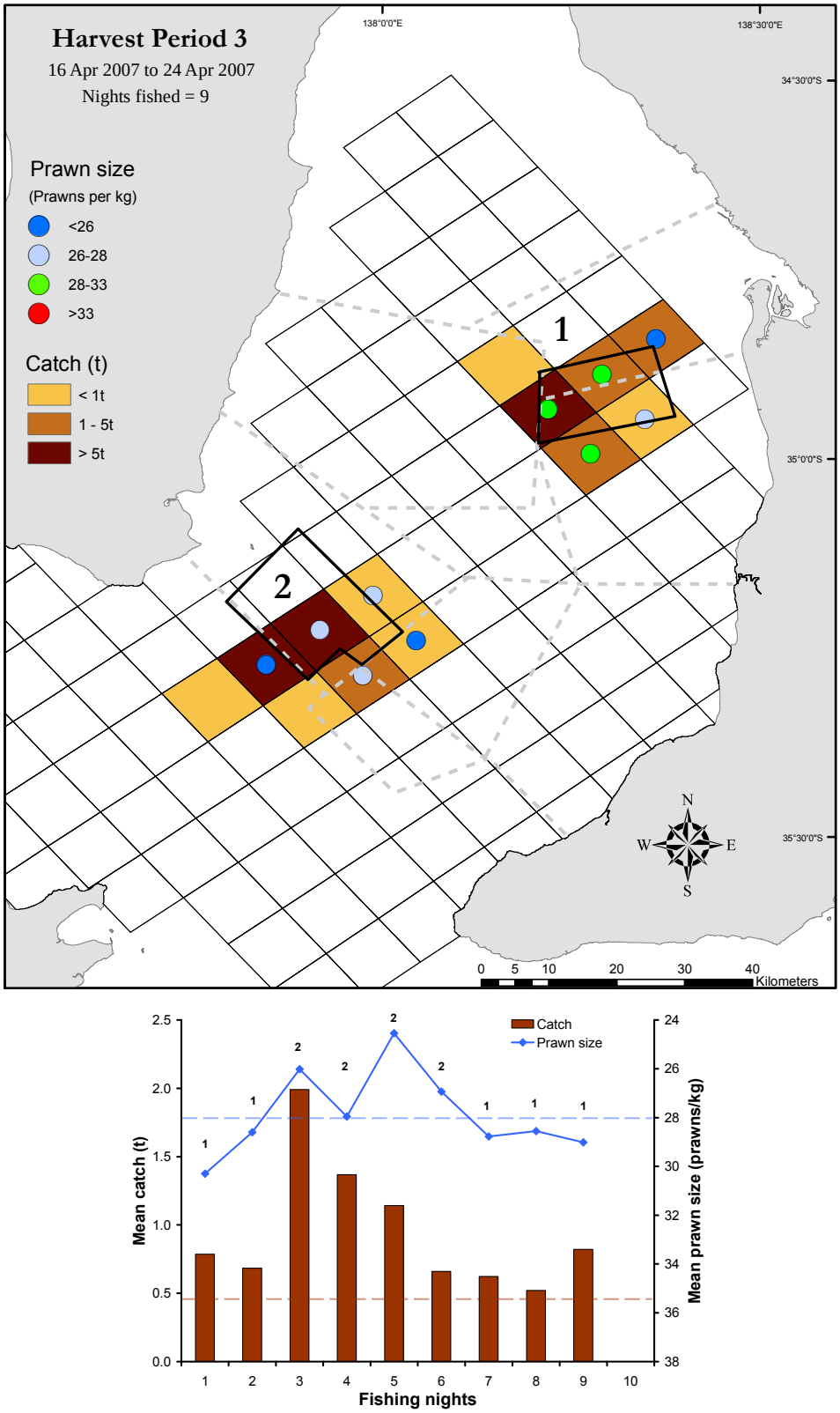

Figure 4.6 Map: Commercial catch (t) and prawn size (prawns/kg) from fishing blocks fished during harvest period 3. Polygons (black line) represent the maximum areas opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented. **Graph:** Mean nightly commercial catch (t) per vessel and mean prawn size (prawns/kg) during harvest period 3. Orange dashed line represents the minimum nightly catch per vessel (450 kg), while the blue dashed line represents target size (<28 prawns/kg) for harvest periods 2-4 (Dixon & Sloan, 2007). Numbers indicate harvest strategy area's that were fished.

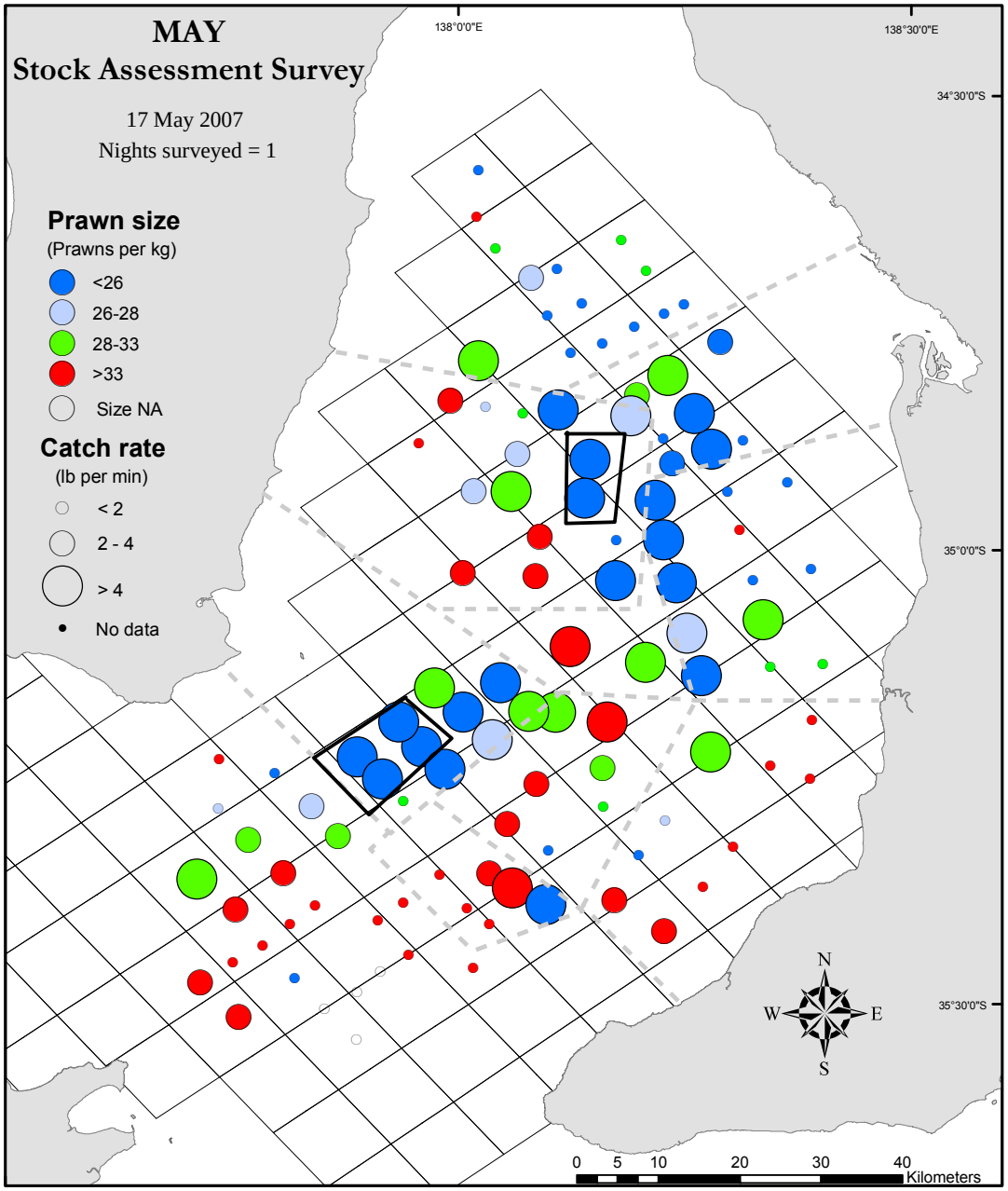

Figure 4.7 Catch rate and mean size during the May 2007 Stock Assessment survey, prior to harvest period 4. Polygons (black line) represent the maximum areas opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented.

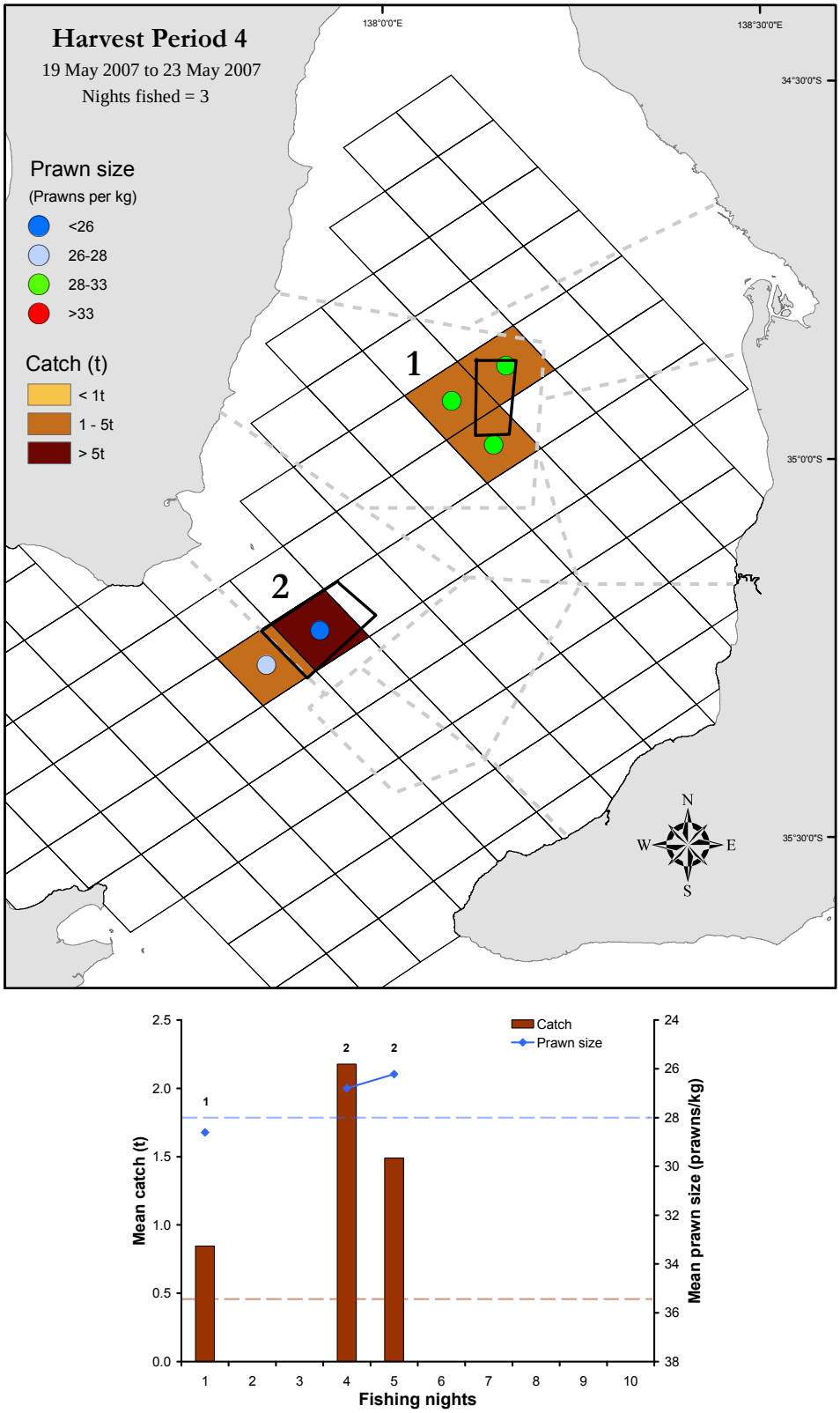

Figure 4.8 Map: Commercial catch (t) and prawn size (prawns/kg) from fishing blocks fished during harvest period 4. Polygons (black line) represent the maximum areas opened to fishing. Commercial fishing blocks (grid squares) and survey regions (pale dotted lines) are also presented. **Graph:** Mean nightly commercial catch (t) per vessel and mean prawn size (prawns/kg) during harvest period 4. Orange dashed line represents the minimum nightly catch per vessel (450 kg), while the blue dashed line represents target size (<28 prawns/kg) for harvest periods 2-4 (Dixon & Sloan, 2007). Numbers indicate harvest strategy area's that were fished.

4.3 Discussion

During harvest period 1, approximately 13% (26.5 t) of the 2006/07 commercial catch (~209 t, excluding surveys) was harvested during four nights of fishing. The magnitude of catch during the harvest period generally reflected observed catch rates during survey. Harvested prawn size was within or greater than target prawn size (27–33 prawns/kg). Commercial nightly catches generally did not breach 'at sea' decision rules for catch and mean harvested prawns size.

During harvest period 2, approximately 25% (51.5 t) of the 2006/07 commercial catch was harvested from nine nights of fishing. The magnitude of catch during the harvest period generally reflected observed catch rates during survey. However, harvested prawn size on the scale of fishing block was smaller than target prawn size (< 28 prawns/kg) for most blocks, and did not generally reflect prawn sizes observed during survey. This was likely attributed to the harvest strategy including: 1) harvest areas with stations observed to have extra-large and large size prawns at low-medium catch rates only, 2) harvest areas with stations observed to have medium size prawns at high catch rates, and 3) all harvest area's with stations immediately adjacent observed to have small-medium size prawns at medium-high catch rates. These lead to greater discrepancies in prawn size between survey and fishing, while prawn movement into harvest areas may also have been greater. Note that for this fishing period, harvest strategy development was limited by the absence of aggregations of stations observed with extra-large or large prawns at high catch rates. Consequently, harvest strategy adjustments during commercial fishing were also limited. Three harvest strategy adjustments were made, which were ineffective at avoiding small prawns. However, it took up to 4-fishing nights harvesting small prawns before the first change to the original harvest strategy was made. Subsequently, each of nine fishing nights resulted in the harvesting of prawns smaller than target size.

During harvest period 3 and 4, approximately 41% (86.0 t) and 22% (45.3 t) of the 2006/07 commercial catch was harvested during nine and three fishing nights, respectively. The magnitude of catch during both harvest periods generally reflected observed catch rates during survey. During both periods, harvested prawn size on the scale of fishing block was within target size in the southern harvest areas, while harvested prawn size was smaller than that observed during surveys in the northern harvest areas. While extra-large to large size prawns at generally medium-high catch rates were included in northern harvest areas, it is noteworthy that stations immediately adjacent were observed to have small-medium size prawns at medium-high catch rates. Harvest strategy adjustments were made during both harvest periods in response to nightly catches of prawns smaller than target size, with most subsequent fishing nights being within target size. Of note, during harvest period 3, a second adjustment to the harvest strategy moved

the fleet from area 2 with catches of target size prawns back to harvest area 1, resulting in mean nightly prawn size below target range during the last 3 fishing nights.

Harvest strategies are developed and refined at three main levels. Firstly, and most importantly, harvest strategies are underpinned by data collected during stock assessment surveys prior to each harvest period, and are developed to allow the harvest of prawns within a sustainable level of exploitation (December <30 t, March–May <18% survey biomass; Dixon & Sloan, 2007). Secondly, harvest strategy areas are identified to include target size prawns. More than one harvest area can be identified. Thirdly, harvest strategies that have been identified can be adjusted during fishing in accordance with 'at sea' decision rules that aim to avoid non-target size prawns and low nightly catches. While harvest strategies for each harvest period were developed within strict exploitation levels in 2006/07, the harvest areas identified in terms of target prawn sizes and the adjustments made to refine target catches can be assessed for the purpose of improving and better refining strategies in the future.

Harvest strategy development was assessed for each harvest period by comparing survey and commercial catch data on a spatial level (maps). During each harvest period, the magnitude of the commercial catch reflected catch rate results observed during surveys. In general, mean harvested prawn size reflected that observed during surveys when catch rates were high. However, this did not hold true when harvest areas included a majority of stations with low-medium catch rates of target prawns, or when stations immediately adjacent to harvest areas were observed to have small-medium size prawns at medium-high catch rates. This was particularly the case during harvest period 2, when in addition, harvest areas included stations observed to have medium size prawns (although near target) at high catch rates. Harvest strategy development could be improved in the future if these factors were considered during decision making.

Harvest strategy adjustment was assessed for each period by analysing commercial catch data on a temporal level (graphs). Adjustments to harvest strategies can be made by either moving the fleet to an alternate harvest area, or by amending an area with the use of 'buffer' lines. Adjustments were implemented during periods when nightly mean harvested prawn size was smaller than target size. During harvest periods 3 and 4 they were effective at increasing size to within target range. However, adjustments were not effective during harvest period 2, which could be attributed to 1) limitations in prawn size within the initial harvest strategy developed, and 2) a slow response at implementing adjustments. During harvest period 2, prawn sizes within GSV were well mixed due to the influx of recruits throughout the fishery. Subsequently, harvest strategy development was impeded by the absence of aggregations of stations observed with extra-large or large prawns at high catch rates, while stations with small size prawns were scattered throughout the gulf. However, in addition to these limitations, the first adjustment was

not made until after 4 nights of harvesting prawns below target size. While adjustments are effective when there is scope in terms of prawn sizes in the original harvest strategy developed, there is room for improving harvest strategy adjustments in the future. Harvest strategy adjustments can be improved by 1) being more responsive to mean harvested prawn size, and 2) greater use of buffer lines to avoid non-target prawns within harvest areas. Scope for implementing improvements to harvest strategies is discussed further in the General Discussion.

Uncertainty associated with the calculation of prawn size data arises from: the number of vessels from which data were available (5 of 10); assumptions regarding the calculation of mean prawn size, and; uncertainty associated with the unvalidated grade data provided in commercial logbooks. Also, note that commercial logbook data are provided per night, whereas catch data are provided per shot. Thus, where two or more fishing blocks are fished in one night, mean prawn size is assumed as equal among fished blocks.

Here, assessment of at-sea harvest strategy decision making is determined from data collected in commercial logbooks. The correlation between bucket count data used to determine at-sea decision rules and the commercial grade data presented here is unknown. Future assessments of at-sea decision rules would be substantially augmented by the collection of data on bucket counts used to assess against at-sea decision rules.

5. PERFORMANCE INDICATORS

In this section, performance of the fishery is assessed against the Performance Indicators (PIs) identified in the new Management Plan (Dixon and Sloan 2007). The Plan provides a set of key PIs (Table 5.1) that, if breached, evoke a management response. That response includes a comprehensive assessment of additional performance measures (Table 5.2). However, it should be noted that the new Management Plan was implemented in September 2007, and as such, management responses would not be required for the following assessment of the 2005/06 and 2006/07 fishing years.

Table 5.1 Summary of Performance Indicators (PI) and Limit Reference Points (LRP) for the 2005/06 and 2006/07 fishing years of the Gulf St Vincent Prawn Fishery (Dixon and Sloan 2007). Shaded cell indicates PI triggered.

PI	LRP	'05/'06	'06/'07
Recruitment index (May: recr/h)	>250	334	480
Total commercial catch (t)*	Increasing each year of Plan	175	209
Mean commercial CPUE (kg/h)*	Increasing each year of Plan	76.5	93.7
Mean prawn size	Within target criteria each harvest period	yes	no
Fishery independent surveys	4 surveys completed	yes	yes
Indices of current biomass	Decreases in 2 consecutive surveys	no	no
Indices of future biomass	Falls below limits in 2 consecutive surveys	no	no

* Total commercial catch and CPUE do not include survey catch

5.1 Recruitment index

Recruitment index is calculated as the mean number of juvenile prawns (males <33 and females <35 mm carapace length) captured per trawl hour from all shots surveyed during May. Length-frequency data were available for 107 and 102 survey shots during May 2005/06 and May 2006/07, respectively.

The recruitment indices of 334 and 480 during 2005/06 and 2006/07 were well above the Limit Reference Point (250 rec/h).

5.2 Total commercial catch

Total commercial catch during 2006/07 (209 t) represented a 20% increase from 2005/06 (175 t). The Limit Reference Point requires an increase in total commercial catch each year of the Management Plan.

5.3 Mean commercial CPUE

Mean commercial CPUE was higher during 2006/07 (93.7 kg/h) than 2005/06 (76.5 kg/h). The Limit Reference Point requires an increase in mean commercial CPUE each year of the Management Plan.

5.4 Mean prawn size

The mean size of prawns harvested for each vessel night was calculated from commercial logbook prawn grade data. Grade data was reported from March to December 2006 from five of ten vessels, and for six of ten vessels from March to May 2007. During the pre-Christmas (December) and March-May harvest periods, prawn size is targeted at 27–33 and <28 prawns/kg respectively.

During 2005/06, mean harvested prawn size was within the target prawn size during each harvested period, being 26.0, 26.2 and 26.7 prawns/kg for the March, April and May periods respectively.

During 2006/07 mean harvested prawn size was within the target prawn size during the December (27.2 prawns/kg), April (27.5 prawns/kg) and May (26.9 prawns/kg) harvest periods. During the March fishing period (29.9 prawns/kg) harvested mean prawn size was smaller than the target size for this period. Subsequently, the PI for prawn size was triggered during 2006/07.

5.5 Fishery independent surveys

A minimum of four fishery independent surveys were conducted during 2005/06 and 2006/07.

5.6 Indices of current biomass

The current biomass index is calculated as the mean total catch rate for each survey conducted in December, March, April and May. Indices of current biomass are an integral component of harvest strategy development in the Management Plan, as they affect the proportion of the stock that can be accessed during the March, April and May harvest periods. They also determine the

extent of change in biomass, defined as the % difference in catch rate between years. Stock recovery is considered to be achieved for each period if the current biomass index is greater than that obtained during the same month the previous year. Failure to achieve stock recovery for two consecutive harvest strategies will trigger the PI for this measure.

Whilst the index of current biomass (mean catch rate) slightly decreased between December 2005 and 2006, it increased between years for subsequent surveys in March, April and May 2007. Therefore, the PI for indices of current biomass during 2006/07 was not triggered.

5.7 Indices of future biomass

The future biomass index is calculated as the mean catch rate of 21+ grade prawns for each survey conducted in March, April and May. In the Management Plan, the index of future biomass also affects the proportion of the stock that can be accessed during these harvest periods.

Mean catch rate of 21+ size prawns was above the reference level for March, April and May during 2006/07. As such, the PI for indices of future biomass during 2006/07 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 2005/06 and 2006/07 fishing years of the Gulf St Vincent Prawn Fishery (Dixon and Sloan 2007).

Performance Measure	LRP	'05/'06	'06/'07
Recruit index December survey all shots	>100	76	153
Recruit index March survey all shots	>200	392	368
Recruit index April survey all shots	>250	335	580
Egg production (eggs$\times 10^6$/h trawled)	>500	535	423
% of >U10 in the survey catch – March to June	>25%	37	33
% of 21+ in the catch – Dec	<7%	NA	5.0
% of 21+ in the catch – March to June	<5%	4.6	4.7

N/A: Data not available

Recruitment index was determined for December, March and April from all survey shots conducted during 2005/06 and 2006/07. Where length frequency data were not available, estimates of the proportion of recruits within the catch were determined from mean prawn size data. This assumption is unlikely to adversely influence overall estimates as the proportion of shots with no length frequency data was low and were usually from shots with very low catch.

Recruitment indices from all stations across GSV during December were less than the Limit Reference Point in 2005/06, although above the Limit Reference Point in 2006/07. During March and April, recruitment indices were above the Limit Reference Point in both fishing years, with recruitment during April substantially greater in 2006/07 compared to 2005/06.

Egg production estimates are determined from the model presented in Section 3.2.6. Egg production was below the Limit Reference Point in 2006/07, and was lower than that estimated for 2005/06. It should be noted that modifications to the model have been made since the Limit Reference Point was established for the new Management Plan (which used 2004/05 data from Dixon *et. al.* 2006), which has been applied to the annual series of data, resulting in different outputs, although with the same trends between years. Therefore, the Limit Reference Point for egg production should use a reference year (ie. 2004/05) with a Limit Reference Point of % change instead of a quantitative number. This amendment to the Management Plan may need to be considered in the future.

Data on prawn grades from the commercial catch were only available for March to May during 2005/06, and available for all months during 2006/07. The proportion of prawns in both >U10 and <21+ prawn size grade categories were within acceptable limits.

5.9 Discussion

During 2006/07, PI's for recruitment, commercial catch and CPUE, conduct of fishery-independent surveys and indices of current and future biomass were all within acceptable levels. However, the PI for mean prawn size harvested was triggered for 2006/07. This was a result of mean harvested prawn size during the March fishing period (29.9 prawns/kg) being smaller than the target size of <28 prawns/kg. Mean harvested prawn size during the remaining fishing periods were all within target size.

Additional performance measures for recruitment and the proportion of prawns harvested within various commercial grades were within acceptable limits during 2006/07. However the additional performance measure for egg production during 2006/07 was below the Limit Reference Point.

Assessment of the key PI and additional performance measures identified some issues that require further consideration for future management and assessment. In particular, the harvest of prawns below target size during the March fishing period. At this time of year: mean prawn size of the population is at its smallest, as recruitment is at or close to its peak, while recruits are distributed throughout the fishery reducing aggregations of survey stations observed with target size prawns. These factors impede harvest strategy development and subsequent commercial

catches in terms of target prawn size. Nevertheless, some suggestions and recommendations for harvest strategy development and adjustment in the future to avoid the harvest of non-target prawns, particularly during fishing periods of small and mixed size prawns, are discussed in section 4.3 and the General Discussion (Section 6).

Refinement of the measure for egg production is also needed for future assessment. Currently, the Limit Reference Point for egg production is determined as a fixed value. As the model for egg production has been only recently developed and the outputs are likely to vary in the future, a more appropriate approach may be to use a Limit Reference Point of % change to a reference year (e.g. 2004/05).

Further, there is a need to collect information on the fishing power of the fleet. These data are critical for interpreting changes in CPUE data that underpin the PI for mean commercial CPUE and for indices of current and future biomass.

6. DISCUSSION

6.1 Assessment of the GSVPF

Fishery assessments for the GSVPF aim to determine the status of the western king prawn resource in GSV and include evaluation against the Performance Indicators defined in the Management Plan. Assessments of the fishery have been regularly conducted since 1997 (Kangas and Jackson 1997; 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). In addition, the first stock status report for the GSVPF (Roberts *et al.* 2007b) provided a brief end-of-year update for 2006/07.

The previous stock assessment report for the GSVPF (Roberts *et al.* 2007a) suggested that the biomass upon which the fishery is based had shown signs of modest stock recovery since the lowest commercial CPUE observed in 2002/03. Since that report was published, the Management Plan for the fishery has been updated (Dixon & Sloan, 2007). The primary aim of the Plan is to promote stock recovery over the next five years.

This report aims to assess the status of the resource in the context of stock recovery. This is primarily achieved through analysis of data obtained from spatially consistent, fishery-independent surveys conducted regularly since 2003. This report also aims to provide a critical assessment of the harvest strategies developed during 2006/07 to achieve stock recovery.

6.2 Information available for assessment of the GSVPF

There are substantial data available for assessment of the GSVPF. Data are available from; 1) commercial catch and effort, 2) fishery-independent surveys and 3) commercial length-frequency from fishery-independent observing. Data from these sources provide a useful insight into the current status of the fishery.

Annual catch and effort information is available since 1968. Daily data are available from 1987/88 and data by trawl shot are available from 1992/93. Estimates of CPUE can be affected by changes in fishing efficiency, harvest strategy and environmental perturbations. While some aspects of fishing efficiency and harvest strategy were previously used to standardise CPUE for the period 1980 to 1998 (Xiao, 2004), more recent data and additional variables need to be incorporated into the model. Thus, for this report, only large changes in raw CPUE over relatively short time periods (i.e. between years or over several consecutive years) can be used confidently for assessing changes in biomass.

Commercial catch and effort data also include fishery-dependent survey data. From 1993/94 to 2003/04, industry vessels conducted "searching" shots to identify areas with prawns of target size and catch rate. "Searching" shots were generally 20 minutes in duration, and thus this type of fishery-dependent survey effort could be distinguished from commercial effort in daily logbook entries. Between February 2000 and March 2004, additional data on bucket counts and catch rate from 6,282 fishery-dependent survey shots were recorded. Whilst these data were not recorded consistently, particularly with respect to the location of shots, they did provide useful information on trends in prawn size over the survey period. During 2004/05, industry "searching" effort was replaced with fishery-independent surveys.

Fishery-independent data have been collected for the GSVPF since 1984 from data sources that include fishery-independent surveys and on-board observers (see Section 1.5.3). These provide five separate datasets for assessment:

1. Surveys conducted in consecutive fishing periods (December, March, April and May) between 2004/05 and 2006/07 (Section 3.2);
2. Surveys conducted during May between 2003 and 2007 (Section 3.3);
3. Surveys conducted from April 1984 to February 1995 (Appendix 8.1) ;
4. Observer data collected during fishing between 1993/94 and 2003/04 (Appendix 8.2); and
5. Small vessel surveys conducted during 2004/05 and 2005/06.

The first two datasets (2004/05–2006/07; May 2003–2007) provide reliable data for assessment of the prawn biomass in GSV in recent years, and are currently an ongoing component of stock assessment for the GSVPF. These structured surveys enable robust comparisons for up to five years on catch rates, prawn size and recruitment to the fishery.

Additional data are available on several other aspects of the fishery. Substantial data were obtained from tagging studies done in GSV, providing valuable information on growth, mortality and movement. Considerable studies were also conducted on the biology of *M. latisulcatus* in GSV, including reproductive biology and morphometric relationships. Information on juvenile habitat, abundance and growth, and larval dispersal is also available.

6.3 Current status of the GSVPF

Fishery independent survey data suggest that the biomass on which the fishery is based has undergone significant recovery during the last two years. It is noteworthy that the increases in abundance were observed across all size classes during May surveys between 2005 and 2007. This recovery has been driven by significant increases in recruitment during the same period. The large

recruitment observed during March, April and May in 2006, along with continued conservative harvest strategies, is conducive to further stock recovery during 2007/08.

In general, survey catch rates during 2006/07 were substantially greater than previous years. Mean catch rates during March, April and May surveys have increased annually between 2004/05 and 2006/07. In 2006/07, increases from the previous year were 13% during March, 34% during April, and 76% during May. Whilst there was some difference in mean water temperature during these survey periods (18.8 °C in 2004/05 compared to 19.9 °C in 2006/07), which is known to affect prawn catchability to some degree (Penn *et. al.* 1988), the significant increases in survey catch rates between these years is likely to reflect an increase in prawn biomass. The continued collection and analyses of water temperature data in the future will be important for the interpretation of trends in catch rates. This interpretation will be further improved by continued collection of bottom water temperatures from data loggers.

Catch rates obtained during December surveys were generally not consistent with that expected of a recovering fishery. Whilst total abundance has generally increased consecutively in each year for each month surveyed between March and May, abundance was not significantly different in December. Further, the abundance of prawns among size classes was highly variable between years. It is likely that December results are influenced by seasonal effects on catchability during the reproductive season. Increases in catchability of female prawns have been previously correlated with reproductive activity (Penn 1976; Penn 1980). Also, during peak reproductive activity, prawns aggregate to a greater extent, which would impact on the spatial variability in catch rates between survey shots. It is noteworthy that reproductive activity during December surveys from 2004 to 2006 varied substantially.

May surveys were also conducted during 2003 and 2004. Whilst the longer term comparison of May survey data are for fewer stations (71 compared to ~110), trends of an increasing biomass and recruitment are evident, particularly in recent years.

Additional evidence to support the conclusion of stock recovery includes increases in commercial catch and CPUE during 2006/07. Commercial catch in 2006/07 was ~223 t, representing an increase of 19% from 2005/06 (~187 t) and a 30% increase from the low catch harvested in 2003/04 (~172 t). Since the lowest recent CPUE in 2002/03 (61.2 kg/h), CPUE was similar during the next year 2003/04 (64.6 kg/h), and then rapidly increased to 91.3 kg/h during 2006/07. Whilst it must be noted that changes to the harvest strategy in December 2004 may affect interpretation of CPUE trends, the rapid increase in CPUE since then is most likely indicative of an increase in biomass.

The improved prognosis for the status of the prawn resource in GSV has likely resulted from a combination of conservative fishing strategies and environmental conditions conducive to successful recruitment to the fishery. Harvest strategies are aimed at; 1) ensuring a viable spawning biomass and 2) linking exploitation with increases in survey biomass. Whilst the continuation of fishery-independent surveys will enable close scrutiny of the trends in relative biomass and recruitment over time, research is needed to improve the understanding of the factors that affect recruitment success. In the absence of this knowledge, a precautionary approach to fishing during the early spawning season should be maintained.

6.4 Assessment of 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 appropriately sized prawns, and 3) harvest strategy adjustments are made during commercial fishing. Stages 1 and 2 are conducted by the GSVPF Research and Management Committee (PIRSA Fisheries, industry, SARDI) and are 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 Management Plan provides specific guidelines for the development of harvest strategies. Harvest strategy adjustment (stage 3) is the process by which the Committee At Sea (lead by industry) adjusts, in "real time", the closure lines during the fishing period in accordance with 'at sea' decision rules to maximize the economic performance of the fishery. Harvest strategy adjustments are informed from data obtained during commercial fishing that are reported to the co-ordinator at sea. It should be noted that these data are not currently recorded or assessed.

Assessing and refining harvest strategy development and adjustment is important to ensure adherence to the decision rules of the Management Plan regarding the harvest of prawns of an appropriate size and catch rate. It should be noted that developing spatial harvest strategies for the GSVPF is only a recent management practice (implemented in December 2004), and formal decision rules have only been recently implemented (September 2007). Therefore, whilst the assessment presented here is a useful indicator of harvest strategy performance, this is not a formal assessment against the rules of the Plan.

Harvest strategy assessment identified several issues regarding the harvest of prawns outside of the target size of the Management Plan. During 2006/07, the very high levels of recruitment to the fishery compared to previous years made harvest strategy development and adjustment challenging with regard to target prawn size, particularly during the March fishing period. While harvest strategies were developed within sustainable levels of exploitation (December <30 t,

March–May <18% survey biomass; Dixon & Sloan, 2007), which enabled stock recovery during 2006/07, mean prawn size harvested during March was smaller than the target size (<28 prawns/kg) on all nights of the fishing run. At this time of year mean prawn size of the population is at its smallest, as recruitment is at or close to its peak, while recruits are distributed throughout the fishery reducing aggregations of survey stations observed with target size prawns. For these reasons, harvest strategies during March harvest periods in the future need to be closely scrutinised. Furthermore, it may be beneficial to adopt conservative fishing effort during March in the future to; 1) reduce the harvest of small prawns and 2) maximise growth and yield in later harvest periods.

The Management Plan provides measures for determining exploitation levels but does not provide 'spatial' guidelines for developing harvest strategy areas. 'Spatial' guidelines could assist and improve harvest strategy development in the future, and may include; 1) all stations within a harvest strategy area should be of target size, 2) the majority (>75%) of stations within a harvest strategy area should have high catch rates, and 3) stations immediately adjacent to harvest strategy areas with non-target size prawns at high catch rates should be avoided where possible, particularly small-size prawns.

To assist harvest strategy adjustment during fishing, the Management Plan does provide 'at-sea' decision rules. These rules are for the Committee at Sea to refine harvest strategies but are not currently assessed. Of note, 'terms of reference' were documented by industry, and reviewed by PIRSA Fisheries and SARDI, which provide greater detail for the 'at-sea' decision rules and processes for harvest strategy adjustment by the Committee at Sea. The management of harvest strategies during fishing to avoid non-target size prawns could be improved in the future if adherence to these 'terms of reference' and 'at-sea' decision rules were improved. In particular, the collection of data that underpins 'at-sea' decision rules would improve assessment of harvest strategy decision rules and reduce the uncertainty associated with relying only on size data gathered as reported grades in commercial logbooks.

6.5 Performance Indicators

The 2007 Management Plan provides a useful framework to assess the performance of the fishery in achieving its goal of stock recovery. Whilst the revised Plan adequately addresses issues raised regarding PIs in previous reports, this report identifies additional issues that warrant further consideration.

Firstly, there is considerable uncertainty in the estimates of mean harvested prawn size. Primarily this results from data being available from only up to 6 of 10 fishers. The collection of regular

reliable processor data would enable representation from the entire fleet and would also enable validation of existing commercial logbook data. Also, the appropriateness of the scale of assessment of prawn size (by harvest period) needs to be considered, particularly in light of the low proportion of nights when the target mean prawn size was achieved between March and May (6–44%).

The additional performance measure for egg production has been given a fixed Limit Reference Point. Given that outputs of the model are likely to be further refined in the future, it is suggested that a more appropriate approach may be to link the Limit Reference Point to a reference year (e.g. 2004/05).

Assessment against the PI for mean commercial CPUE and indices of future and current biomass are limited by a lack of knowledge on the fishing power of the fleet. This will be of particular importance if fleet dynamics change substantially (e.g. if more vessels are upgraded from "wet boats" to "freezer boats").

A critical aspect of the Plan is the ability to review, and change if necessary, the Limit Reference Point for the key PI's and additional performance measures. It is anticipated that these stock assessment reports provide the formal opportunity for SARDI to provide scientific advice regarding the appropriateness of Limit Reference Points in the Management Plan. This will become increasingly important in future years as assessments track the performance of stock recovery during the life of the Management Plan.

6.6 Future research

Assessment of harvest strategies at fine spatial and temporal scales, as presented in this report, would be augmented by the collection of data during commercial fishing by the committee at sea. These data should include estimates of nightly catch and mean harvested prawn size from at least three vessels in the fleet.

Several key elements of the biology of *M. latisulcatus* of the Gulf St Vincent Prawn Fishery remain poorly understood, particularly regarding spawning and recruitment success, and issues of prawn health. Of highest priority for research in the GSVPF is an improved understanding of spawning, recruitment and their influencing factors. This requires research on aspects of the biology of western king prawns including; 1) the frequency of individual spawning events and the influence of temperature during the spawning season, 2) factors affecting fertilization success, and 3) an improved understanding of larval behaviour. In addition, knowledge of the environmental factors that affect recruitment success is required. Knowledge of the effects of water temperature on

spawning and larval duration and survival, and of larval advection mechanisms (i.e. winds, tides etc.) would enable the development of a combined physical and biological model to track egg production through to post-larval settlement. Such a model would be able to; 1) provide an improved understanding of recruitment to the fishery, 2) determine environmental conditions that result in favourable recruitment and 3) provide advice on optimal harvest strategies during the spawning season to minimise the effect of harvest on future recruitment to the fishery. A current FRDC funded project aims to achieve this for the Spencer Gulf Prawn Fishery. Knowledge gained from that study could be used to achieve similar objectives for the GSVPF at a reduced cost.

Another high priority for research in the GSVPF is the collection of information to determine changes in fishing power. Understanding changes in fishing efficiency is essential for interpretation of the CPUE data that underpins performance assessment and the development of harvest strategies.

In addition, 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 size 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".

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8. APPENDIX

8.1 Surveys conducted between 1984 and 1995

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

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

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

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

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

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

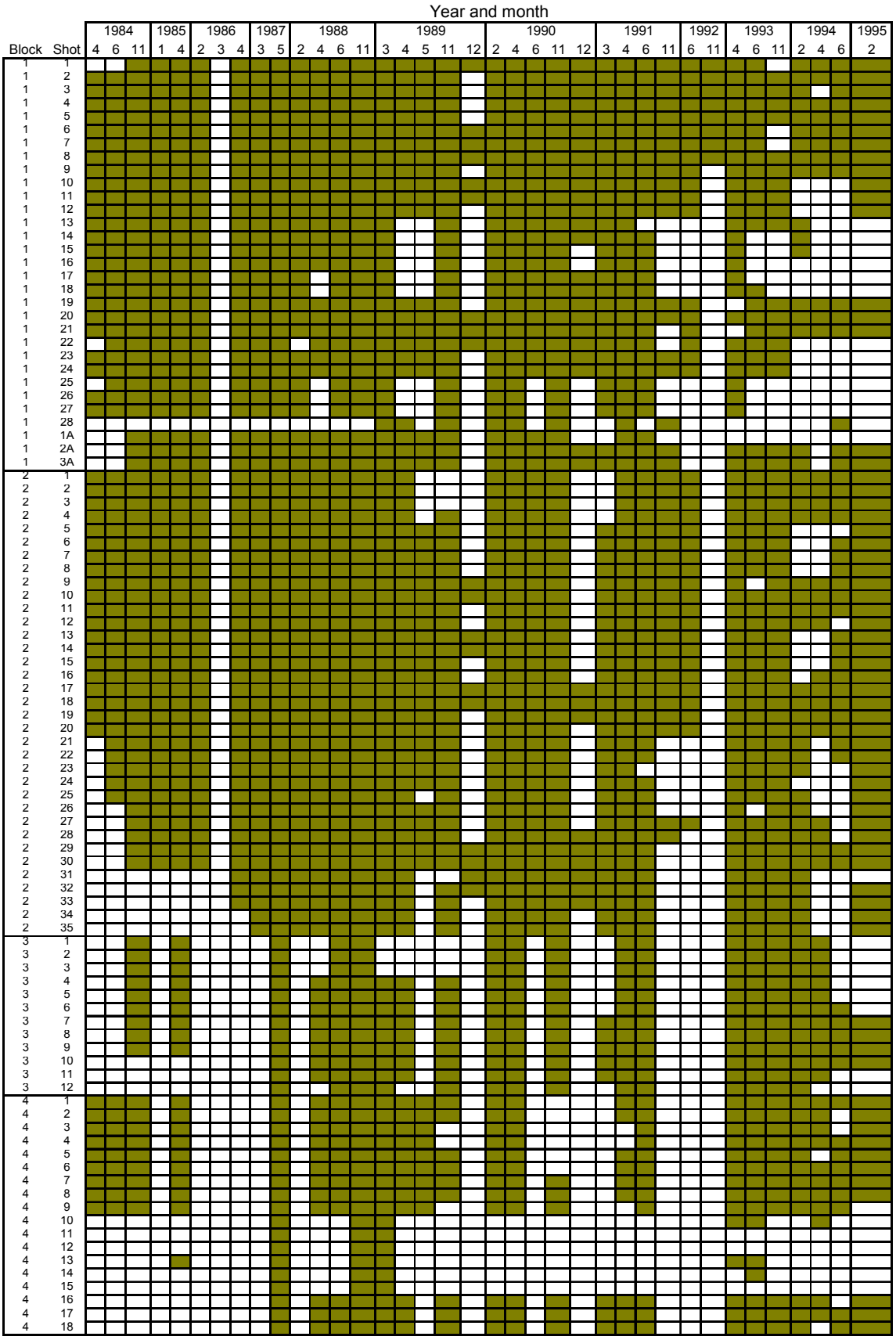

Table 8.1b Stock assessment survey shots (shaded) conducted in blocks 5, Deep Hole (DH), Little Hole (LH) and Investigator Straits (IS) of GSV from April 1984 to February 1995.

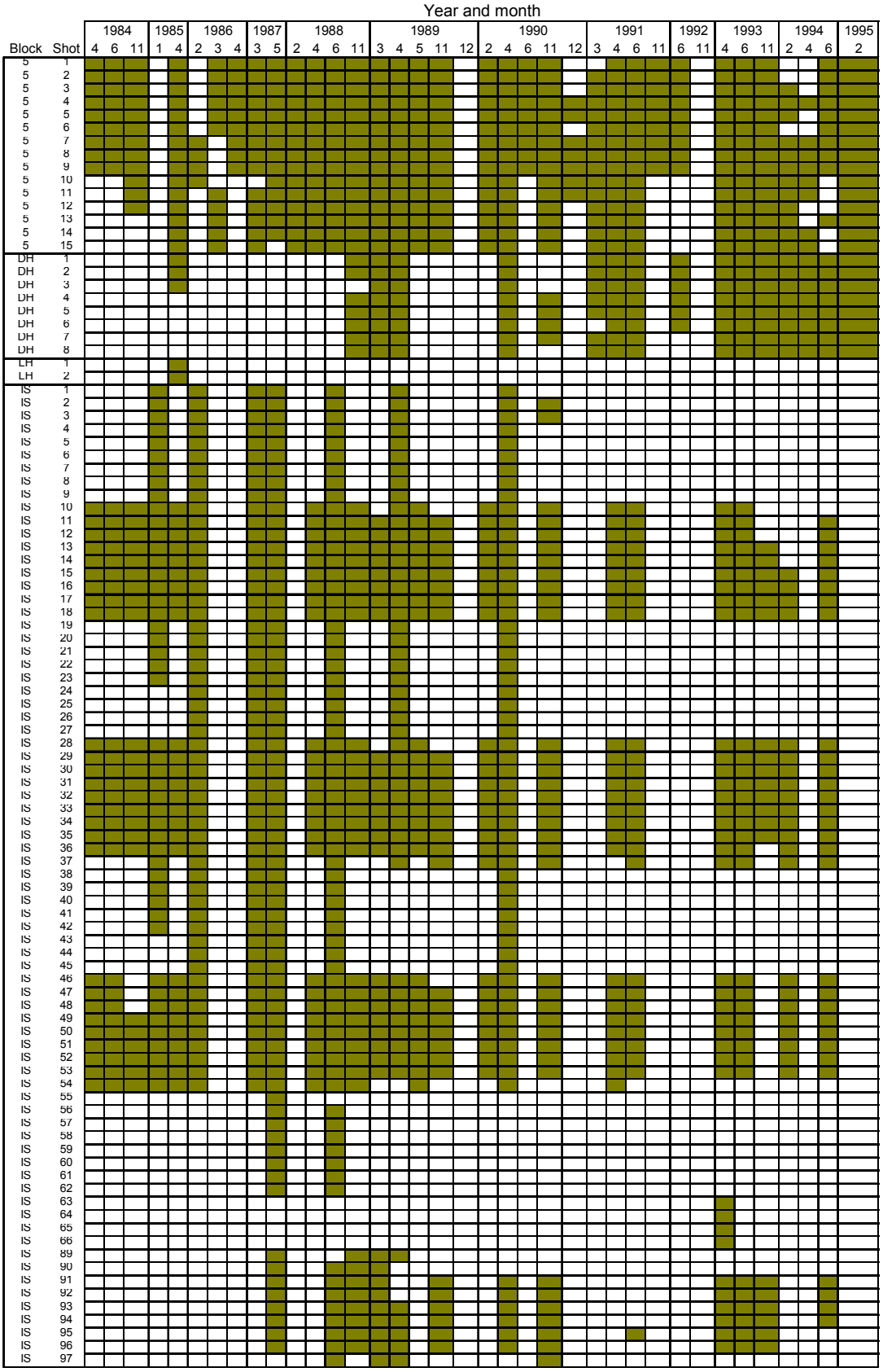

Table 8.2 The timing and number of stock assessment survey shots in relation to the new moon during surveys conducted in GSV from April 1984 to February 1995.

Night of the new moon | last quarter | first quarter

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

8.1.1 Mean catch rate and prawn size from pooled data

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

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

Catch rate ranged considerably among regions, with lows of 3.9 and 4.0 kg/nautical mile (nm) in the Investigator Straits (IS) and Region 4, and a high of 11.7 kg/nm in the Deep Hole (DH) region (Figure 8.3). Of note, commercial CPUE was also lowest in the IS region and Region 4 for the period 2000/01–current (see Section 2.3.3). 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.

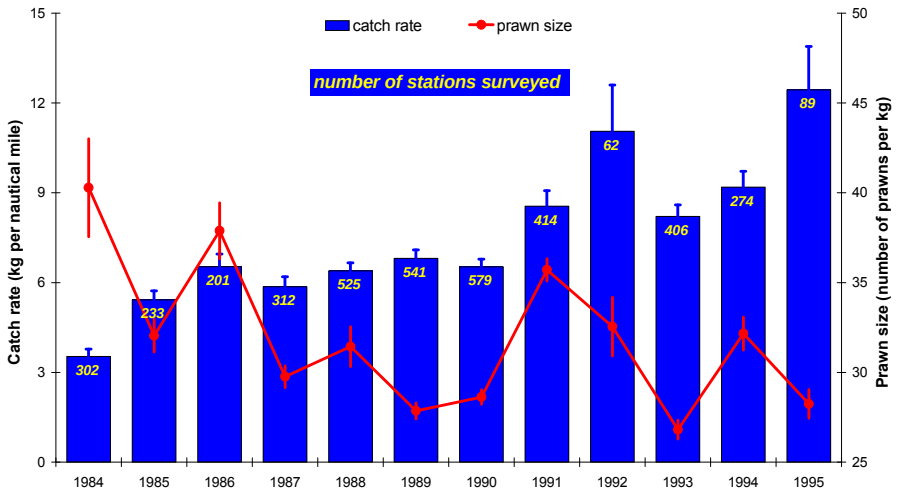

Figure 8.1 Mean (SE) catch rate (kg/nm) and the mean (SE) number of prawns/kg across months and blocks surveyed from 1984 to 1995 in GSV.

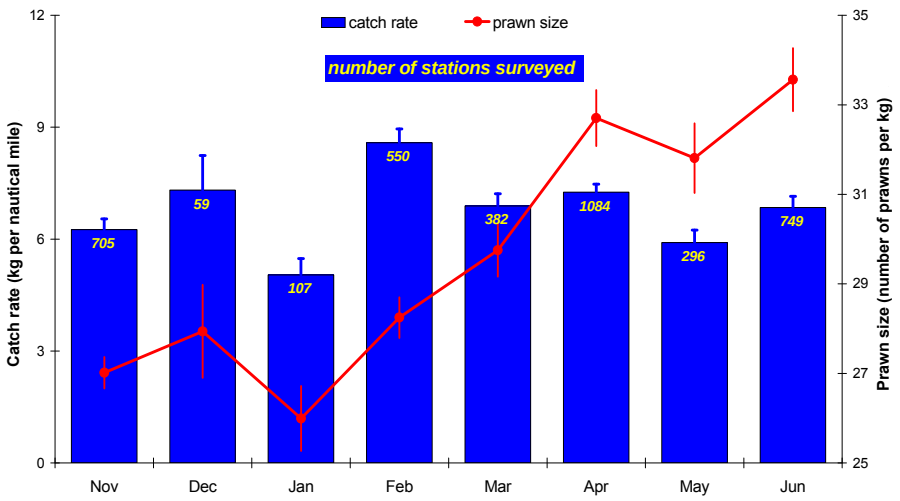

Figure 8.2 Mean (SE) monthly catch rate (kg/nm) and the mean (SE) monthly number of prawns/kg across years and blocks surveyed from 1984 to 1995 in GSV.

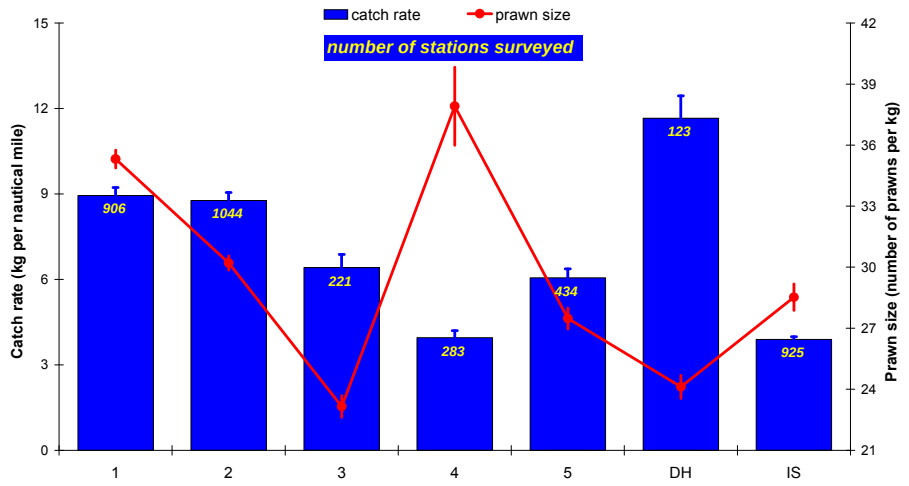

Figure 8.3 Mean (SE) regional catch rate (kg/nm) and the mean (SE) regional number of prawns/kg across years and months surveyed from 1984 to 1995 in GSV.

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.

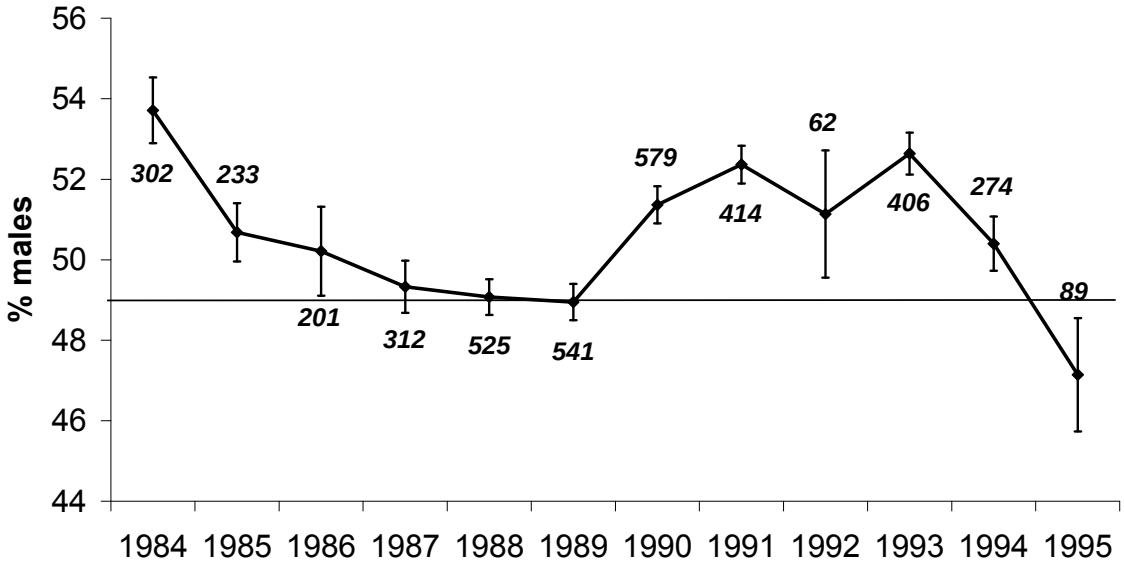

Figure 8.4 Mean (SE) % of males in the sampled population from GSV surveys done during 1984–1995. Numbers indicate the numbers of shots done.

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 3.2.3).

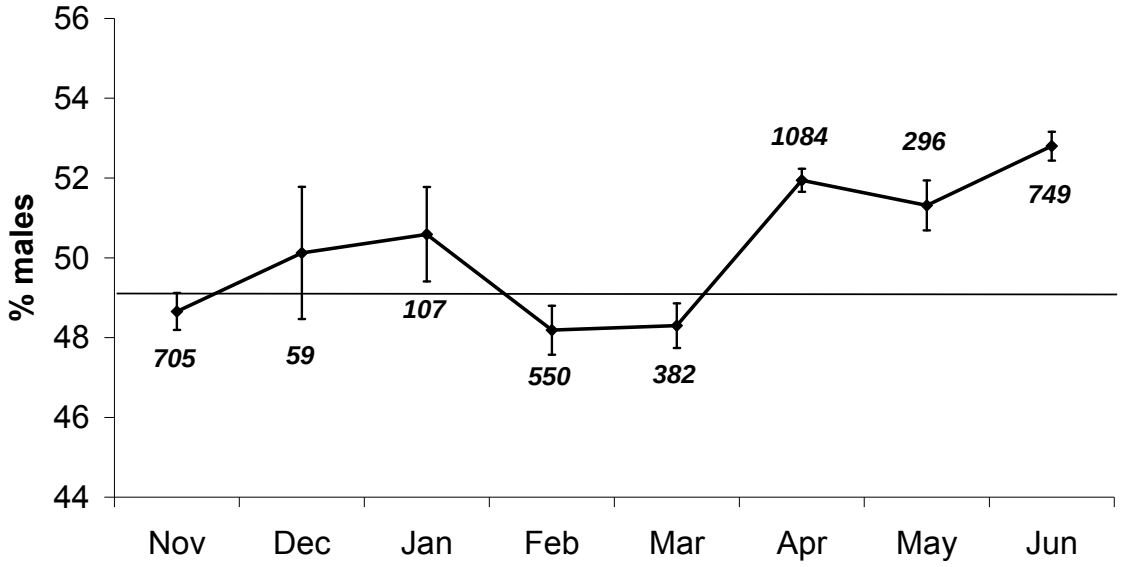

Figure 8.5 Mean (SE) monthly % of males in the sampled population from GSV surveys done during 1984–1995. Yellow numbers indicate the numbers of shots done.

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.

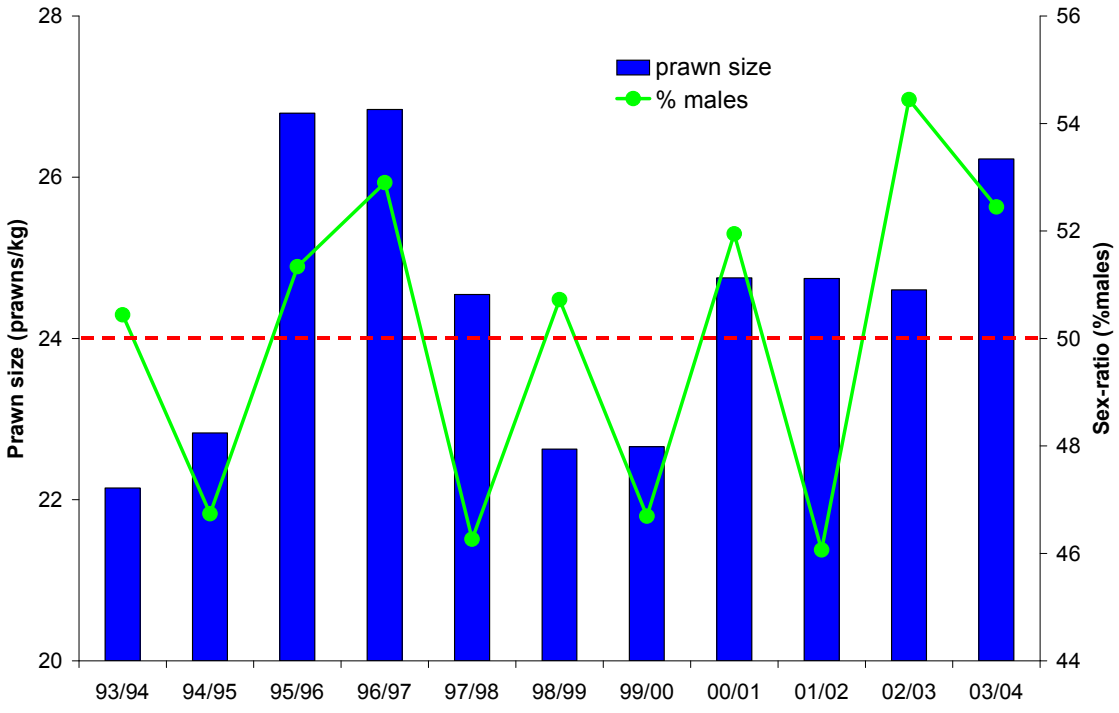

Figure 8.6 Sex-ratio (% males) and prawn size (prawns/kg) from data collected during commercial fishing operations in GSV from 1993/94 to 2003/04. The dotted red line indicates the target size of 24 prawns/kg and an equal sex-ratio.

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).

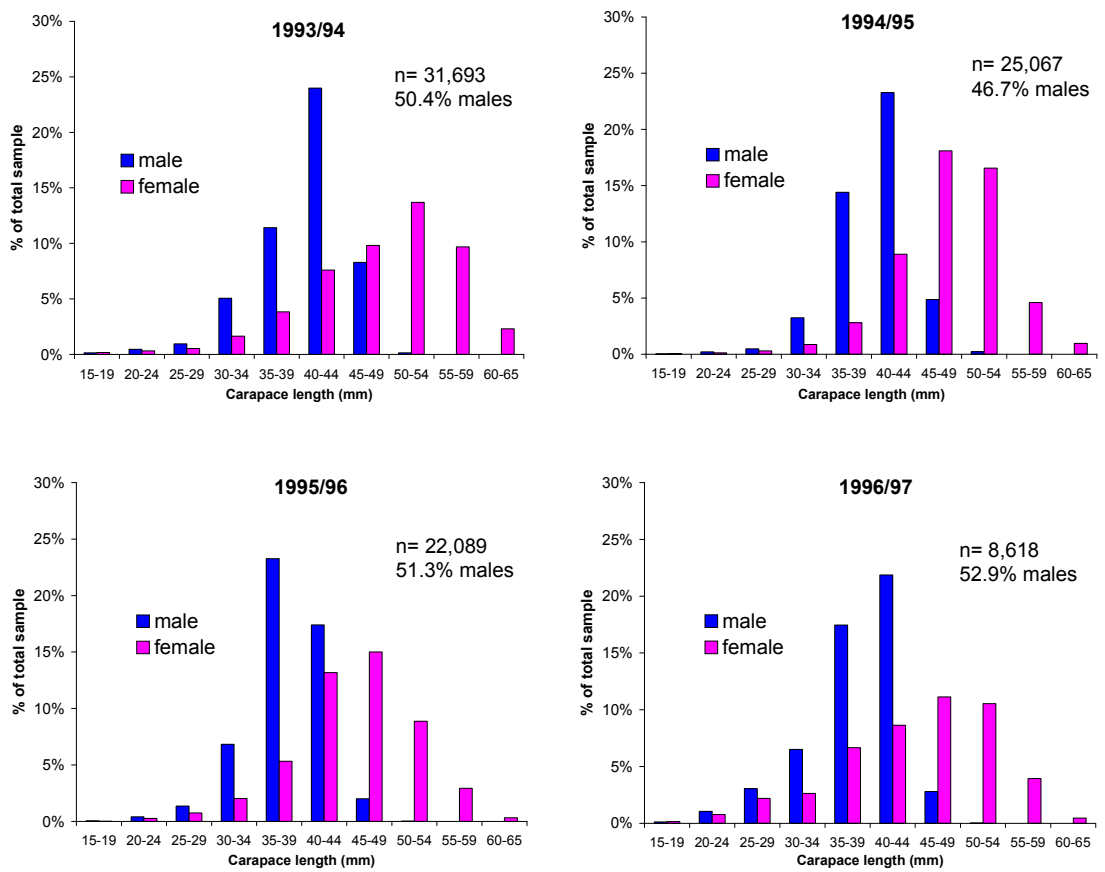

Figure 8.7a Size-frequency distributions from data collected during commercial fishing operations in GSV from 1993/94 to 1996/97.

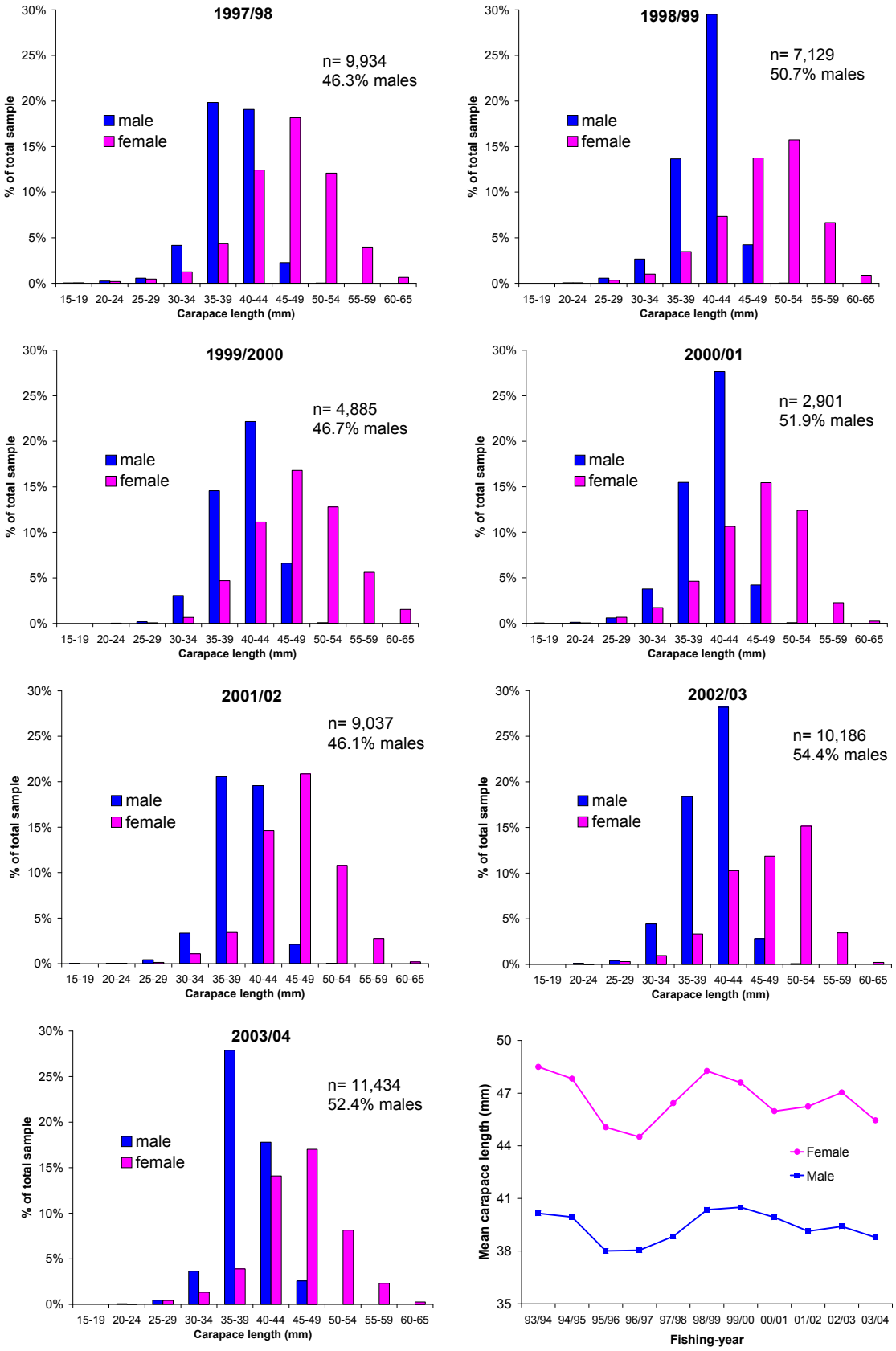

Figure 8.7b Size-frequency distributions from data collected during commercial fishing operations in GSV from 1997/1998 to 2003/04, and mean size (mm CL) of male and female prawns measured from 1993/94 to 2003/04.

8.2.2 Trends in graded catch from 1993/94 to 2003/04

The weight of prawns per size grade was estimated from observer data collected between 1993/94 and 2003/04. Firstly, 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 8.4. 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 total catch (see Section 2.2) to determine the estimated weight of each prawn grade (Figure 8.8).

Table 8.4 Prawn grades and associated weight ranges from commercial processors

Prawn grade (No. prawns per pound)	U10	10–15	16–20	21+
Weight range (g)	>46	31–45	23–31	<23

Catches of large prawns (U10 grade and larger) comprised >50% of the annual catch during 1993/94 and 1994/95, the first two years after the closure (Figure 8.8). During 1995/96 the catch of large prawns was similar to previous years, however the proportion of large prawns in the total catch reduced to 34%. From 1996/97 to 1999/2000, the total catch of large prawns and the proportion of large prawns in the catch increased annually, with 186 t of large prawns, comprising 48% of the total catch, being harvested in 1999/2000. Thereafter, both the total catch of large prawns and the proportion of large prawns within the catch reduced annually. The catch of large prawns in 2003/04 was estimated to be the lowest since the closure period.

Whilst the total catch of 10–15 grade prawns varied between 44 and 153 t, the proportion of these graded prawns within the catch was relatively consistent (range 31–40%). Catches of 16–20 grade prawns were lowest immediately after the closure (1993/94 and 1994/95). Of note, peak catches for this prawn grade were obtained in both 2000/01 and 2001/02 (~70 t) and followed the two years that the highest catches of large prawns were obtained. Catches of small prawns (grade 21+) were <20 t in all years.

There is considerable uncertainty in these estimates due to: the assumption that prawns measured by observers were representative of the annual catch, and; the conversion of length-frequency data into graded prawn weight categories.

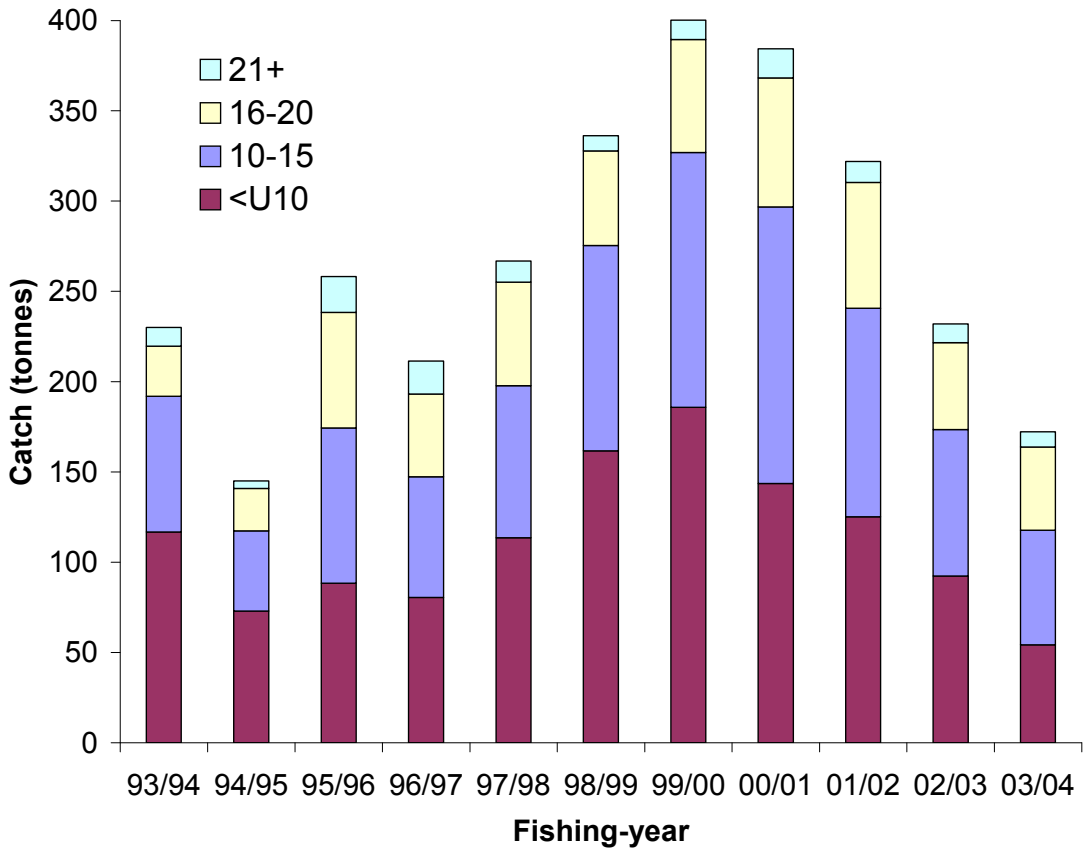

Figure 8.8 Prawn catch by commercial size grade estimated from prawn size data obtained during on-board observation and catch data obtained from commercial logbooks for GSV during 1993/94–2003/04.