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Blue Crab (*Portunus armatus*) Fishery 2014/15

C. L. Beckmann and G. E. Hooper

SARDI Publication No. F2007/000729-12
SARDI Research Report Series No. 897

SARDI Aquatics Sciences
PO Box 120 Henley Beach SA 5022

May 2016

Fishery Assessment Report to PIRSA Fisheries and Aquaculture

PREMIUM FOOD AND WINE FROM OUR CLEAN ENVIRONMENT

SOUTH AUSTRALIA

Government of South Australia
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This publication may be cited as:
Beckmann, C. L. and Hooper, G. E. (2016). Blue Crab (*Portunus armatus*) Fishery 2014/15. Fishery Assessment Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007/000729-12. SARDI Research Report Series No. 897. 57pp.

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Printed in Adelaide: May 2016

SARDI Publication No. F2007/000729-12
SARDI Research Report Series No. 897

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Date:	19 May 2016
Distribution:	PIRSA Fisheries and Aquaculture, SAASC Library, SARDI Waite Executive Library, Parliamentary Library, State Library and National Library
Circulation:	Public Domain

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ACKNOWLEDGMENTS

Funds for this research were provided by Primary Industries and Regions South Australia (PIRSA) Fisheries and Aquaculture, obtained through licence fees. The South Australian Research and Development Institute (SARDI) Aquatic Sciences provided substantial in-kind support. Dennis Holder and Mick Aston provided their crew and vessel for the 2014/15 fishery-independent survey. Fieldwork was undertaken by Matt Lloyd, Nat Navong, Mick Drew, Owen Burnell and Graham Hooper. The catch and effort data from the SARDI Information Management System were provided by Melleessa Boyle of the Information Systems and Database Support Unit at SARDI Aquatic Sciences. This report was formally reviewed by Dr Lachlan McLeay, Dr Adrian Linnane and Dr Craig Noell of SARDI Aquatic Sciences, and Keith Rowling of PIRSA Fisheries and Aquaculture, and approved for release by Dr Stephen Mayfield, Science Leader, Fisheries (SARDI Aquatic Sciences).

EXECUTIVE SUMMARY

STOCK	Gulf St. Vincent	Spencer Gulf	West Coast
Status	Sustainable	Sustainable	Undefined
Indicators	FIS CPUE (legal-size/potlift) FIS CPUE (pre-recruits/potlift) Commercial CPUE (kg/potlift)		Limited data

This stock assessment determined the current status of South Australia's blue swimmer crab resource through analysis of data collected by several long-term monitoring programs. The harvest strategy for the Blue Crab Fishery (BCF) does not define when the stock is considered 'recruitment-overfished' and performance indicators (PIs) are not explicitly linked to a definition of stock status. Consequently, this assessment uses a 'weight of evidence' method to determine stock status.

In 2014/15, almost the entire Spencer Gulf (SG) component of the total allowable commercial catch (TACC) for the fishery was caught for the eleventh consecutive year and commercial catch per unit effort (CPUE) remained at a high level. Fishery-independent surveys (FIS') indicate that legal-size CPUE has exceeded the upper limit reference point (LRP) since 2009, and pre-recruit CPUE was above the upper LRP in the most recent survey (2014). On the basis of this information, the biological stock is unlikely to be recruitment overfished and the current level of fishing mortality is unlikely to cause the biological stock to become recruitment overfished. Consequently, using the national framework for stock status reporting, the SG fishing zone of the BCF is classified as **'sustainable'.**

There are multiple lines of evidence indicating that the relative abundance of blue swimmer crabs in Gulf St Vincent (GSV) continued to improve from the relatively weak position observed during 2012/13. Firstly, the CPUE of legal-size crabs was the highest value on record and above the upper LRP in the 2015 FIS. Secondly, pre-recruit CPUE measured during the FIS increased in 2015, reaching the highest value recorded since 2010. Thirdly, legal-size and pre-recruit crabs were broadly distributed throughout GSV during the 2015 FIS. Fourthly, in 2014/15, all PIs were above the lower LRP for the second consecutive season. Lastly, commercial CPUE remained high and the entire GSV component of the TACC was harvested in 2014/15. On the basis of this information, the biological stock is unlikely to be recruitment overfished and the current level of fishing mortality is unlikely to cause the biological stock to become recruitment overfished. Consequently, using the national framework for stock status reporting, the GSV fishing zone of the BCF is classified as **'sustainable'.**

There were insufficient data to confidently classify stock status for the west coast zone, consequently, using the national framework for stock status reporting, this zone of the BCF is classified as **'undefined'.**

1. INTRODUCTION

1.1. Overview

Stock assessments for the South Australian blue swimmer crab *Portunus armatus,* (previously *P. pelagicus*, Lai *et al.*, 2010) fishery have been produced annually since 2004 (Svane and Hooper, 2004) as part of the South Australian Research and Development Institute (SARDI) Aquatic Sciences' ongoing assessment program. This report has four aims: 1) to present information from the fishery and biology of the species; 2) to assesses the current status of the blue swimmer crab resource in each gulf and consider the uncertainty associated with each assessment; 3) to comment on the current biological performance indicators (PIs) and reference points for the fishery; and 4) to identify future directions for the research program.

1.2. Description of the fishery

1.2.1. Access

Blue swimmer crabs (hereafter referred to as blue crabs) support an important inshore fishery in South Australia, with 617 t harvested in 2014/15 at an approximate value of $4.5M (SARDI unpublished data). This harvested value includes commercial quantities of blue crabs taken from the west coast, which is not part of the total allowable commercial catch (TACC) for the Blue Crab Fishery (BCF).

There are three major stakeholders: the commercial pot fishery (Figure 1.1), the commercial Marine Scalefish Fishery (MSF; Figure 1.2) and the recreational fishery. Access to take blue crabs is provided via a BCF or a MSF licence endorsed with quota entitlements. MSF licences are also permitted to take blue crabs on the west coast of South Australia (west of longitude 135°E) outside of the quota management system. BCF licence holders (pot fishers) generally fish in waters deeper than those fished by MSF and recreational fishers. The ability to access deeper water provides for an extended season as fishers can access blue crabs in waters where they continue to be caught during the cooler months.

Commercial pot fishers generally haul their gear once or twice every 24 hours using specifically designed crab pots covered with mesh. MSF licence holders use hoop/drop nets and on the west coast they may also use crab pots, rakes or dab nets. Recreational fishers mostly use crab nets (hoop or drop nets) or hand held rakes. Current output controls for blue crabs caught in South Australia include restrictions on the total commercial catch through a quota system, spatial and temporal commercial closures, bag and boat limits for recreational fishers, a minimum legal size limit (MLS: 110 mm carapace width measured from the anterior base of the first spine) and restrictions on taking berried females.

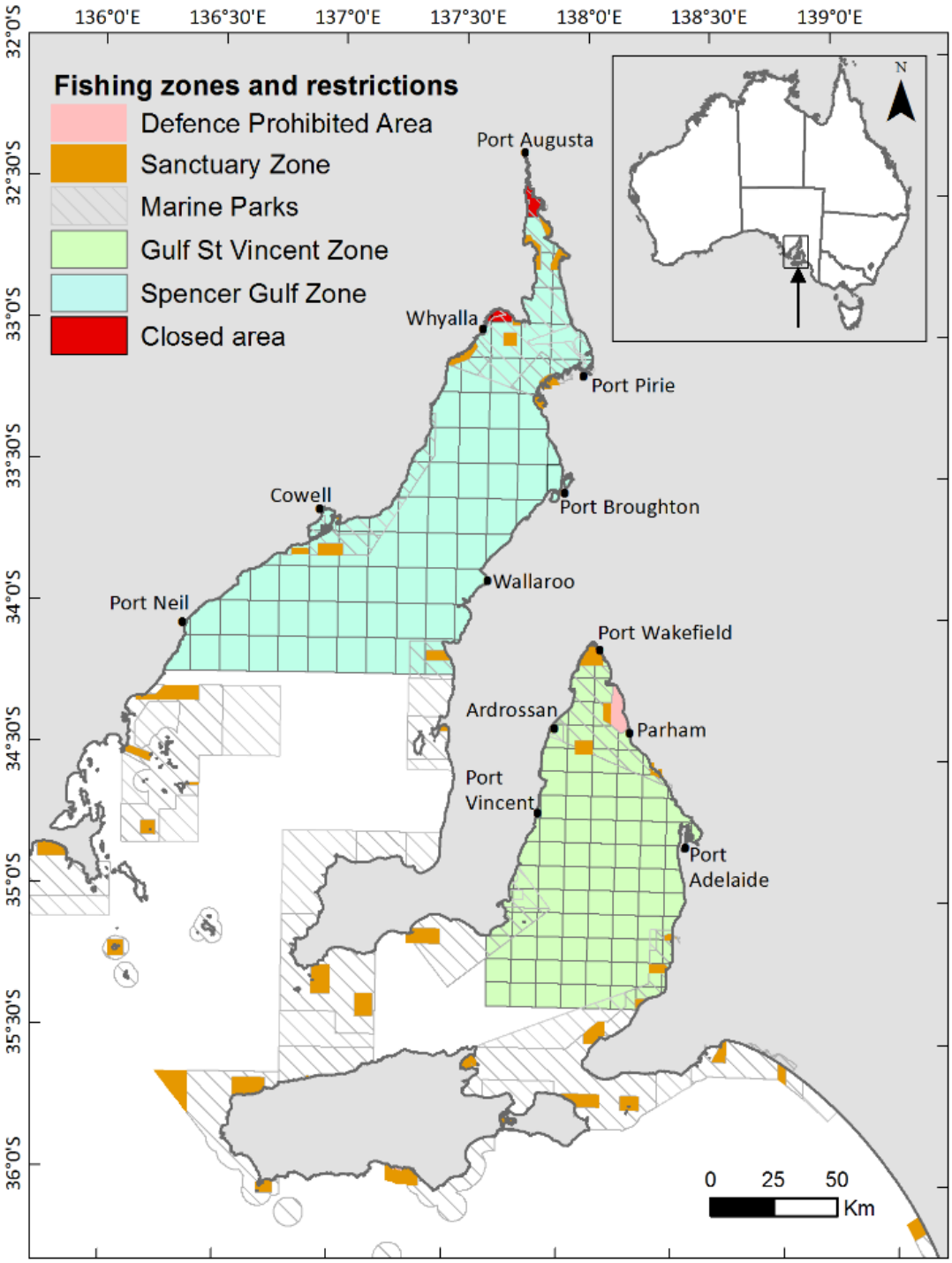


Figure 1.1 Spencer Gulf and Gulf St Vincent fishing zones of the South Australian Blue Crab Fishery.

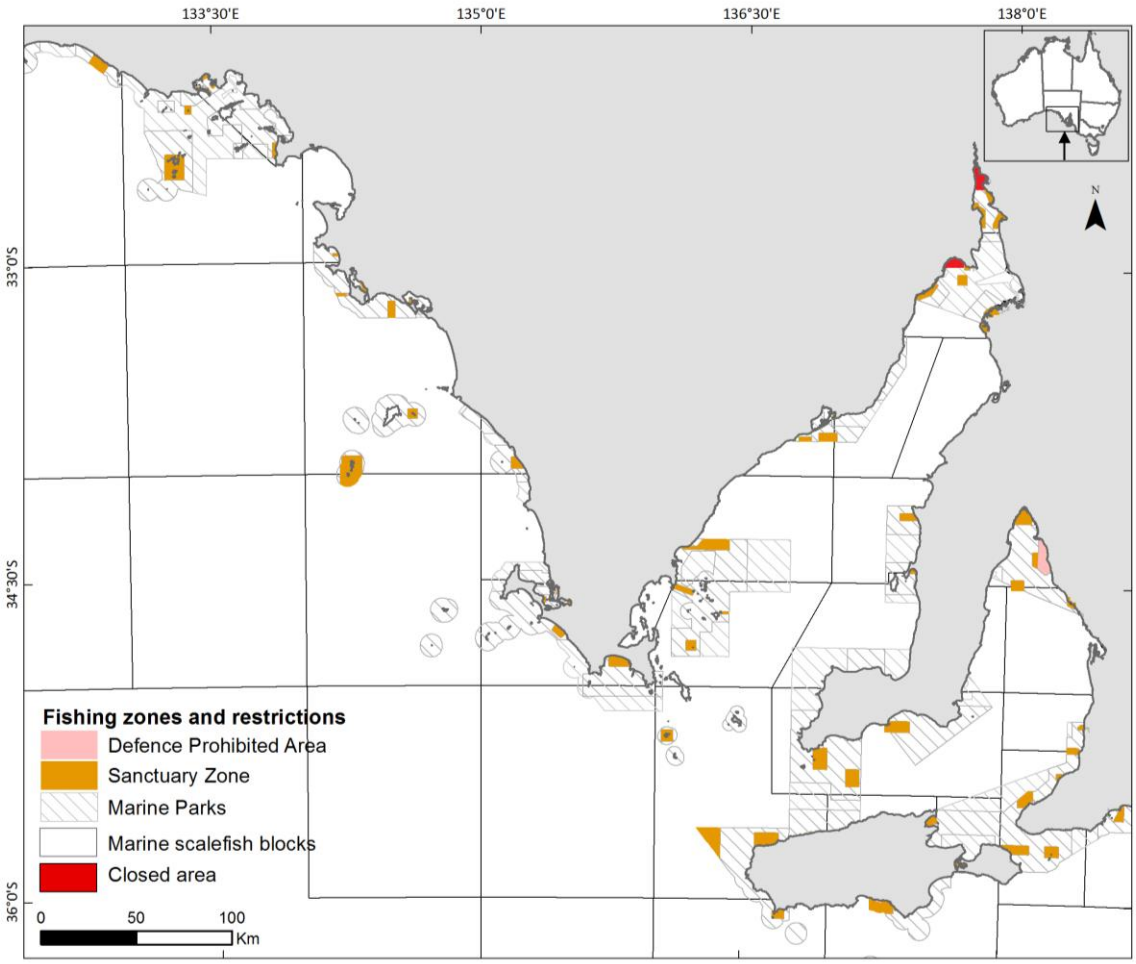


Figure 1.2 South Australian Marine Scalefish Fishery blocks. The west coast zone (not subject to quota) operates in all waters west of longitude 135° East.

1.2.2. Marine parks

The South Australian Government introduced 19 multiple-use marine parks on 1 October 2014. This network covers a total area of 27,526 km^2, encapsulating approximately 46% of South Australia's waters (DEH 2009). The marine park network includes four levels of protection. They are: "general and managed use zones", "habitat protection zones", "sanctuary zones" and "restricted zones". Of these, the sanctuary and restricted zones (see Figure 1.1 and 1.2) are the most relevant to fisheries as they are areas of high conservation and prohibit any forms of fishing within their boundaries.

1.2.3. Management arrangements

As with all of South Australia's fisheries and aquatic resources, the *Fisheries Management Act 2007* ('the Act') provides the statutory framework for management of the South Australian blue crab resource. The schemes of management for the fishery are prescribed in the *Fisheries Management (Blue Crab Fishery) Regulations 2013* and the *Fisheries Management (Marine*

Scale Fisheries) Regulations 2006, while general regulations pertaining to commercial and recreational take of blue crabs from State waters are described in the *Fisheries Management (General) Regulations 2007*.

The BCF was established in 1996, with formalised management arrangements that included pot restrictions, formation of two fishing zones in Spencer Gulf (SG) and Gulf St Vincent (GSV) and a single TACC with quota units allocated separately for each zone. Quota is transferable between the pot fishers of the BCF and eligible MSF licence holders, but only within the same zone. Since the introduction of quota in the BCF, there has been a transfer of fishing effort from the MSF to the pot fishing sector, with the number of MSF licences holding blue crab quota steadily decreasing from 29 in 1996 to 3 licence holders in 2014.

The TACC for the BCF was initially set by Primary Industries and Regions South Australia (PIRSA) Fisheries and Aquaculture at 520 t for the 1996/97 fishing season. Over the next four quota years the TACC gradually increased to 627 t in 2000/01, where it remained until 2012/13. In 2013/14 and 2014/15, the TACC for the GSV zone was reduced by 20% from 245 t to 196 t, which resulted in a reduction of the fishery-wide baseline quota to 578 t (SG: 382 t; GSV: 196 t). A voluntary commercial closure in GSV was also implemented from 1 July 2013 to 15 January 2014.

The BCF fishing zones are subject to annual temporal closures, when the abundance of spawning females is greatest. The GSV zone is closed between 1 November and 15 January. The closure in SG (21 December to 19 February) was modified from 2004/05 to take advantage of higher market prices in the lead up to Christmas. In addition, temporary spatial commercial closures have been put in place in recent years in GSV to allow greater recreational access to blue crabs during the peak recreational period (i.e. December, January and April). The commercial closures operate between St Kilda Beach to the northern Outer Harbor breakwater; and the southern Outer Harbor breakwater to Marino Rocks. The temporary commercial fishery closure also applies to a2 nm area adjacent to the Ardrossan, Black Point, Port Vincent, and Stansbury boat ramps.

Recreational fishers are restricted to a bag limit of 40 crabs (blue crabs and/or sand crabs combined) per person per day and a boat limit of 120 crabs per day in SG. Concurrent with the reduction in quota for the GSV pot fishing zone, recreational bag and boat limits for GSV have been reduced by 50%, to 20 and 60 crabs per day, respectively, since 2013/14.

1.3. Biology of the blue crab

1.3.1. Distribution

Blue crabs are distributed within near-shore, marine embayments and estuarine systems in Australia and New Caledonia (Lai *et al*., 2010). In the relatively cool, temperate waters of South Australia, rates of growth and reproduction increase in response to rising water temperatures during the warmer months of the year, while reducing during the colder winter months.

Blue crabs occur in a wide range of algal and seagrass habitats, and on sandy and muddy substrata, from the intertidal zone to a depth of at least 50 m (Williams, 1982; Edgar, 1990). In coastal waters, smaller crabs are generally found in shallow waters less than 1 m, while adults are found in deeper waters. Juvenile blue crabs occur in mangrove creeks and mud flats for eight to twelve months, by which time they attain a size of 80 to 100 mm carapace width. Within South Australia, there is a distinct seasonal pattern of movement of adult blue crabs into shallow inshore waters during the warmer months of September to April, and out to deeper offshore waters during the cooler months of May to August (Smith, 1982).

1.3.2. Reproductive biology

Our early understanding of the biology of blue crabs in South Australia was based on a research program which commenced in 1977 (Smith, 1982). This work was updated in the late 1990s with an extensive study that sampled fishery catches throughout GSV and SG (Kumar *et al.*, 2000; 2003; Xiao and Kumar, 2004).

Male and female blue crabs generally reach sexual maturity at carapace widths of similar sizes between 70 and 90 mm (Smith, 1982). The spawning season lasts for three to four months over the summer/autumn period. The duration of the growing season varies among individuals because those settling in early summer have a longer growing season than those settling in mid to late summer. In South Australian waters, blue crabs close to the MLS (110 mm carapace width) are approximately 14 to 18 months old, sexually mature, and females have produced at least two batches of eggs within one season. Kumar *et al.,* (2000; 2003) found that the fecundity of female blue crabs was size-dependent, increasing up to a carapace width of 134 mm and decreasing thereafter, with females producing between 650,000 and 1,760,000 eggs per spawning. From 105 mm to 125 mm, fecundity was shown to increase by 83.9%, indicating that a single large female can produce as many eggs as two small females (Kumar *et al.*, 2003).

In South Australia, late stages of ovarian development were observed in blue crabs during late October to November in conjunction with rising seawater temperatures (Kumar *et al.*, 2000). During copulation, the spermatophore is transferred to the female spermatheca. The eggs are subsequently fertilised on extrusion (Smith, 1982). Van Engel (1958) found that, for another portunid, the Chesapeake blue crab *Callinectes sapidus*, the sperm in the female spermatheca could remain viable for at least 12 months. This is likely to also be the case for the blue crab. Egg extrusion is independent of the timing of copulation.

1.3.3. Early life history

A plankton-sampling program for blue crabs was conducted in GSV in 1994–95 (Bryars and Havenhand, 2004). Larvae are hatched mainly offshore during November to March and wind (strength and direction) and temperature influence the dispersal of larvae. Laboratory experiments suggest that the effects of constant and varying temperatures have marked effects on larval development (Bryars and Havenhand, 2006). In years of average seasonal temperature changes, the larval developmental period was predicted to range from 26 to 45 days depending on the date of hatching with peak post-larval settlement occurring between mid-January and mid-March.

1.3.4. Stock structure

Using allozyme markers, Bryars and Adams (1999) determined that the populations of *P. armatus* within SG, GSV and west coast regions of South Australia represented separate sub-populations with limited gene flow. They also found that inter-regional larval dispersal is restricted, and each sub-population is most likely dependent on its own larval supply.

Using microsatellite markers, Chaplin *et al.* (2001) found that the assemblages of *P. armatus* in different embayments in South Australia constituted genetically different meta-populations, which suggests that the level of migration between these populations is limited and likely to be determined by local factors.

1.4. Research program

Since 2004, fishery assessment reports have documented the biology and management of the BCF in South Australia, presented analyses of commercial logbook and fishery-independent survey (FIS) data, and provided assessment against the PIs of the Management Plan for the fishery (PIRSA, 2012). Since 2008, the report has presented information and conclusions for each fishing zone separately and included information gathered from the fishery-dependent pot-sampling program.

The current research program for the BCF conducted by SARDI Aquatic Sciences comprises four components: 1) a fishery-independent (stock assessment) survey (FIS) during winter to inform fishing strategy decisions and assess the fishery against the PIs defined in the Management Plan; 2) management of fishery-dependent commercial logbook data; 3) collation and analyses of fishery-dependent pot-sampling data; and 4) production of an annual stock assessment report for the fishery.

The annual stock assessment report provides the information required to make decisions in accordance with the TACC decision rules provided in the harvest strategy. The report is prepared for Primary Industries and Regions South Australia (PIRSA) Fisheries and Aquaculture, and presented to PIRSA and industry each year to inform the TACC decision and supporting research program (in line with the strategic research plan in the Management Plan) for the following season.

1.5. Information sources used for assessment

1.5.1. Commercial catch and effort statistics

SARDI maintains a comprehensive catch and effort database for the BCF using data recorded by licensed fishers from the compulsory '*South Australian Commercial Blue Crab Pot Fishery Logbook'*. These data were first collated for the 1996/97 fishing season. Historical data from the fishery were recorded into the 'GARFIS' catch and effort database of the South Australian Fisheries Department from 1983/84.

In addition to the two PIs from the stock assessment FIS, the only other indicator for the fishery, commercial catch per unit effort (CPUE), is derived from the catch and effort logbook, which is completed daily and submitted at the end of each month.

1.5.2. Recreational catch and effort statistics

Quantifying the recreational sector's contribution to the State's total catch is important in determining the overall status of fish stocks and resolving resource allocation issues. There have been four extensive recreational fishing surveys carried out in South Australia over the past 20 years. The first was a creel survey that was undertaken throughout 1994 to 1996 (McGlennon and Kinloch, 1997). State-wide telephone/diary surveys were undertaken in 2000/01 (Henry and Lyle, 2003), 2007/08 (Jones, 2009) and 2013/14 (Giri and Hall, 2015). Of these four surveys, only the results from the three most recent can be reliably compared as their data were collected using similar methods.

1.5.3. Fishery-independent survey

Fishery-independent surveys have been conducted for the BCF during June or July on an annual basis since 2002. The primary aim of the FIS is to determine the relative abundance and size composition of blue crabs in SG and GSV during winter (June/July), when juveniles generally recruit to the fishery. This also coincides with the end/beginning of the quota season.

Of the three PIs, the two that are primarily used to inform the annual TACC decision for the fishery are derived from these FIS: 1) survey CPUE of legal-size crabs; and 2) survey CPUE of pre-recruits.

1.5.4. Fishery-dependent pot-sampling

The pot-sampling program sampled small-mesh pots used in the fishery to estimate CPUE of pre-recruits (pre-recruits.potlift^{-1}) and to quantify the size composition of blue crabs throughout the fishing season to provide information on recruitment strength and sex ratio. Pot-sampling data have been voluntarily collected since May 2006 in SG and July 2006 in GSV.

1.6. Harvest strategy

1.6.1. Management Plan

The Management Plan for the BCF (PIRSA, 2012) was prepared by the Fisheries Council of South Australia as required under the *Fisheries Management Act* 2007. It includes a specific harvest strategy for the BCF to set the TACC at a level that aims to ensure stock sustainability, as well as retain certainty and stability for the industry.

The key objectives of the Management Plan are: (1) ensure the blue crab resource is harvested within ecologically sustainable limits; (2) allocate access to the blue crab resource to achieve optimum utilisation and equitable distribution to the benefit of the community; (3) minimise impacts on the ecosystem; and (4) deliver cost-effective and participative management of the fishery.

The Management Plan provides a strategic direction for management of the fishery. In addition to providing details of the current harvest strategy, it emphasises the need to improve the quality of both fishery-dependent and fishery-independent information, thereby building scientific knowledge and developing a future harvest strategy that comprises more robust fishery PIs and reference points that are explicitly linked to TACC decisions. Explicit TACC decision rules in the future will provide greater certainty on how the fishery will be sustainably managed under the quota management system.

1.6.2. Performance indicators

Key biological PIs and reference points have been established to guide the annual TACC decision-making process (Table 1.1). Harvest decision rules stipulate that if the limit reference point for any PI is not achieved, PIRSA Fisheries and Aquaculture and the South Australian Blue Crab Pot Fishers' Association (SABCPFA) will review the TACC and consider the possibility of a decrease from the baseline TACC. This is deemed to be a precautionary response in the Management Plan that reflects the current level of understanding about the species, fishery production and dynamics, and the limitations of existing fishery data.

Table 1.1 Key biological performance indicators and reference points for the BCF. Abbreviation: FIS, fishery-independent survey; CPUE, catch per unit effort; Spencer Gulf SG; Gulf St Vincent, GSV.

Gulf	Data source	Performance indicator	Limit ref. point	
			Lower	Upper
SG	1. FIS	CPUE of legal-size crabs (legal-size crabs.potlift^{-1})	5	8
	2. FIS	CPUE of pre-recruits (pre-recruits.potlift^{-1})	2	9
	3. Commercial catch and effort	CPUE of legal-size crabs (kg.potlift^{-1})	2	4
GSV	1. FIS	CPUE of legal-size crabs (pre-recruits.potlift^{-1})	1.5	4
	2. FIS	CPUE of pre-recruits (legal-size crabs.potlift^{-1})	1.5	8.5
	3. Commercial catch and effort	CPUE of legal-size crabs (kg.potlift^{-1})	2	4

1.6.3. Allocation of access

The Act provides that a Management Plan must specify the share of the fishery to be allocated to each fishing sector under the plan. The Act also provides that, in determining the share of aquatic resources to be allocated to a particular fishing sector under the first Management Plan for an existing fishery, the share of aquatic resources to which that fishing sector had access to at the time the Minister requested the Council to prepare the plan (based on the most recent information available to the Minister) must be taken into account.

The Minister formally requested that the Fisheries Council prepare the Management Plan for the BCF on 3 July 2008. Therefore, the plan must take into account the share of the blue crab resource that the commercial fishing sector had access to at that time. Allocations for the recreational and Aboriginal traditional fishing sectors must be determined at the same time. The shares allocated to each sector in relation to the BCF are detailed in Table 1.2.

Table 1.2 Allocation of shares to each sector in the Blue Crab Fishery (PIRSA, 2012).

Commercial		Recreational	Aboriginal traditional
Blue Crab Fishery	Marine Scalefish Fishery	29%	1%
65.5%	4.5%		

1.7. Stock status classification

A national stock status classification system was recently developed for the consistent stock determination of key Australian fish stocks (Flood *et al.,* 2014). It considers whether the current level of fishing pressure is adequately controlled to ensure that stock abundance is not reduced to a point where the production of juveniles is significantly compromised. The system combines information on both the current stock size and level of catch into a single classification for each stock against defined biological reference points. Each stock is then classified as either: ‘sustainable’, ‘transitional-recovering’, ‘transitional-depleting’, ‘overfished’, ‘environmentally limited’, or ‘undefined’ (Table 1.3). PIRSA has adopted this classification system to determine the status of all South Australian fish stocks (PIRSA 2015).

Table 1.3 Stock status terminology (Flood *et al.,* 2014).

	Stock status	Description	Potential implications for management of the stock
	Sustainable	Stock for which biomass (or biomass proxy) is at a level sufficient to ensure that, on average, future levels of recruitment are adequate (i.e. not recruitment overfished) and for which fishing pressure is adequately controlled to avoid the stock becoming recruitment overfished	Appropriate management is in place
↑	Transitional–recovering	Recovering stock—biomass is recruitment overfished, but management measures are in place to promote stock recovery, and recovery is occurring	Appropriate management is in place, and the stock biomass is recovering
↓	Transitional–depleting	Deteriorating stock—biomass is not yet recruitment overfished, but fishing pressure is too high and moving the stock in the direction of becoming recruitment overfished	Management is needed to reduce fishing pressure and ensure that the biomass does not deplete to an overfished state
	Overfished	Spawning stock biomass has been reduced through catch, so that average recruitment levels are significantly reduced (i.e. recruitment overfished). Current management is not adequate to recover the stock, or adequate management measures have been put in place but have not yet resulted in measurable improvements	Management is needed to recover this stock; if adequate management measures are already in place, more time may be required for them to take effect
	Environmentally limited	Spawning stock biomass has been reduced to the point where average recruitment levels are significantly reduced, primarily as a result of substantial environmental changes/impacts, or disease outbreaks (i.e. the stock is not recruitment overfished). Fisheries management has responded appropriately to the environmental change in productivity	Appropriate management is in place
	Undefined	Not enough information exists to determine stock status	Data required to assess stock status are needed

2. METHODS

2.1. Commercial catch and effort statistics

Commercial logbook data are compulsorily recorded by licensed fishers in the SG and GSV pot fishing zones and the MSF. Detailed analyses of these data in the SG and GSV pot fishing zones since the introduction of quota (1996/97) are provided in the results. Confidentiality agreements preclude the presentation of catch and effort data from a small number of MSF participants (<5 fishers) since 2007/08.

In addition to catch and effort data, daily records of fishing block, depth, sex and number of blue crabs caught are also recorded by the pot fishing sector. With respect to catch and effort, additional information is recorded on second potlifts, when pot fishers have lifted and reset their gear on the same day. Under these circumstances, soak time is generally 18 to 20 hours for the first potlift, and 4 to 6 hours for the second potlift. Logbooks also provide for recording the numbers of undersized blue crabs (pre-recruits) and berried females before being returned to the water.

For analyses and presentation of commercial logbook data throughout this report, effort data are expressed in boat days (days fished per licence). CPUE is expressed as kg.boat day^{-1} or kg.potlift^{-1}.

2.2. Recreational catch and effort statistics

The specific details of the methods used in the three recreational surveys considered in this chapter can be found in their respective reports (2000/01: Henry and Lyle, 2003; 2007/08: Jones, 2009; 2013/14: Giri and Hall, 2015).

2.3. Fishery-independent survey

Fishery-independent surveys are conducted using industry vessels, skippers and crews, with independent observers placed on each vessel to collect data on blue crab size and CPUE. While there has been some inter-annual variability in the timing of the FIS, they have been generally undertaken during the winter months of June and July in both gulfs with an additional FIS in March 2015 in GSV (Figure 2.1). Information on the March 2015 survey is presented in Appendix A.

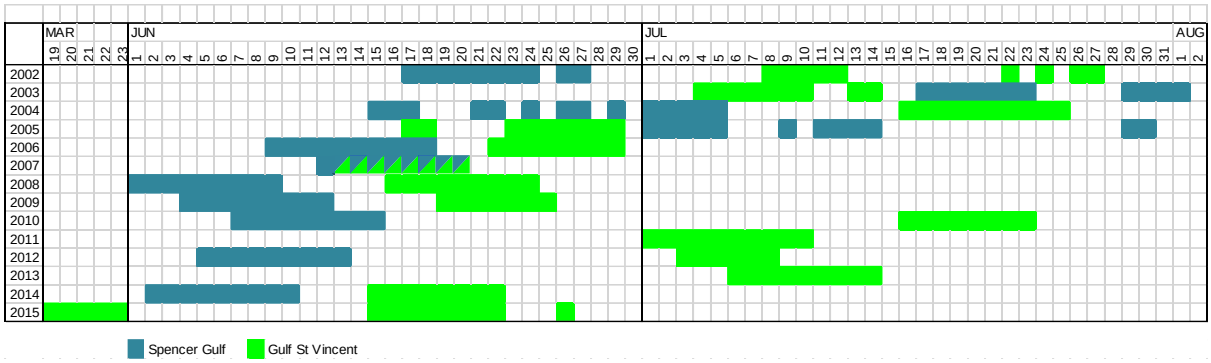


Figure 2.1 Fishery-independent survey calendar for Spencer Gulf and Gulf St Vincent from 2002 to 2015.

In the event that the FIS quantifies CPUE of pre-recruits to be above the average for the previous 10-years in either gulf, the Management Plan provides the option for the FIS to be omitted for that gulf in the following year (PIRSA, 2012). As a result of high CPUE of legal-size and pre-recruit crabs in SG determined from the 2010, 2012 and 2014 FIS, the decision was made by the SABCPFA and PIRSA Fisheries and Aquaculture to not conduct a FIS in that gulf in 2011, 2013 and 2015.

The area of the FIS encompasses waters with depths ranging from 3 to 22 m northwards of a line from Wallaroo to Cowell in SG and northwards of a line from Glenelg to Port Vincent in GSV (Figure 2.2). Sampling locations were determined based on fisher knowledge and historical catch and effort data. From these recommendations, four FIS sites were selected in each fishing block. For the March 2015 GSV FIS, the survey was rationalised by not sampling sites with consistently low abundances of legal-size and pre-recruit crabs. In addition, several other sites were excluded to minimise vessel travel time between sampling locations. These changes were required to reduce sampled to reduce the FIS duration to the five-day limit stipulated by PIRSA Fisheries and Aquaculture (see appendix A).

Fewer potlifts (approximately 22% less in SG and 41% less in GSV) were undertaken during June/July 2002 than in subsequent years. From June 2008, the FIS design was modified by SARDI, PIRSA and industry to provide a more representative measure of relative abundance of blue crab in each gulf. Changes included removing all sampling locations from some fishing blocks, adding new FIS locations to previously un-surveyed blocks, and relocating sampling locations within existing blocks (Figure 2.2) Unless stated otherwise, 'standard' refer to locations that have not changed since 2002, while 'revised' locations refer to all locations sampled since 2008.

At each FIS location, commercial and small-mesh pots were set and hauled on a daily basis, except for the GSV July 2012 FIS, where only small-mesh pots were used. Commercial pots

have increased in size and larger mesh or escape gaps have become common since 2006/07. Most operators have also switched from single or double set pots to long lines since 2006/07 (Beckmann *et al.,* 2015). To standardise data collected in the FIS, research pots have remained unchanged with a diameter of 140 cm, a height of 50 cm, and a mesh size of 5.5 cm. At each FIS location, five sets of gear were deployed, each set comprising one commercial pot (except for GSV in July 2012) and one small-mesh pot. Each set of gear was spaced 150 m apart and, where both pot types were used, each pot was separated by 40 m of rope. Since June 2014, pots in GSV have been set along a single line (long line) at each FIS location with each set of gear spaced at 76 m apart. Pots were baited with fresh Australian salmon, sardines or striped trumpeter, and hauled from dawn each day.

A global positioning system (GPS) was used to locate the gear, and depth was recorded at each FIS location. Carapace width (mm) of blue crabs was measured using Vernier callipers, and details of sex (male or female) and condition (dead, soft, berried) were recorded. Data on by-catch species were collected during the FIS, however, these are not presented in this report. An assessment of by-catch data from 2002 to 2006 was presented in Currie *et al.* (2007). This dataset will be useful for future work examining changes in community structure.

Fishery-independent survey CPUE is expressed as the average number of legal-size per potlift or pre-recruits per potlift (small-mesh pots only) for each FIS and is used as a measure of relative abundance. Size frequency information is presented as the number of crabs in the specified size class per potlift for FIS undertaken since 2008. ArcGIS (ArcMap 10.1) software was used to depict the spatial patterns in crab abundance over time that were then evaluated visually. The kernel density method was used to calculate the density of point features within each output raster cell (100 m * 100 m). Conceptually, a smoothly curved surface is fitted over each point, where the surface value is highest at the location of the point and diminishes with increasing distance from the point, reaching zero at the search radius. A search radius of 7500 m was used to generate kernel density maps for both SG and GSV.

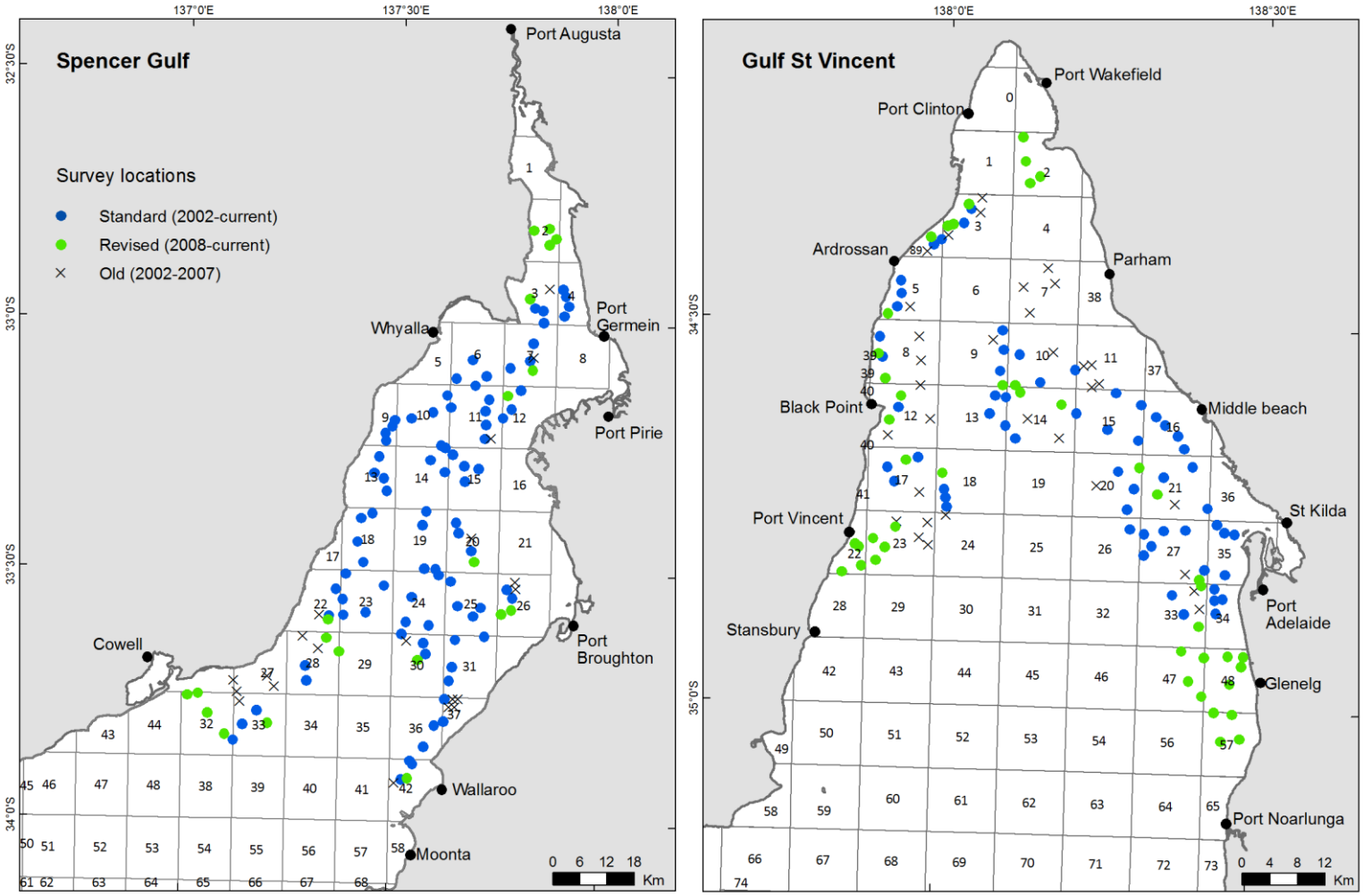


Figure 2.2 Commercial fishing blocks (grid) and fishery-independent survey locations In the Spencer Gulf and Gulf St Vincent zones of the Blue Crab Fishery.

2.4. Fishery-dependent pot-sampling program

The pot-sampling program collects fishery-dependent catch and effort data from small-mesh pots. The size and sex composition of blue crabs throughout the fishing season is recorded to provide supplementary information on recruitment strength. These data have been collected since May 2006 in SG and July 2006 in GSV, although data have only been considered reliable since 2008 (a summary of these data are presented in Tables 2.1 and 2.2).

Initially, sampling was voluntarily undertaken from one small-mesh pot and one commercial pot each fishing day. The focus of the sampling program shifted towards the CPUE of pre-recruits, so data were collected exclusively from one small-mesh pot only from May 2008 to July 2010, and from up to two small-mesh pots from July 2010 onwards. Data collected from participating licensed fishers include date, licence number, fishing block, GPS coordinates of pot locations, depth, water temperature, and sex and size of individual crabs. CPUE is expressed as the annual and monthly mean number of pre-recruits per potlift.

Table 2.1 Summary of the pot-sampling data collected in the Spencer Gulf pot fishing zone from 2008–2015 (calendar year).

Statistic	2008	2009	2010	2011	2012	2013	2014	2015
No. of active licences	5	5	4	4	4	4	4	4
No. of licences providing data	4	4	4	3	4	4	4	2
No. of boat days during sampling period	971	696	734	526	664	732	700	628
No. of boat days sampled	434	523	493	128	532	665	581	80
% of total boat days sampled	45%	75%	67%	24%	80%	91%	78%	13%
No. of blocks sampled	28	27	28	8	32	29	20	7
% of total blocks fished	72%	93%	78%	35%	97%	69%	61%	64%
Pots sampled	435	526	514	129	537	688	584	81
No. of crabs measured	8,526	8,750	10,204	2,585	12,699	16,307	12,216	2,291

Table 2.2 Summary of the pot-sampling data collected in the Gulf St Vincent pot fishing zone from 2008–2014 (calendar year).

Statistic	2008	2009	2010	2011	2012	2013	2014	2015
No. of active licences*	4	3	3	3	3	3	3	3
No. of licences providing data	3	3	3	3	3	3	3	3
No. of boat days during sampling period	443	492	425	512	407	203	590	638
No. of boat days sampled	169	327	352	353	300	188	465	535
% of total boat days sampled	38%	66%	83%	69%	74%	93%	79%	84%
No. of blocks sampled	10	13	19	15	21	14	18	24
% of blocks fished sampled	67%	59%	70%	63%	72%	70%	86%	86%
No. of pots sampled	170	331	374	371	385	261	537	720
No. of crabs measured	3,485	5,473	7,308	6,845	6,423	4,960	13,595	20,619

2.5. Fishery Performance

Primary biological PIs are identified to provide measures of the status of the fishery and predictions about the future performance of the fishery. Analysis of these indicators is incorporated into the decision rules for the fishery, which are used to inform the annual TACC decisions for the fishery.

For the BCF the three key biological PIs specified in the Management Plan (PIRSA 2012) are:

1. Survey CPUE of pre-recruit crabs (crabs.potlift^{-1})
2. Survey CPUE of legal-sized crabs (crabs.potlift^{-1})
3. Commercial CPUE of legal-sized crabs (kg.potlift^{-1})

2.6. Quality assurance of data

All logbook data are entered and validated according to the quality assurance protocols identified for the BCF in the SARDI information systems quality assurance and data integrity report (Vainickis, 2010). The data are stored in an Oracle database, backed up daily, with access restricted to SARDI Information Systems staff. Extracts from the database are provided to SARDI crab researchers on request. All fishery-independent data are entered into Excel spreadsheets. Accuracy of data entry is verified by checking a subset (20%) of the data against the original data sheets. Once validated, data are stored on a network drive with restricted access to SARDI staff involved in research projects undertaken by the Inshore Crustaceans Subprogram.

Data are extracted from the databases using established protocols. Accuracy of the data extracted is checked by comparing pivot table summaries with previous data extractions. The analyses in this report were carried out independently for multiple years at a time to confirm they were accurate compared to the results of previous reports.

The results, their interpretation and conclusions provided in the reports are discussed with peers, PIRSA Fisheries and Aquaculture, and BCF licence holders. All co-authors review the report prior to the report being formally reviewed by at least two independent scientists at SARDI in accordance with the SARDI report review process.

3. RESULTS

3.1. State-wide

Since 1985/86, the majority of the State's blue crab catch has been harvested in SG and GSV. The State-wide commercial catch of blue crabs increased from 87 t in 1983/84 to 618 t in 1995/96 (Figure 3.1). Following the introduction of quota in the gulfs in 1996/97, State-wide catch was reduced by 29% and then catch increased until 2007/08 when the entire TACC of 627 t was caught. The total commercial catch remained below the TACC from 2008/09–20013/14, although the entire TACC was nearly caught (>98%) in 2011/12 and 2013/14. In 2014/15, 196 t was harvested by the GSV pot fishing (PF) sector, 377 t by the SG pot fishing sector and 3 t by the MSF sector (in GSV and SG). This catch equates to 577 t or 99.8% of the TACC (578 t).

Although MSF licence holders are permitted to harvest blue crabs on the west coast, their relative contribution to the harvest has been low since 1986/87 (Figure 3.1). In 2014/15, 41 t was harvested from the west coast (7% of the total commercial harvest). This represents a 28% decrease from 2013/14 (57 t).

Estimates of recreational harvest have ranged from 390 t between May 2000 and April 2001 (Henry and Lyle, 2003), 283 t between November 2007 and October 2008 (Jones, 2009), and 376 t between December 2013 and November 2014 (Giri and Hall, 2015). Also, McGlennon and Kinloch (1997) estimated an annual recreational catch of 161 t, of which 116 t was taken in GSV and 45 t in SG. This estimate was derived from a 'creel survey' of recreational vessels only and does not include the recreational shore-based fishery, thus making it difficult to compare with the more comprehensive surveys of 2000/01, 2007/08 and 2013/14.

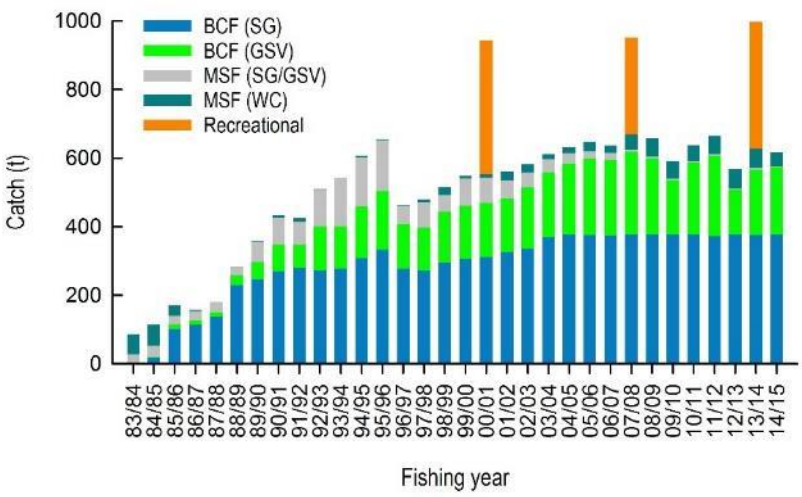


Figure 3.1 Commercial and recreational catch (t) of blue crabs from 1983/84 to 2014/15. Abbreviations– Blue Crab Fishery, BCF; Spencer Gulf, SG; Marine Scalefish Fishery, MSF; Gulf St Vincent, GSV; west coast, WC; total allowable commercial catch, TACC.

3.2. Spencer Gulf

Spencer Gulf has been the most productive zone of the BCF since 1984/85. The highest recorded commercial catch was 382 t in 2007/08 and the lowest was 5 t in 1983/84 when the fishery began (Figure 3.2a). Following the introduction of quota in 1996/97, a 19% reduction in catch occurred from 367 t in 1996/97 to 297 t in 1997/98. Catch gradually increased from 1998/99, stabilised in 2003/04 with greater than 98% of the quota allocation thereafter. In 2014/15, 380 t was harvested from SG, equating to approximately 99.6% of the TACC (382 t).

Prior to the introduction of quota, there was a long-term trend of increasing fishing effort in SG, from 89 boat days in 1983/84 to 1,365 boat days in 1994/95 (Figure 3.2b). After the introduction of quota, effort declined from 1,255 boat days in 1996/97 to 663 boat days in 2010/11. Trends in effort were largely driven by the pot fishing sector which consistently contributed to more than 78% of fishing effort since 1985/86 and more than 90% of effort since 2002/03. In 2014/15 effort increased by 10% to 779 boat days compared to 709 boat days in 2013/14. The value of effort recorded in 2014/15 was the highest level of effort since 2008/09, but below the previous 10-year mean of 828 ± 48 boat days (standard error, SE).

The number of total potlifts in SG has fluctuated through time (Figure 3.2c). Between 2002/03 and 2006/07, the number of potlifts was relatively stable with a mean of 133,057±1,511 potlifts. A large reduction in effort was recorded between 2008/09 and 2011/12 with a historical low of 84,756 potlifts recorded in 2011/12. Between 2011/12 and 2014/15 the total number of potlifts increased 12% to 104,832. Less than 18,000 second potlifts were recorded from 1997/98 to 2003/04. From 2003/04 to 2008/09, the number of second potlifts increased by 57% to 60,398 potlifts before declining in 2010/11 by 93% to 27,118 potlifts. Since 2011/12, the number of second potlifts has remained below 12,000. The proportion of total potlifts recorded as second potlifts also decreased between 2008/09 and 2014/15 from 41% to 11%.

Nominal CPUE for the pot fishing (PF) sector ranged from 63 kg.boat day^{-1} in 1984/85 to 323 kg.boat day^{-1} prior to the introduction of quota in 1995/96 (Figure 3.2d). Following the introduction of quota, CPUE remained below 370 kg.boat day^{-1} until 2006/07, before peaking at 616 kg.boat day^{-1} in 2010/11. In 2014/15, the CPUE remained relatively high at 519 kg.boat day^{-1} and this was above the 10-year mean (504 ± 29 kg.boat day^{-1}). CPUE in the MSF sector have not exceeded 140 kg.boat day^{-1} in the history of the fishery and were 61 kg.boat day^{-1} in 2014/15. Following the introduction of quota, mean nominal potlift CPUE remained below 3.8±0.1 kg.potlift^{-1} until 2010/11 and reached a maximum of 4.4±0.1 kg.potlift^{-1} in 2011/12. Potlift CPUE decreased from 4.0±0.1 kg.potlift^{-1} in 2013/14 to 3.7±0.1 kg.potlift^{-1} in 2014/15.

There has been a generally increasing trend in mean nominal survey CPUE for legal-size crabs in SG since 2003 (Figure 3.2e) with mean legal-size survey CPUE measured from the FIS ranging between 5.1±0.3 legal-size.potlift^{-1} in 2003 and 10.0±0.3 legal-size.potlifit^{-1} in 2014. Since 2009, legal-size CPUE has exceeded the upper limit reference point. A similar trend observed at standard and revised locations since 2008. In 2014, the survey CPUE of legal-size crabs was 10.0±0.3 legal-size.potlift^{-1} at standard locations compared to 10.3±0.3 legal-size.potlift^{-1} at revised locations.

Pre-recruit CPUE recorded in the FIS have fluctuated since 2002 (Figure 3.2g). Between 2002 and 2005, pre-recruit CPUE decreased by 67% to a low of 2.3±0.2 pre-recruits.potlift^{-1}. Between 2006 and 2007, pre-recruit CPUE increased 226% to a historical high of 10.1±0.3 pre-recruit.potlift^{-1} and above the upper limit reference point. Since 2008 when new potlifts were introduced, pre-recruit CPUE at revised locations has followed a similar trend to standard locations. Low survey CPUE of pre-recruits was observed in 2009 with 3.0±0.2 pre-recruits.potlift^{-1} and 2.9±0.2 pre-recruits.potlift^{-1} recorded at standard and revised locations, respectively. The CPUE of pre-recruits increased by 212% between 2009 and 2014 at standard locations, and 214% at revised locations. In 2014, the survey CPUE of pre-recruit crabs was above the upper limit reference point for the second time with 9.4±0.4 pre-recruits.potlift^{-1} observed at standard locations and 9.1±0.3 pre-recruits.potlift^{-1} at revised locations.

Similar to the trends in pre-recruit abundance recorded by the FIS, yearly estimates of pre-recruit CPUE from the pot-sampling program suggest that pre-recruit abundance has generally increased since 2009/10 (Figure 3.2h). The CPUE of pre-recruits reached a low of 4.6±0.2 pre-recruits.potlift^{-1} in 2009/10 before increasing to a historical high of 10.9±0.4 pre-recruits.potlift^{-1} in 2013/14. In 2014/15, the CPUE of pre-recruits was 9.1±0.4 pre-recruits.potlift^{-1}.

There is some evidence of seasonal trends in in the CPUE of pre-recruits from the pot-sampling program, with peaks in the CPUE of pre-recruits generally occurring in mid-winter and early-summer (Figure 3.3). In 2015, the CPUE of pre-recruits was high from October–December, peaking at a historical high of 20.5±2.9 pre-recruits.potlift.$^{-1}$ in December. However, participation in the pot-sampling program for 2015 was the lowest observed since 2007 with voluntary potlifts making up less than 1% of the total potlifts undertaken.

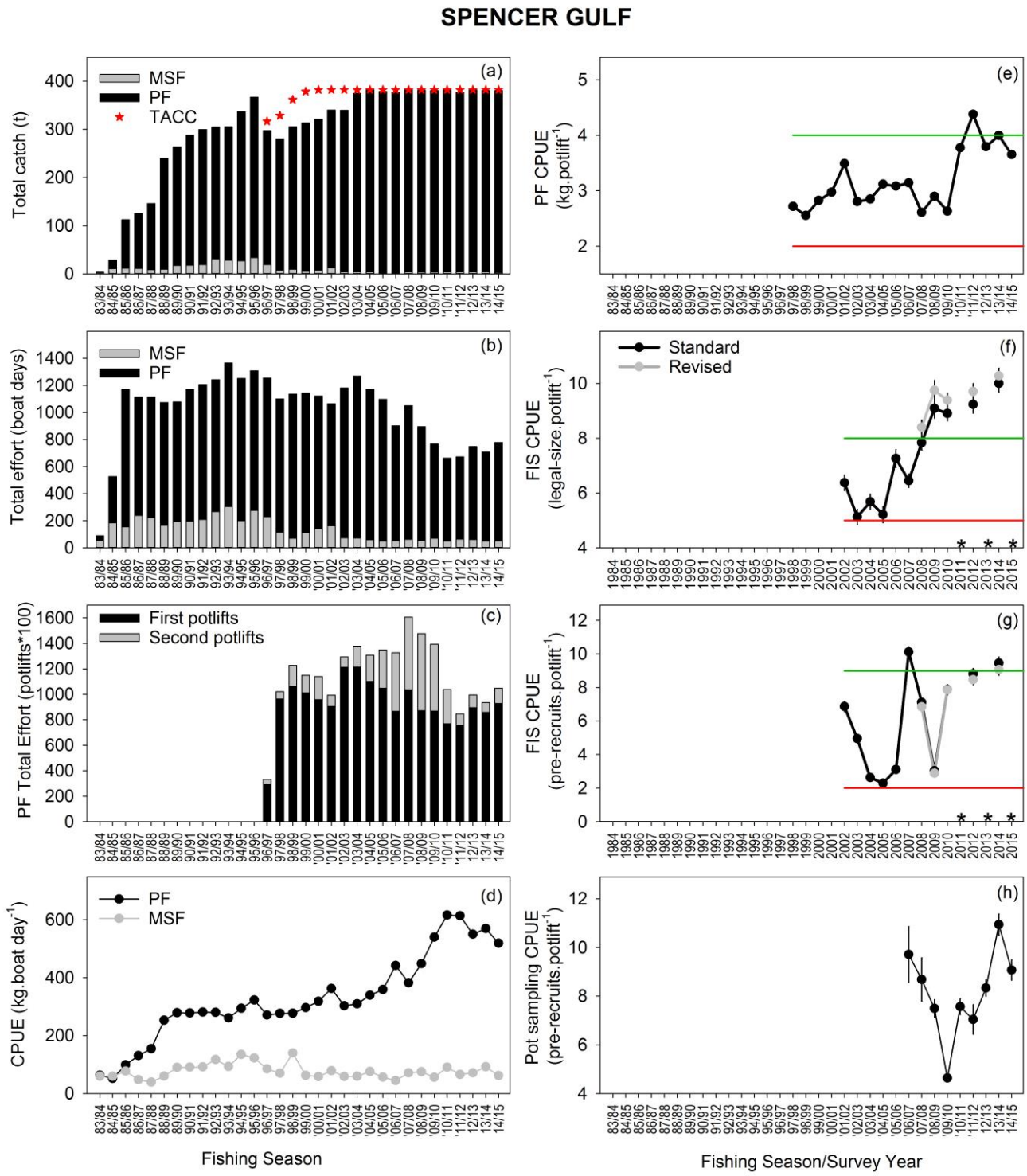


Figure 3.2 Key outputs used to assess the status of the Spencer Gulf zone of the Blue Crab Fishery. (a) Trends in total catch (t) for pot fishing (PF) and Marine Scalefish Fishery (MSF) including total allowable commercial catch (TACC) limit; (b) total effort (boat days) for PF and MSF sector; (c) total effort from first and second potlifts for PF sector; (d) CPUE (kg/boat day) for the PF and MSF sectors; (f) CPUE (kg.potlift) for the PF sector; (f) fishery-independent survey (FIS) pre-recruit CPUE (pre-recruits.potlift^{-1}); (g) FIS legal-size CPUE (legal-size.potlift^{-1}); (h) pre-recruit CPUE from the pot-sampling program (pre-recruits.potlift^{-1}). Green and red lines represent the upper and lower trigger reference points identified in Table 3.1; error bars, standard error; FIS were not conducted in 2011, 2013 and 2015*.

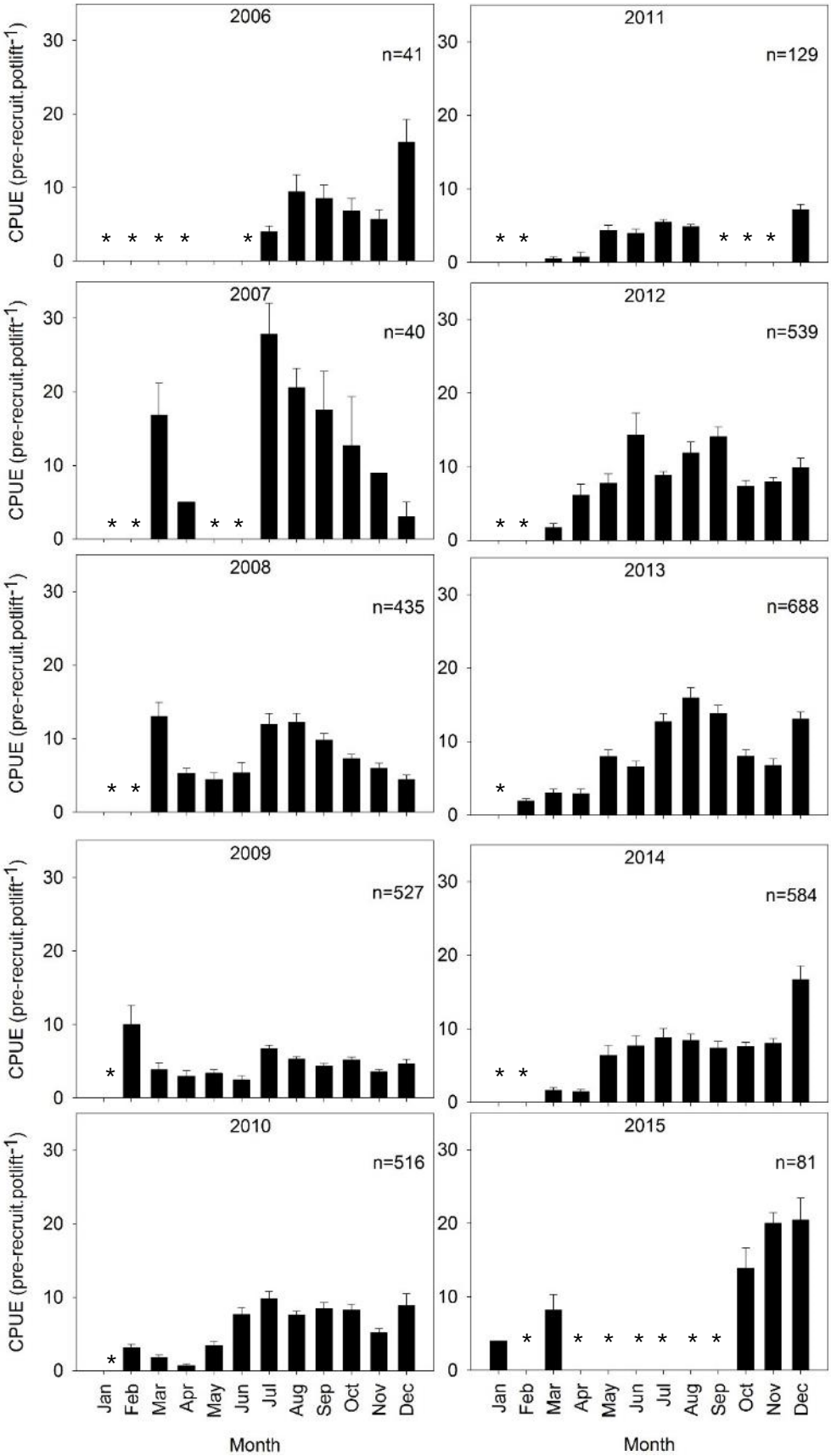


Figure 3.3 Monthly mean catch per unit effort (CPUE) of pre-recruits from pot-sampling undertaken by the Spencer Gulf pot fishing zone. Sample size (n), number of pots. Error bars, standard error. *No sampling during this month.

Spatial mapping of density data obtained from the FIS indicate that the average relative densities of legal-size crabs measured in 2008–10, 2012 and 2014, were distributed widely throughout the gulf (Figure 3.4). In 2008-09, the relative densities of legal-size crabs were concentrated in the northern gulf. In 2010, high densities of legal-size crabs were observed in the northern gulf. In 2012, the density of legal-size crabs was high in the southern gulf. Legal-size crabs were also broadly distributed in 2014, with high densities recorded in all three zones.

Spatial mapping of density data obtained from the FIS indicate that pre-recruit crabs showed a similar distribution to legal-size crabs in most years (Figure 3.5). The exception was in 2009 when low pre-recruit density was observed throughout the gulf. The most recent FIS in 2014, identified record high pre-recruit CPUE with high densities observed at sites throughout the gulf but particularly in the central zone.

Since 2008, a large proportion (53–77%) of crabs sampled during the June/July FIS have been of legal-size (110 mm carapace width, CW). The modal size of male crabs sampled was 110–114 mm CW in 2008 and 2012 while crabs in the size range 115–119 mm CW dominated samples in 2009 and 2014 (Figure 3.6). Larger modal sizes of male crabs were observed in 2010 at 120–124 mm CW. Female crabs tended to be slightly smaller, with crabs of the size range 105–109 mm CW dominating in 2008 and 2014. The modal size of female crabs was larger in 2012 at 110–114 mm CW and 115–119 mm CW in 2009 and 2010.

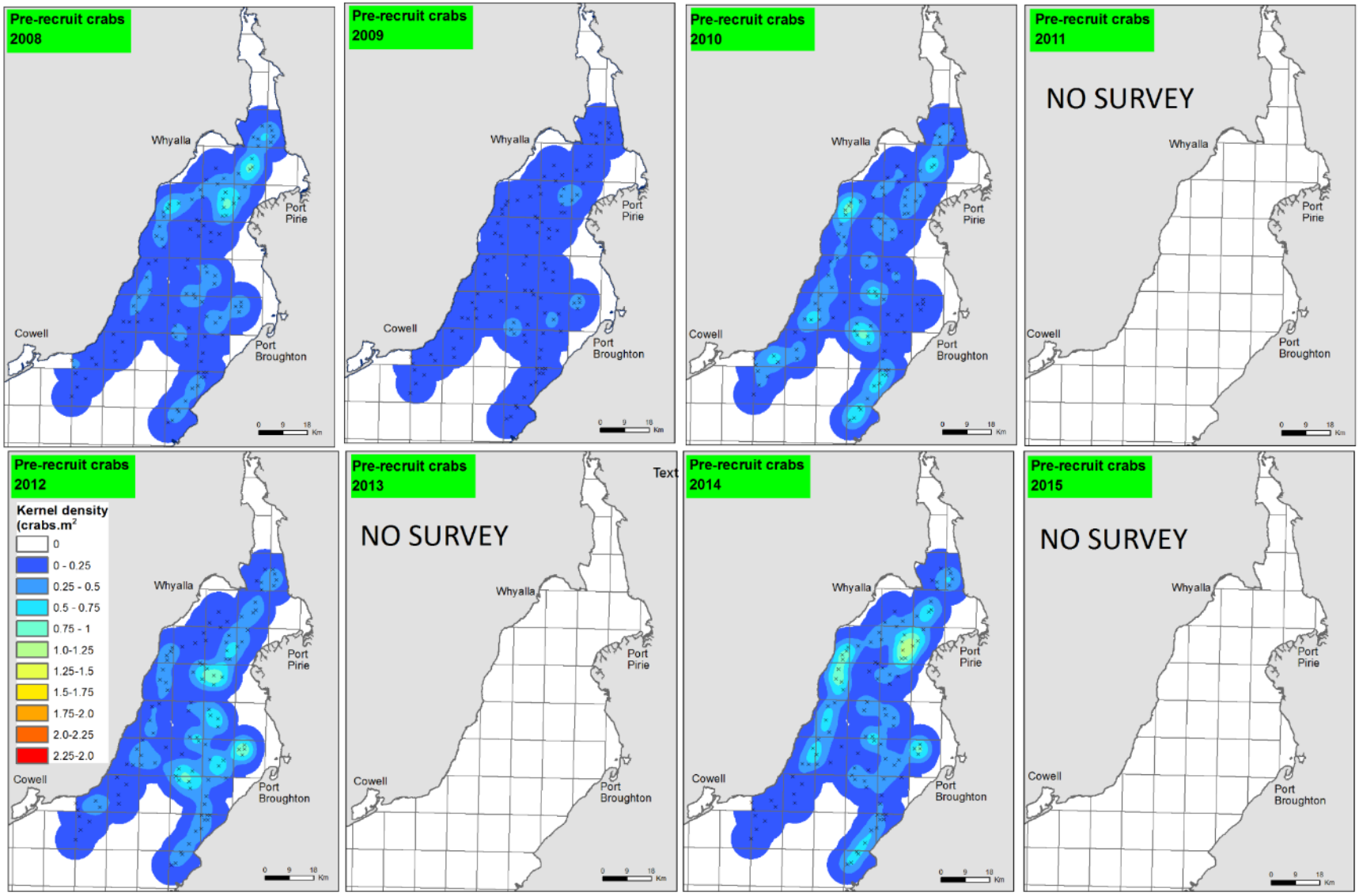


Figure 3.4 Kernel density maps showing the relative density (crabs per square metre) of pre-recruit crabs from June/July fishery-independent surveys (FIS) sampled at revised locations from 2008–15 in Spencer Gulf. FIS were not conducted in 2011, 2013 or 2015. Sampling locations denoted by x.

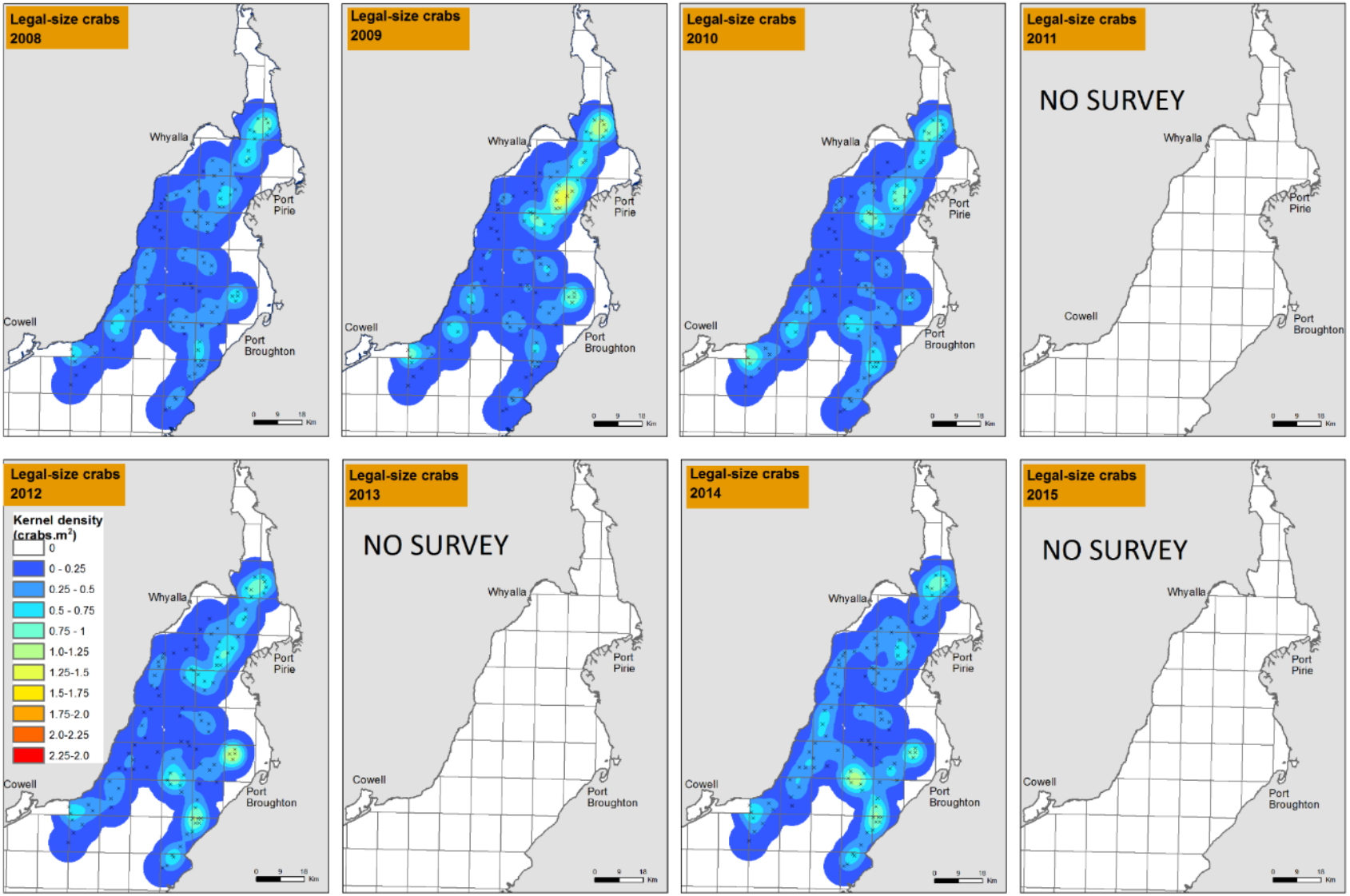


Figure 3.5 Kernel density maps showing the relative density (crabs per square metre) of legal-size crabs from June/July fishery-independent surveys (FIS) sampled at revised locations in Spencer Gulf from 2008–15. FIS were not conducted in 2011, 2013 or 2015. Sampling locations denoted by x.

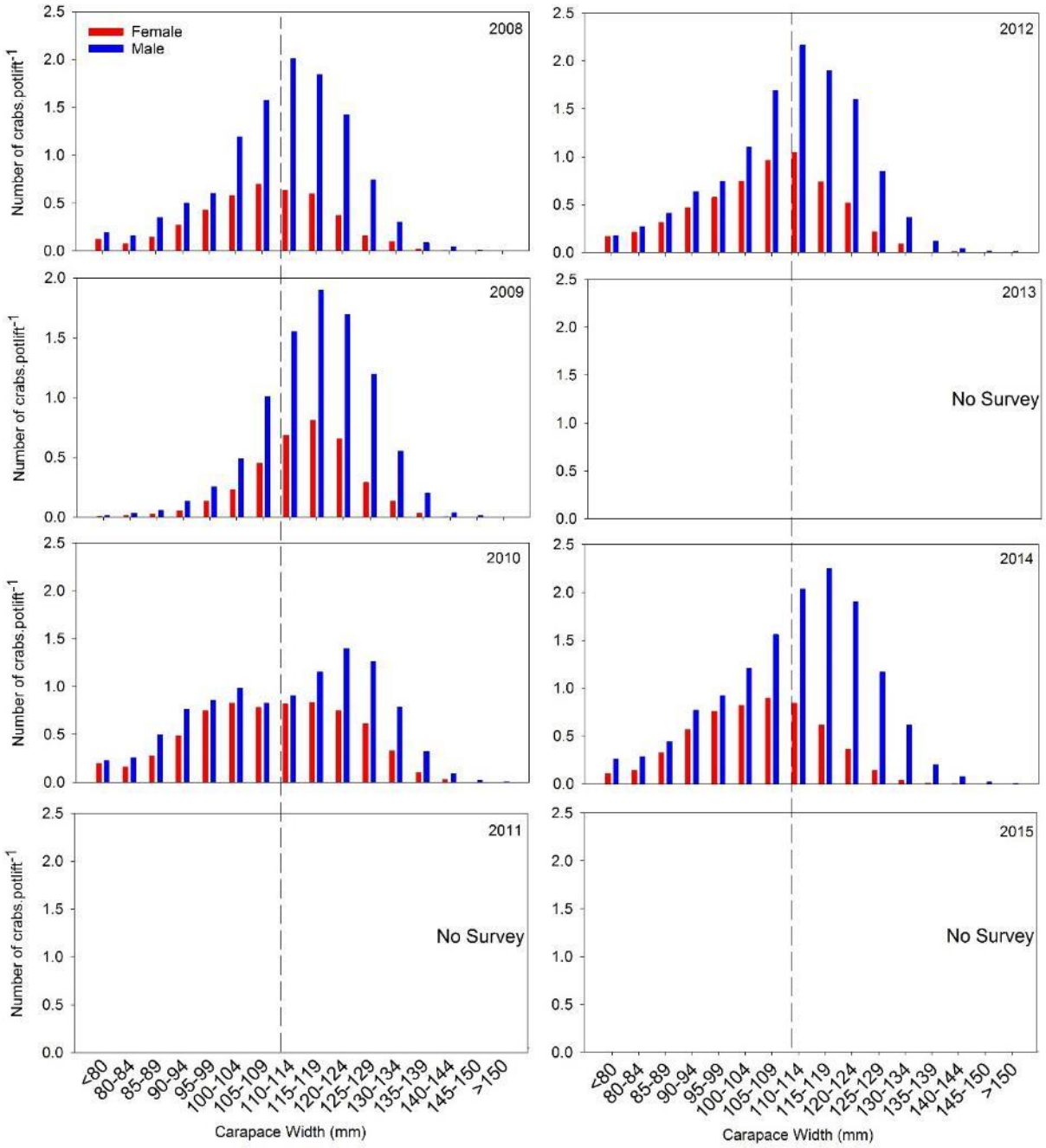


Figure 3.6 Length frequency distributions of male and female blue crabs from June/July fishery-independent surveys in Spencer Gulf sampled at revised locations from 2008–2015 and 2014. Minimum size limit 110 mm carapace width, CW (---). FIS were not conducted in 2011, 2013 or 2015

3.3. Gulf St Vincent

In terms of catch, GSV is the second most productive zone of the BCF, producing more than 100 t of blue crabs per season since 1990/91. The highest recorded commercial catch was 285 t in 1995/96 and the lowest catch was 22 t in 1983/84 when the fishery began (Figure 3.7a). Following the introduction of quota in 1996/97, a 42% reduction in catch occurred from 285 t in 1996/97 to 165 t in 1997/98. Catch gradually increased from 1997/98, with 234 t harvested in 2007/08 comprising 99% of the TACC (245.1 t). Catch then fluctuated reaching a low of 129 t in 2012/13, when commercial catch was voluntarily reduced by almost 50%. The GSV share of TACC was subsequently reduced by 20% in 2013/14 and 2014/15 to 196 t. In 2014/15, the entire TACC for the GSV (196 t) was harvested for the first time.

Prior to the introduction of quota there was a long-term trend of increasing fishing effort in this region, from 441 boat days in 1983/84 to 2,111 boat days in 1995/96 (Figure 3.7b). The MSF sector contributed between 54% and 93% of the annual effort prior to the introduction of quota. After the introduction of quota, effort was largely transferred to the pot fishing sector resulting in a 55% decline in effort to 958 boat days in 1996/97. Effort reached a minimum of 315 boat days in 2012/13 and since 2008/09, the MSF sector has not contributed to catch in GSV. In 2014/15, effort increased by 22% to 492 boat days compared to 404 boat days in 2013/14. This was the highest level of effort since 2007/08, but remained below the 10-year mean (516±43 boat days).

The number of total potlifts and boat days in GSV followed similar trends from 1997/98 to 2004/05. Thereafter, the two measures of effort diverged, with the number of potlifts increasing relative to the number of boat days (Figure 3.7c). The number of total potlifts peaked at 75,508 in 2005/06 and decreased by 12% to 66,416 potlifts in 2010/11. In 2012/13, the number of total potlifts decreased a further 23% to 56,373. The total number of potlifts has remained below 57,000 since 2012/13 with 56,264 potlifts recorded in 2014/15. The number of second potlifts has fluctuated since the introduction of quota, reaching a maximum number of potlifts (13,367 potlifts) in 2008/09. The proportion of total potlifts recorded as second potlifts was also the highest in 2008/09 (20%). A low number of second potlifts (<1,000 potlifts) were recorded in 1998/99 (432 potlifts), 2001/02 (620 potlifts) and 2013/14 (139 potlifts), and 2012/13 and 2014/15 were the only years in which no second potlifts were recorded.

Nominal daily CPUE for the pot fishing sector ranged from 33 kg.boat day^{-1} in 1983/84 to 323 kg.boat day^{-1} prior to the introduction of quota in 1995/96 (Figure 3.7d). Following the introduction of quota, CPUE declined by 21% to 255 kg.boat day^{-1} in 1996/97 and remained below 300 kg.boat day^{-1} until 2003/04. Catch per unit effort gradually increased from 308 kg.boat day^{-1} in 2003/04 to 393 kg.boat day^{-1} in 2007/08. Substantial declines in CPUE occurred in 2009/10 and 2012/13, however, CPUE remained above 400 kg.boat day^{-1} from 2010/11 and reached a historical high 490 kg.boat day^{-1} in 2011/12. In 2014/15, CPUE decreased by 15% from 472 kg.boat day^{-1} to 399 kg.boat day^{-1}, this was

the lowest CPUE since 2009/10 and below the 10-year mean (413±19 kg.boat day^{-1}). In the MSF sector, CPUE remained below 150 kg.boat day^{-1} until 2005/06 and 2006/07, when CPUE reached 269 and 216 kg.boat day^{-1}, respectively. In 2007/08, MSF CPUE declined to 122 kg.boat day^{-1} and since 2008/09 there have been no MSF catches of blue crabs recorded in this region.

Following the introduction of quota in 1995/96, mean nominal potlift CPUE remained below 3.2 kg.potlift^{-1} until 2006/07 (Figure 3.7e). Between 2006/07 and 2007/08 CPUE increased by 15%. In most years, CPUE has remained above 3.2 kg.potlift^{-1} with the exception of 2009/10 and 2012/13 where CPUE declined to 2.6±0.0 kg.potlift^{-1} and 2.3±0.0 kg.potlift^{-1}, respectively. In 2013/14 the CPUE was 3.9±0.1 kg.potlift^{-1}, this was the highest on record. CPUE declined from 3.9±0.1 kg.potlift^{-1} in 2013/14 to 3.3±0.1 kg.potlift^{-1} in 2014/15.

The mean nominal CPUE of legal-size crabs recorded by the FIS has fluctuated through time, with similar trends observed at standard and revised locations (Figure 3.7f). The Survey CPUE of legal-size crabs was relatively low (<2 legal-size.potlift^{-1}) in 2004, 2012 and 2013, reaching a minimum of 1.3±0.1 legal-size.potlift^{-1} at revised locations in 2012 and 1.4 legal-size.potlift^{-1} at standard locations in 2013. Relatively high survey CPUE (>4 legal-size.potlift^{-1}) was observed in 2003, 2006, 2007 and 2015. In 2015, the survey CPUE of legal-size crabs peaked at 5.5±0.4 legal-size.potlift^{-1} and 4.4±0.3 legal-size.potlift^{-1} at standard and revised locations, respectively.

The mean nominal CPUE of pre-recruit recorded by the FIS has followed a similar trend to legal-size crabs in this region (Figure 3.7g). The survey CPUE of pre-recruit crabs was relatively low (<3 legal-size.potlift^{-1}) in 2003, 2004, 2009 and from 2011–14. A historically low value of 0.4±0.1 pre-recruits.potlift^{-1} was recorded in 2004 and similarly low values were observed at standard and revised locations in 2012 (0.8±0.1 pre-recruits.potlift^{-1}). The survey CPUE of pre-recruits reached a historical high in 2006 at 10.7±0.9 pre-recruits.potlift^{-1}. The survey CPUE of pre-recruits peaked again in 2010 at 7.3 pre-recruits.potlift^{-1} and 5.6 pre-recruits.potlift^{-1} at standard and revised locations, respectively. Since 2014 the survey CPUE of pre-recruits has increased by 172% at standard locations (5.8±0.5 pre-recruits.potlift^{-1}) and 189% at revised locations (5.2±0.3 pre-recruits.potlift^{-1}).

Similar to the trends in pre-recruit abundance recorded by the FIS, yearly estimates of pre-recruit CPUE from the pot-sampling program indicate that annual levels of recruitment have fluctuated since 2006/07 (Figure 3.7h). In 2014/15, the CPUE of pre-recruits was 9.7 ±0.5 pre-recruits.potlift^{-1}, a 25% increase compared to 2013/14 (5.8±0.3 pre-recruits.potlift^{-1}. Monthly estimates of the CPUE of pre-recruits were variable between years (Figure 3.8), particularly between July and October. Following several years of low recruitment values, no fishing was undertaken in the latter half of 2013. When fishing recommenced in 2014, the CPUE rate of pre-recruits increased to a high of 17.1±3.5 pre-recruits.potlift^{-1} in September. Similarly in 2015, the CPUE of pre-recruits peaked in September, reaching a historical high of 29.8±4.2 pre-recruits.potlift^{-1}.

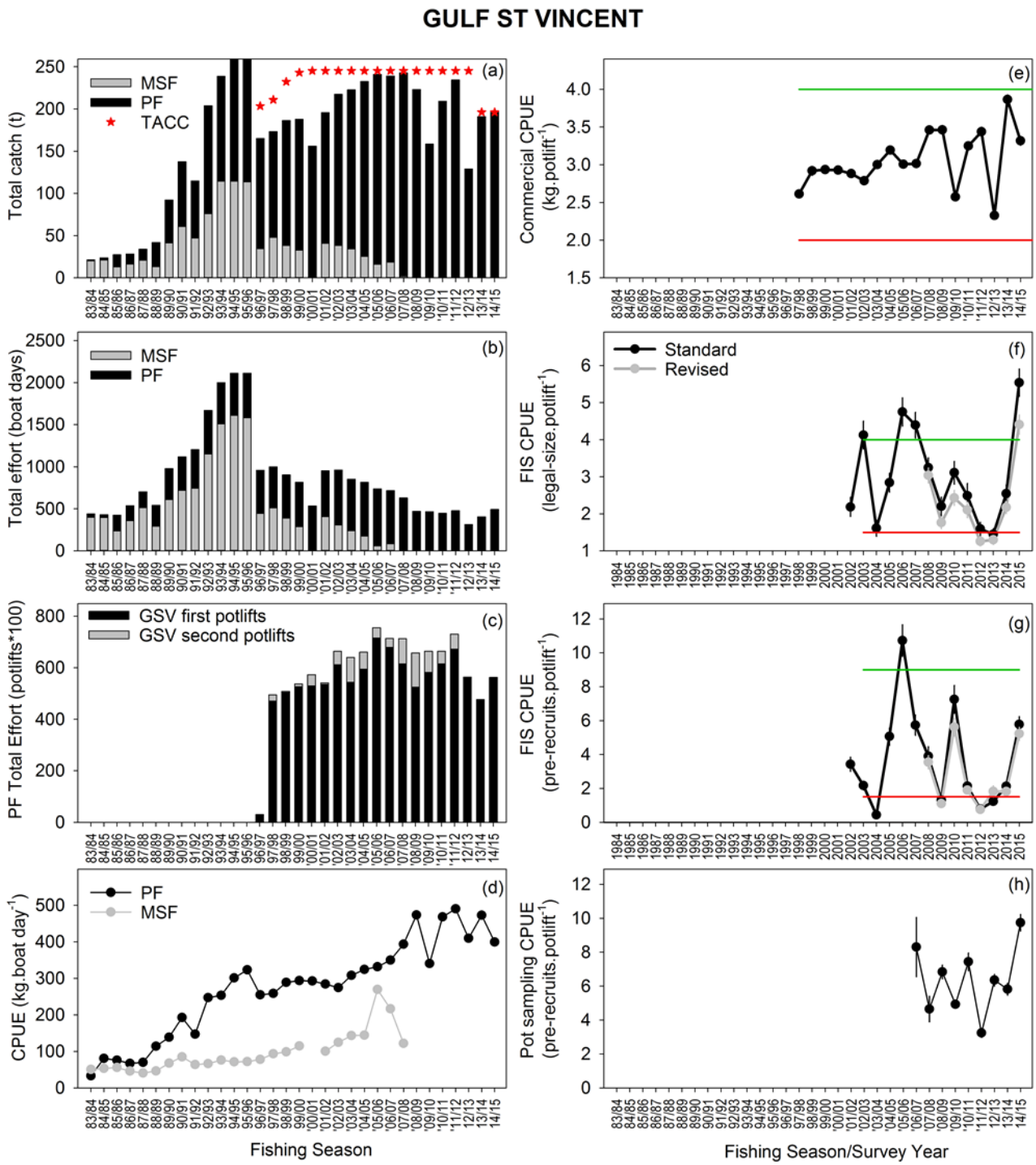


Figure 3.7 Key outputs used to assess the status of the Gulf St Vincent zone of the Blue Crab Fishery. (a) Trends in total catch (t) for pot fishing (PF) and Marine Scalefish Fishery (MSF) including total allowable commercial catch (TACC) limit; (b) total effort (boat days) for PF and MSF sector; (c) total effort from first and second potlifts for PF sector; (d) catch per unit effort (CPUE) for PF and MSF sectors, (e) CPUE (kg.potlift) for PF sector; (f) FIS (FIS) pre-recruit CPUE (pre-recruits.potlift^{-1}); (g) FIS legal-size CPUE (legal-size.potlift^{-1}); (h) pre-recruit CPUE from the pot-sampling program (pre-recruits.potlift^{-1}). Green and red lines represent the upper and lower trigger reference points identified in Table 3.1; error bars, standard error.

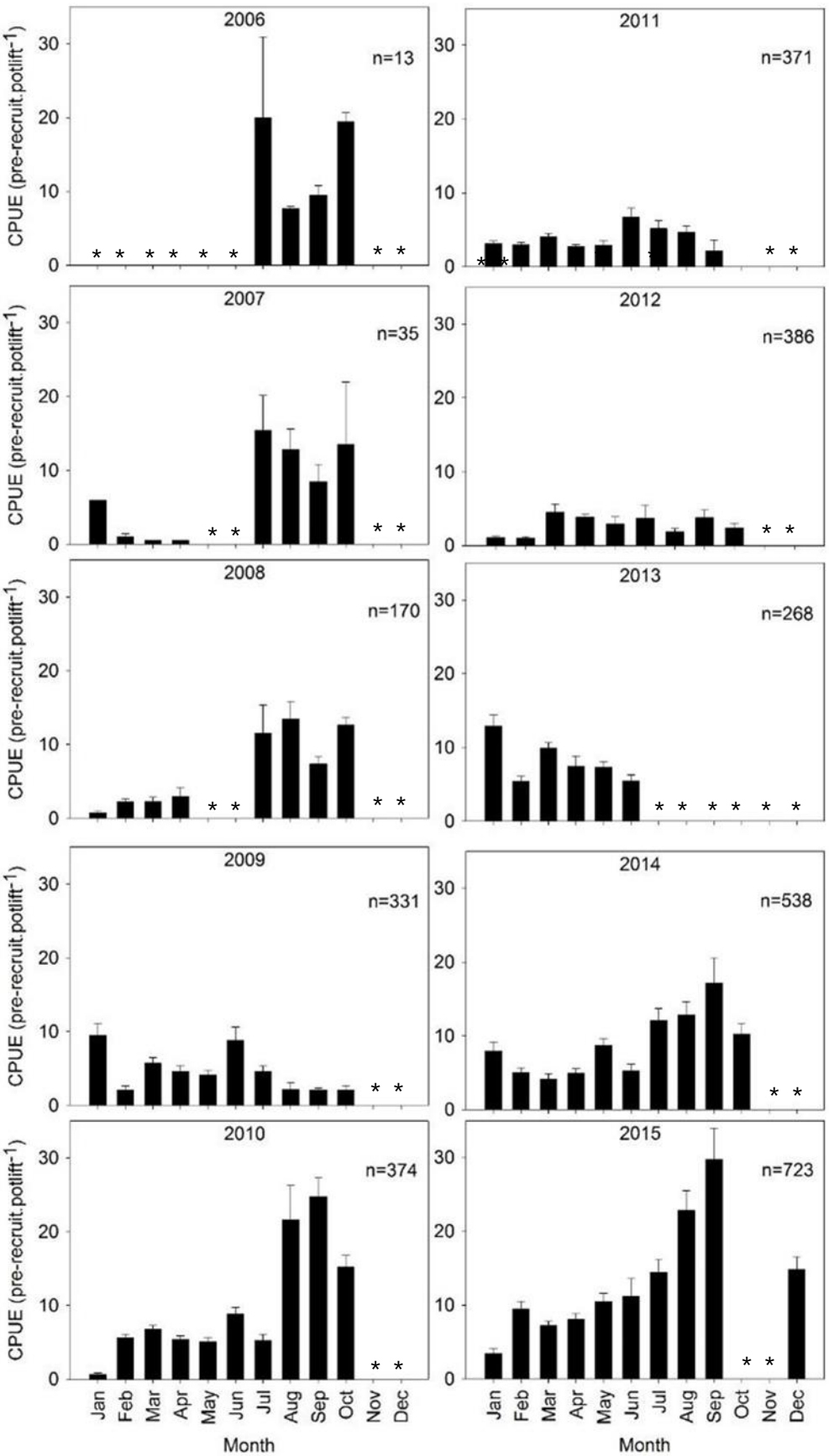


Figure 3.8 Monthly mean catch per unit effort (CPUE) of pre-recruits from pot-sampling undertaken by the Gulf St Vincent pot fishing zone. Sample size (n), pots sampled. Error bars, standard error. * No sampling in this month.

Spatial mapping of density data obtained from the FIS in from 2008–10, 2012 and 2014 indicates that pre-recruit and legal-size crabs were distributed patchily throughout GSV (Figure 3.9 and 3.10). Pre-recruit density was high adjacent to Ardrossan and in the central gulf and adjacent to Port in 2008. Legal-size abundance remained relatively low in 2008 and both legal-size and pre-recruit abundances were low throughout the gulf in 2009. In 2010, pre-recruits were abundant in similar regions to 2010, while legal-size crab density was concentrated adjacent to Port Adelaide and in the central gulf. Legal-size abundance remained high in 2011, particularly adjacent to Port Adelaide where moderate levels of pre-recruits were also observed. From 2012–14, both pre-recruit and legal-size abundance remained relatively low across the gulf, with exception on the Ardrossan region which had a concentration of pre-recruit density in 2013. The most recent FIS in 2015, identified increased pre-recruit abundance, particularly in the central gulf, between Port Vincent and Ardrossan and adjacent to Port Adelaide. Similarly, legal-size crabs were widely distributed with relatively high abundances observed adjacent to Port Adelaide.

Since 2008, similar proportions of legal-size and pre-recruit crabs have been sampled during the June/July FIS (Figure 3.11). The modal size of male crabs was small in 2010 and 2013–15 at 100–104 mm CW. Increased modal size for male crabs was observed in 2008, 2009 and 2011 at 110–114 mm CW and 115–115 mm CW in 2012. The size distribution of females varied substantially among years. In 2008, 2010, 2014, female crabs had a relatively small modal size of 100-104 mm CW and in 2013–14 the modal size was 105–109 mm CW. The modal size of female crabs increased to 115–119 mm CW in 2009 and remained high at 110–114 mm CW in 2011 and 2012.

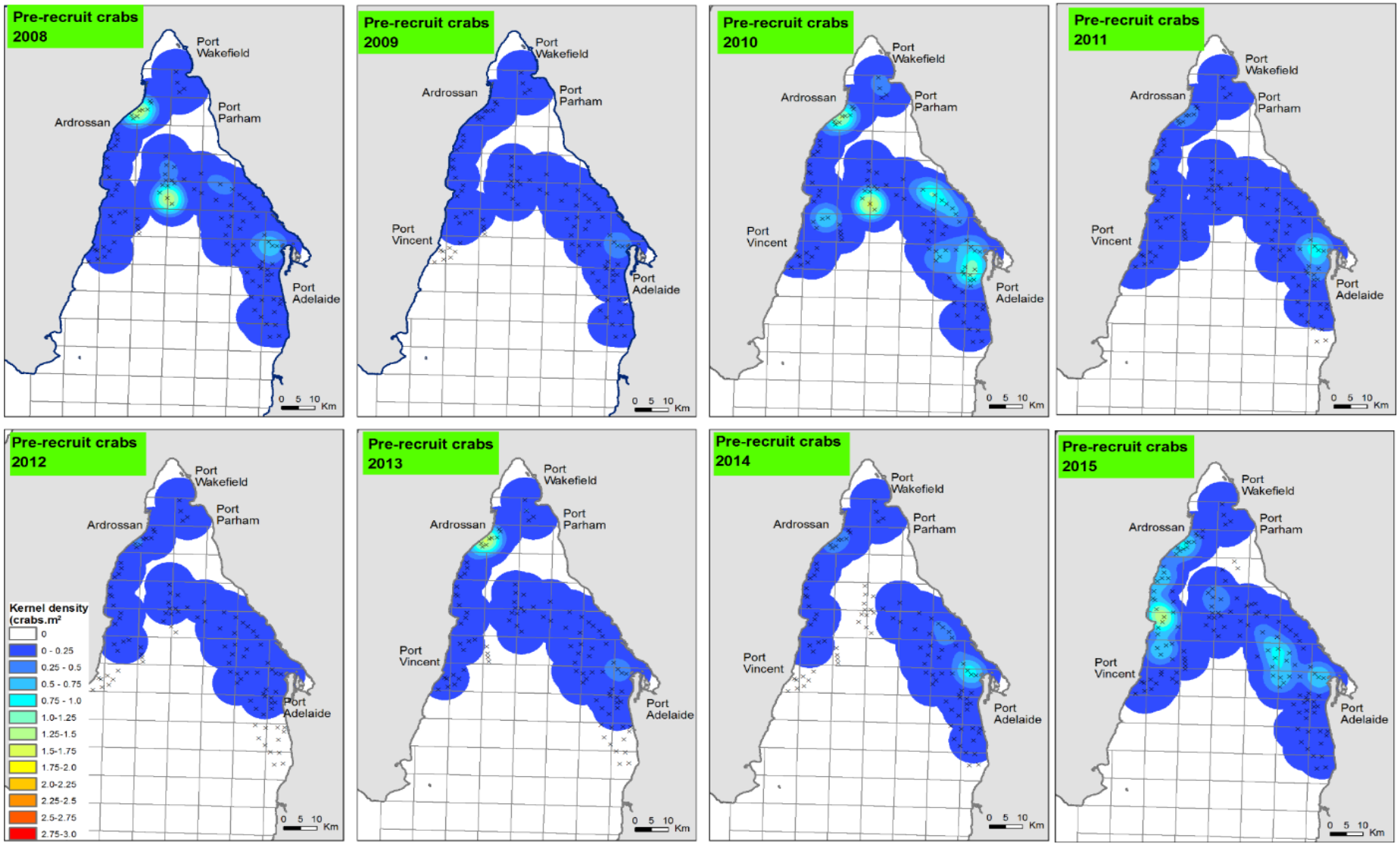
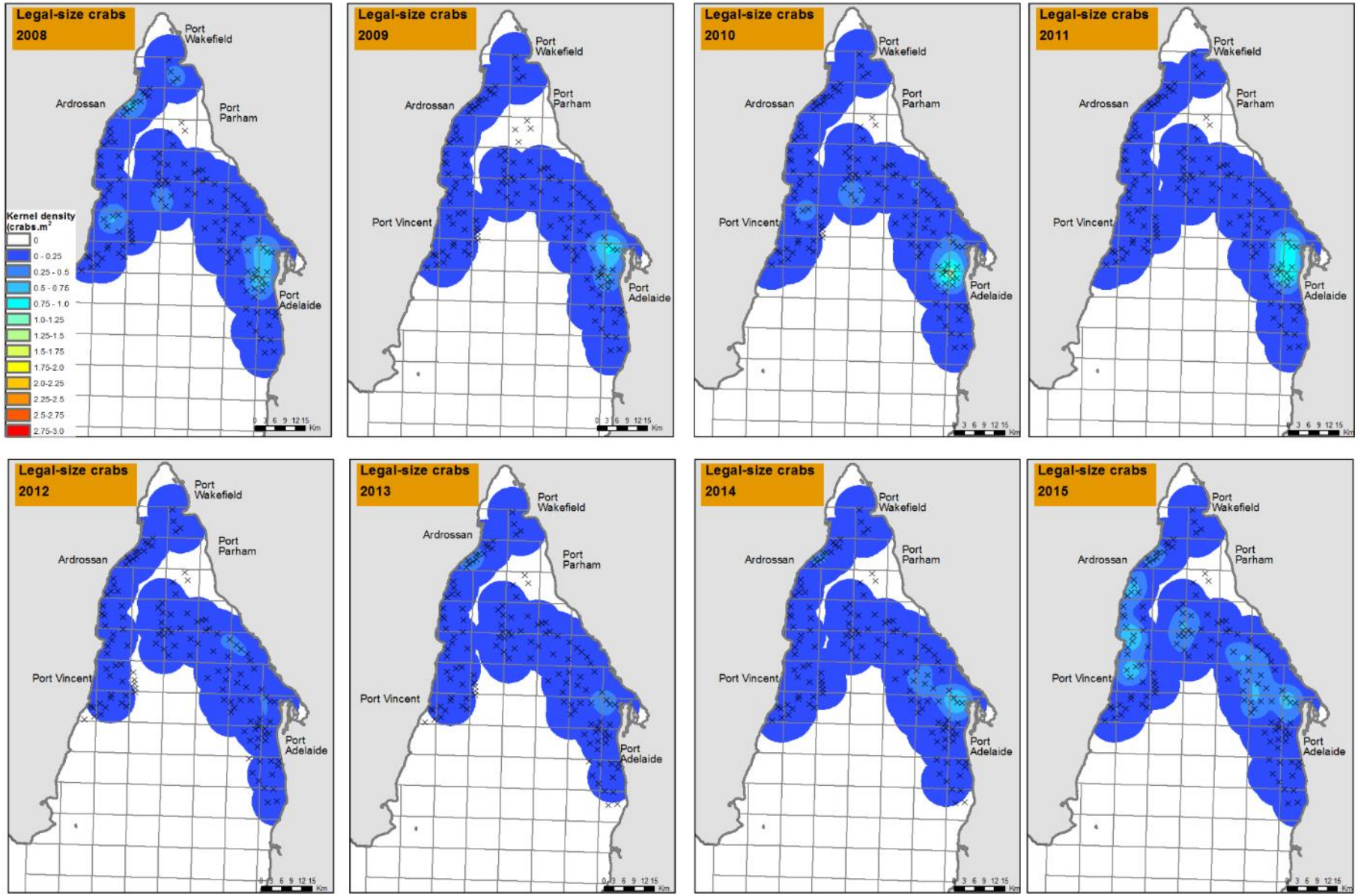


Figure 3.9 Kernel density maps showing the relative density (crabs per square metre) of pre-recruit crabs from June/July fishery-independent surveys sampled at revised locations in Gulf St Vincent from 2008–15. Sampling locations denoted by x.

Figure 3.10 Kernel density maps showing the relative density (crabs per square metre) of legal-size crabs from June/July fishery-independent surveys sampled at revised locations in Gulf St Vincent from 2008–15. Sampling locations denoted by x.



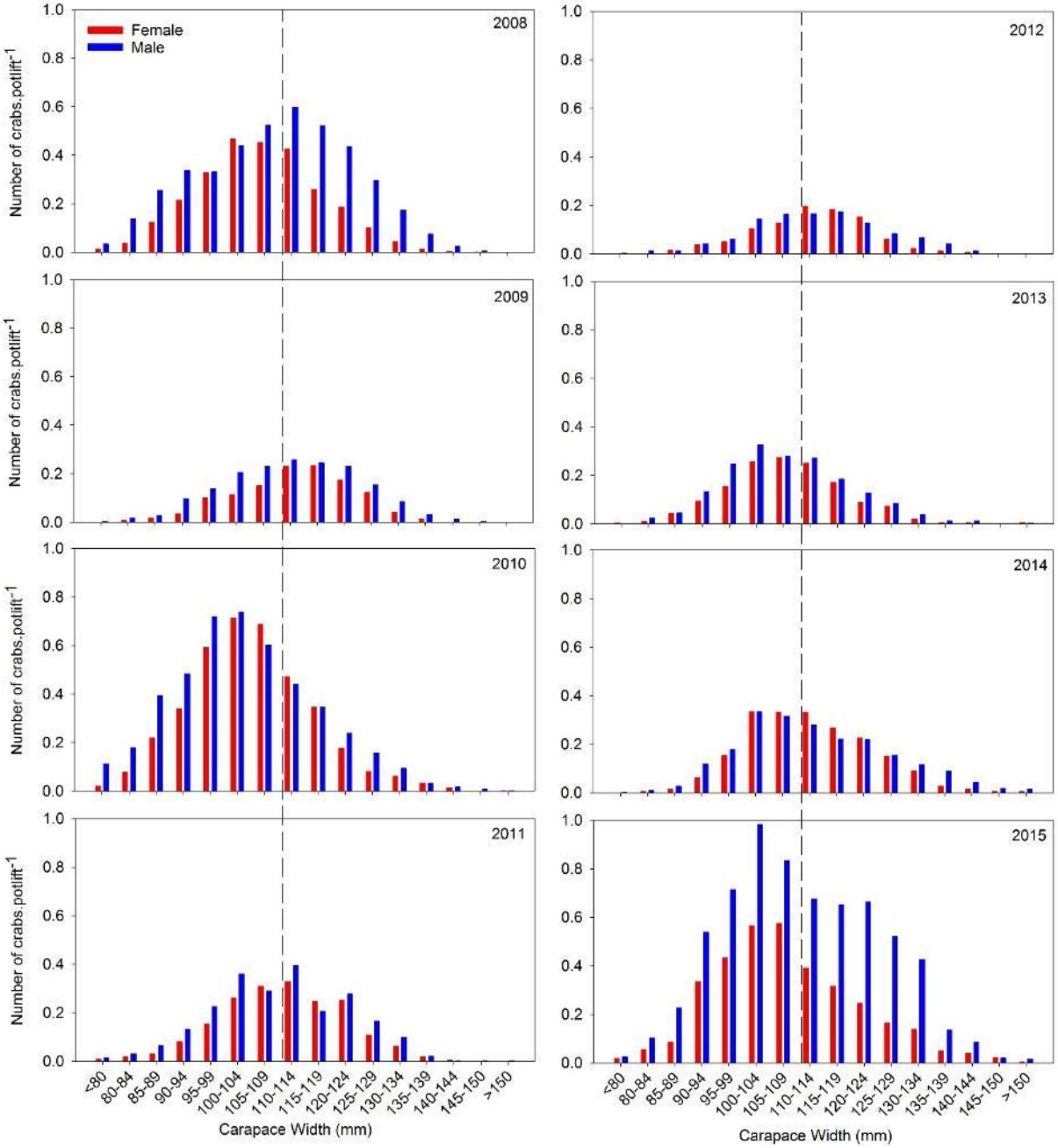


Figure 3.11 Length frequency distributions of male and female blue crabs from June/July fishery-independent surveys in Gulf St Vincent sampled at revised locations from 2008–2015. Minimum size limit 110 mm carapace width, CW (---).

3.4. West coast

Blue crab catches from the west coast region dominated the State-wide catch in 1983/84 and 1984/85, making up 69% (60 t) and 54% (61 t) of catch, respectively. Thereafter, catches from the west coast have comprised a minor proportion of the State-wide catch (up to 18%, Figure 3.12). From 1985/86–2006/07, annual catch remained below 30 t. In 2007/08, catch increased to 44 t and has remained above that level since, peaking at 58 t in 2012/13. In 2014/15, 41 t was harvested from the west coast region, a decrease of 28% from 2013/14 (57 t). Trends in effort generally followed trends in catch. Peak levels of effort occurred in 2013/14 at 892 boat days and effort decreased 32% from 892 boat days in 2013/14 to 608 boat days in 2014/15. Catch per unit effort declined from 1983/84 to a low of 15 kg.boat day^{-1} in 1987/88. A large increase in CPUE was observed in 1989/90 where a maximum of 162 kg.boat day^{-1} was observed. Since then, CPUE have remained below 100 kg.boat day^{-1}. In 2014/15 the annual CPUE increased 6% to 68 kg.boat day^{-1} compared to 64 kg.boat day^{-1} in 2013/14.

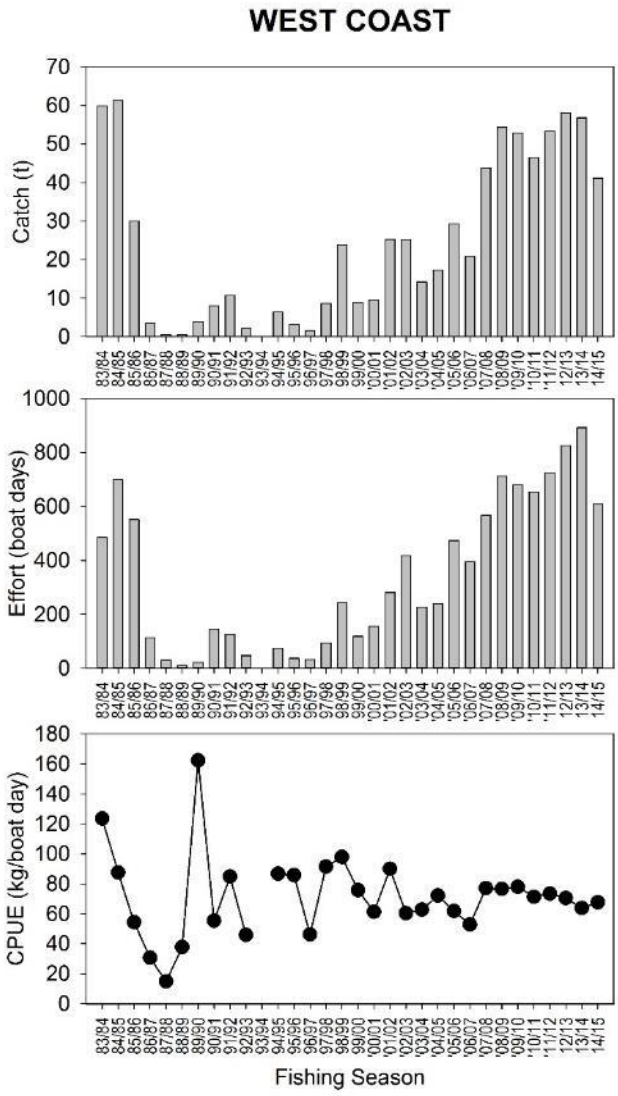


Figure 3.12 Key outputs used to assess the status of the west coast blue crab stock. From top. Trends in catch (t), effort (boat days) and catch per unit effort (CPUE, kg.boat day^{-1}).

3.5. Fishery performance

Data were available for one of the three PIs for the SG pot fishing zone in 2014/15 (Table 3.1). The mean commercial CPUE of legal-size crabs remained above the lower limit reference point (LRP) at 3.7 kg.potlift^{-1}.

Data were available for all three PIs for the GSV pot fishing zone in 2014/15 and all PIs were above the LRPs (Table 3.1). The PI for survey CPUE of legal-size crabs was above the upper LRP for the first time since 2007. The PI for survey CPUE of pre-recruit crabs remained above the lower LRP for a second consecutive year. The mean commercial CPUE of legal-size crabs remained above the lower limit reference point at 3.3 kg.potlift^{-1}.

PIs have not been developed to facilitate stock assessment of the west coast region.

Table 3.1 Summary of the performance of the Spencer Gulf (SG) and Gulf St Vincent (GSV) pot fishing zone for 2014/15 against the key biological performance indicators. The values highlighted in green indicate that the value was above the upper limit reference point for that performance indicator. No surveys were conducted in Spencer Gulf in 2014/15.

Zone	Data source	Performance indicator	Limit ref. point		2014/15
			Lower	Upper	
SG	FIS	CPUE of legal-size crabs (legal-size crabs/potlift)	5.0	8.0	-
	FIS	CPUE of pre-recruits (pre-recruits/potlift)	2.0	9.0	-
	Catch & effort	CPUE of legal-size crabs (kg/potlift)	2.0	4.0	3.7
GSV	FIS	CPUE of legal-size crabs (legal-size crabs/potlift)	1.5	4.0	**5.5**
	FIS	CPUE of pre-recruits (pre-recruits/potlift)	1.5	8.5	5.8
	Catch & effort	CPUE of legal-size crabs (kg/potlift)	2.0	4.0	3.3

4. DISCUSSION

4.1. Stock status

The harvest strategy for the fishery does not provide a definition of when the stock is considered 'recruitment-overfished' and the PIs in this fishery are not explicitly linked to a definition of stock status. Consequently, in this assessment, a ‘weight of evidence’ method has been used to determine stock status.

Three primary datasets were available to assess the status of the BCF in 2014/15: 1) fishery-independent surveys; 2) fishery-dependent commercial logbooks; and 3) fishery-dependent voluntary pot-sampling data.

The FIS are considered to provide the most reliable indices of relative abundance. This is because: 1) FIS include a standardised sampling design (with respect to locations, months and gear), including improved spatial coverage of these indices from 2008; 2) the difficulty in quantifying the effects of fisher experience, temporal and spatial shifts in catch and effort, and improvements in catching efficiency (e.g. gear modification, vessel technology, selectivity of commercial pots) on commercial CPUE; and 3) the limited data (spatially and temporally) available from the voluntary pot-sampling program.

4.1.1. Spencer Gulf

In 2014/15, commercial legal-size CPUE was the fifth highest recorded since 1996/97 and was above the lower limit reference point, despite a 9% decrease compared to 2013/14. This was coupled with almost the entire SG component of the TACC being caught for the eleventh consecutive fishing season. High survey CPUE has been observed throughout SG with the legal-size mean CPUE exceeding the upper LRP since 2009, and pre-recruit CPUE exceeding the upper LRP in the most recent survey (2014). On the basis of this information, the biological stock is unlikely to be recruitment overfished and the current level of fishing mortality is unlikely to cause the biological stock to become recruitment overfished. Consequently, using the national framework for stock status reporting (Flood *et al.,* 2012), the SG zone of the BCF is classified as **'sustainable'.**

In accordance with the Management Plan for the fishery (PIRSA 2012), the recent FIS have occurred biennially in SG because of persistent high levels of CPUE for legal-size and pre-recruit crabs. The next FIS will be conducted in 2016. These data will be a key component of determining if relative biomass has changed since 2014 and for validating the current assessment of stock status.

4.1.2. Gulf St Vincent

In response to the decline in biomass of pre-recruits in GSV first reported in 2011/12 (Dixon *et al*., 2013), a number of initiatives were taken to promote recovery of the stock: 1) the commercial catch in 2012/13 was voluntarily reduced by almost 50% through reduction in effort, 2) in 2013/14 and 2014/15 the TACC was reduced by 20% from 245.1 t to 196.1 t, 3) industry voluntarily closed the gulf to commercial fishing for more than six months (1 July 2013 to 15 January 2014), and 4) recreational bag and boat limits were halved from 2012/13.

There are multiple lines of evidence that the relative abundance of blue crabs has improved from the recent relatively weak position. Firstly, during the June 2015 FIS, the CPUE of legal-size crabs was the highest value on record and above the upper LRP. Secondly, pre-recruit CPUE measured during the FIS rapidly increased from 2014–2015, reaching the highest value recorded since 2010. Thirdly legal-size and pre-recruit crabs were broadly distributed throughout GSV in June 2015. Fourthly, in 2014/15 all three PIs were above the lower LRP for the second consecutive season. Lastly, the commercial CPUE remained above 3kg.potlift^{-1} for the second consecutive season and the entire GSV component of the TACC was harvested in 2014/15. On the basis of this information, the GSV zone of the BCF is not considered to be recruitment overfished, and the current level of fishing pressure is unlikely to cause the fishery to become overfished. Therefore, using the national framework for stock status reporting (Flood *et al.,* 2012), the GSV zone of the BCF is classified as **'sustainable'.**

4.1.3. West coast

A negligible amount of blue crabs are landed by the commercial sector on the west coast. Consequently, there is insufficient information available to confidently classify the status of this stock. Therefore, using the national framework for stock status reporting (Flood *et al.,* 2012), the west coast zone of the BCF is classified as '**undefined'**.

4.2. Current performance indicators

Assessing the status of the BCF through multiple lines of evidence that describe fishery performance and biological indicators is of considerable value. Tracking the relative trends in these indicators is particularly informative, and the LRPs serve as 'precautionary limits' that indicate when further management action may be required. The current review of the harvest strategy permits re-evaluation and re-consideration of the current PIs used in the BCF harvest strategy (Table 3.1). The current PIs are commercial and survey catch rates.

4.2.1. Commercial CPUE

Considerable uncertainty exists in some aspects of the fishery-dependent data; 1) changes in fisher experience and demographics, 2) changes in gear and vessel technology, 3) temporal and regional

shifts in catch and effort, and 4) changes in potlift behaviour such as the conduct of second potlifts. The impact of such factors on CPUE, which are unrelated to abundance, could be accounted for by standardising the data collected through model-based statistical procedures. The collection of additional data through commercial logbooks would also facilitate standardisation of commercial CPUE. This could include more detailed spatial information on the level of catch and effort in each fishing block. Currently, commercial logbooks include daily records of the total catch and effort and the blocks in which fishing took place. However, fishing can take place over multiple blocks each day making it difficult to determine fine scale spatial trends in CPUE. The introduction of electronic logbooks may improve the spatial resolution at which data are collected.

4.2.2. Fishery-independent survey catch per unit effort

CPUE of legal-size and pre-recruit crabs obtained during the FIS are measured using small-mesh research pots at sampling locations which have remained consistent since 2002 (standard locations). Since 2008, additional sites have been sampled. There are two options for revising the current PIs to reflect this change. Firstly, survey CPUE from the standard and revised locations could be integrated across the existing time series using a general linear model (GLM). The GLM would seek to account for variation in the spatial distribution of sampling. This option would enable new reference levels for each PI to be based on the entire time series of data collected since 2002. Secondly, CPUE from standard and revised locations sampled since 2008 could be used to set the new reference levels, excluding data from 2002–2007. The latter option may require more conservative reference levels due to the shorter time series, particularly in SG where FIS have only been undertaken biennially since 2010.

Currently, survey CPUE is measured as number-per-unit-effort (NPUE) rather than weight per unit effort (WPUE). Broadly, very similar trends have been observed for NPUE when compared to the WPUE (see Appendix B). The advantage of WPUE as a measure of relative biomass is that it potentially yields more information about stock status by capturing data on crab size. Regardless of which measure of relative abundance or biomass is used, consideration should be given to the continued use of standard research pots during the FIS. This is because standard research pots maintain consistent size selectivity while commercial pots evolve through time and configurations vary among operators. Variable size selectivity between commercial pots may influence the size and type of crabs or other fish already in the pot and this may influence the number and size range of crabs captured (Millar and Fryer, 1999). Although research and commercial pots have been sampled side by side during FIS (Appendix C), only one operator per gulf participates in the annual or biennial FIS and, as a result, there is limited information on the temporal differences in gear selectivity for all pot types used throughout the history of the fishery. Further information on changes in gear configuration through time is also required to inform CPUE standardisation.

4.3. Future directions

The BCF harvest strategy is currently being reviewed. This will include the development of clearly defined decision rules for setting the annual TACC, principally based on fishery-independent data. A decision-making framework has been drafted that links measures of current biomass from the June/July FIS (CPUE of legal-sized crabs) and future biomass (CPUE of pre-recruit crabs) to catch limits. Economic decision rules are also being developed by industry to guide TACC selection within the range of biologically acceptable TACC levels.

A key requirement of a future harvest strategy is to reduce the time period between the FIS and subsequent setting of the TACC. Currently, the FIS data used to set the TACC are nine to 11 months old. Reducing the time period between the FIS and any required management responses may result in increased profitability (i.e. taking advantage of high blue crab abundance) and a decreased risk of depletion from exploitation if blue crab abundance is low.

Options to reduce this time delay may include: (1) amending the quota year from 1 July–30 June to 1 October–30 September; and (2) changing the timing of the FIS in GSV and SG to March/April. While the first of these offered several advantages (e.g. immediate reduction in the time lag between the FIS and quota setting, avoidance of the analytical work required to develop meaningful PIs based on the March/April time series), the latter was selected to increase certainty in the estimates of adult crab biomass available at the start of the current season (1 July) and minimise the potential loss of market opportunities through changing the season start date. An amended timing of FIS from June/July to March/April requires consideration of several issues.

Firstly, the current time lag between the FIS and quota setting will persist until at least three paired surveys have been completed in each gulf. This is because there is limited information available on blue crab abundance and distribution during March/April requiring that, during the transition to a March/April FIS, use of an interim harvest strategy will require continuation of the June/July FIS.

Secondly, to reduce cost during the transition, partial surveys (approximately 50% of the normal sites) will be undertaken in March/April and June/July to generate three paired survey datasets. This approach will require the development of new reference points based on the subset of sites included in the June/July FIS (see Appendix A) to support management decisions using the interim harvest strategy.

Thirdly, once three years of paired survey data are available, revised PIs and reference levels will need to be considered. There are two potential options for achieving this: (1) integrate the March/April and June/July data series using a modelling approach; (2) use the March/April time series of data directly to set the new reference levels. The first of these will require a strong correlation between the abundance estimates generated from the FIS. If the correlation between abundance estimates is weak

after three paired surveys, additional years of paired sampling may be necessary. Using the March/April time series of data to directly set the new reference levels is likely to require more than three years of data, to account for inter-annual variability. If this were the case, the interim harvest strategy (which requires June/July surveys) may need to be used for longer than currently anticipated.

Fourthly, as preliminary results have indicated that sub-legal-sized crabs have been less abundant in the pot-sampling program during March/April, it may not be possible to develop a meaningful PI for pre-recruit abundance from a March/April FIS. Pre-recruit abundance is currently a secondary PI under the draft harvest strategy (enabling higher exploitation rates when above a pre-determined threshold level) and information on recruitment levels is a key component of determining stock status (see Flood *et al.,* 2012) and informing future levels of harvestable biomass. As there are existing data, the two most tractable options for a pre-recruit abundance index would be to continue a reduced June/July survey and/or modify the pot sampling program to expand temporal coverage to increase the likelihood of capturing the variable timing of peak recruitment.

There are several other avenues of research that would reduce uncertainty in assessment of blue crab stocks. These include (1) increasing the frequency of data on the catch from the recreational sector; and (2) increasing the understanding of environmental and ecosystem changes on blue crab stocks. Recreational catch data are required to enhance understanding of the temporal variation in recreational catch and to monitor relationships between catches and sector allocations. This is important in a species with a short life-history because substantial changes in abundance, catch and effort can occur in a relatively short time period. The impact of ecosystem changes on blue crab stocks is being addressed as part of an FRDC project (2013-031), focusing on the impact of changes in the abundance of snapper on the GSV ecosystem. Interactions between environmental parameters (e.g. water temperature and physical-oceanographic processes) and patterns of larval settlement for blue crabs were investigated for the SG zone as part of an FRDC project (2008-011; McLeay *et al.,* 2015).

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APPENDIX A: FIS DESIGN RATIONALISATION

At each site for each gulf, legal-size and pre-recruit abundance in standardised research pots were ranked according to their contribution to relative abundance. Survey CPUE was then projected based on 12 sites sampled per day, reducing the number of days sampled while maintaining maximum possible abundance for pre-recruit and legal size crabs.

A1 Spencer Gulf

Analysis of the June/July FIS data from 2008-2014 for SG demonstrates that a 60 site (300 pot) sampling design would also be unlikely to result in the loss of temporal signal (Figure A.1). This is because 60–69% of legal-size and pre-recruit crabs would be retained when compared to the current 108 site design. The reduction from 108 to 60 sites reflects removal of sites in areas with consistently low abundance, resulting in significant cost savings. Following consultation with industry, several sites were also removed to reduce travel time and allow the completion of the survey within 5 days.

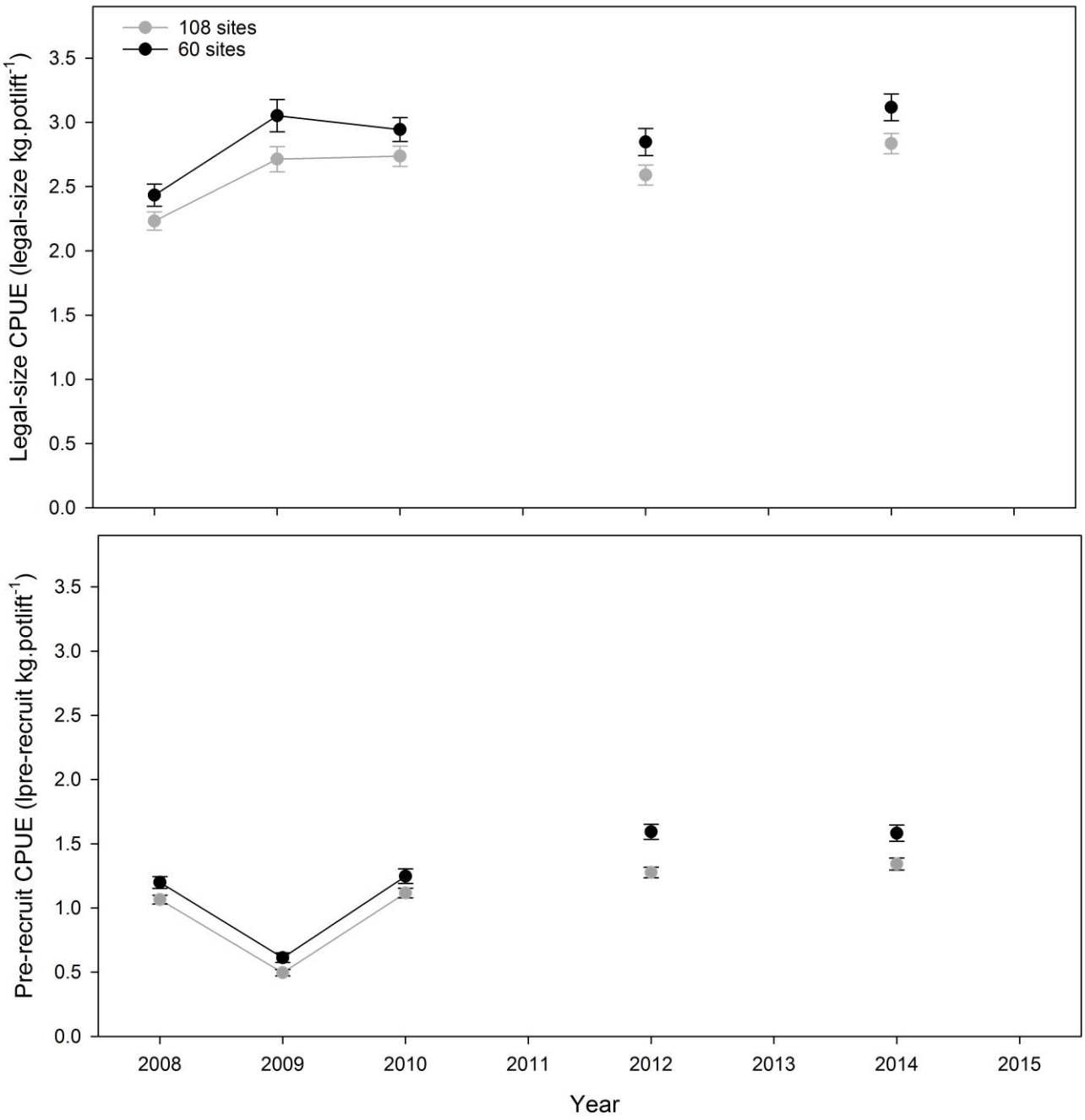

Figure A.1 Projected catch per unit effort (CPUE) under different FIS designs with five research pots sampled at each site in SG.

A.2 Gulf St Vincent

Analysis of the June/July FIS data from 2008-2014 for GSV demonstrates that a 60 site (300 pot) sampling design would be unlikely to result in the loss of temporal signal (Figure A.2). This is because 68–94% of legal-size and pre-recruit crabs would be retained when compared to the current 104 site design. The reduction from 104 to 60 sites reflects removal of sites in areas with consistently low abundance, resulting in significant cost savings. Following consultation with industry, several sites were also removed to reduce travel time and allow the completion of the survey within 5 days. The 60 site survey design shown in Figure A. 1 will be undertaken in April and June 2016.

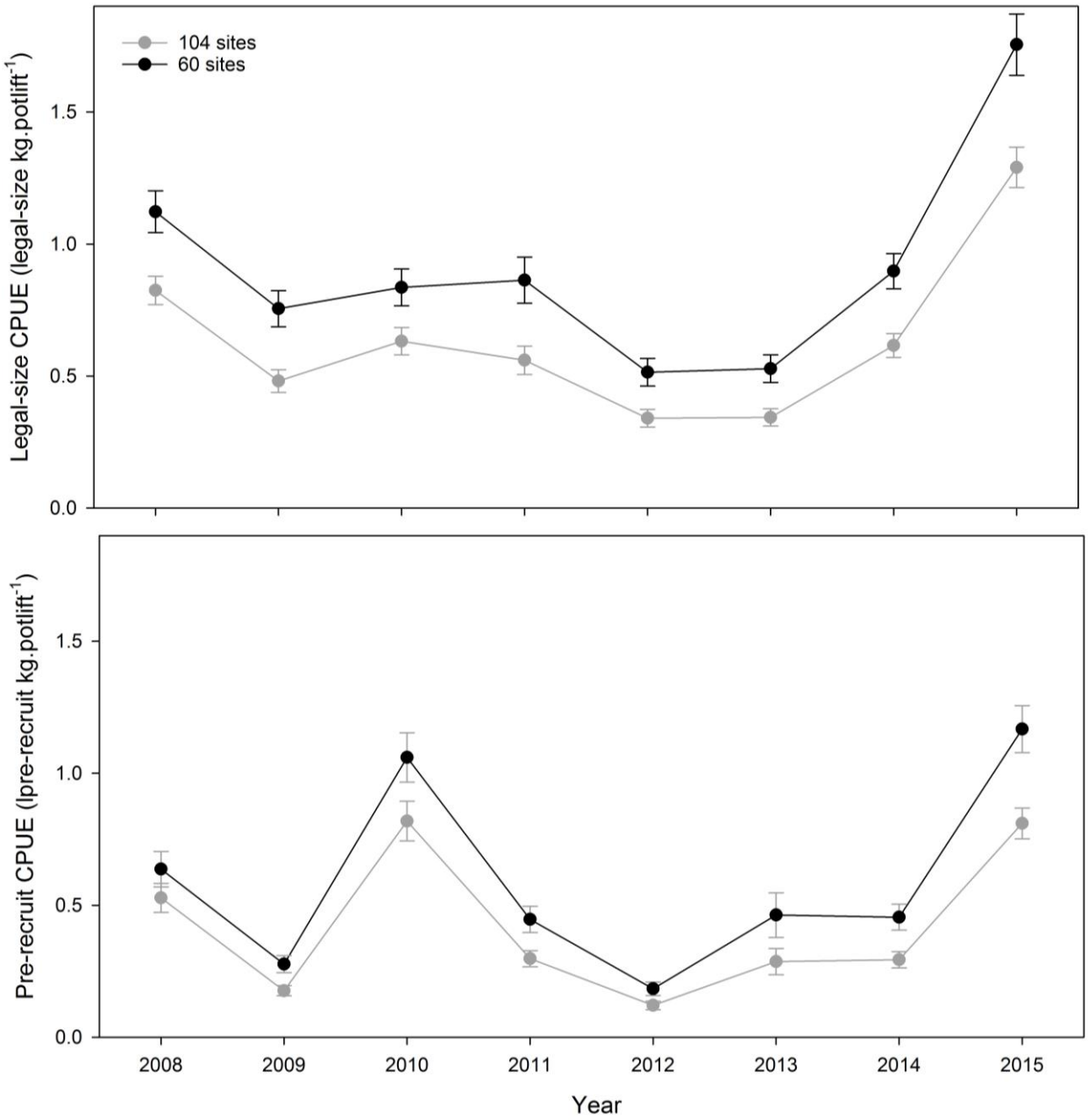

Figure A.2 Summary of FIS results from 2008–2015 in Gulf St Vincent using research pots under a complete survey design (104 sites; 520 potlifts) and a reduced survey design (60 sites, 300 potlifts).

In March 2015, a reduced FIS was undertaken because the ongoing review of the Management Plan and harvest strategy was evaluating (1) the need for timely FIS data to inform quota setting versus (2) retaining the existing FIS timing and amending the start date of the quota year. The FIS took place in GSV from 18-23 March 2015 using industry vessel *Silver Spectre* (K04). A total of 247 research potlifts were conducted at 50 sites in March 2015. The abundance and sex ratios of legal-sized and pre-recruit crabs in research pots are summarised in Table A.1.

The March FIS results indicate high relative abundance of legal-size and pre-recruit crabs (Figure A.3 and A.4). However, CPUE were driven by male crabs, with female crabs rare. Male size distribution was bimodal with peaks at 105—109mm and 120–124 mm (Figure A.5). The modal size for male crabs was 120–124 mm, up from 100–104 mm in the 2014 and 2015 June FIS. The modal size for female crabs was smaller at 105–109 mm. This was an increase compared to the June 2014 FIS (100–104 mm) and on par with the June 2015 FIS.

Table A.1 Summary of FIS results from March 2015 in GSV using research pots.

Potlifts	Size	Abundance	Males (%)	Females (%)	CPUE (crabs/potlift)
247	Legal	2,059	1,931 (94%)	128 (6%)	8.3
	Pre-recruits	1,288	1,172 (91%)	116 (9%)	5.2
	Total	3,347	3,103 (93%)	244 (7%)	13.6

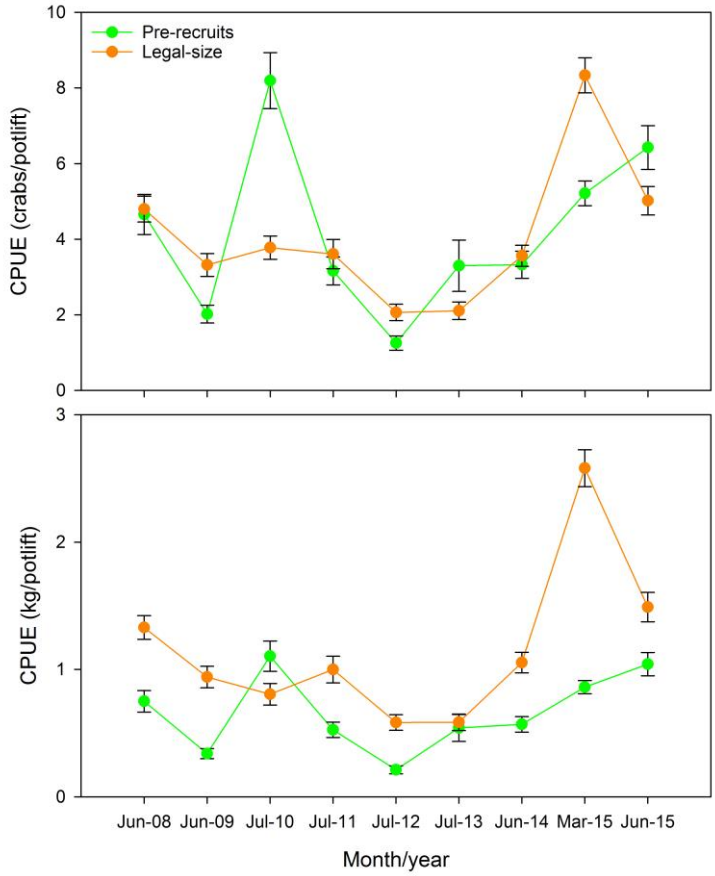

Figure A.3 Summary of FIS results from 2008–2015 in GSV using research pots. March sampling locations (n=247 potlifts) compared across all years.

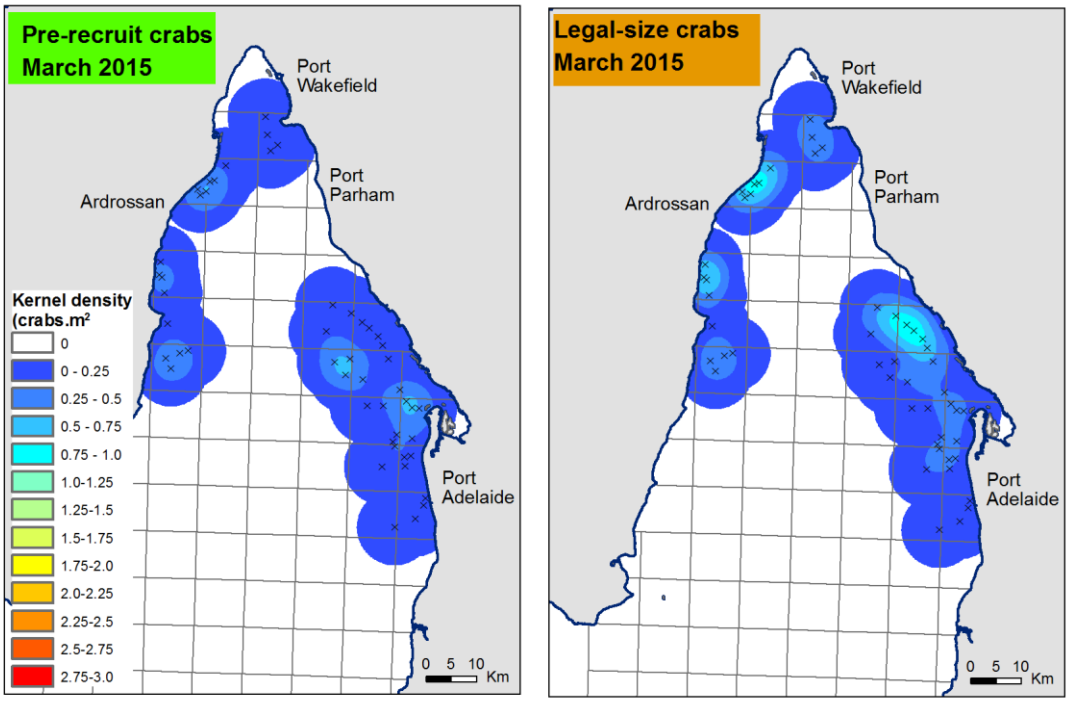

Figure A.4 Kernel density maps showing the relative density (crabs per square metre) of pre-recruit and legal-size crabs from the 2015 March FIS in GSV. Sampling locations denoted by x.

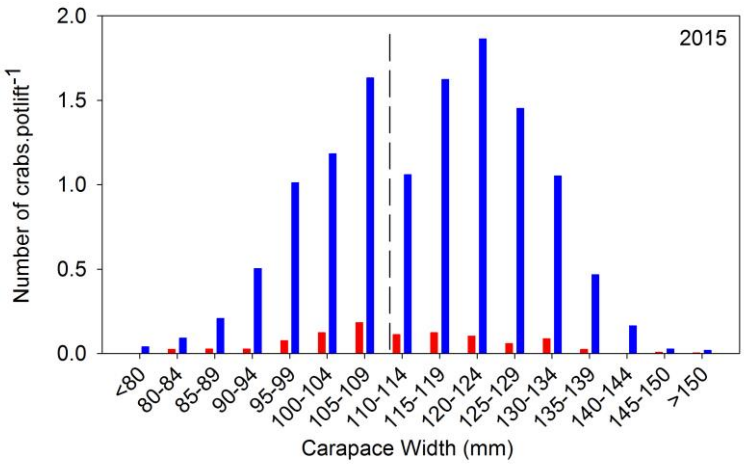

Figure A.5 Length frequency distributions of male and female blue crabs from the March 2015 FIS in GSV. Minimum size limit 110 mm carapace width, CW (---).

APPENDIX B: DEVELOPMENT OF NEW PERFORMANCE INDICATORS

Under the new management framework, it has been proposed that CPUE will be expressed by weight (kg.potlift^{-1}) rather than by abundance (crabs.potlift^{-1}). These conversions were performed using the length weight relationship (Figure B.1) for each crab measured since 2008 in SG (Figure B.2 and B.3) and GSV (Figure B.4 and B.5). Catch per unit effort have been presented for both gulfs utilizing the full suite of FIS locations and the reduced 60 site design as outlined in appendix A.

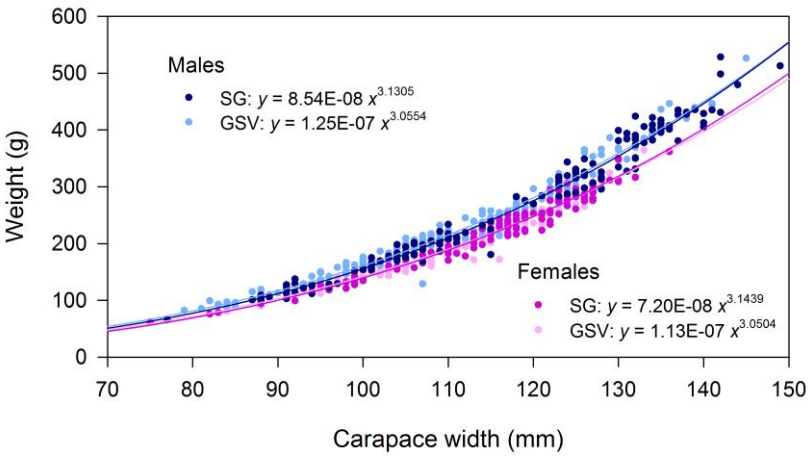

Figure B.1 Length-weight relationships of male and female blue crabs from SG and GSV.

B.1 Spencer Gulf

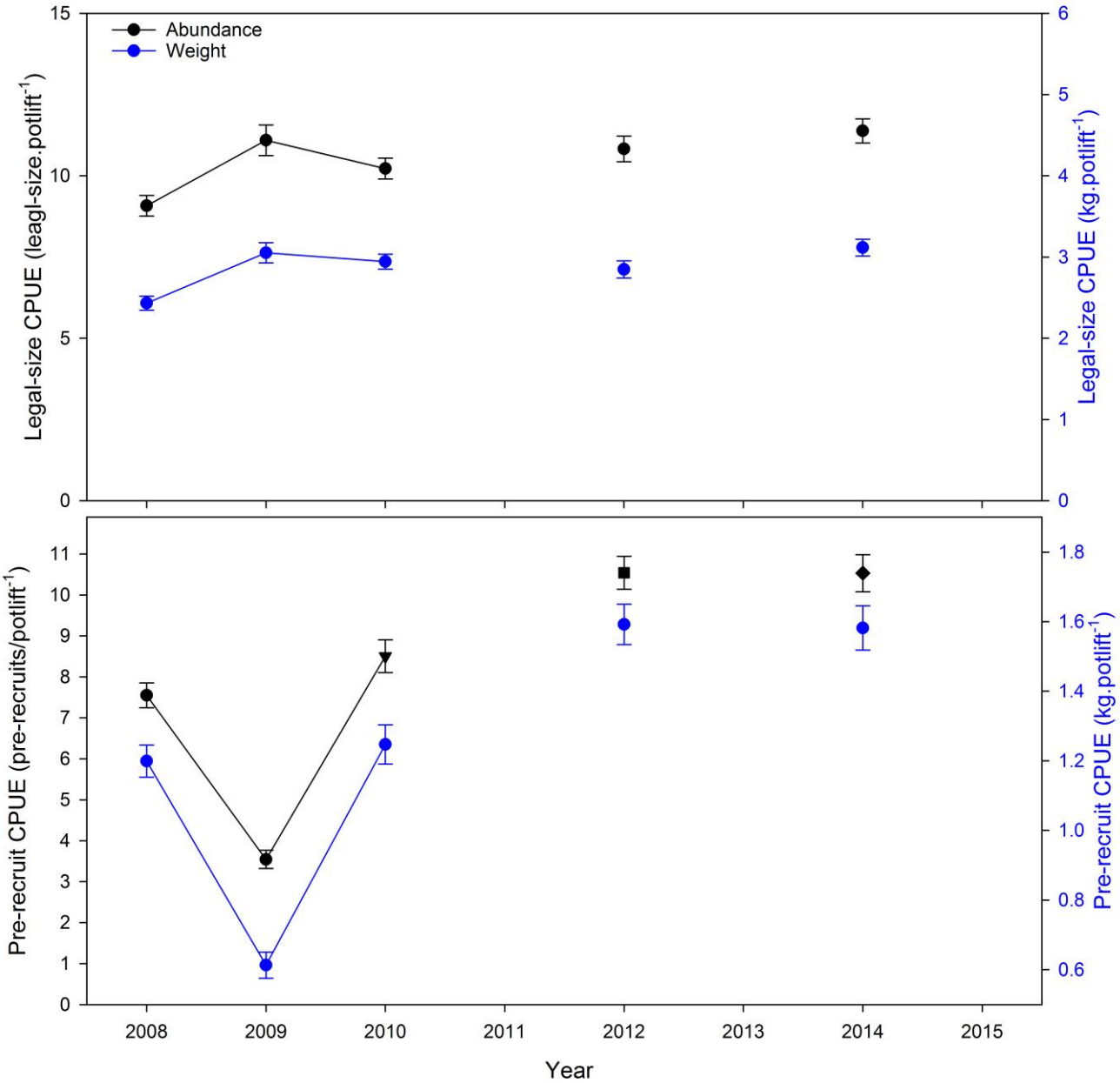

Figure B.2 Survey CPUE for the Spencer Gulf zone of the Blue Crab Fishery expressed by abundance and weight for the reduced suite of sites sampled (n= 60 sites). (Top) CPUE of legal-size crabs; (bottom) CPUE of pre-recruit crabs.

B.2 Gulf St Vincent

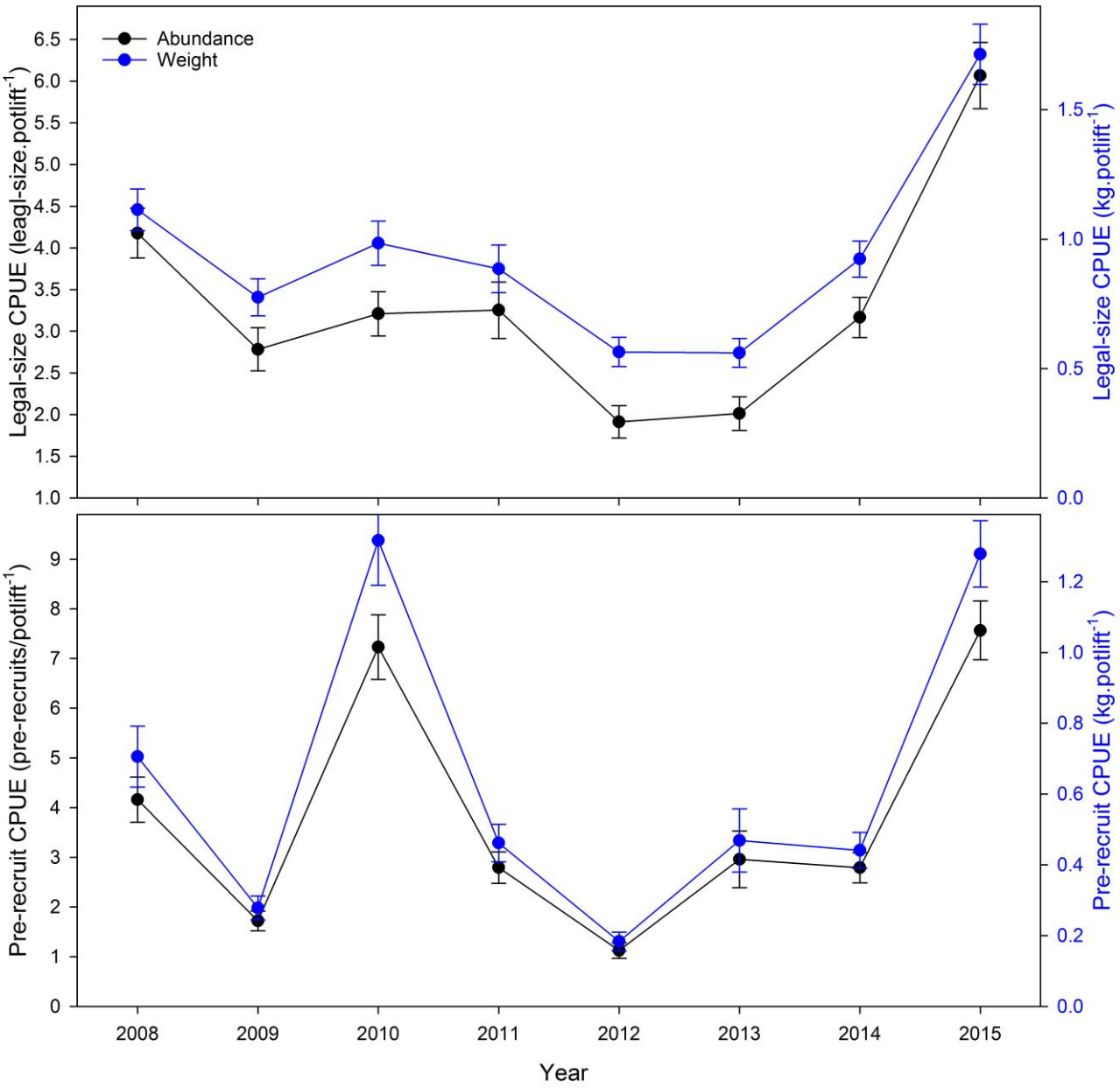

Figure B.3 Survey CPUE for the Gulf St Vincent zone of the Blue Crab Fishery expressed by abundance and weight for the reduced survey design (n= 60 sites). (Top) CPUE of legal-size crabs; (bottom) CPUE of pre-recruit crabs.

APPENDIX C: GEAR SELECTIVITY

C.1 Spencer Gulf

The survey CPUE of legal-size crabs in SG has generally increased since 2002, however, since 2008 the survey CPUE of legal-size crabs has been higher in research pots compared to commercial pots (Figure C.1). In 2014, the survey CPUE of legal-size crabs from research pots reached a high of 10.0±0.3 legal-size.potlift^{-1} from standard locations (10.3±0.3 legal-size.potlift^{-1} from revised locations) compared to 8.0±0.3 legal-size.potlift^{-1} (8.2±0.2 legal-size.potlift^{-1} from revised locations). From 2012–14, a smaller increase in the survey CPUE of legal-size crabs was observed for research potlifts (8% standard; 6% revised) than for commercial potlifts (15% standard; 10% revised).

The relative abundance of undersize crabs (pre-recruits) in SG has fluctuated greatly since 2002 (Figure C.1). The CPUE of pre-recruits from commercial pots followed similar trends to CPUE from research pots until 2010 and since then CPUE from commercial pots has remained at low levels. In 2014, the survey CPUE of pre-recruit crabs from research pots reached a high of 9.4±0.4 pre-recruits.potlift^{-1} from standard locations (9.1.3±0.3 pre-recruits.potlift^{-1} from revised locations) compared to 2.1±0.1 pre-recruits.potlift^{-1} (2.0±0.1 pre-recruits.potlift^{-1} from revised locations). From 2012–14, a 7% increase in the survey CPUE of pre-recruit crabs was observed for research potlifts while survey CPUE from commercial potlifts decreased substantially (37% standard; 42% revised).

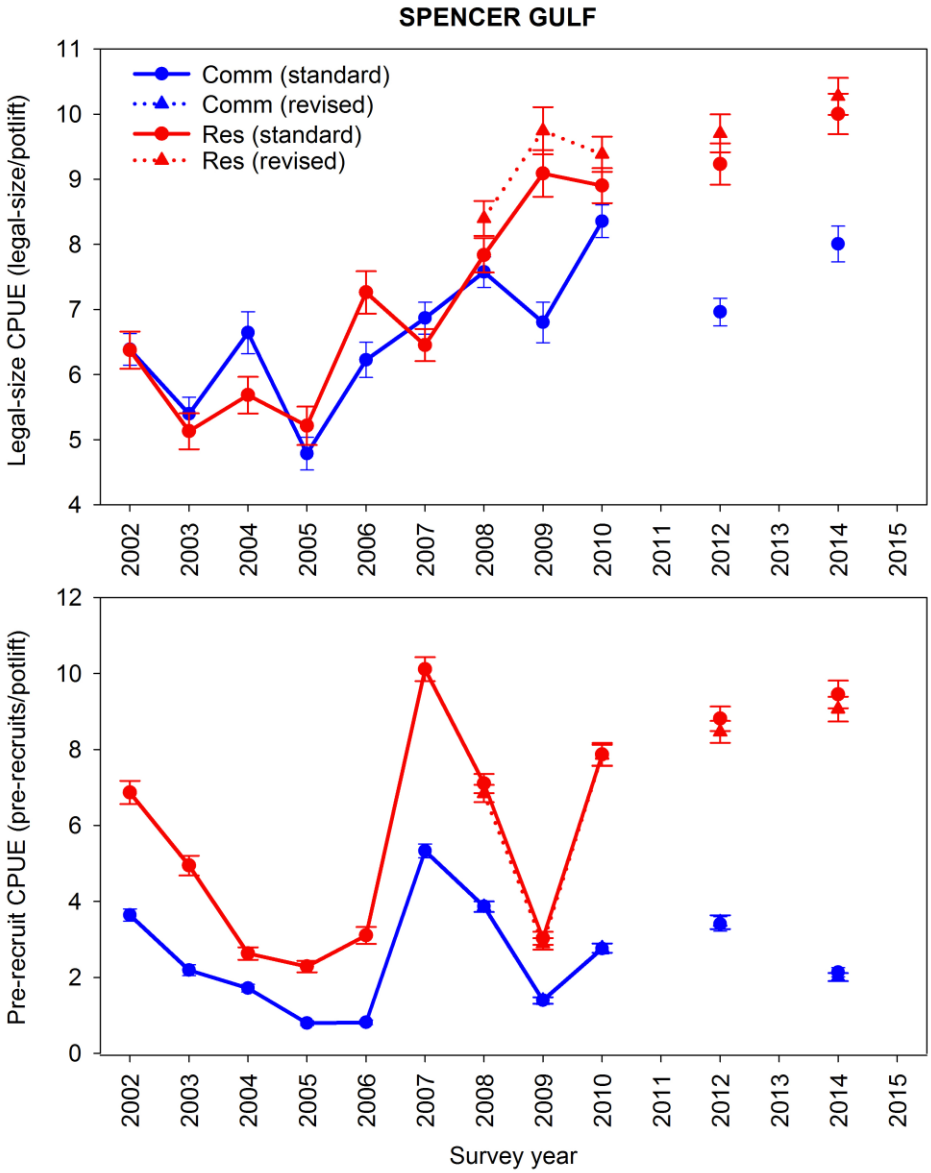

Figure C. 1 Mean catch per unit effort (CPUE, legal-size/potlift or pre-recruit/potlift) of crabs from research and commercial pots from standard locations (2002-current) and revised locations (2008-current) sampled in SG during June and July from 2002 to 2015. Error bars, standard error. Note, FIS were not conducted in 2011, 2013 or 2015.

C.2 Gulf St Vincent

The CPUE of legal-size crabs has fluctuated through time, with similar trends in CPUE observed in most years for commercial and research pots despite the larger mesh used in commercial pots (Figure C.2). In June 2015, the CPUE of legal-size crabs at standard locations was 5.5 legal-size.potlift^{-1} in both commercial and research pots. Similarly, at revised locations legal-size CPUE was 4.6±0.2 legal-size.potlift^{-1} and 4.4±0.3 legal-size.potlift^{-1} in commercial and research pots, respectively. From 2014–15, a larger increase in CPUE was observed for research potlifts (118% standard; 103% revised) than for commercial potlifts (76% standard; 38% revised.

The relative abundance of undersize crabs (pre-recruits) in GSV has fluctuated greatly since 2002 (Figure C.2). Estimates of the CPUE of pre-recruits from research pots (smaller mesh) were generally higher than CPUE estimated from commercial pots. In June 2015, the CPUE of pre-recruits at standard locations was 2.7±0.2 and 5.8±0.5 pre-recruits.potlift^{-1} in commercial and research pots, respectively. Similarly, in June 2015 at revised locations legal-size CPUE was 2.4±0.2 pre-recruits.potlift^{-1} and 5.2±0.4 pre-recruits.potlift^{-1} in commercial and research pots, respectively. From 2014–15, a larger increase in CPUE was observed for commercial potlifts (822% standard; 690% revised) than for research potlifts (172% standard; 189% revised).

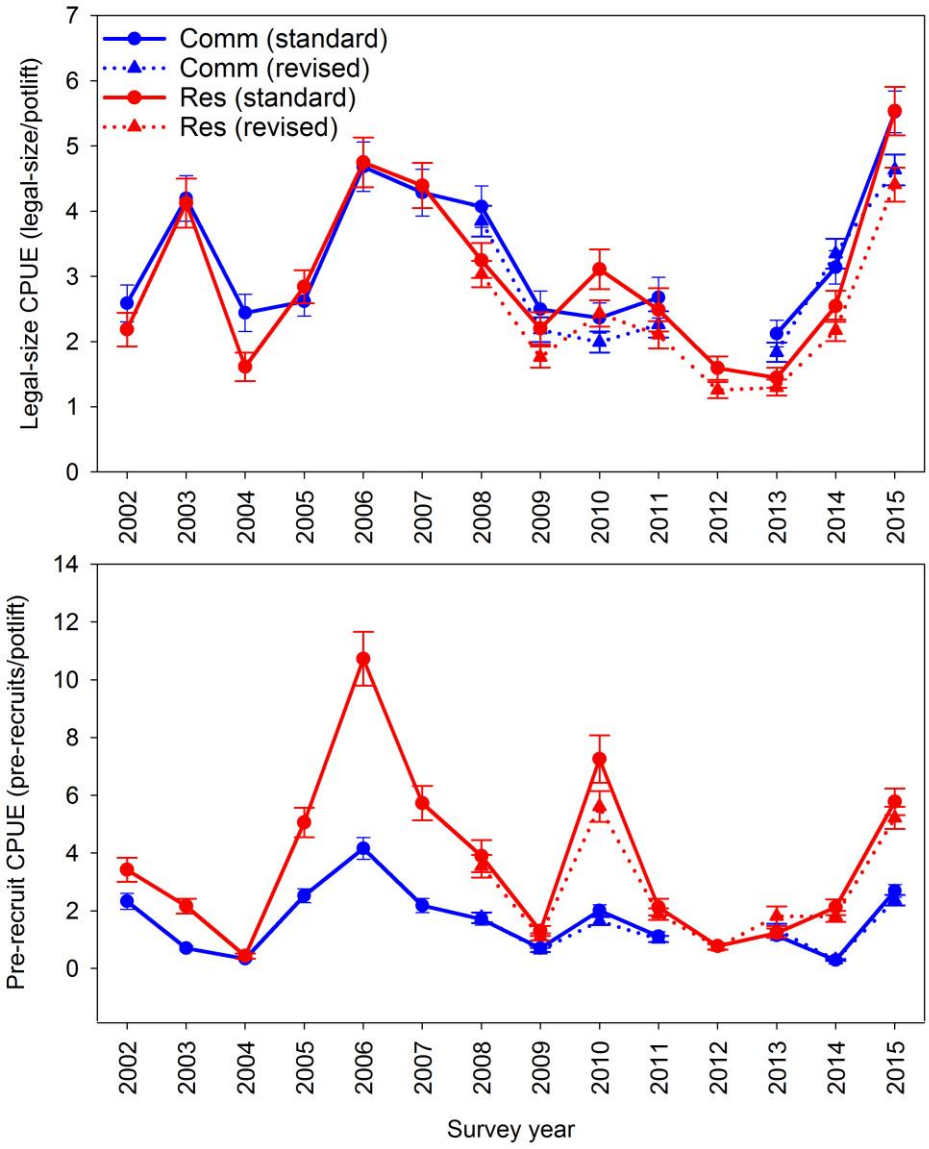

Figure C. 2 Mean catch per unit effort (CPUE, legal-size/potlift or pre-recruit/potlift) of crabs from research and commercial pots from standard locations (2002-current) and revised locations (2008-current) sampled in GSV during June and July from 2002 to 2015. Error bars, standard error. Note, research pots were not sampled in 2012.