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Status of the Blue Swimmer Crab Fishery in Shark Bay, Western Australia

Fishery Assessment Document

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Executive Summary

The Shark Bay Crab Fishery on the central coast of Western Australia has developed rapidly in the last 10 years to become Australia's highest producing blue swimmer crab fishery, with peak landings in 2010 of 828t valued at over AU$6 million. The resource is harvested commercially by the Shark Bay crab trap and Shark Bay prawn trawl fisheries, with negligible amounts retained by the Shark Bay scallop fishery. There are currently five 300-trap licences and 28 trawl (18 prawn and 10 scallop) licences authorized to take blue swimmer crabs in Shark Bay. The crab stock also supports a small (~1 t) but important recreational fishery. During the developmental phase of the commercial trap fishery, catches increased steadily with effort from 87t (1998) to 564t (2005). In 2005, the trap fishery transitioned to interim managed status and trap catches have stabilized at around 500t. The Shark Bay prawn fishery has taken crabs since its inception in the 1960s. The level of retained catch was relatively low up until 2001 (89t), but has since increased steadily to peak at 338t in 2010. However, since July 2011 the relative abundance of all size classes of crabs in Shark Bay declined significantly. The reasons for this unexpected and substantial decline are yet to be understood, but it may be linked to several adverse extreme environmental events (associated with a very strong La Nina event) that occurred during the summer of 2010/11. The effect of fishing on the breeding stock will also need to be examined, but preliminary assessment indicates that the spawning stock responsible for the low recruitment was within historic ranges.

Despite its status as the highest producing blue swimmer crab fishery in Australia, relatively little information has been published on the crab fishery or the biology and population structure of the blue swimmer crab stock in Shark Bay. This report: i) documents the management and catch history of the blue swimmer crab fishery in Shark Bay; ii) describes the spatial distribution and stock structure of the commercial trap catch; iii) summarises available recreational catch and effort data; iv) presents a preliminary assessment of the status of the crab stocks; v) highlights management issues pertinent to the fishery; and vi) identifies gaps in the scientific knowledge and provides recommendations on future research.

Information on fishing and stock dynamics in the Shark Bay crab fishery was derived from a number of ongoing programs run by the Department of Fisheries, Western Australia (DoF). Commercial trap catch and effort and trap catch composition was derived from statutory monthly returns and daily research logbooks submitted by fishers, processor's factory unloads, and monitoring surveys conducted 3 – 4 times a year aboard commercial trap vessels. Additional information on stock dynamics was derived from an annual fishery-independent trawl survey conducted in November/December that covered the main trawl grounds of Shark Bay, and several pilot trawl surveys along the eastern side of Shark Bay. Limited information on recreational fishing in Shark Bay has been derived from a creel survey conducted in the Gascoyne bio-region in 1998/99, and from creel surveys in Shark Bay targeting pink snapper fishers in 2000/01, 2001/02, 2005/06, 2006/07 and 2007/08.

The commercial trap catch in Shark Bay is dominated by large male crabs, with 80-90% of the catch taken from the fishing grounds north of Cape Inscription with peaks in March-May and again in October-December. Proportions of extra large (≥ 150 mm carapace width) males were also highest over the summer months from October through to April, accounting for 37% – 51% of the trap catch. This period coincides with the seasonal closure of the trawl fishery (October to March) during which trap fishers can access the central deeper areas of these northern grounds. However, the proportion of males in the trap catch decreased from 82% in 2001/02 to 69% in 2010/11, with the proportion of very large male crabs showing a significant decrease from

44% in 2007/08 to 21% in 2010/11. This decline in large males was not evident in the Eastern Gulf. During the developmental phase of the trap fishery there was a gradual increase in the mean carapace width of crabs measured during commercial trap monitoring surveys. However, since 2005 mean carapace widths have decreased. Similar trends emerged from the November fishery-independent trawl surveys, with standardized carapace widths increasing from 2002 to 2005 followed by a declining trend.

Spawning activity in Shark Bay occurs year-round, peaking in July – September in waters deeper than 12m. Berried females were most abundant in trap catch monitoring surveys in the northern-most latitudes to the east of Koks Island, and southern latitudes in the Eastern Gulf, suggesting possible spawning grounds in the deeper water of these areas. Given that spawning is continuous, it is assumed that mating also occurs throughout the year, with the higher incidence of moulted female crabs reported in Mar-May suggesting a peak period of mating during these months.

Conflicting evidence exists as to the sustainability of current total harvest levels in the data collected in the Shark Bay crab trap fishery. Linear relationships of nominal and standardized effort against commercial catch for the trap fleet over the past decade suggest the Shark Bay crab stock is yet to show signs of excessive fishing effort, and that fluctuations in catch are dependent on changes in effort and environmental conditions. Conversely, signs of high exploitation include: standardised catch rates of crabs from fishery-independent trawl surveys decreasing in the last three years; a decrease in mean standardized carapace widths of crabs from both commercial trap monitoring surveys and fishery-independent trawl surveys; a reduction in the proportion of extra large male crabs in the commercial catch; and a downward trend in the standardized catch rate in the Eastern Gulf. Concern also exists over the level of latent effort in the fishery, with the trap sector currently operating at 70 – 80% of its potential effort and the capacity for further increases in crab landings by the trawl fleet.

There is sufficient biomass and productivity within the blue swimmer crab stock in Shark Bay to sustain a significant commercial fishery. The current challenge for the research and management of this fishery is to clarify the causes for the recent decline, and establish an appropriate harvest strategy to ensure the future sustainability of the stock.

1.0 Introduction

The blue swimmer crab, *Portunus armatus* (A. Milne Edwards, 1861) (formerly *Portunus pelagicus* Linnaeus, 1758; Lai *et al*., 2010) inhabits near-shore, marine embayment and estuarine systems around most of Australia and east to New Caledonia (Lai *et al*., 2010). They live in a wide range of inshore and continental shelf habitats, including sandy, muddy or algal and seagrass habitats, from the intertidal zone to at least 50 m depth (Williams, 1982; Edgar, 1990). The species supports significant commercial and recreational fisheries in the Australian states of Queensland, New South Wales, South Australia and Western Australia (WA). Blue swimmer crabs are found along the entire Western Australian coast, although the majority of commercial and recreationally fished stocks are concentrated in coastal embayments and estuaries between Port Hedland (20°S) and Geographe Bay (34°S). The WA commercial blue swimmer crab fishery is the largest in Australia (2009/10 commercial catch of 1071 t valued at $5.4 million), and the Shark Bay crab fishery is the largest single commercial blue swimmer crab fishery in Australia (2009/10 commercial catch of 852 t; Johnston and Harris, 2011). The blue swimmer crab also represents one of the most targeted recreational species in the state in terms of participation rate (Campbell, 1997; Sumner *et al*., 2000).

1.1 Management history of trawling for blue swimmer crabs in Shark Bay

Blue swimmer crabs were likely to have been first exploited commercially in Shark Bay during the 1960s, with small quantities of crab retained by trawlers from Fremantle and Geraldton. The fishery was declared limited-entry in 1962 with a maximum of 25 boats, increasing to 30 in 1964 and peaking at 35 vessels in 1975. Spatial and temporal closures were first introduced in 1964, with a trawl season from March/April to September/October. Two significant changes in the prawn fishery occurred in 1990, with the prawn trawl fleet reduced from 35 to 27 boats, and the establishment of a temporal closure in the eastern part of northern Shark Bay via the Carnarvon/Peron line (Fig. 1). Permanent closures to commercial trawling were implemented in waters on the eastern side of Bernier and Dorre Islands, and the Wooramel seagrass banks in the eastern part of Shark Bay to provide protected nursery areas for juvenile prawns and crabs (Fig. 1). These closures have significantly decreased the actual area trawled in Shark Bay.

Since 2000 the prawn licensees have steadily increased their capacity to process and retain crabs, which now form an important economic component of their fishing enterprise. A significant marketing campaign has been developed across all aspects of the trawl catch, focused on “Shark Bay” as a pristine world heritage based fishery. In 2010, licensees further reduced the trawl fleet to 18 boats through an industry funded Fishery Adjustment Scheme (FAS).

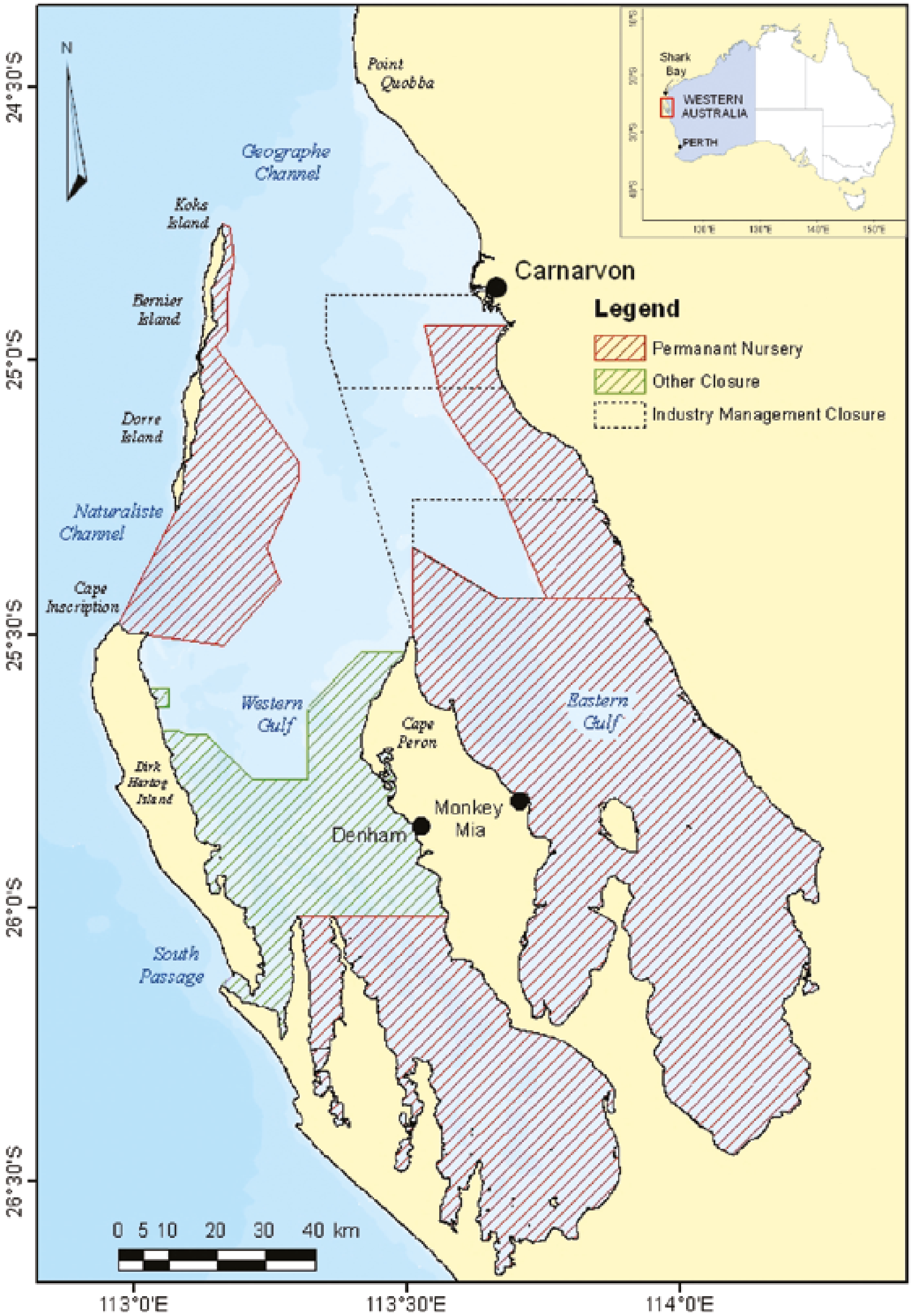

Figure 1. Map showing the location of Shark Bay within Western Australia, and the boundaries and exclusion zones of the Shark Bay Prawn Managed Fishery.

1.2 Management history of trap fishing for blue swimmer crabs in Shark Bay

Authorisation was granted to trial purpose-designed crab traps in Shark Bay in the early 1980s, allowing for a maximum of 450 hourglass traps to be used in the waters of the Shark Bay Beach Seine and Mesh Net Fishery (SBBSMNF) which covers the western and eastern gulfs of Shark Bay south of Cape Inscription (Fig. 2). While traps were found to be effective, the logistics of processing and transporting product to market from a remote location like Denham meant trap catch and effort remained relatively low through to the mid 1990s.

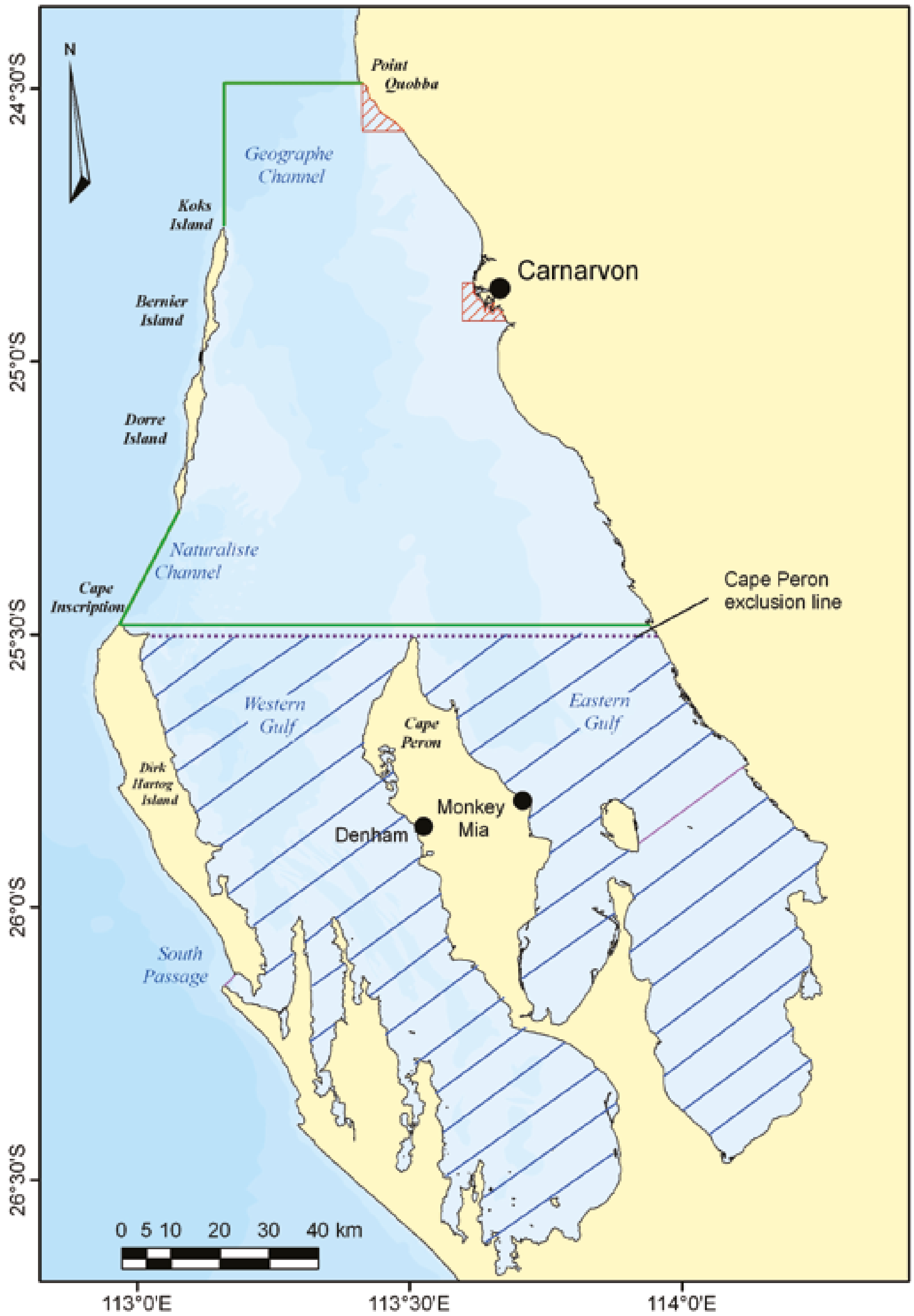

Figure 2. Map showing the boundaries (□) and exclusion zones (/ / /) of the Carnarvon Experimental Crab Trap Fishery, and the waters of the Shark Bay Beach Seine and Mesh Net Fishery (/ / /).

In November 1996, the Minister for Fisheries initiated a review of the WA blue swimmer and sand crab fishery to develop a management strategy for the sustainable harvest of blue swimmer crabs by both commercial and recreational sectors. A process of public consultation identified a range of issues that were compiled and published in Fisheries Management Paper No.112 (1998). The paper outlined the potential areas for further development and exploitation of *P. armatus* in WA waters, including Shark Bay, leading to a Fisheries Development Policy that sought expressions of interest from people keen to develop new crab trap fisheries.

The Carnarvon Experimental Crab Trap Fishery (CECTF) was established in 1998 to determine the potential for sustainable trap fishing of blue swimmer crabs in the waters of Shark Bay north of Cape Inscription. One fisher already authorized to trap in the SBBSMNF (the waters of the lower gulfs) was given access to the northern grounds with a maximum of 200 traps, another fisher already authorized to fish in all the waters of Shark Bay had his authority formalised with a maximum of 200 traps, and three new 200-trap endorsements were issued to fish the northern grounds only. The historic minimum size limit of 127 mm CW (distance between the tips of the two lateral spines of the carapace) applied, however, trappers fished a voluntary minimum limit of 135 mm CW. The management guidelines for the experimental fishery set no temporal closures to commercial trapping, however fishers were restricted to pulling their traps once in any 24-hour period (commencing at midnight) and spatial closures were implemented around Point Quobba and Carnarvon to minimise user conflict with recreational fishers (Fig. 2). The policy was to be reviewed after a three-year period. The substantial increase in fishing effort, along with improvements in fishing and an exponential increase in local fishing knowledge, saw the trap catch of blue swimmer crabs from Shark Bay increase significantly.

In 2001, the three 200-trap CECTF exemptions were re-issued to fish within the northern grounds, with an additional 100 traps allocated to each fisher to further explore economic viability and sustainable levels of catch and effort in this area of Shark Bay. An additional 100 traps were also issued to the two fishers endorsed to operate in the waters of the lower gulfs, with their use restricted to the waters north of Cape Inscription. This took the total allocation of commercial traps in the northern waters of Shark Bay to 1500, with two fishers each able to use a maximum of 200 traps of their 300-trap allocation in the lower gulfs. The crab catch over the next three years continued to increase in line with effort. In 2004 the trap fishery was certified as environmentally sustainable by the Department of Sustainability, Environment, Water, Population and Communities (formerly the Department of Environment and Heritage) under the provisions of the *Environment Protection and Biodiversity Act 1999*, declaring it an approved Wildlife Trade Operation allowing fishers to export their product (Department of the Environment and Heritage, 2004).

A comprehensive review of the CECTF was undertaken by the DoF in 2004 to examine trends in catch and effort and provide recommendations to aid the implementation of a formal management plan for the future management of the fishery. The review found that blue swimmer crab stocks in Shark Bay were healthy and coping adequately with the current levels of exploitation, and recommended that the CECTF was capable of further expansion since the stock did not display a strong annual cycle of depletion (Bellchambers *et al*., 2005). The total catch ranged from 364t to 671t between 2001 and 2004. The fishery moved to interim management status in 2005, formalising the existing management arrangements governing the CECTF. There currently remains a total of 1500 traps in the Shark Bay crab trap fishery, with a maximum of 400 of the 1500 traps able to be used in the Eastern and Western Gulfs south of Cape Peron.

While most trap fishers delivered whole fresh or cooked crabs to the market, one fisher has established a processing facility in Carnarvon and is now focused on the development of value-added crab products including cooked and frozen product, picked crab meat, and a variety of products that utilize previously discarded parts of the animal (eg. crab mornay, commercial cooking stock). Effort has also been put into the marketing of Shark Bay blue swimmer crabs as a premium seafood product, with fishers using the World Heritage listing of the Shark Bay region to emphasise the pristine nature of the habitat and the sustainability of the managed crab fishery.

1.3 Recreational fishing for blue swimmer crabs in Shark Bay

The recreational blue swimmer crab catch in the Gascoyne bioregion is considered to be modest, and was estimated in a 1998/99 recreational creel survey to account for less than 1% of the total annual catch in Shark Bay (Sumner *et al*., 2002). Nonetheless, the fishery is of significant importance to local communities and tourist operators. Recreational crabbing in Shark Bay tends to be localized around the townsites of Denham, Monkey Mia and Carnarvon, and south of Carnarvon at Bush Bay.

Recreational fishers employ a variety of methods to fish for blue swimmer crabs, including drop nets (maximum of 10 drop nets per boat or per shore-based fisher), scoop nets and by snorkelling/diving. There is a bag limit of 20 crabs per fisher and 40 crabs per boat (when there are two or more fishers in the boat), reduced from 24 per fisher and 48 per boat in 2003. A Recreational Fishing from Boat Licence was introduced in 2010. The minimum recreational size limit is set at 127 mm CW, and berried females must be returned to the water.

1.4 Physical description of Shark Bay

Covering an area of 13,000 km^2, Shark Bay is the largest marine embayment in Australia and supports the most extensive and diverse seagrass meadows in the world (Walker, 1989) (Fig. 1). The embayment, 800 km north of Perth, is of great significance to recreational, commercial and conservation sectors, and was added to the World Heritage List in 1991 (Francesconi and Clayton, 1996).

Shark Bay is an inverse estuary formed by an elongate chain of three islands; Dirk Hartog, Bernier and Dorre Island (Nahas, 2004). The southern half of the embayment is divided by the Peron Peninsula into Eastern and Western gulfs, characterized by narrow inlets and basins. The embayment is for the most part relatively shallow, with an average depth of 9m and deepest at 29m in the north (Francesconi and Clayton, 1996).

Shark Bay has a semi-arid climate, characterized by mild winters (mean minimum/maximum temperatures of 11/24^{o}C) and hot, dry summers (mean min/max temperatures of 21/33^{o}C) punctuated by infrequent cyclones. Mean annual rainfall is low, ranging from 200mm in the west of the Bay to 400mm to the east.

The hydrology of Shark Bay is influenced by the Leeuwin Current which carries warm, low saline water southward down the WA coast. Substantial exchange of oceanic water in the northern waters of Shark Bay occurs through the broad Naturaliste and Geographe channels, while a lesser exchange occurs in the western gulf through the narrow South Passage (Fig. 2). Extensive meadows of seagrass in the lower gulfs further restrict water movement. Currents slow as the water passes over these meadows, causing increased deposition of suspended sediments that over time have produced large sedimentary banks (Francesconi and Clayton, 1996). The most significant sedimentary bank is the Faure Sill, which greatly inhibits the outflow of dense, haline waters from Hamelin Pool maintaining a hyper-saline environment in the lower half of the eastern gulf (Francesconi and Clayton, 1996). The limited exchange of oceanic water, minimal freshwater input and high evaporation rates has resulted in Shark Bay containing three distinct water body types: oceanic (salinity of 35 – 40‰) in the northern waters and upper gulf regions, metahaline (40 – 56‰) in the middle gulf regions and hypersaline (56 – 70‰) in the lower gulfs. These distinct salinity regimes influence habitat and species distribution, resulting in three different biotic zones within Shark Bay (Francesconi and Clayton, 1996).

1.5 Biology of blue swimmer crabs

The reproductive cycle of blue swimmer crab populations along the WA coast is strongly influenced by water temperature (de Lestang *et al*., 2010). While the spawning period of blue swimmer crabs in the temperate waters of southwest WA is restricted to spring/summer (de Lestang *et al*., 2010, Johnston *et al*., 2011), the warmer, tropical waters of Shark Bay induce spawning all year round (de Lestang *et al*., 2003a). Incubation of released eggs takes 10 to 18 days, and the larval phase extends for up to six weeks (Kangas, 2000). Blue swimmer crabs moult frequently during the juvenile phase, and growth is rapid.

Female crabs undergo a pubertal moult in Shark Bay at around 6 – 10 months, when they are mated by a hard-shelled male. The male courting response is triggered by a pheromone released by the female (Meagher 1971). The courtship behaviour of *P. armatus* is described by Fielder and Eales (1972). Mature males moult some weeks before the maturing females, and each male carries a female clasped beneath him for 4 – 10 days before she moults. Mating occurs immediately after the female has moulted and when the shell is still soft. Males can mate with a number of females during the season. In the crab stocks of southwest WA, most of the large mature females mate only once a year as they moult only once a year, but receive enough sperm to fertilise millions of eggs in multiple clutches (Kangas, 2000, de Lestang *et al*., 2010). However, as moulting is more continuous in Shark Bay, it is possible that mature females may mate several times in a year. In Shark Bay, the mean size at maturity (male = 97.0 mm CW; female = 92.4 mm CW; de Lestang *et al*., 2003a) for blue swimmer crabs is well below the minimum legal size (commercial – 135 mm CW; recreational –127 mm CW), allowing females to spawn at least once before being available for capture.

Blue swimmer crabs reach legal size for capture around 12 – 14 months of age, with most animals in exploited crab stocks having died through natural or fishing mortality by the time they are 20 months (Potter *et al*., 2001). However, without fishing pressure blue swimmer crabs can live for three to four years.

Sezmiş (2004) investigated the population genetic structure of *P. armatus* in Australian waters, including the Shark Bay crab stock. He reported that crab assemblages on the WA coast become more and more distinct as one moves from north to south, with those in the southwest forming a homogenous but highly distinctive group. Essentially, the Shark Bay crab stock was genetically heterogeneous from crabs stocks to the north (Exmouth Gulf and Broome), and even more distinctive than crab stocks to the south.

1.6 Report objectives

Despite it's status as the highest producing single blue swimmer crab fishery in Australia, little information has been published on the commercial or recreational catch history of the Shark Bay crab fishery or the biology and population structure of the blue swimmer crab stocks in Shark Bay.

Campbell (1998) presented a summary of public submissions to a review of the West Australian inshore crab fishery, which included support for more research, a reduction in commercial and recreational catch and effort, the banning of set nets in favour of crab traps in the commercial fishery and the introduction of a recreational crabbing licence. Kangas (2000) summarised existing studies that had provided information on the biology, population characteristics and exploitation of the blue swimmer crab, *Portunus armatus*, in Western Australia, and identified gaps in the existing knowledge. The report concluded that research on blue swimmer crab fisheries within Australia at that point was generally limited, due largely to the low production output and value of commercial crab fisheries compared to species such as prawns, rock lobster and abalone. However, increased interest and exploitation of blue swimmer crabs, and the likelihood of further development of blue crab fisheries within Australia, meant a national approach to research was required (Kumar 1997, 1998).

Since 2000 a substantial amount of information has been published on *P. armatus* in sub-tropical waters along the east coast of Australia. However, most of the research on blue swimmer crabs in WA has been carried out in the temperate waters of the Leschenault and Peel-Harvey Estuaries (Meagher 1970, 1971, Potter *et al.* 1983, 1998, Potter and de Lestang, 2000, de Lestang *et al.,* 2003b), and marine embayments of Cockburn Sound (Penn 1977; de Lestang *et al.,* 2003a, 2010; Bellchambers *et al*., 2005; Johnston *et al*., 2011), Koombana Bay (de Lestang *et al*., 2003a) and Geographe Bay (Sumner and Malseed, 2004; Bellchambers *et al*., 2006). One dietary study (Edgar 1990) on *P. armatus* has been undertaken at Cliff Head. Potter *et al.* (2001) described a range of biological parameters that could facilitate a formal assessment of crab stocks in Shark Bay, however, spatial coverage of the study site was limited and did not include the main commercial crabbing grounds. Bellchambers *et al.* (2005) presented a preliminary stock assessment of the CECTF. Data from commercial fishers' statutory returns and catch monitoring surveys was analysed to describe commercial trap catch and effort and assess the sustainability of current commercial harvest levels, while research logbook and tagging survey data was used to provide a summary of the spatial distribution of crab stocks in Shark Bay. Sezmiş (2004) investigated the population genetic structure of *P. armatus* in Australian waters, including the Shark Bay crab stock. White *et al.* (2004) described predation of *P. pelagicus* in Shark Bay by four species of elasmobranch. He reported a significant level of predation by the giant shovelnose ray (*Rhinobatus typus*) and adult specimens of the nervous shark *Carcharhinus cautus,* with only moderate predation by the lemon shark *(Negaprion acutidens)* and the milk shark (*Rhizoprionodon acutus*). Consequently, our understanding of blue swimmer crab biology and recent fishing status in Shark Bay remains relatively weak.

This report documents the Shark Bay commercial trap and trawl catch history and builds on the general biology of blue swimmer crab stocks in Shark Bay. The specific objectives of this report are to:

1. document the management and catch history of the blue swimmer crab fishery in Shark Bay;
2. describe the spatial distribution and stock structure of the commercial trap catch in Shark Bay;
3. present a summary of available recreational catch and effort data for blue swimmer crabs in Shark Bay;
4. present a preliminary assessment of the status of the crab stocks;
5. highlights management issues pertinent to the fishery; and
6. identifies gaps in the scientific knowledge and provides recommendations on future research.

2.0 Methods

2.1 Study Location

Shark Bay is located 800km to the north of Perth, Western Australia (between latitudes 24°30'S and 26°00'S), and covers an area of approximately 13,000km^2 (Fig. 1).

2.2 Commercial catch and effort

2.2.1 Trap

Commercial trap fishers submit statutory monthly returns that include total catch of all retained species and an estimate of fishing effort (days fished per month and mean number of traps used per day in that month) by spatial block (Fig. 3). Commercial catch and effort for comparison between the trawl and trap fleets in Shark Bay is presented by calendar year from 1990 to 2010 as the trawl fleet fishes from March to October each year. Statistical analysis of commercial trap catch and effort is presented by financial year, as this is more appropriate to the biology of the species. Catch is reported by weight (tonnes), while effort and catch per unit effort (CPUE) for the trap fishery are reported in numbers of traplifts and kg/traplift respectively. The possibility of bias in the spatial allocation of catch and effort by trap fishers should be noted, particularly for fishers operating close to block boundaries. On occasion, fishers have reported fishing in multiple fishing blocks during a month, but have only recorded a total catch and effort figure. The assumption has been made for these records that the fisher had operated equally in all reported fishing blocks in that month, with that month’s catch and effort apportioned equally across the reported blocks.

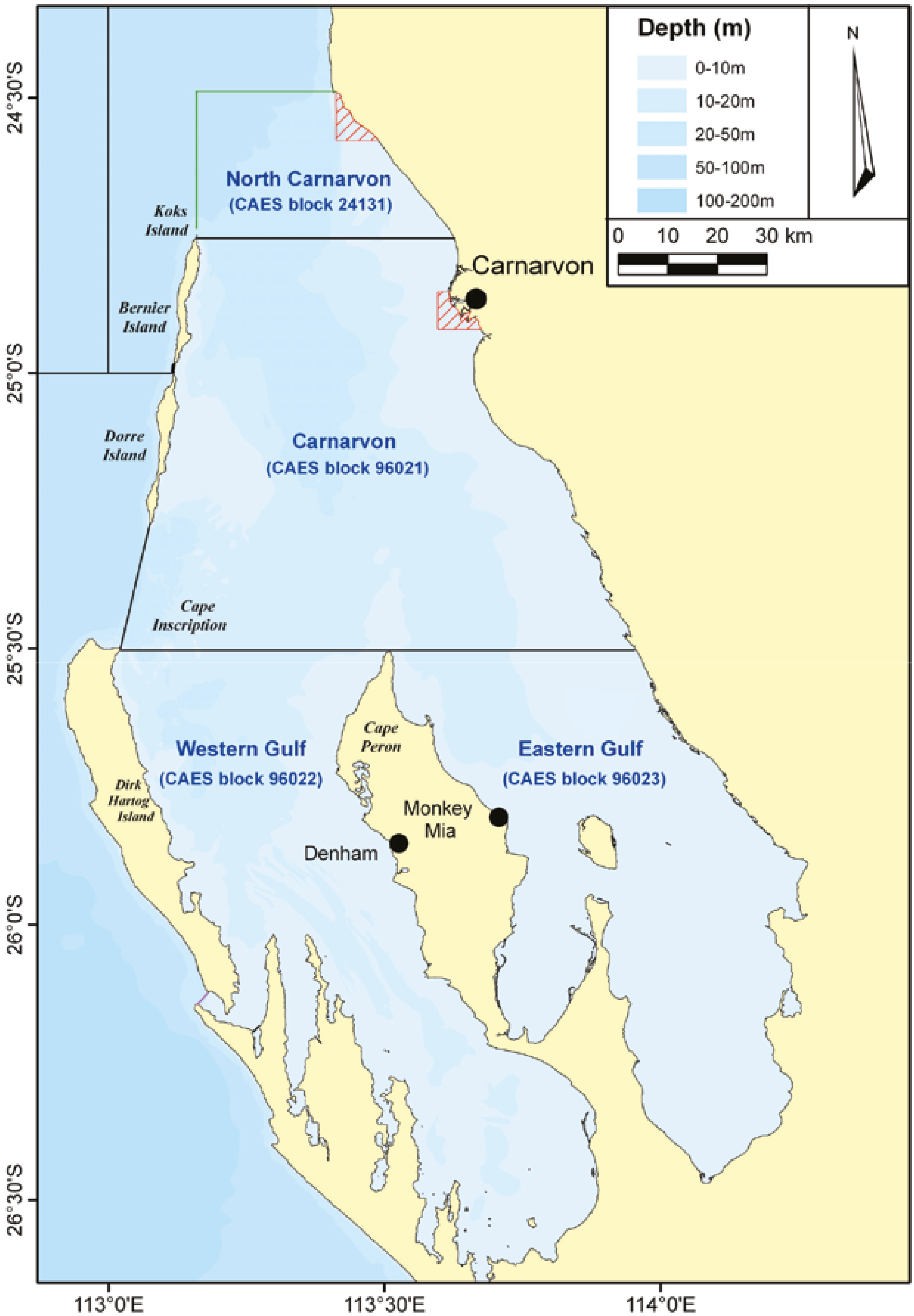

Figure 3. Map displaying the fishing blocks reported by Shark Bay commercial trap fishers in statutory monthly catch and effort (CAES) returns.

2.2.2 Trawl

Both prawn and scallop fishers provided statutory monthly returns that focused on the target species and retained byproduct (including blue swimmer crabs). This information provided an estimate of catch and recorded days fished rather than shot duration as the monthly effort. Fishers also maintained daily logbooks that initially recorded blocks or fish ground (up to 1997) and only the catch of target species (prawn and scallops) for each trawl. Since 1998, the start position (latitude and longitude) of each trawl was recorded, along with the total catch of byproduct species for each night of fishing. From 2008 the daily logbook system has replaced the monthly returns as the fisher's statutory submission of catch and effort for the Shark Bay trawl fishery.

2.3 Commercial monitoring

Monitoring of commercial crab trap catches in Shark Bay has been conducted in the March/April/May, July/August/September and October/November/December periods since 2000 (Fig. 4). Commercial fishers were accompanied by research staff during daily crabbing operations and the day's catch and effort recorded. Each fisher serviced 200 – 450 hourglass traps (set in lines of 20 – 50 traps) daily, with all crabbers operating in the fishery monitored on each monitoring trip where possible. Carapace width (the distance between the tips of the two lateral spines of the carapace measured to the nearest millimetre), sex, moult stage, female breeding condition (absence/presence of externally visible eggs), the number of pots in the line, soak time (number of hours the traps have been in the water since they were last serviced) and a latitude, longitude and depth for each trap line were recorded.

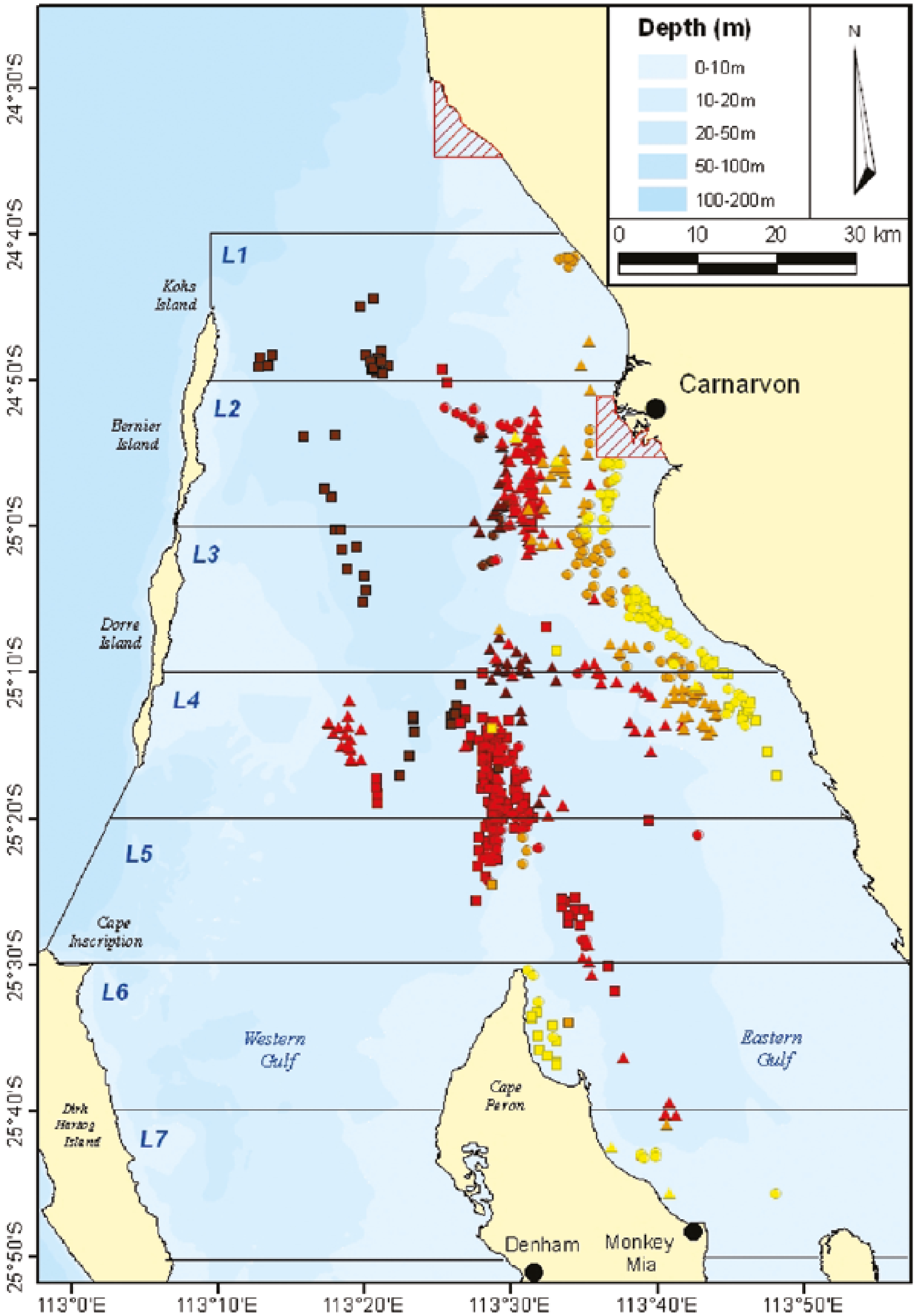

Figure 4. Map displaying the location, sampling period (▲March/April/May; ● July/August/September; ■ October/November/December) and depth (● <5m; ● 6-11m; ● 12-17m; ● >17m) of potlines sampled during catch monitoring surveys aboard commercial crab trap vessels in Shark Bay between 2000 and 2010, and the 10-minute latitudinal classifications (***L#***) used in the statistical spatial analysis of the commercial monitoring data.

Table.1. Months (■) in which commercial trap monitoring surveys were conducted in Shark Bay between 2000 and 2010. Numbers of vessels sampled during each survey are included in white.

	NORTH of CAPE INSCRIPTION												EASTERN GULF											
	Month												Month											
YEAR	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
2000				1				4			2												1	
2001					3			2				3												
2002				2				4																
2003			4					3																
2004				4							4													
2005										3												2		
2006			3				4																	
2007			3					2																
2008				3				1												1				
2009					3			2			3						1			1			1	
2010					3				1			3												

2.4 Fishery-independent trawl surveys

2.4.1 November trawl survey

Fishery-independent trawl surveys to assess the recruitment of scallops, and to a lesser extent pink snapper, have been undertaken during November in Shark Bay since 1983. While this survey does not cover all areas where crabs occur, it has provided valuable crab information for the time and area surveyed. Data on blue swimmer crab has been collected since 2002. From 2002 to 2007 inclusive, trawling was undertaken using the research vessel *RV Naturaliste* (22.7 m in length). The trawl system used is a prawn low opening otter trawl system in double or twin net rig configuration. Each net has 6 fathoms of headrope length for a combined headrope length of 12 fathoms (22 m). Each net had 50 mm mesh in the wings and 45 mm mesh in the cod-ends. Ten millimetre ground chains were attached to the footrope of the nets, which are set ahead of the net. A net efficiency factor (0.6 × net headrope length in metres) is incorporated to adjust for the effective spread of the net on the seabed (Joll and Penn 1990), giving the effective mouth opening of each net of 7.3 m. Each trawl is twenty minutes in duration and up to approximately 80 sites were sampled throughout Shark Bay (Fig. 5) over 5 – 10 nights in November each year. Trawling was undertaken during nighttime, commencing 30 minutes after sunset. The carapace width, sex, moult stage and female breeding condition of each crab was recorded. In the years 2008 to 2010 inclusive, surveys have been undertaken using a commercial Shark Bay prawn trawler, with Department of Fisheries researchers on board conducting the survey operation. The trawl system used on the commercial boat is the same used on the *R.V. Naturaliste* for this sampling regime.

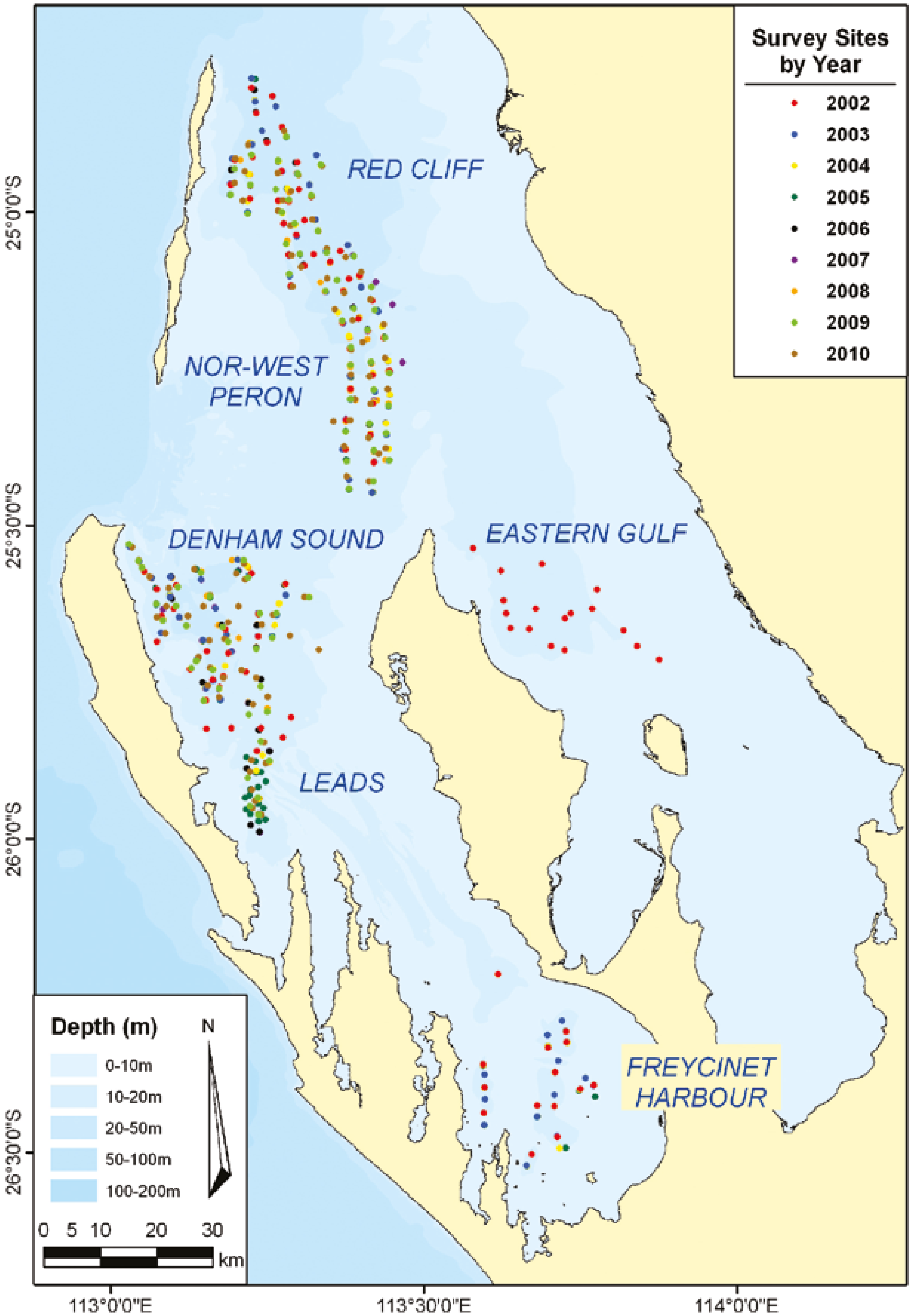

Figure 5. Map displaying the location of trawl sites sampled each year during the annual November Fishery-Independent Trawl Survey in Shark Bay between 2002 and 2010 and the relevant fishing grounds referred to in the data analysis.

2.4.2 Pilot sampling in eastern Shark Bay (ENA)

Fishery-independent trawl surveys to assess prawn recruitment and the size structure of king and tiger prawns along the eastern side of Shark Bay (including ENA) have been undertaken in March and April each year since 2000. In April and November 2010, and March 2011, abundance and size distribution information was also collected blue swimmer crabs. The DoF trawler *RV Naturaliste* (see methods in scallop survey) was used in the November survey, and a commercial boat in the March and April surveys. The commercial prawn boat was rigged with a prawn low opening otter trawl system in quad-gear configuration. Each net had a headrope length of 5.5 fathoms (a combined headrope of 22 fathoms or 40.2m), with 50 mm meshes in the wings and 48 mm meshes in the cod-ends. Each trawl was thirty-minutes duration and 18 standard sites were sampled (Fig. 6). The survey-was undertaken around the third moon phase with trawling occurring during night-time (1900 – 0700 hours).

Crab numbers (retained and discarded crabs) were recorded for each trawl and sex, reproductive condition and carapace width measurements were recorded for every two or three sites. Due to the large volume of crabs encountered using quad gear during 30-minute trawls, insufficient time was available to measure all crabs captured at each site.

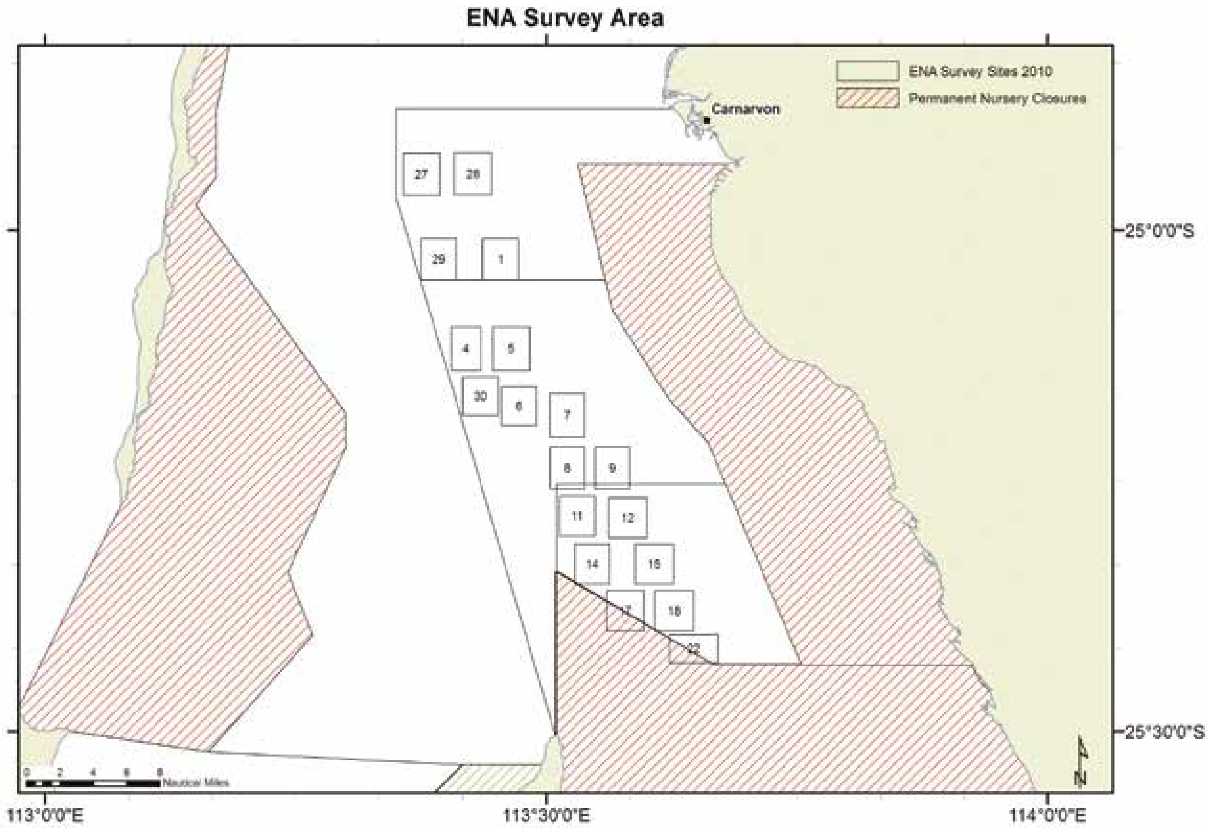

Figure 6. Map displaying the sites sampled during the Eastern Shark Bay (ENA) Survey in April and November 2010, and March 2011.

2.5 Commercial trap factory unloads

In addition to fisher's statutory monthly returns, data on retained commercial crab trap catches in Shark Bay was derived from unload information obtained from crab processors. Catch data from returns were apportioned into four categories:

- Male – <150 mm CW
- Extra large male – 150+ mm CW
- Female
- Soft and broken – animals with either one or both claws missing, and/or with a carapace that indented when pressed firmly by the thumb on the anterior left portion of the carapace.

Crabs that had been cooked by processors prior to being weighed were converted back to live weight using the formula:

Green weight (kg) = cooked weight (kg) x 1.13164.

2.6 Daily research logbooks

2.6.1 Trap

In addition to their statutory monthly catch and effort returns, trap fishers operating in Shark Bay were requested to complete the more comprehensive daily Blue Swimmer Crab Research Logbook. However, research logbook data was only submitted covering the fishing grounds north of Cape Inscription.

The research logbook details catch and effort information by trap line. For each line of crab traps set, fishers were required to record a latitude and longitude or block area, the number of traps in the line, depth, trap soak-time and a total catch estimate in either kilograms or baskets of crab. If reporting in baskets, the fisher was to include an average basket weight to allow for the conversion of the basket estimate to a catch in kilograms for that line.

A subset of the daily research logbook data (2003 to 2008) was used in a preliminary analysis of the spatial distribution of commercial trap catch and effort in Shark Bay. This data accounted for approximately two thirds of the commercial fishing effort during this period, determined by comparing the numbers of fishing days where trap fishers submitted daily research logsheets with the number of days fishers reported crabbing each month in their statutory monthly returns. Approximately 7% of this research logbook data was discarded due to erroneous or incomplete information.

2.6.2 Trawl

Daily research logbooks are completed by all skippers operating in the prawn and scallop fleets in Shark Bay. These logbooks have recorded start of the tow location, trawl duration and the weight of each prawn or scallop species retained by size grade for each night's trawl. However, the crab catch is recorded as a total catch weight each night rather than for each tow, with no information on discarded bycatch. Because of this, the crab data is not as useful as the prawn catch data. The crab information from the logbooks cannot be used to assess total crab abundance as only a portion of the total catch of crabs is retained (larger size crabs > = 135 mm carapace width for one sector of the prawn boats and >=150 mm for the other sector) and the retention rate may be variable during the season depending on the abundance of the target species and crab prices paid to the boat.

The trawl effort is targeted towards prawns (and or scallops) rather than crabs, so effective effort cannot be accurately apportioned to crabs.

2.7 Recreational Fishing

A 12-month survey of recreational boat-based and shore-based fishing in the Gascoyne bioregion was conducted between April 1998 and March 1999 (Sumner *et al*., 2002). A total of 1738 boat-based fishing parties were interviewed at public boat ramps, while 695 groups of boat-based fishers and 1060 groups of shore-based fishers were interviewed during patrols of fishing locations and camp sites along the coastline.

An estimate of the total recreational blue swimmer crab catch in the Gascoyne bioregion for the 12-month period was calculated, but not specifically for Shark Bay. Details of the experimental design and statistical analysis of the survey data can be found in Sumner *et al*. (2002).

Information on recreational blue swimmer catches in the inner gulfs of Shark Bay has also been extracted from recreational surveys targeting pink snapper fishers (Sumner and Malseed, 2002). A 12-month creel survey of recreational boat-based fishing in Shark Bay was conducted between May 2000 and April 2001, during which 456 boat fishers were interviewed at public boat ramps. An estimate of the total recreational blue swimmer crab catch in the inner gulfs for the 12-month period was calculated. Details of the experimental design and statistical analysis of survey data can be found in Sumner and Malseed (2002). The pink snapper survey was repeated in 2001/02, 2005/06, 2006/07 and 2007/08, replicating the experimental design and statistical analysis of survey data from the 2000/01 survey.

2.8 Statistical Analysis

2.8.1 Commercial trap catch and effort (CAES)

Trap catch per unit effort (CPUE) trends were analysed by ANOVA with the variables: financial year (1990/91 – 2010/11*), month, fisher and block (Western Gulf, Eastern Gulf, Carnarvon, N Carnarvon; Fig. 3). *2010/11 data is provisional to December 2010 inclusive. The main effects model incorporated four fishers, with one fisher excluded due to difficulties separating spatial versus fisher trends. A fisher x financial year interaction was analysed with the variables: financial year (2002/03 – 2010/11*), month, fisher (Northern grounds), and block (Western Gulf, Eastern Gulf, Carnarvon, North Carnarvon). A separate analysis was also undertaken for fishers operating in the Eastern Gulf only (same main effects and interaction models) due to differences in fishing location and approach by the two groups of fishers.

CPUE (kg / traplift) was calculated as landed weight / average number of pots serviced each day in a month / number of fishing days in fishing block in that month. Weighting observations by the number of pot lifts, CPUE has been modeled for the fishery as:

$$\log(y_{i,j,k,l,m} + \Delta) = \alpha_i + \beta_j + \gamma_k + \delta_l + \alpha_i\gamma_k + \varepsilon_m$$

where:

$y_{i,j,k,l,m}$ is the CPUE for financial year i, month j, fisher k, block l;

Δ is a constant chosen to give Normal errors;

α_i is year i ∈ (financial year: 1990/91-2010/11);

β_j is month j ∈ (Jul – Jun);

γ_k is fisher k ∈ (4 fishers for north of Cape Inscription; 1 fisher for south of Cape Inscription);

δ_l is block l ∈ (W Gulf, E Gulf, Carnarvon, N Carnarvon)

$\alpha_i\gamma_k$ is an interaction between year i and fisher k.

Analysis of inter-annual trends in effort versus catch were based on the technique of Hall and Penn (1979), with consideration given to the spatial and temporal variations in fishing effort and efficiency between fishers by standardizing CPUE with the variables: financial year (1990/91 – 2010/11*), month, fisher (3 fishers operating in the northern fishing grounds) and block (Western Gulf, Eastern Gulf, Carnarvon, N Carnarvon). Nominal catch was then divided by the standardized CPUE to provide the standardized effort, which was plotted against nominal catch. However, this standardized effort does not take into account any increase in efficiency that has occurred for these 20 years. R^2 values were calculated.

As the dataset was unbalanced (unequal numbers of replicates per treatment), type III sums of squares were studied and least-square means (as opposed to arithmetic means) were presented (SAS Institute Inc. 1989). Back-transformed least-square means have been calculated to obtain standardized estimates for the catch rates (animals per potlift) at each factor level.

2.8.2 Commercial trap catch monitoring

Catch rate trends were analysed by ANOVA with the variables financial year (2000/01 to 2010/11*), month (Jul/Aug/Sep, Oct/Nov/Dec, Mar/Apr/May), depth (<6m, 6 – 11m, 12 – 17m, >17m), fisher and latitude. *2010/11 data is provisional to December 2010 inclusive.

The seven latitude groupings, L1 to L7 (Fig. 4), were in 10' transects from 24° 40'S to 25° 50'S.

Three-way interactions were not included in the analysis due to the dataset not being complete at this level. Data missing the number of pots sampled was removed. The number of observations for each level of the interaction are shown in Tables 2 and 3.

Table. 2. Number of observations for each month and latitude category.

	Latitude Category						
Month	**L1**	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**
Jul/Aug/Sep	8	46	75	52	31	5	6
Oct/Nov/Dec	21	5	21	118	35	16	2
Mar/Apr/May	4	118	39	80	4	3	4

Table 3. Number of observations for each month and depth category.

Month	Depth Range			
	< 6m	6 – 11m	12 – 17m	> 17m
Jul/Aug/Sep	62	63	64	9
Oct/Nov/Dec	36	2	121	44
Mar/Apr/May	3	46	131	27

The categories of blue swimmer crab modeled were:

- Commercial male: ≥ 135 mm CW;
- Commercial female: ≥ 135 mm CW, with no externally visible eggs protruding from beneath the abdominal flap (non-berried);
- Sub-legal sexually mature male: 116 – 134 mm CW;
- Sub-legal sexually mature female: 93 – 134 mm CW, with no externally visible eggs protruding from beneath the abdominal flap (non-berried);
- Sub-legal sexually immature male: ≤ 115 mm CW;
- Sub-legal sexually immature female: ≤ 92 mm CW;
- Berried female: crabs with externally visible eggs protruding from beneath the abdominal flap;
- Soft male: crabs with a carapace that indented when pressed firmly by the thumb on the anterior left portion of the carapace; and:
- Soft female.

At the time of this analysis, length at sexual maturity for blue swimmer crabs was considered to be 115.1 mm CW for males and 92.4 mm CW for females, as reported in Potter *et al.*, (2001). Consequently, these values were used to define size at maturity categories in this analysis. These values were also used in statistical analyses conducted by Bellchambers *et al.* (2005). Subsequent analysis has revised male size at maturity in Shark Bay to be 97.0 mm CW (de Lestang *et al.*, 2003a), and this value will be used in all future statistical analyses of the Shark Bay crab stock.

As commercial fishers avoid undersize crabs and the size of mesh used on their hourglass traps selects against the retention of small crabs, only very small numbers of sub-legal sexually immature female crabs (standardized catch rates of between 0.00006 – 0.001 crabs/traplift) were caught during catch monitoring surveys. Consequently, statistical analysis of this category was not robust and results are not presented for this category. There were also insufficient samples of soft-shelled male and female crabs in the 6 – 11 m depth range, and this category was deleted from the analysis.

Weighting observations by the number of pot lifts, catch rates (animals per potlift) have been modeled for the fishery as:

$$\log(y_{i,j,k,l,m} + \Delta) = \alpha_i + \beta_j + \gamma_k + \delta_l + \zeta_m + \alpha_i\zeta_m + \alpha_i\gamma_k + \varepsilon_n$$

where:

$y_{i,j,k,l,m}$ is the catch rate (animals per potlift) for month i, financial year j, depth k, fisher l, and latitude m;

Δ is a constant chosen to give Normal errors;

α_i is month i ∈ (Jul/Aug/Sep, Oct/Nov/Dec, Mar/Apr/May);

β_j is financial year j ∈ (2000/01 - 2010/11);

γ_k is depth k $\in$ (< 6m, 6 – 11m, 12 – 17m, > 17m);

δ_l is fisher l $\in$ (3 fishers for north of Cape Inscription; 1 fisher for south of Cape Inscription);

ζ_m is latitude m $\in$ (L1-L7);

$\alpha_i\zeta_m + \alpha_i\gamma$ are interactions between the month, latitude, and depth.

As the dataset was unbalanced (unequal numbers of replicates per treatment) type III sums of squares were studied and least-square means (as opposed to arithmetic means) were presented (SAS Institute Inc. 1989). Back-transformed least-square means have been calculated to obtain standardized estimates for the catch rates (animals per potlift) at each factor level.

Crab carapace widths were also analysed, with the exception that no transformation was applied to the data and no weighting was applied.

2.8.3 Fishery-independent November trawl survey

Catch rate trends were analysed by ANOVA with the variables year (2002 – 06 and 2008 – 10), depth (6 – 11m, 12 – 17m, >17m) and fishing ground (Denham Sound, Freycinet Harbour, Leads, Eastern Gulf, North-West Peron and Red Cliff;). No trawls were conducted in water shallower than 6m. 2007 data was excluded from this analysis as the survey was severely affected by poor weather.

Fishing ground boundaries (Fig. 5) were defined as follows:

- Red Cliff: Lat > 25.15°S
- North-west Peron: 25.5°S < Lat < 25.15°S
- Denham Sound: Long < 113.4°E & (25.85°S < Lat < 25.5°S)
- Leads: Long < 113.4°E & Lat < 25.85°S
- Freycinet Harbour: Lat < 26°S
- Eastern Gulf: Lat > 26°S & Long > 113.5°E

Other than soft crabs which were not analysed, the categories of blue swimmer crab modeled were the same as those listed above for the commercial monitoring program.

Length at sexual maturity for blue swimmer crabs in Shark Bay was considered to be 115.1mm CW for males and 92.4mm CW for females (de Lestang *et al*., 2003a).

Weighting observations by the distance trawled, catch rates (animals/1000m^2 trawled) have been modeled for the fishery as:

$$\log(y_{i,j,k,l} + \Delta) = \alpha_i + \beta_j + \gamma_k + \varepsilon_n$$

where:

$y_{i,j,k,l,m}$ is the catch rate (animals/1000m^2) for financial year i, fishing ground j and depth k;

Δ is a constant chosen to give Normal errors;

α_i is financial year i $\in$ (2002/03 – 2010/11);

β_j is ground j $\in$ (Denham Sound, Freycinet, Leads, Eastern Gulf, NW Peron and Red Cliff);

γ_k is depth k $\in$ (6 – 11m, 12 – 17m, > 17m).

As the dataset was unbalanced, type III sums of squares were studied and least-square means were presented (SAS Institute Inc. 1989). Back-transformed least-square means have been calculated to obtain standardized estimates for the catch rates (animals per potlift) at each factor level.

3.0 Results

From the 1950s, small quantities (<5 t annually) of blue swimmer crabs have been landed from Shark Bay by the prawn and scallop trawl fleet. Following the introduction of purpose-designed crab traps to Shark Bay in the 1980s, annual catch from both the trawl and trap sectors increased to 20 t in 1990 and 92 t by 1997 (Fig. 7; Table 4). Following the commencement of the CECTF in 1998, the combined trap and trawl annual catch increased significantly to 716 t in 2005. Since the trap fishery moved to interim management in 2005, the annual combined catch from both sectors has fluctuated between 620 t and 830 t, with variation largely dependent on the retention of crabs by the trawl fleet (Fig. 7; Table 4).

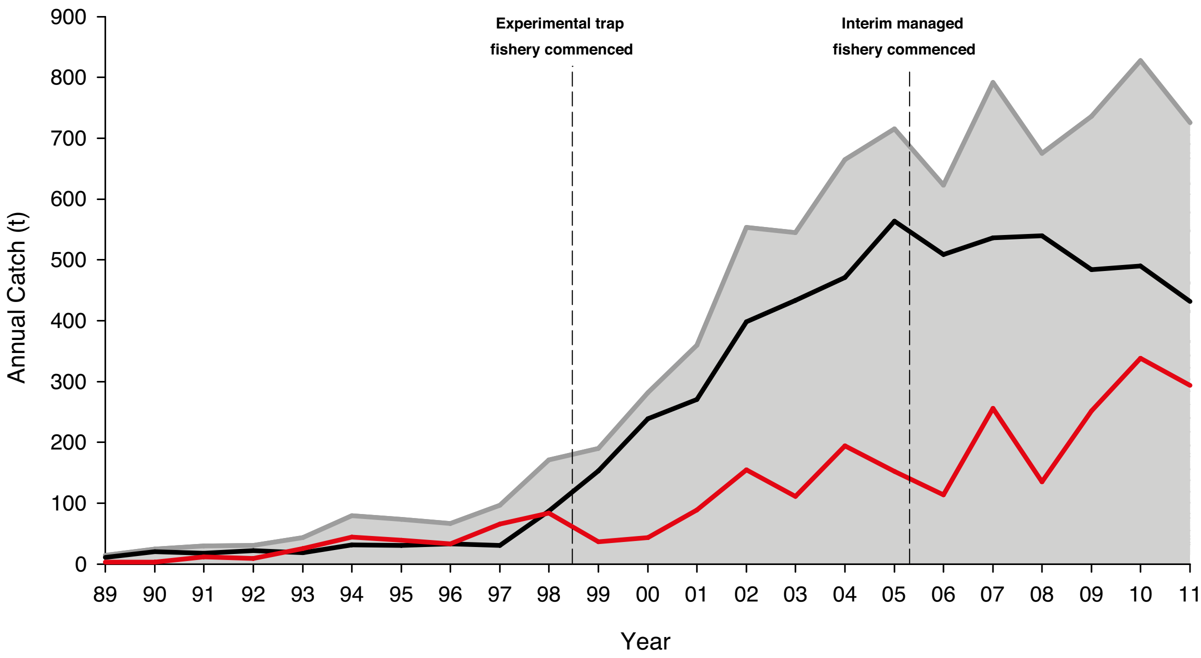

Figure 7. Annual trap (—), trawl (—) and total (■) commercial catch (t) of blue swimmer crabs from Shark Bay by method by calendar year between 1989 and 2011.

Table 4. Annual commercial catch (t) and proportion (%) of total catch for trap and trawl fishers operating in Shark Bay by calendar year between 1989-2011.

Year	Method						Total (t)
	Trap		Trawl Fleet				
			Prawn		Scallop		
	Catch (t)	Prop'n (%)	Catch (t)	Prop'n (%)	Catch (t)	Prop'n (%)	
1989	11	75	4	25		0	15
1990	21	88	3	12		0	24
1991	18	61	12	39		0	30
1992	22	70	9	30		0	31
1993	19	43	25	57		0	44
1994	31	42	44	58		0	75
1995	30	43	39	57		0	69
1996	33	50	33	50		0	66
1997	31	32	66	68		0	97
1998	87	48	84	46	12	7	183
1999	153	77	37	19	8	4	198
2000	238	85	43	15	0	0	281
2001	270	74	89	24	5	1	364
2002	398	71	155	28	8	2	561
2003	434	80	110	20		0	544
2004	471	70	194	29	6	1	671
2005	564	78	152	21	2	0	719
2006	509	81	114	18	6	1	630
2007	536	68	256	32	2	0	794
2008	540	80	135	20	3	1	679
2009	484	66	251	34	2	0	737
2010	490	59	338	41	2	0	830
2011	396	57	293	42	1	0	690

3.1 Trap Sector

3.1.1 Fishers' Catch and Effort Returns (CAES)

Commercial catch history

Prior to the establishment of the CECTF in 1998, trap catches of blue swimmer crabs in Shark Bay were relatively low (11 – 33 t), with mean annual catch rates ranging from 0.9 to 1.4 kg/traplift (Fig. 8). During the period spanning the CECTF (1998 – 2005), the trap catch of blue swimmer crabs increased significantly from 87 t in 1998 to a peak of 564 t in 2005. Mean annual catch rate during this developmental phase of the trap fishery also increased markedly, from

0.9 kg/traplift in 1998 to 1.7 kg/traplift in 2000 (Fig. 8). For the four years following the trap fishery's move to interim management in 2005, the annual trap catch in Shark Bay stabilized between 509 t and 540 t, at a mean catch rate of 1.6 – 1.7 kg/traplift (Fig. 8). However, there has been a slight decline in the past two years, with annual trap catches of 484 t at 1.4 kg/traplift, and 490 t at 1.5 kg/traplift, for 2009 and 2010 respectively (Fig. 8).

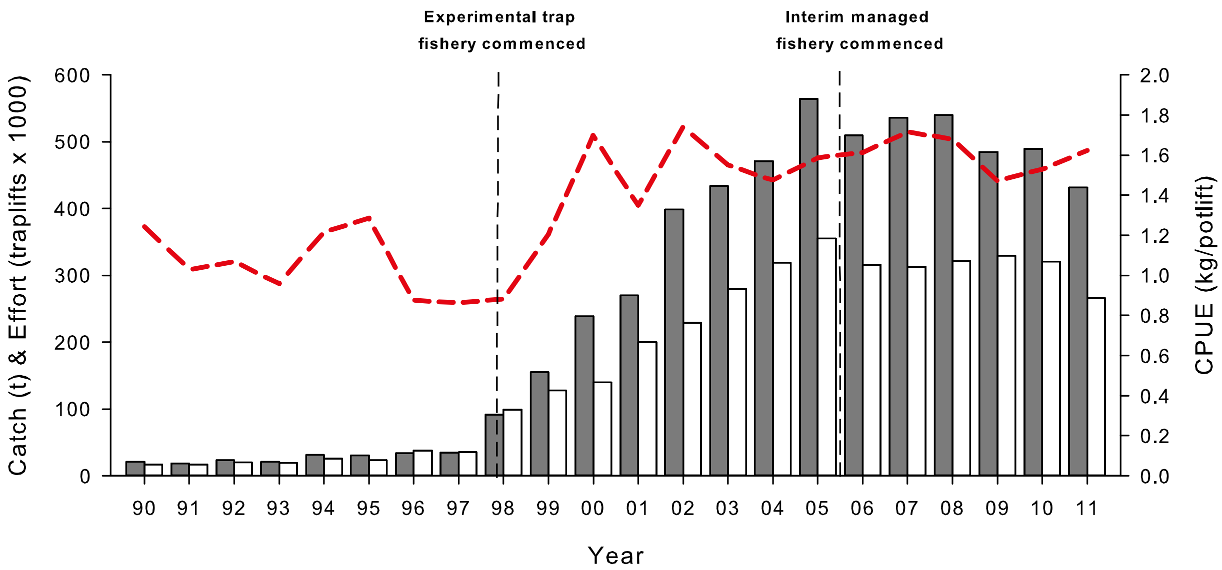

Figure 8. Annual catch (■), effort (□) and catch per unit effort (−−) for commercial blue swimmer crab trap fishers in Shark Bay by calendar year from 1990-2011. Data from CAES.

Annual trends in catch rate

While the annual catch rate of blue swimmer crabs by commercial trap fishers in Shark Bay has been fairly consistent in recent years, statistical analysis (ANOVA) of fisher's statutory catch and effort returns showed that financial year had a significant effect on the historic (1990/91 – 2010/11) standardized annual trap catch rate of commercial blue swimmer crabs in both the fishing grounds north of Cape Inscription ($F_{17,590} = 6.4$, $p < 0.01$), and in the Eastern Gulf ($F_{20,258} = 4.3$, $p < 0.01$) (Fig. 9a, b). Annual standardized catch rates in the main northern fishing grounds fluctuated markedly through the early nineties, before a sharp increase in the first three years following the implementation of the CECTF from 0.9 kg/traplift in 1998/99 to 1.7 kg/traplift by 2000/01. Annual catch rates fluctuated markedly over the next three years, from 1.3 to 1.6 kg/traplift, as fishers continued to develop their fishing practices and explore new fishing grounds throughout the waters of Shark Bay north of Cape Inscription. From 2004/05 to 2009/10, however, the annual catch rate was consistent between 1.4 and 1.5 kg/traplift, before once more increasing to 1.7 kg/traplift in 2010/11 (data is provisional to December 2010 only) (Fig. 9a).

Annual standardized catch rates in the Eastern Gulf of Shark Bay initially followed a similar pattern to the northern fishing grounds, fluctuating between 0.8 and 1.3 kg/traplift through the early nineties before increasing significantly from 0.8 kg/traplift in 1997/98 to peak at 1.6 kg/traplift in 2001/02 (Fig. 9b). However, following this point there has been a steady decline in annual catch rates to just 0.8 kg/traplift in 2010/11 (Fig. 9b).

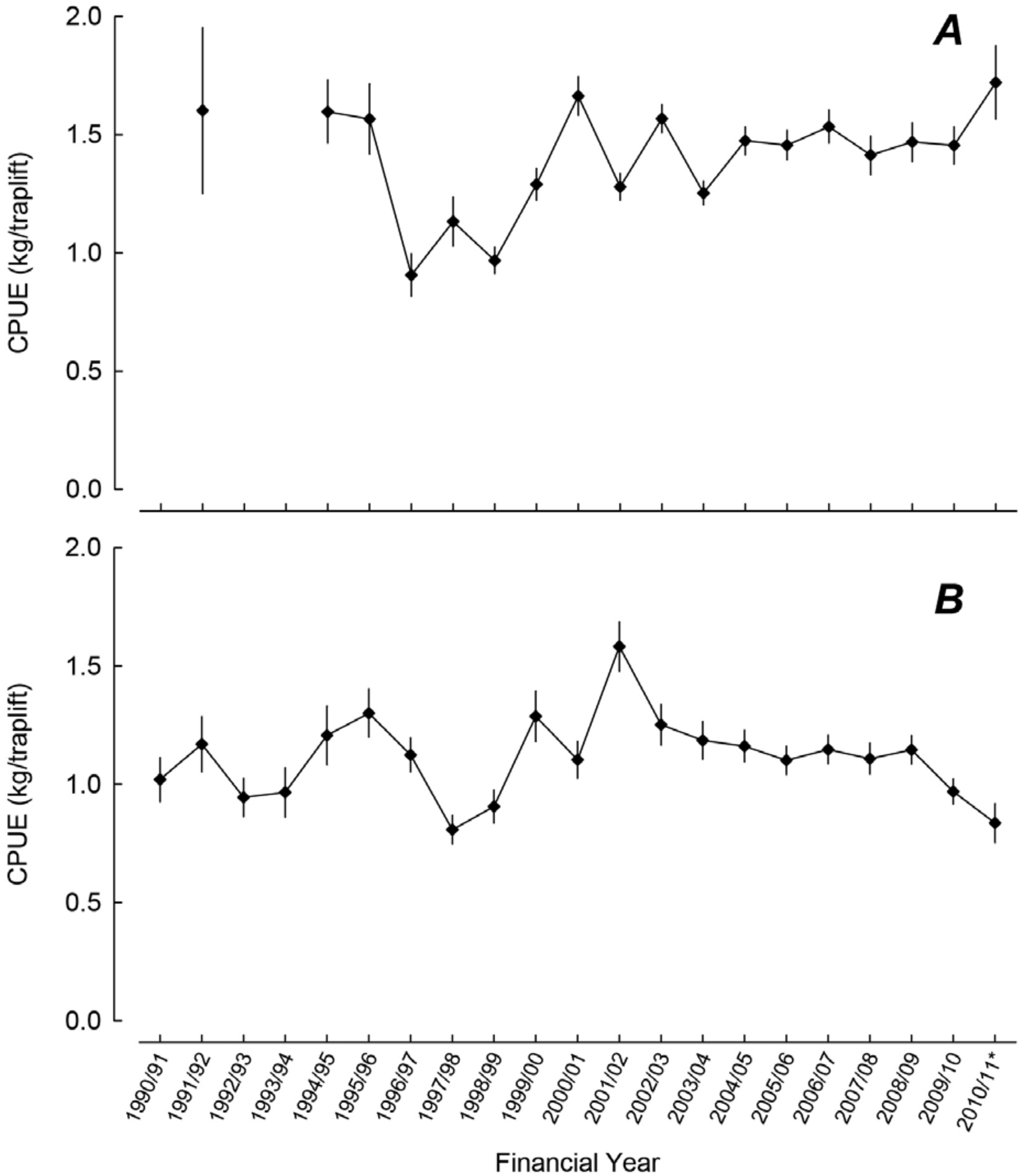

Figure 9. Annual standardized catch rates of commercial trap catch in Shark Bay by financial year from 1990/91 to 2010/11* derived from fisher's statutory catch and effort returns for: ***A)*** the fishing grounds north of Cape Peron, and ***B)*** the Eastern Gulf. ± standard errors are included. *2010/11 data preliminary to December 2010 inclusive.

Monthly trends in catch rate

Trap catch and effort within each year was reasonably consistent between months (Fig. 10) between 1998 and 2005. However, since 2006 trap fishers in the northern grounds have progressively focused their fishing effort on the more productive months between November and June (Fig. 10), with standardized catch rates of commercial crabs north of Cape Inscription highest in March, April and May ($F_{11,590} = 18.9$, $p < 0.01$), (Fig. 11a). However, there was a significant interaction between year and month ($F_{63,247} = 2.19$, $p < 0.01$), so while catch rates peaked in March, April and May from 2002/03 to 2007/08, they were highest in July in 2008/09 and August in 2009/10 (Fig. 12). Month also had a significant effect on the standardized catch rate of commercial crabs ($F_{11,258} = 8.15$, $p < 0.01$) from the Eastern Gulf. However, in contrast to the northern grounds, catch rates in the Eastern Gulf were highest in July, August and September (Fig. 11b).

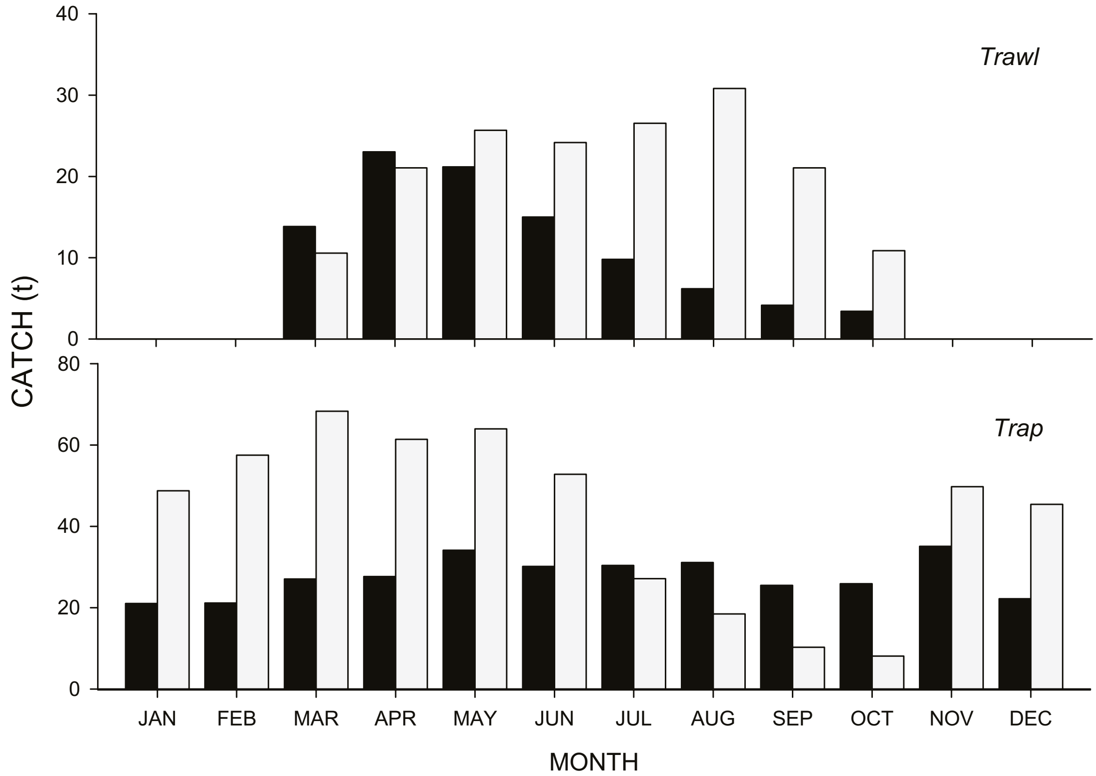

Figure 10. Mean monthly blue swimmer crab catch for the trap and trawl fleets for the periods 1998 – 2005 (■) and 2006 – 2010 (□).

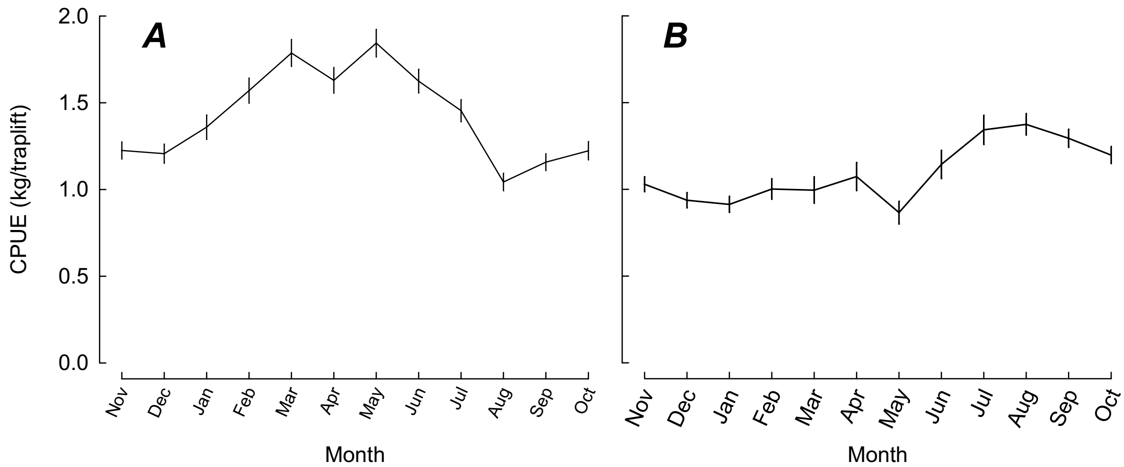

Figure 11. Standardized catch rates of commercial-sized crabs by month derived from fisher's statutory catch and effort returns from 2001/02 to 2009/10 inclusive for: ***A)*** the northern grounds and ***B)*** the eastern gulf. ± standard errors are included.

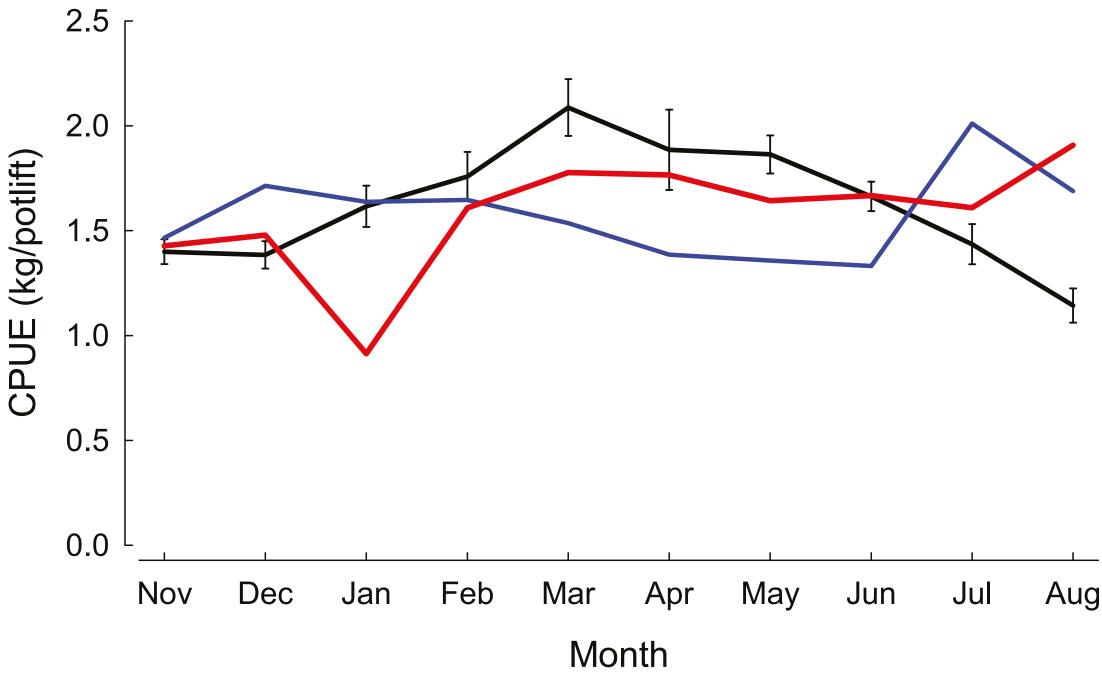

Figure 12. Mean standardized catch rates for the financial years between 2002/03 – 2007/08 (▬), and standardized catch rates for 2008/09 (▬) and 2009/10 (▬), of commercial-sized crabs by month for the fishing grounds north of Cape Inscription derived from fisher's statutory catch and effort returns between 2002/03 to 2009/10 inclusive. Data for September and October was not included as there was no commercial fishing north of Cape Inscription in 2008 or 2009. ± standard errors are included for the mean standardized catch rates for the financial years between 2002/03 – 2007/08.

Location

The majority of blue swimmer crab catches taken by Shark Bay commercial trap fishers between 1998/99 and 2009/10 came from the northern fishing grounds between Cape Peron and Koks Island (CAES block 96021) (Figs 3, 13). This area accounted for 84% (SE±1.05%) of the annual catch, compared to just 8% (SE±0.79%), 5% (SE±0.76%) and 3% (SE±1.62%) for the Eastern Gulf, Western Gulf and North Carnarvon fishing grounds respectively (Fig. 13). Despite the considerable disproportion in quantity of catch, catch per unit effort was not significantly different between the four fishing grounds ($F_{3,537} = 2.39$, $p = 0.07$).

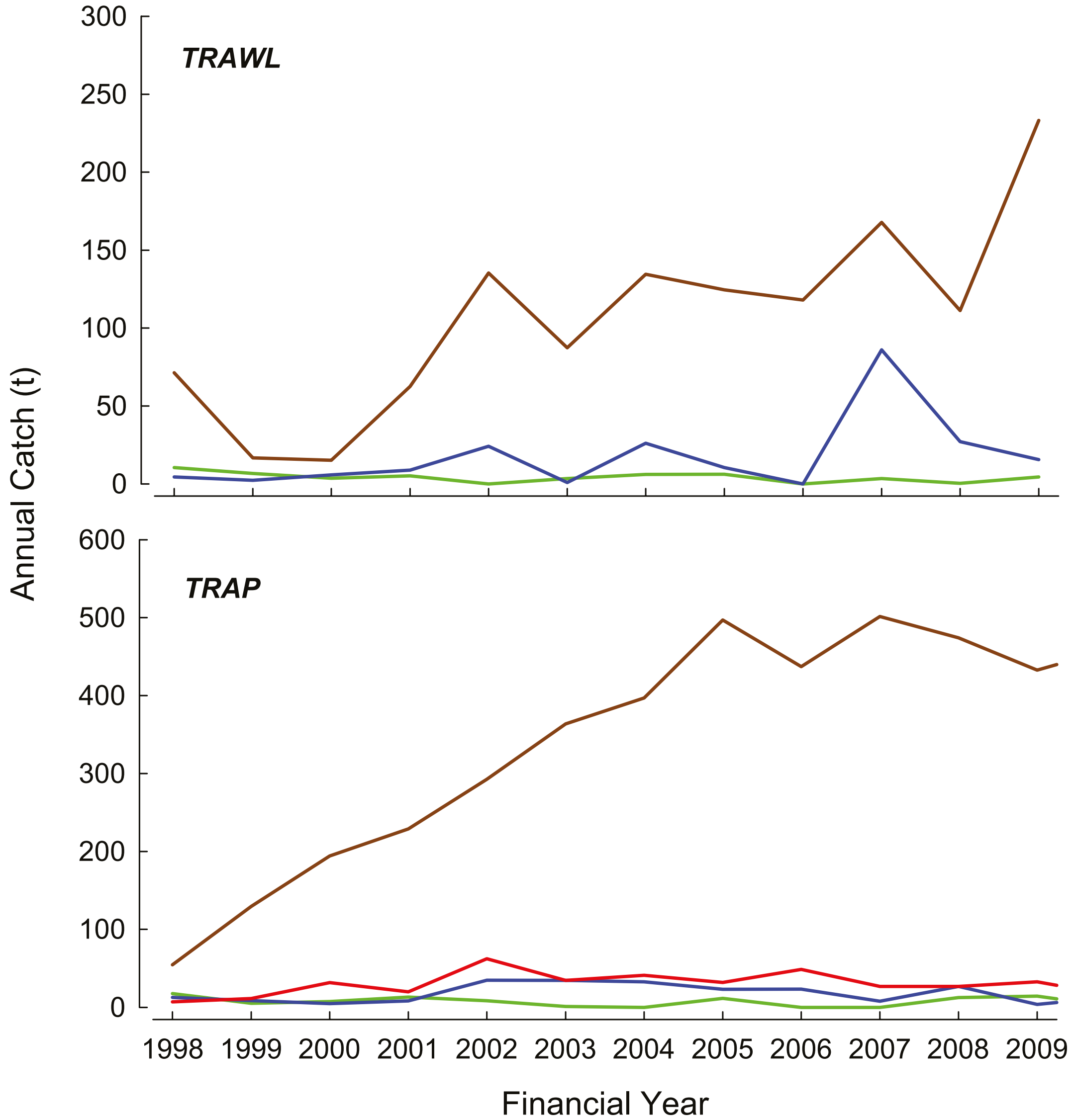

Figure 13. Annual commercial trawl and trap catch (t) from the North Carnarvon (▬), Carnarvon (▬), Western Gulf (▬) and Eastern Gulf (▬) fishing grounds in Shark Bay between 1998 and 2009.

Catch versus effort

A plot of annual catch versus nominal annual effort by financial year produced a linear relationship ($R^2 = 0.983$), with catch varying in line with fluctuations in effort (Fig. 14). Re-plotting annual catch versus standardized effort (nominal catch/standardized catch rate) to account for fisher, fishing ground and month produced a similar linear relationship for both the fishing grounds north of Cape Inscription ($R^2 = 0.984$) and for the Eastern Gulf ($R^2 = 0.940$) (Figs 15, 16). These show that the developing phase of the fishery occurred from the 1990s until 2004/05 with catch and effort steadily increasing and catch and effort being relatively stable since then. These assessments do not take into account any increases in fishing efficiencies that may have occurred in the fleet.

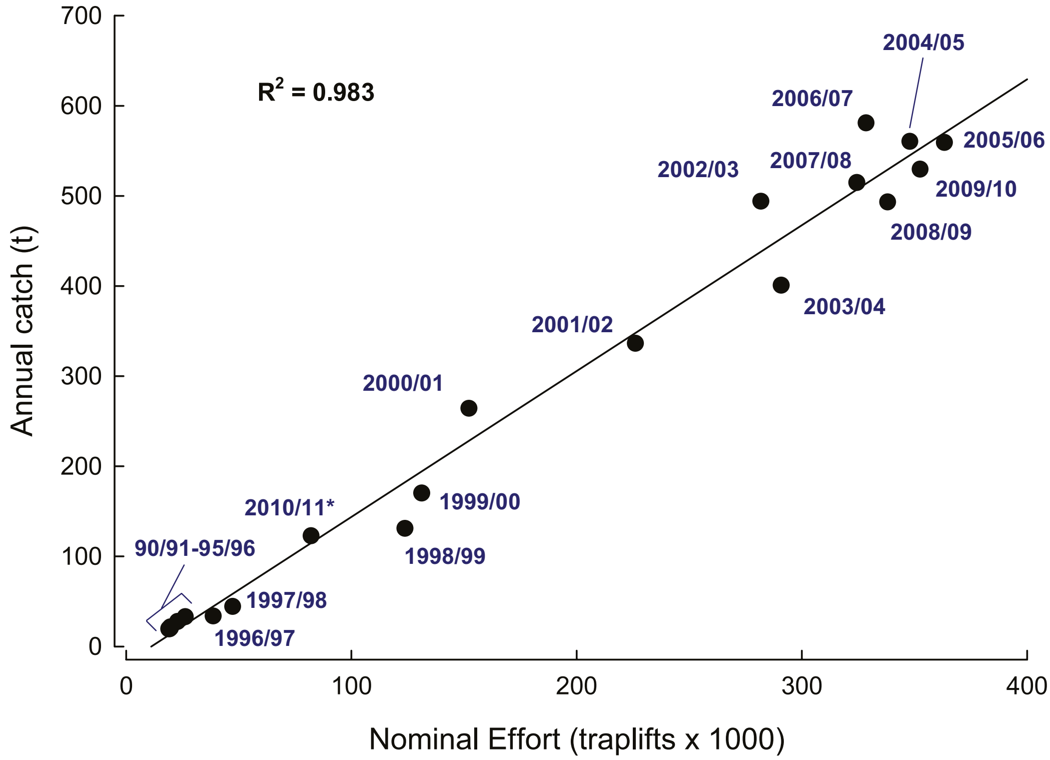

Figure 14. Plot of nominal effort (traplifts x 1000) versus total annual catch (t) by financial year from 1990/91 to 2010/11* for all commercial trap fishers operating in Shark Bay derived from fisher's statutory monthly catch and effort returns. *2010/11 data preliminary to December 2010 inclusive. R2=0.983.

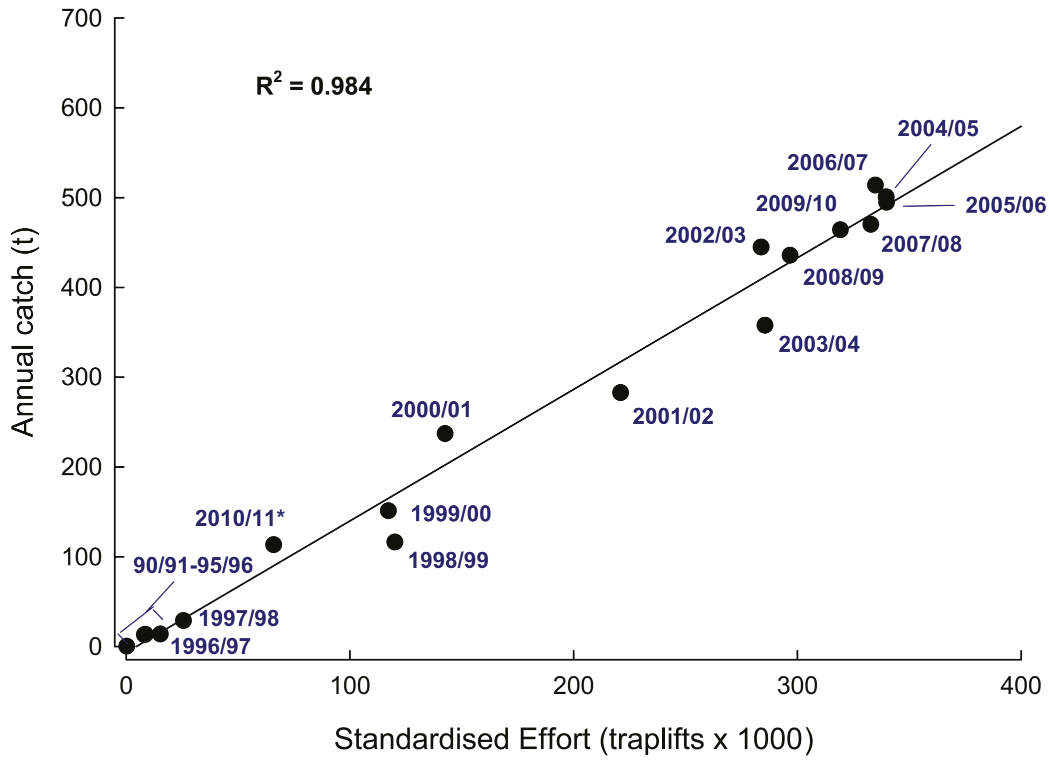

Figure 15. Plot of standardized effort (traplifts x 1000) versus total annual catch (t) by financial year from 1990/91 to 2010/11* for commercial trap fishers operating in the fishing grounds in Shark Bay north of Cape Inscription derived from fisher's statutory monthly catch and effort returns. *2010/11 data preliminary to December 2010 inclusive. R2 = 0.984.

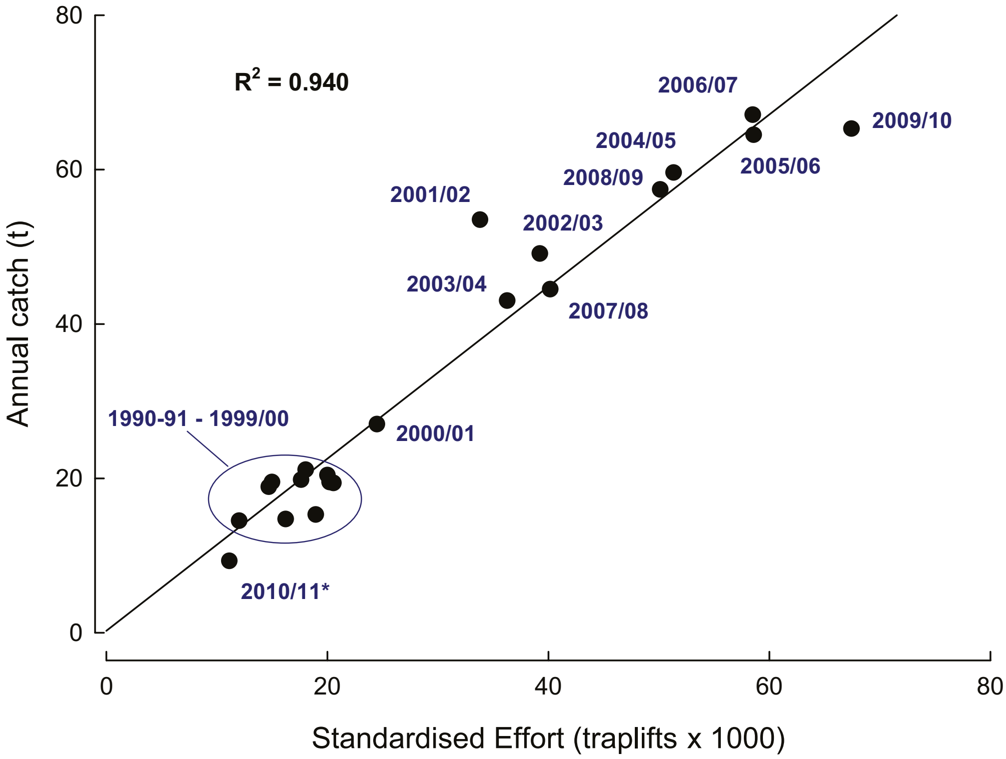

Figure 16. Plot of standardized effort (traplifts x 1000) versus total annual catch (t) by financial year from 1990/91 to 2010/11* for commercial trap fishers operating in the Eastern Gulf derived from fisher's statutory monthly catch and effort returns. *2010/11 data preliminary to December 2010 inclusive. R2=0.940.

3.1.2 Factory unloads

Factory unloads for commercial trap fishers operating in the fishing grounds north of Cape Inscription showed that male crabs dominated the annual retained commercial trap catch from this area between 2001/02 and 2010/11 (Fig. 17), although the proportion of males in the catch decreased from 82% in 2001/02 to 69% in 2010/11. Furthermore, the proportion of very large male crabs (150+ mm CW) showed a significant decrease in recent years, falling from 44% in 2007/08 to 21% in 2010/11. There was also a slight decrease in the proportion of females, from 20% in 2002/03 to 14% in 2010/11 (Fig. 17). It is likely that these downward trends were in part due to more rigorous grading of catch by processors, as the proportion of crabs classified as soft and broken rose from just 6% in 2001/02 to 18% in 2010/11 (Fig. 17).

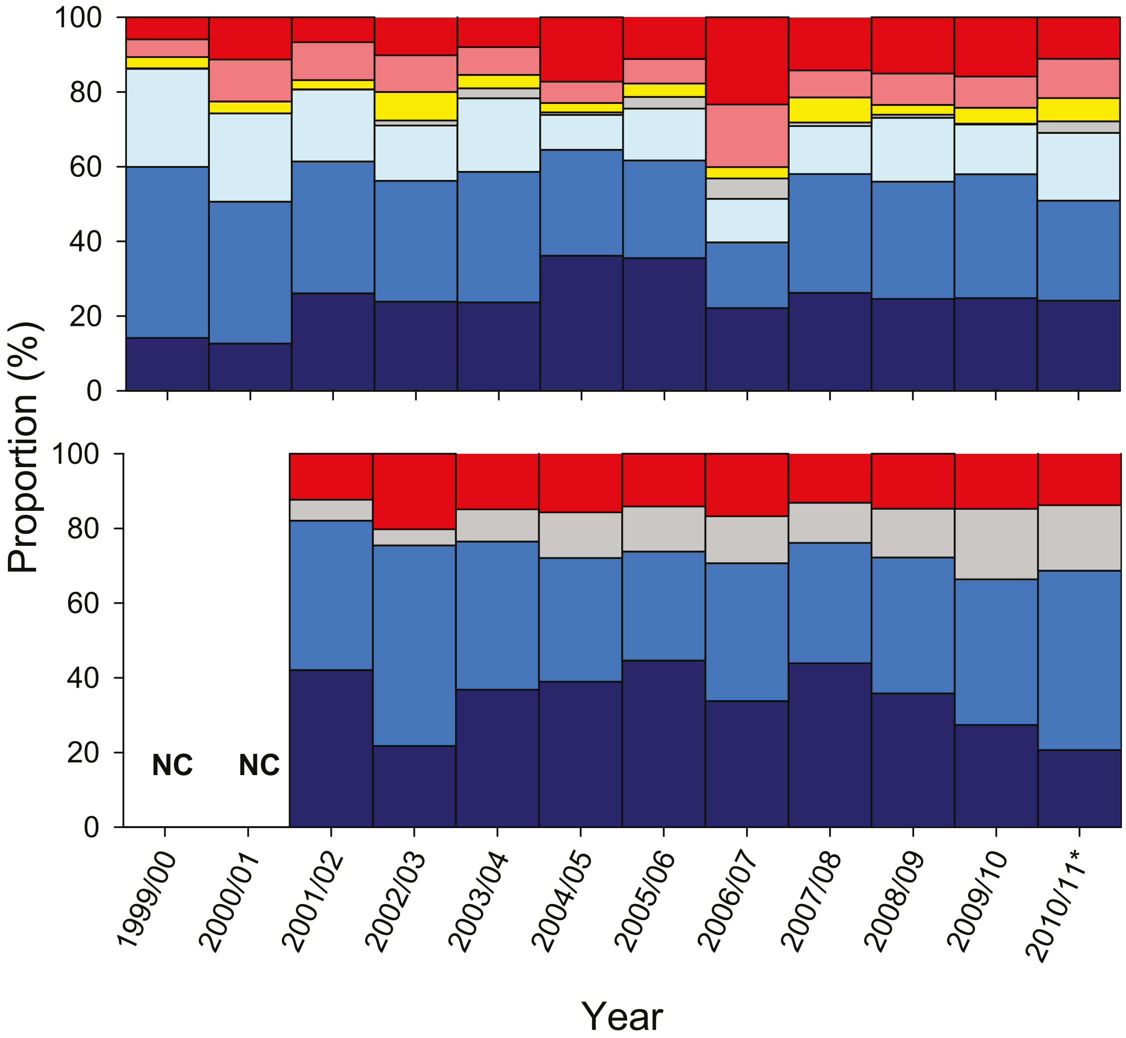

Figure 17. Mean annual proportions of large commercial male (150+ mm CW; ■), commercial male (135-149 mm CW; ■), undersize male (<135 mm CW; ■), commercial non-berried female (135+ mm CW; ■), undersize non-berried female (<135 mm CW; ■), ovigerous female (■) and soft and broken (■) blue swimmer crabs from the northern grounds of Shark Bay in: (***A***) commercial trap catches derived from monitoring surveys in the fishing grounds of Shark Bay north of Cape Inscription between 1999/00 and 2010/11*; and (***B***) the retained commercial trap catch derived from processors returns from 2001/02 to 2010/11. NC indicates years in which no processors returns for landed commercial trap catches were collected.

Male crabs dominated the retained commercial catch from these northern fishing grounds throughout the year, with peaks in the Mar/Apr/May period (82%, 85% and 75% of the catch respectively) and again in October (78%) and November (76%) (Fig. 18). Proportions of extra large males were also highest over the summer months from October through to April, accounting for between 37% and 51% of the catch. This period coincides with the closure of the trawl fishery, which operates from April to September. During the trawl season, trap fishers are restricted from the central areas of the fishing grounds north of Cape Inscription and most of the northern half of Denham Sound. Proportions of soft and broken were highest in January (17%) and February (18%), and in the winter months from June to September (17%, 15%, 14% and 14% respectively) (Fig. 18).

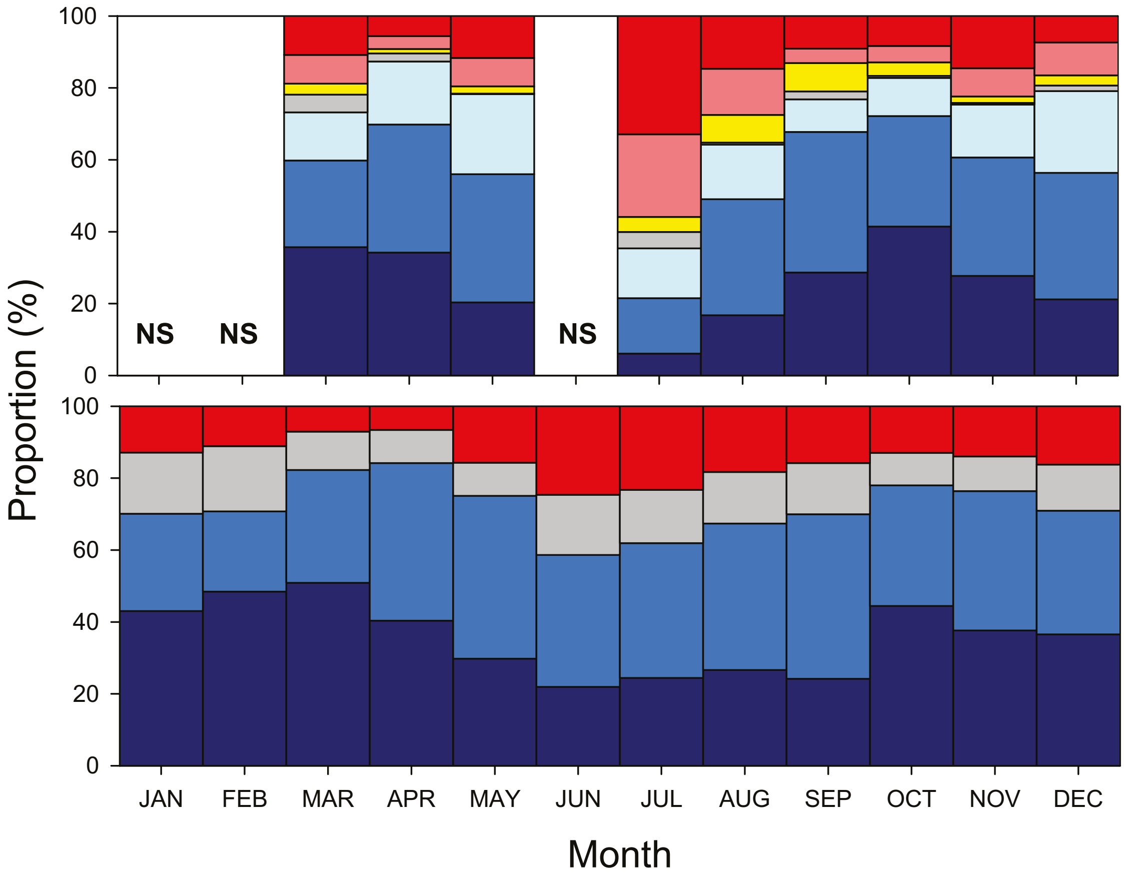

Figure 18. Mean monthly proportions of large commercial male (150+ mm CW; ■), commercial male (135-149 mm CW; ■), undersize male (<135 mm CW; ■), commercial non-berried female (135+ mm CW; ■), undersize non-berried female (<135 mm CW; ■), ovigerous female (■) and soft and broken (■) blue swimmer crabs in: (***A***) catches derived from commercial trap monitoring surveys between 2000 and 2010; and (***B***) the retained commercial trap catch derived from processors returns from 2002 and 2010 for the fishing grounds of Shark Bay north of Cape Inscription. NS indicates months in which commercial trap monitoring surveys were not conducted.

Male crabs were even more dominant in commercial trap catches in the Eastern Gulf, accounting for 93 – 99% of the retained catch between 2006/07 and 2009/10 (Fig. 19). However, it should be noted that there was a slight level of under-reporting of female catches in factory unloads from fishers operating in this area during 2008/09 and 2009/10.

In contrast to the northern fishing grounds, the annual proportion of extra large (150+ mm CW) male crabs in the retained catch increased slightly in recent years, from 46% in 2006/07 to 49% in 2009/10 (Fig. 19). However, there was a similar intra-annual monthly pattern of depletion in the proportion of extra large crabs, peaking at 65% of the retained catch in February before steadily declining with fishing pressure to 34% by August (Fig. 20).

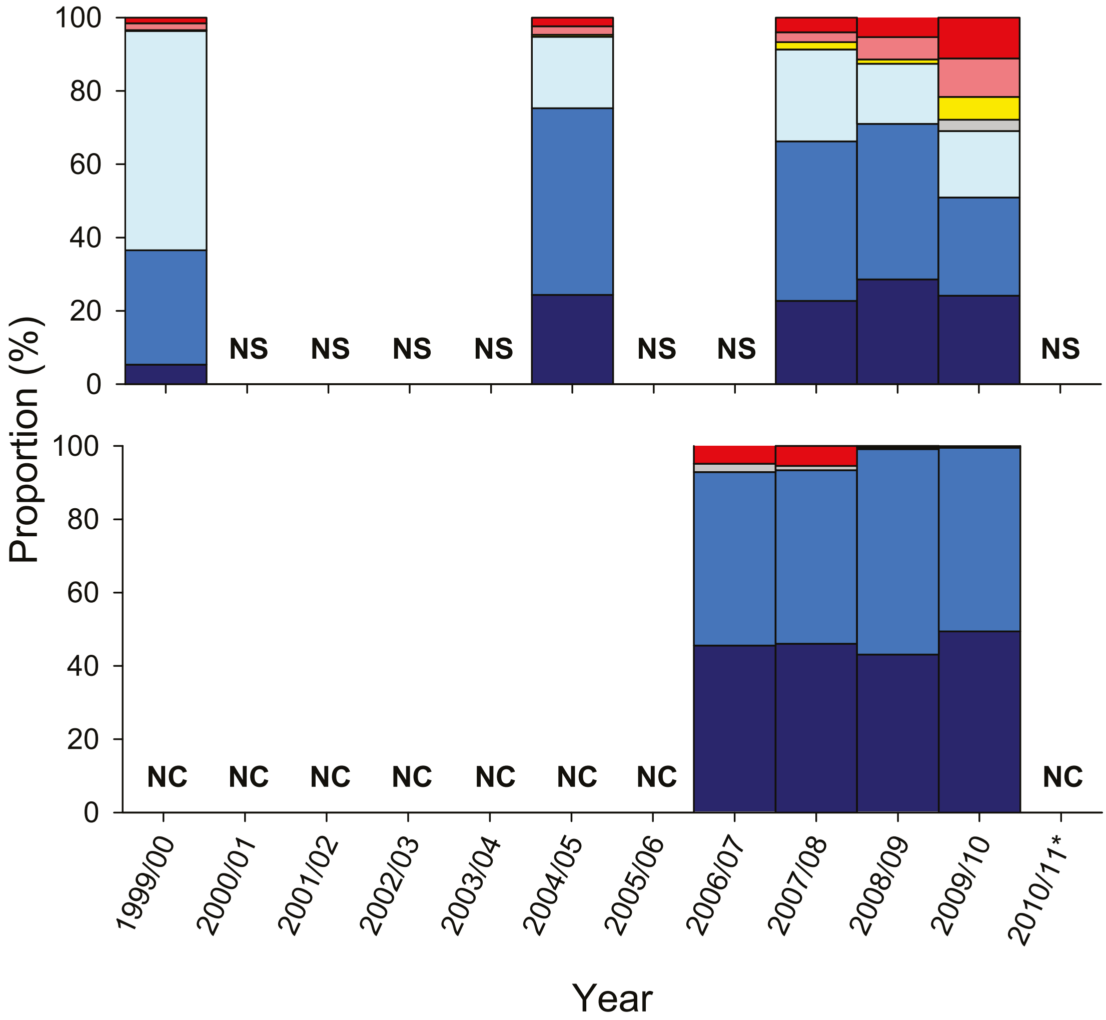

Figure 19. Mean annual proportions of large commercial male (150+ mm CW; ■), commercial male (135-149 mm CW; ■), undersize male (<135 mm CW; ■), commercial non-berried female (135+ mm CW; ■), undersize non-berried female (<135 mm CW; ■), ovigerous female (■) and soft and broken (■) blue swimmer crabs from the northern grounds of Shark Bay in: (***A***) commercial trap catches derived from monitoring surveys in the Eastern Gulf of Shark Bay between 1999/00 and 2010/11*; and (***B***) the retained commercial trap catch from the Eastern Gulf of Shark Bay derived from processors returns from 2001/02 to 2010/11. NC indicates years in which no processors returns for landed commercial trap catches were collected.

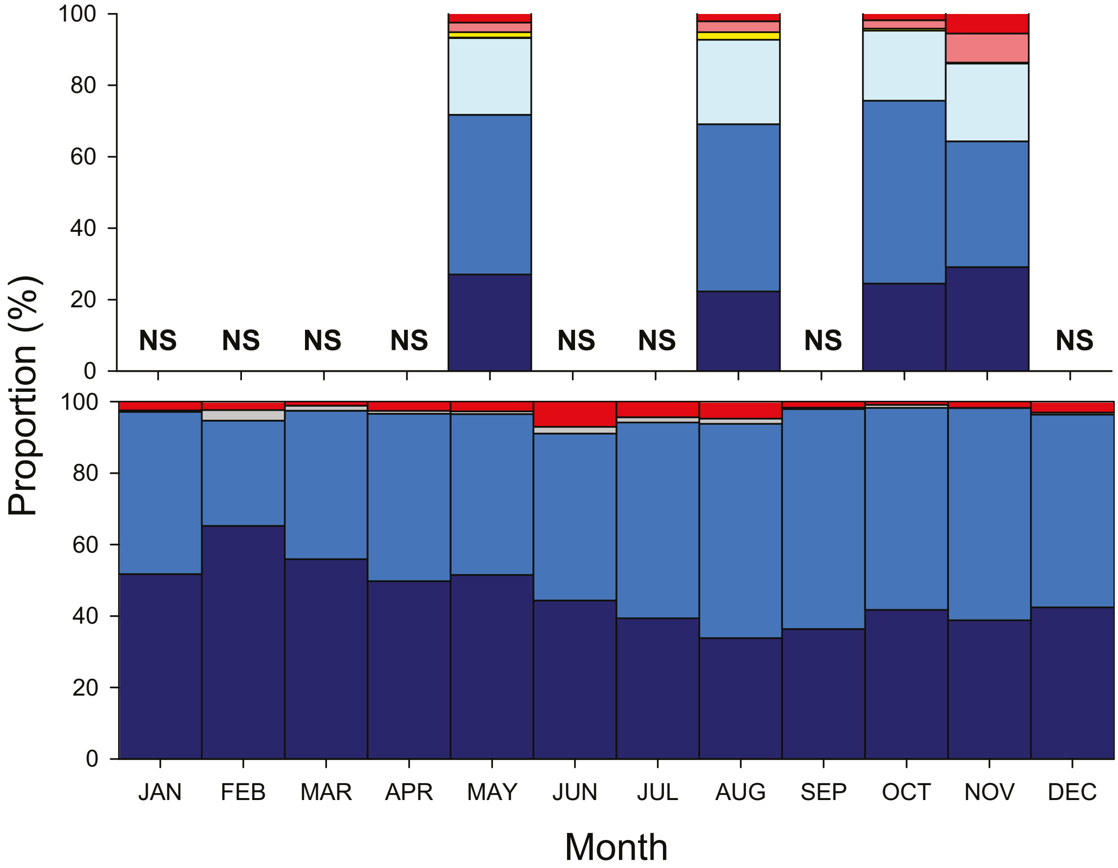

Figure 20. Mean monthly proportions of large commercial male (150+ mm CW; ■), commercial male (135 – 149 mm CW; ■), undersize male (<135 mm CW; ■), commercial non-berried female (135+ mm CW; ■), undersize non-berried female (<135 mm CW; ■), ovigerous female (■) and soft and broken (■) blue swimmer crabs in: (A) commercial trap catches derived from monitoring surveys in the Eastern Gulf of Shark Bay between 2000 and 2010; and (B) the retained commercial trap catch for the Eastern Gulf of Shark Bay derived from processors returns from 2002 and 2010. NS indicates months in which commercial trap monitoring surveys were not conducted.

3.1.3 Catch monitoring

Annual trends in catch rate

Male crabs made up the majority of the catch during most commercial trap monitoring surveys conducted in Shark Bay between 1999/00 and 2010/11. However, there was a slight decrease in the annual proportion of males over this period, from 86% in 1999/00 to 69% in 2010/11 (Figs 17, 21). This trend was reflected in proportions of small commercial male (135 – 149 mm CW) and undersize male (<135 mm CW) crabs, which fell from 46% to 27%, and 26% to 18%, respectively. In contrast, the proportion of large commercial male crabs (150+ mm CW) increased from 14% of the catch in 1999/00 to 36% in 2004/05, however, there was a slight downward trend from this point to 24% in 2010/11 (Fig. 17).

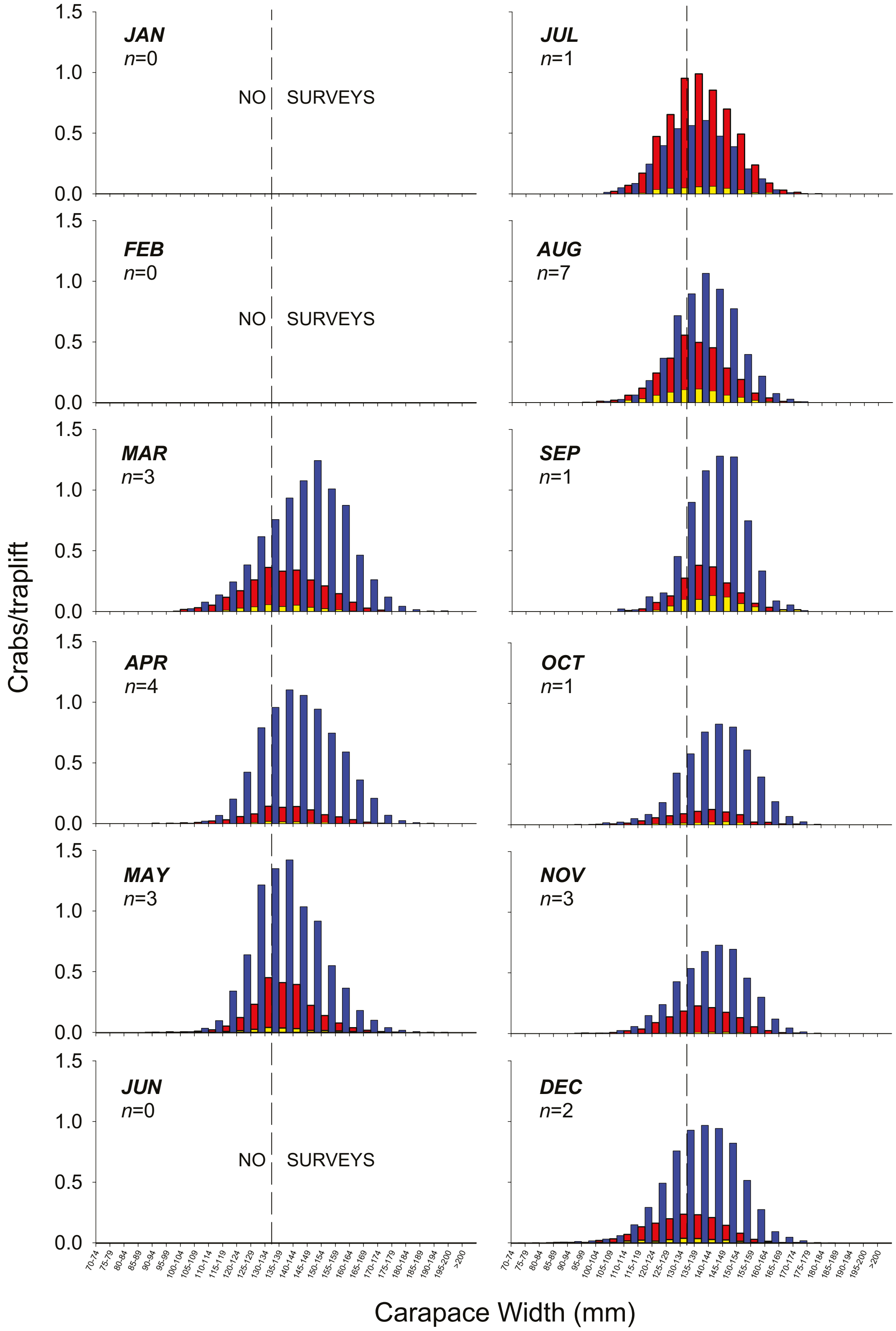

Figure 21. Mean monthly length frequency distributions for male (■), female berried (■) and female non-berried (■) blue swimmer crabs captured during commercial trap monitoring surveys in Shark Bay between 2000 and 2010. n = number of surveys conducted in that month over the 11 year period between 2000 and 2010.

Annual standardized catch rates for each of the five size categories of blue swimmer crabs fluctuated significantly during the past decade. Catch rates of commercial male crabs fell from 5.9 crabs/traplift in 2002/03 to 2.8 crabs/traplift by 2008/09, before increasing sharply again to 5.3 crabs/traplift in 2010/11* (* data is provisional to December 2010 inclusive) (Fig. 22) There was an increasing trend in commercial female crab catch rates from 0.2 crabs/traplift in 2004/05 to 0.8 crabs/traplift by 2010/11, with a peak of 1.1 crabs/traplift in 2006/07 (Fig. 22). As with commercial male crabs, there was initially a steady decline in sub-legal sexually mature male catch rates from 2.0 crabs/traplift in 2000/01 to 0.6 crabs/traplift in 2007/08, before increasing to 2.1 crabs/traplift by 2010/11 (Fig. 23). Catch rates of sub-legal sexually mature female crabs fluctuated significantly between 0.2 – 1.2 crabs/traplift from 2000/01 to 2009/10, before increasing sharply to 1.8 crabs/traplift in 10/11 (Fig. 23). Catch rates of sexually immature male blue swimmer crabs were generally very low (0.02 – 0.07 crabs/traplift) between 2000/01 and 2009/10, but also rose noticeably in 2010/11 to 0.2 crabs/traplift (Fig. 24).

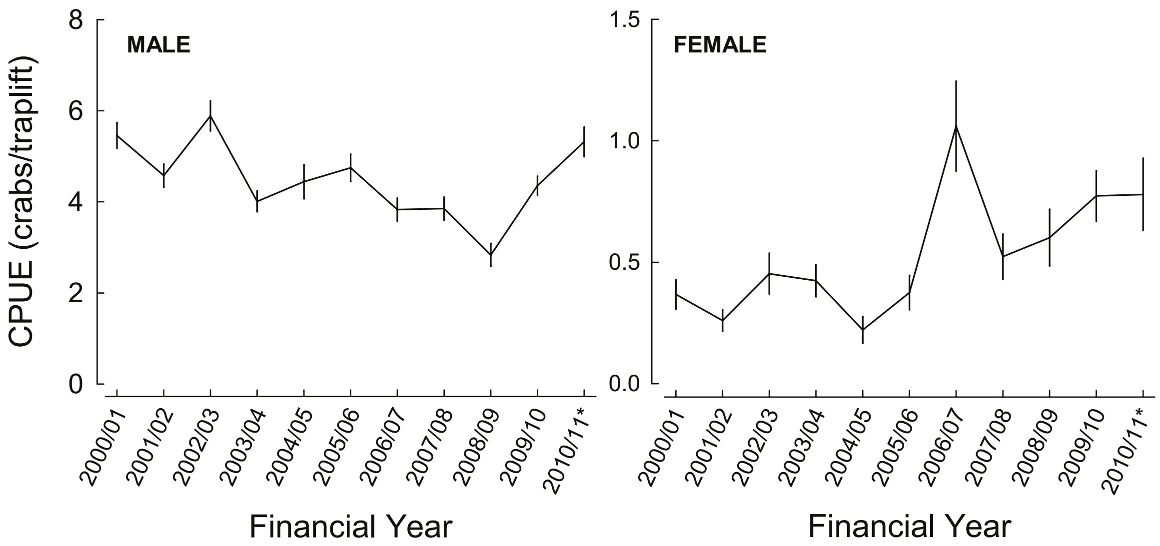

Figure 22. Standardized catch rates of commercial ***A***) male and ***B***) female blue swimmer crabs by financial year derived from commercial trap monitoring surveys in Shark Bay between 2000 and 2010. ± standard errors are included. *2010/11 data provisional to December 2010.

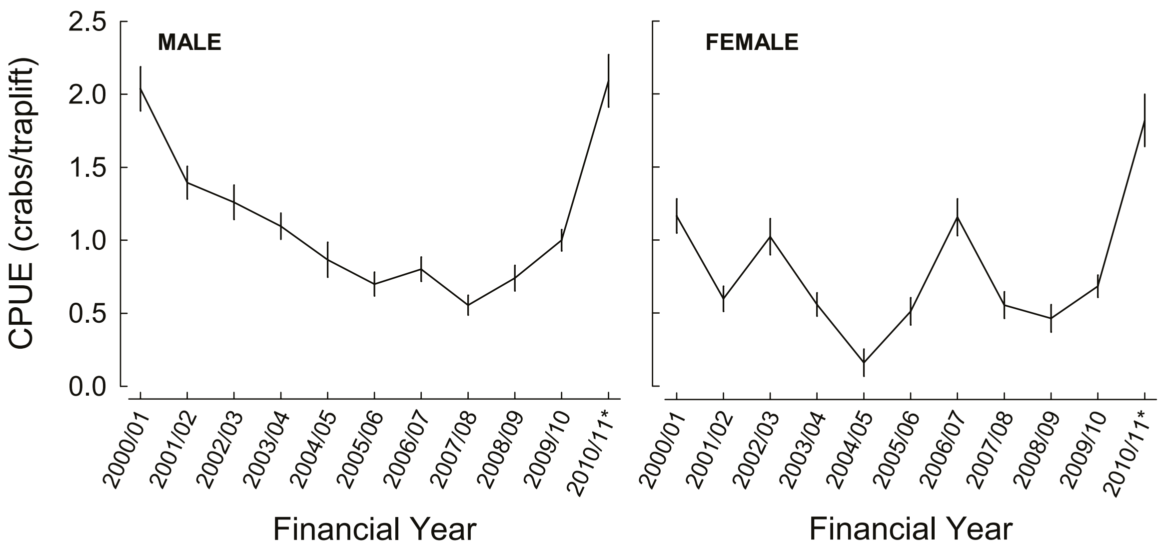

Figure 23. Standardized catch rates of sub-legal sexually mature ***A***) male and ***B***) female blue swimmer crabs by financial year derived from commercial trap monitoring surveys in Shark Bay between 2000 and 2010. ± standard errors are included. *2010/11 data provisional to December 2010.

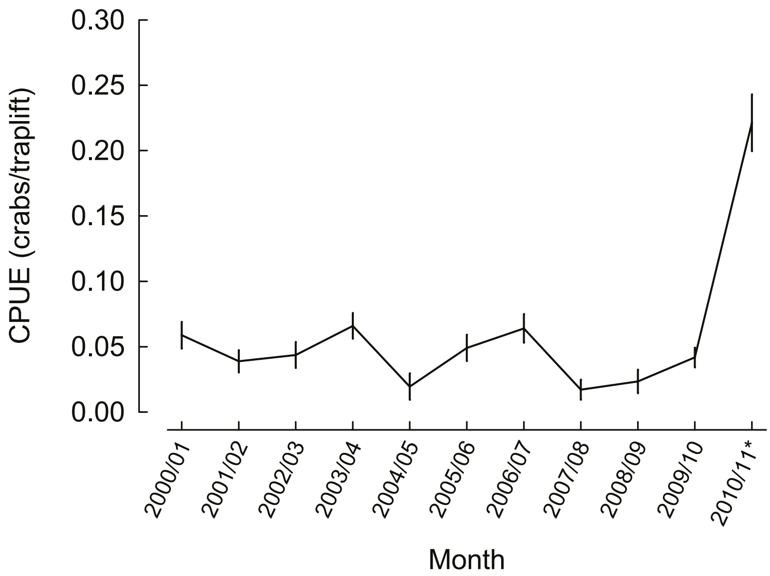

Figure 24. Standardized catch rates of sexually immature male blue swimmer crabs by financial year derived from commercial trap monitoring surveys in Shark Bay between 2000 and 2010. ± standard errors are included. *2010/11 data provisional to December 2010.

Catch composition

Male blue swimmer crabs dominated catches from commercial trap monitoring surveys throughout Shark Bay during most months of the year. Male crabs accounted for 60 – 90% of crabs captured during surveys in all months other than July, when female crabs accounted for 60% of the catch (Figs 18, 21). However, it should be noted that only one survey was carried out in July (2006) over the 10-year period. Highest proportions of male crabs were recorded in March and April, accounting for 89% and 90% of the total retained commercial catch, respectively.

Statistical analysis (ANOVA) of catch monitoring data was consistent with this trend, showing month had a significant effect on the standardized catch rates of commercial male ($F_{2,583}$ = 35.14, p <0.01) commercial female ($F_{2,583}$ = 29.6, p<0.01), sub-legal sexually mature male ($F_{2,565}$ = 24.494, p <0.01) and sub-legal sexually mature female ($F_{2,583}$ = 45.44, p <0.01) crabs. Catch rates of commercial and sub-legal sexually mature male crabs peaked in the Mar/Apr/May period, while catch rates of commercial and sub-legal sexually mature females were highest in the Jul/Aug/Sep period (Fig. 25). There was a significant interaction between month and latitude on sexually immature male crabs ($F_{12,571}$ = 4.17, p <0.01), with highest catch rates in the Eastern Gulf in Oct/Nov/Dec and north of Carnarvon in Mar/Apr/May (Fig. 26). Numbers of sexually immature female crabs were very low so analysis of this category is not presented for commercial trap monitoring data.

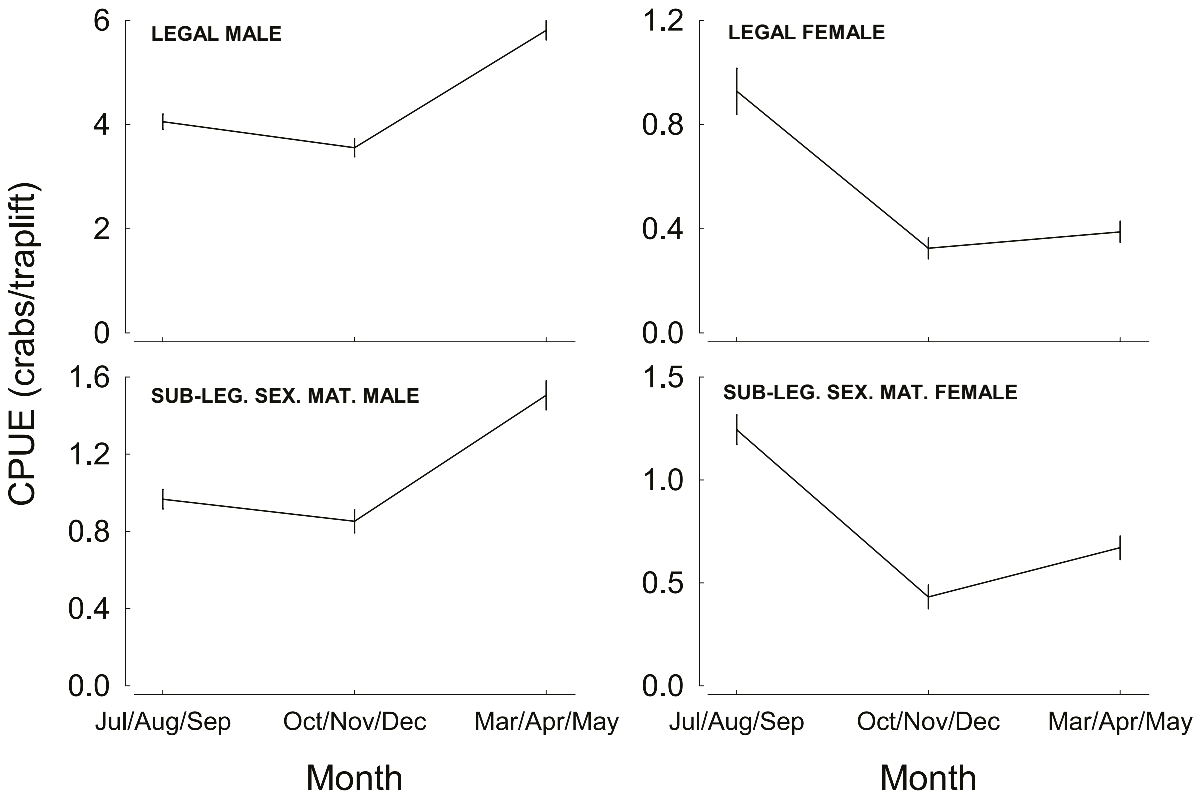

Figure 25. Standardized catch rates of commercial male, sub-legal sexually mature male, commercial female and sub-legal sexually mature female blue swimmer crabs by sampling period derived from commercial trap monitoring surveys in Shark Bay between 2000 and 2010. ± standard errors are included.

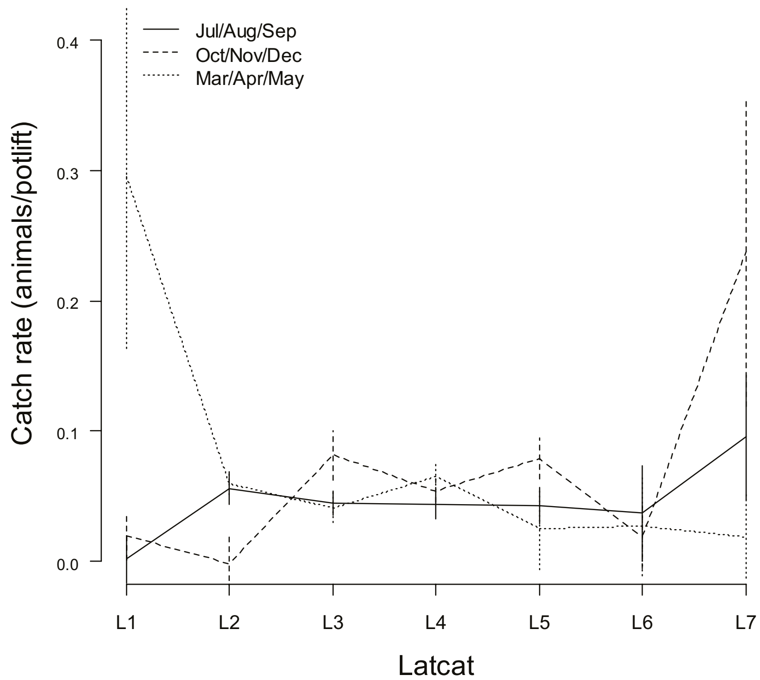

Figure 26. Standardized catch rates of sexually immature male crabs for Jul/Aug/Sep (—), Oct/Nov/Dec (---) and Mar/Apr/May (····) by latitude derived from commercial trap monitoring surveys in Shark Bay between 2000 and 2010. ± standard errors are included.

Depth

There was a significant interaction between month and depth on commercial male crabs ($F_{6,565} = 2.49$, $p = 0.02$), with highest catch rates occurring in Mar/Apr/May in waters deeper than 6m (Fig. 27). In contrast, catch rates of sub-legal sexually mature males were highest in shallow (<6m) waters ($F_{3,583} = 6.35$, $p < 0.01$), while catch rates of sexually immature males were highest in waters deeper than 17m and then waters less than 6m (Fig. 28). Catch rates of commercial female crabs were highest in waters deeper than 17m across all sampling periods ($F_{3,583} = 17.7$, $p < 0.01$), while catch rates of sub-legal sexually mature females were consistent across all depths in Mar/Apr/May and Oct/Nov/Dec, but higher in waters deeper than 17 m in Jul/Aug/Sep ($F_{6,565} = 5.31$, $p < 0.01$) (Figs 29, 30).

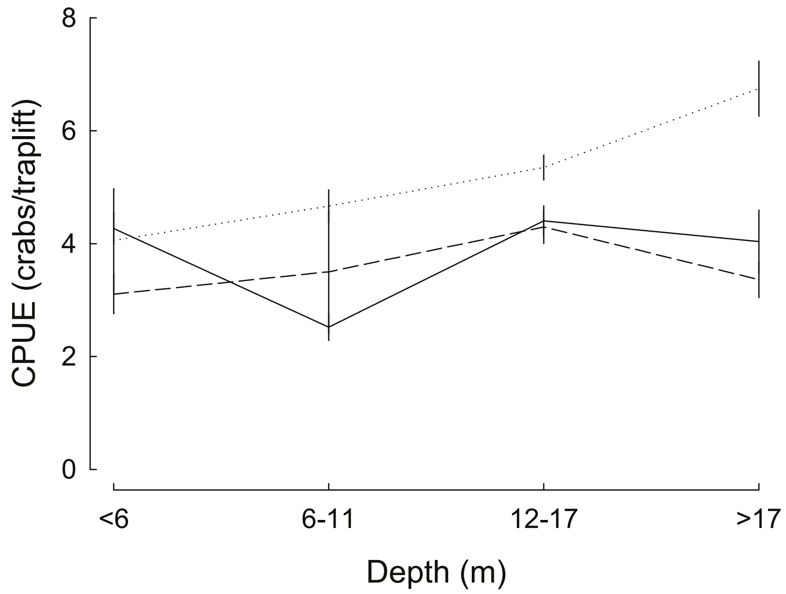

Figure 27. Standardized catch rates of commercial-sized male crabs for Jul/Aug/Sep (—), Oct/Nov/Dec (---) and Mar/Apr/May (····) by depth derived from commercial trap monitoring surveys in Shark Bay between 2000 and 2010. ± standard errors are included.

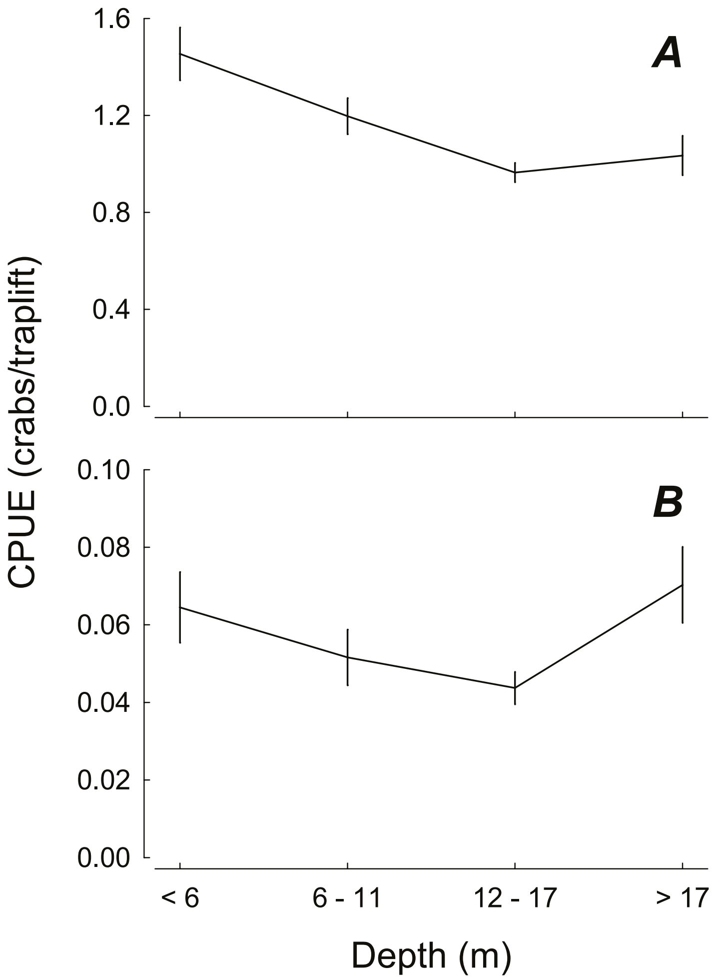

Figure 28. Standardized catch rates of A) sub-legal sexually mature male and B) sexually immature male crabs by depth derived from commercial trap monitoring surveys in Shark Bay between 2000 and 2010. ± standard errors are included.

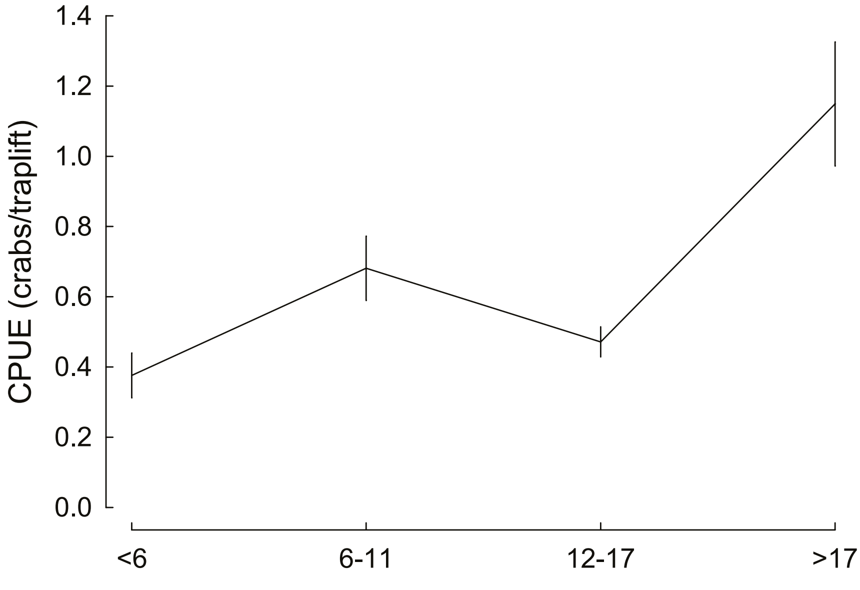

Figure 29. Standardized catch rates of commercial-sized female crabs by depth derived from commercial trap monitoring surveys in Shark Bay between 2000 and 2010. ± standard errors are included.

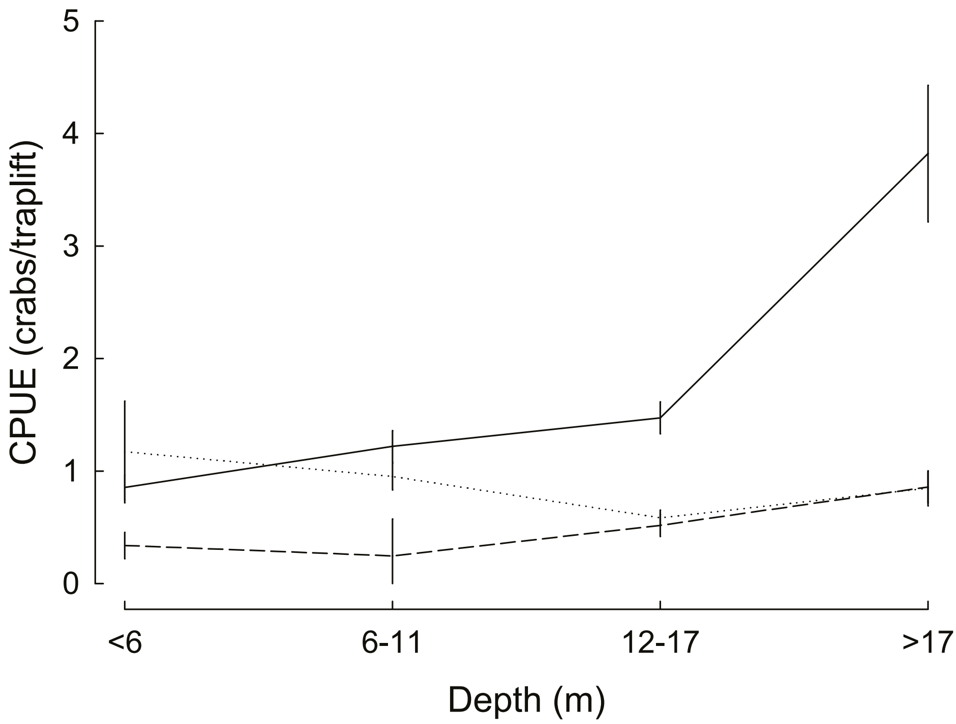

Figure 30. Standardized catch rates of sub-legal sexually mature female crabs for Jul/Aug/Sep (—), Oct/Nov/Dec (---) and Mar/Apr/May (····) by depth derived from commercial trap monitoring surveys in Shark Bay between 2000 and 2010. ± standard errors are included.

Location

There was a significant interaction between month and latitude on commercial male ($F_{12,565}$ = 5.66, p <0.01), commercial female ($F_{12,565}$ = 2.33, p <0.01), sub-legal sexually mature male ($F_{12,565}$ = 2.33, p <0.01), sub-legal sexually mature female ($F_{12,565}$ = 2.33, p <0.01) and sexually immature male ($F_{12,565}$ = 2.33, p <0.01) crabs. Catch rates of commercial male, commercial female and sub-legal sexually mature female crabs were constant across latitudes in Oct/Nov/Dec and Mar/Apr/May. However, male catch rates in Jul/Aug/Sep were highest in the Eastern Gulf (Fig. 31) while female catch rates were highest in the northern latitudes (Fig. 32). Catch rates of sub-legal sexually mature and immature male crabs peaked in the northern latitudes in Mar/Apr/May, but were highest in the southern latitudes from July to December (Figs 26, 31).

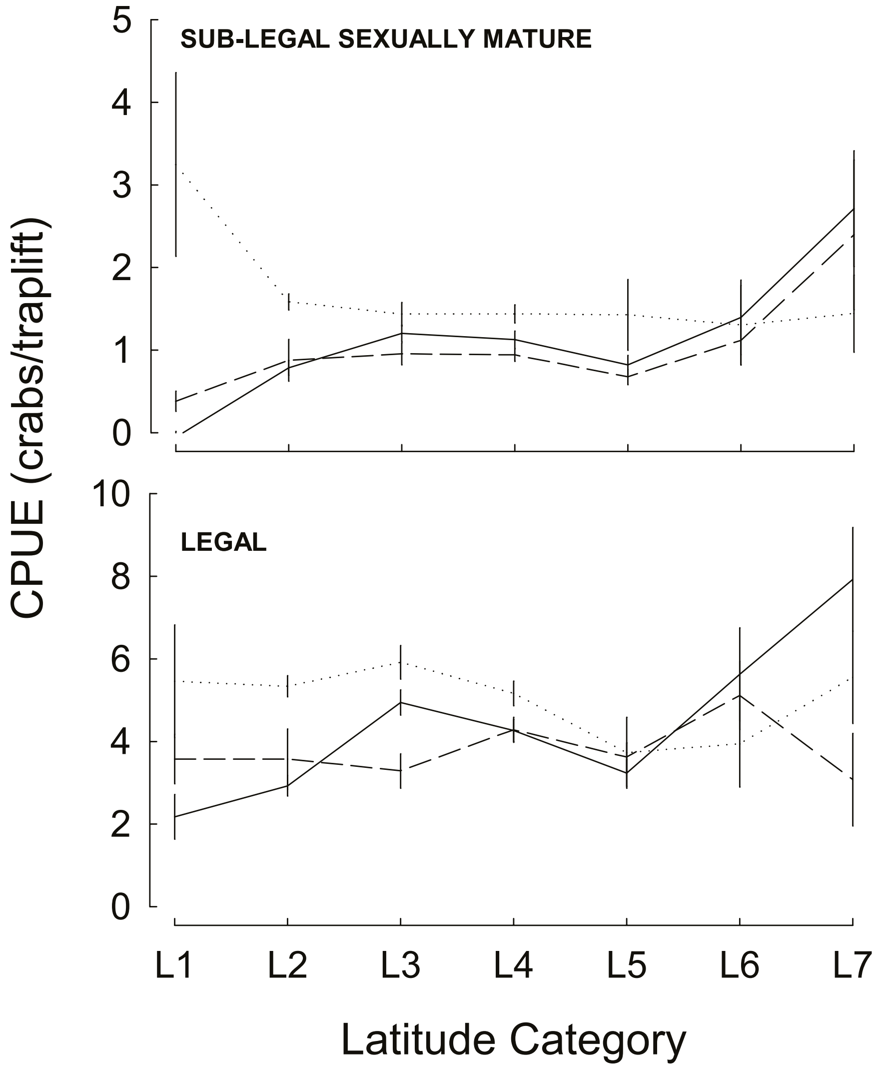

Figure 31. Standardized catch rates of commercial male and sub-legal sexually mature male crabs for Jul/Aug/Sep (—), Oct/Nov/Dec (---) and Mar/Apr/May (····) by latitude derived from commercial trap monitoring surveys in Shark Bay between 2000 and 2010. ± standard errors are included.

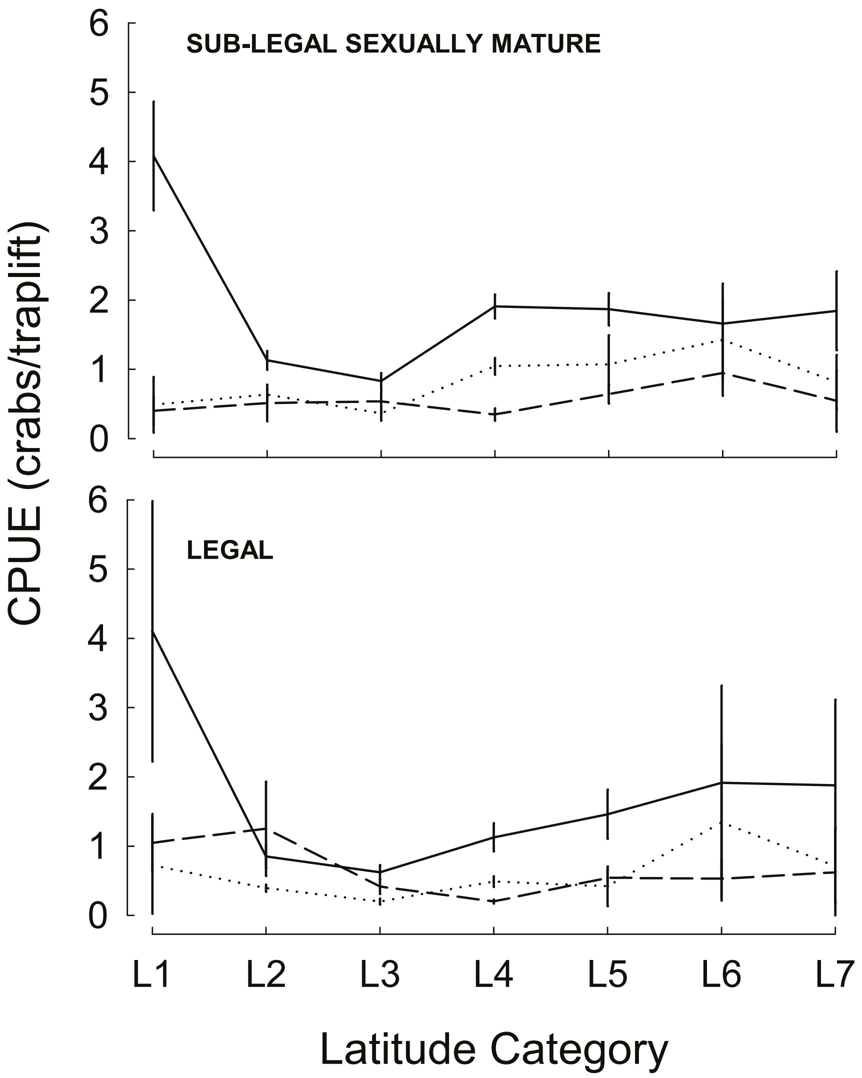

Figure 32. Standardized catch rates of commercial female and sub-legal sexually mature female crabs for Jul/Aug/Sep (—), Oct/Nov/Dec (---) and Mar/Apr/May (····) by latitude derived from commercial trap monitoring surveys in Shark Bay between 2000 and 2010. ± standard errors are included.

Size

During the developmental phase of the commercial crab trap fishery in Shark Bay there was a gradual increase in the mean carapace width of male blue swimmer crabs measured during commercial trap monitoring surveys, from 140mm in 1999/00 to a peak of 148 mm in 2004/05 (Fig. 33). However, from that point mean male carapace widths decreased to 143 mm by 2010/11. Following the same trend, non-berried female carapace widths increased from 133 mm in 2000/01 to 142 mm in 2004/05 before decreasing to 133 mm by 2010/11, while berried females increased from 131 mm in 2000/01 to 143 mm in 2004/05 before dropping to 135 mm in 2010/11 (Fig. 33). Similar trends emerged from statistical analysis of the catch monitoring data, with standardized carapace widths for male, female non-berried and berried blue swimmer crabs increasing over the first half of the decade before a declining trend to 2010/11 (Fig. 33).

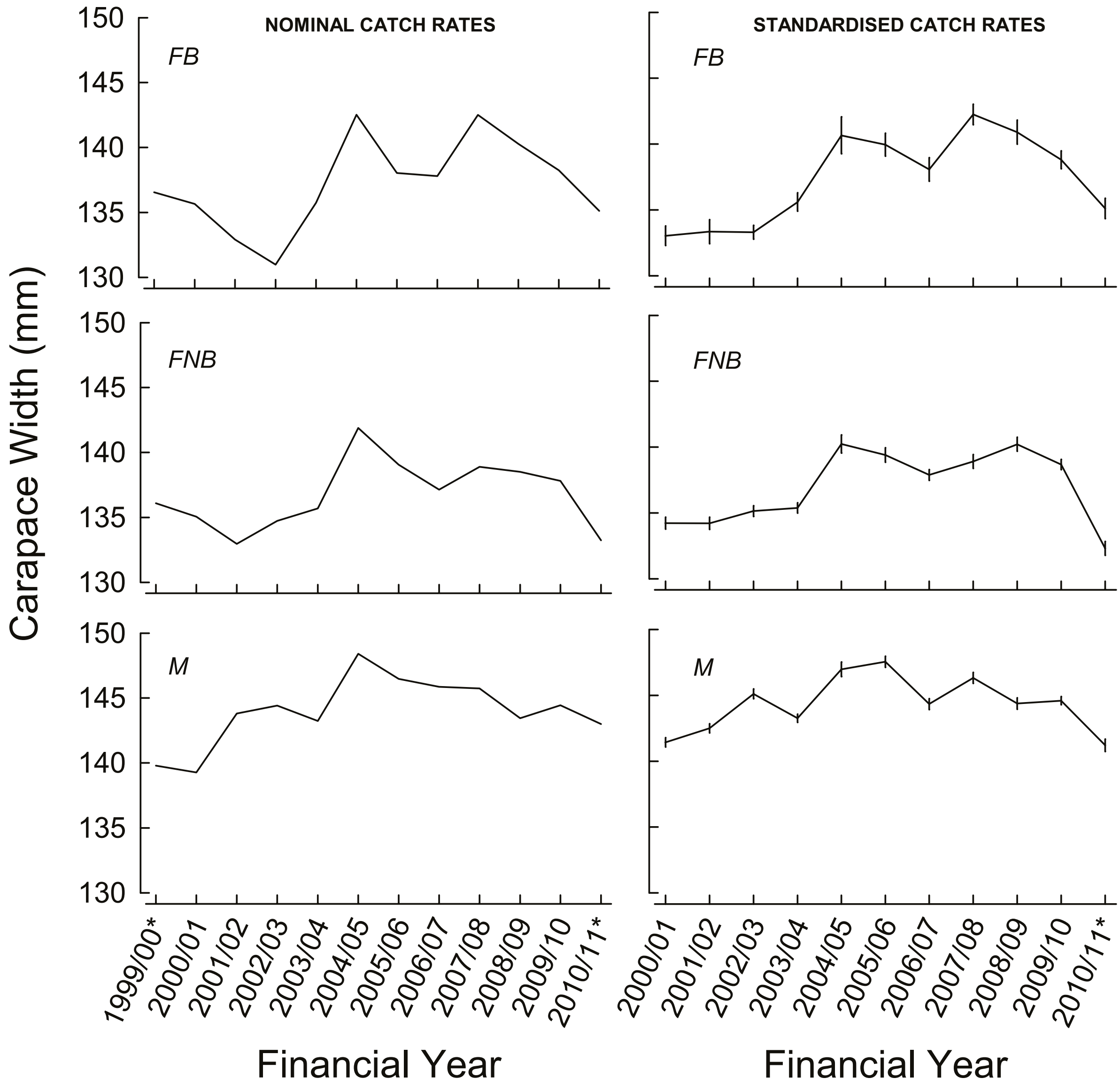

Figure 33. Mean annual nominal and standardized carapace widths of ***M***) male, ***FNB***) non-berried female and ***FB***) ovigerous female crabs by financial year derived from commercial trap monitoring surveys in Shark Bay between 1999/00* and 2010/11*. ± standard errors are included. *1999/00 data includes just one survey in April 2000; 2010/11 data provisional to December 2010.

Berried crabs

Berried females were captured during all commercial trap monitoring surveys between 2000 and 2010, with highest catch rates in Jul/Aug/Sep (Figs 18, 21). Statistical analysis showed a significant interaction between fishing month and depth on berried crabs ($F_{6,565} = 5.30$, $p < 0.01$), with catch rates consistently low across all depths in Oct/Nov/Dec and Mar/Apr/May, but highest in the deeper water (>12 m) in Jul/Aug/Sep (Fig. 34). Berried females ($F_{6,583} = 6.93$, $p < 0.01$) were most abundant in the northern-most latitudes (L1) to the east of Koks Island, and southern latitudes (L6, L7) in the Eastern Gulf (Fig. 35).

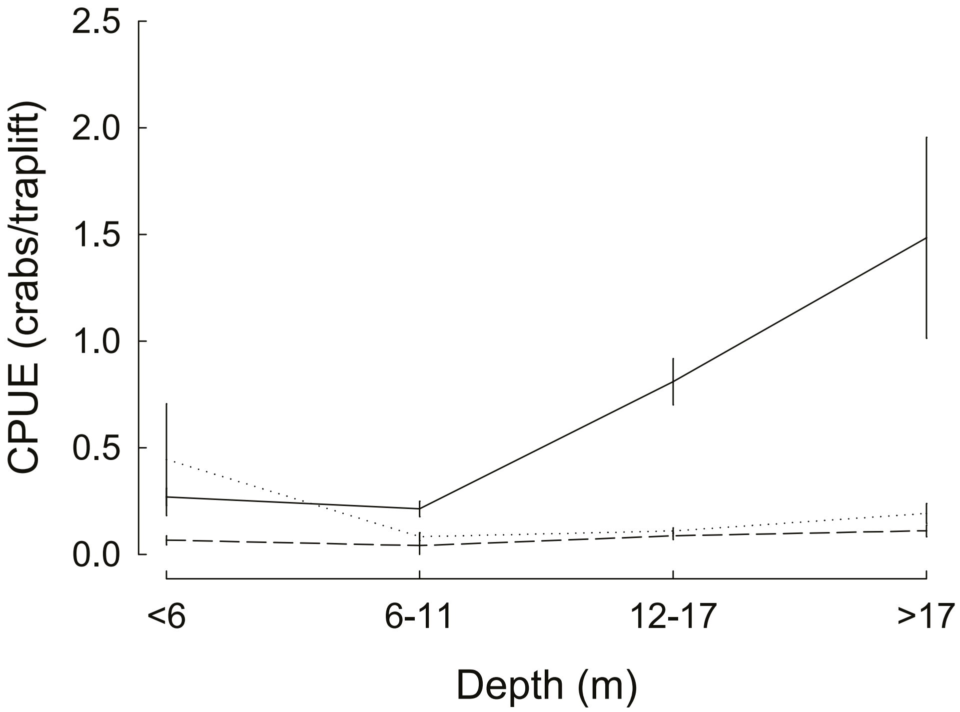

Figure 34. Standardized catch rates of ovigerous female crabs for Jul/Aug/Sep (—), Oct/Nov/Dec (---) and Mar/Apr/May (····) by depth derived from commercial trap monitoring surveys in Shark Bay between 2000 and 2010. ± standard errors are included.

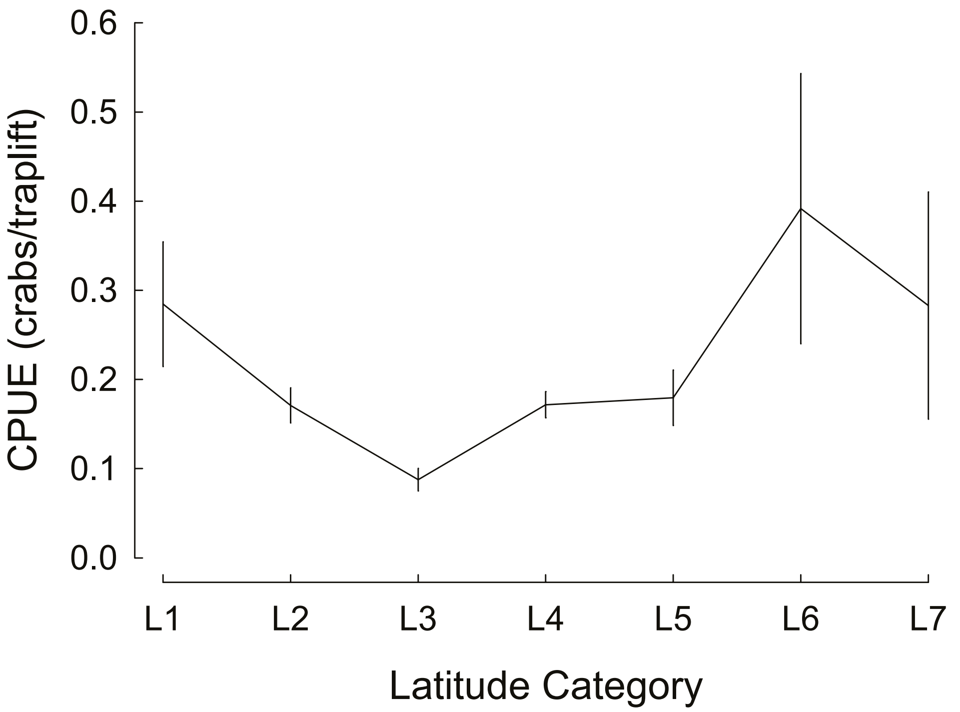

Figure 35. Standardized catch rates of ovigerous female crabs by latitude derived from commercial trap monitoring surveys in Shark Bay between 2000 and 2010. ± standard errors are included.

Soft crabs

Highest catch rates of soft (recently moulted) male ($F_{2,590}$ = 26.92, p <0.01) and female ($F_{2,590}$ = 14.13, p <0.01) crabs occurred in Mar/Apr/May (Fig. 36). Depth also had a significant effect on the catch rate of soft male ($F_{2,590}$ = 17.69, p <0.01), with highest catch rates in waters deeper than 17 m (Fig. 37). There was a significant interaction between month and depth on soft female crabs ($F_{2,572}$ = 3.89, p <0.01), with catch rates of soft female crabs in Mar/Apr/May lowest in shallow water (<6 m) and highest in the deeper water (>17 m). However, by Jul/Aug/Sep the trend had reversed and the highest catch rates were in the shallows (Fig. 38). There was also a significant interaction between month and latitude on the catch rate of soft male crabs ($F_{2,572}$=3.89, p<0.01), with catch rates reasonably consistent across latitudes in Jul/Aug/Sep and Oct/Nov/Dec, but significantly higher in the northern-most latitudes in Mar/Apr/May (Fig. 39).

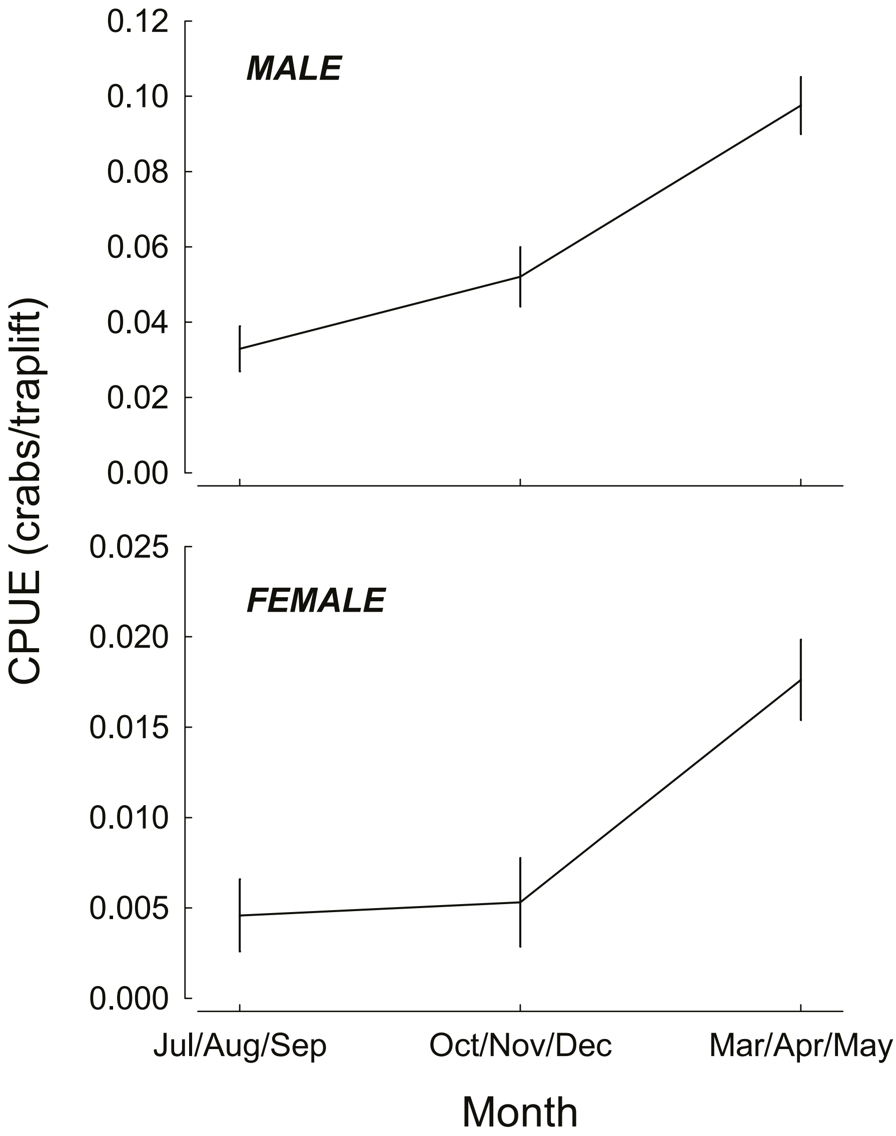

Figure 36. Standardized catch rates of soft-shelled male and female crabs by month derived from commercial trap monitoring surveys in Shark Bay between 2000 and 2010. ± standard errors are included.

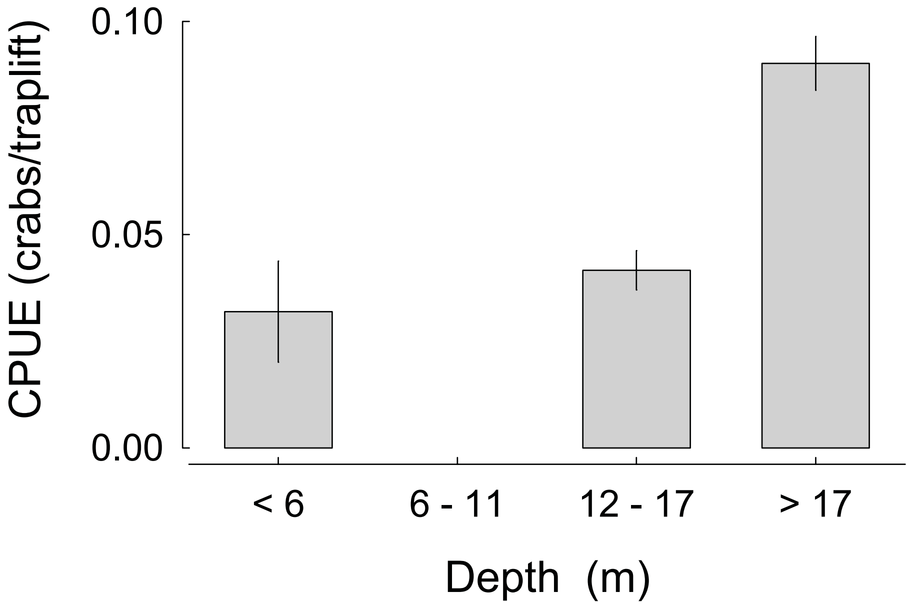

Figure 37. Standardized catch rates of soft-shelled male crabs by depth derived from commercial trap monitoring surveys in Shark Bay between 2000 and 2010. ± standard errors are included.

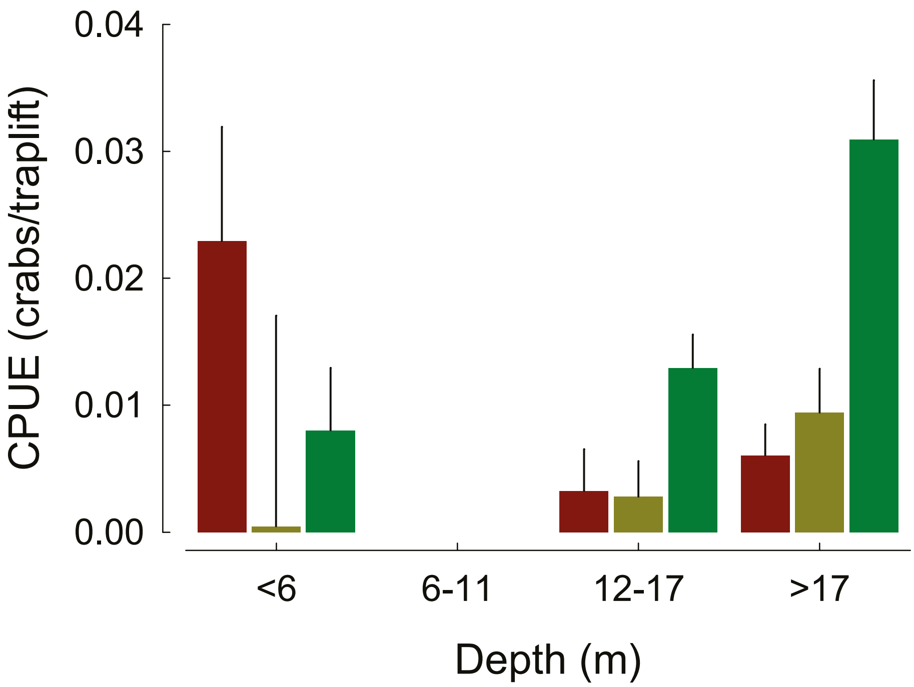

Figure 38. Standardized catch rates of soft-shelled female crabs for Jul/Aug/Sep (■), Oct/Nov/Dec (■) and Mar/Apr/May (■) by depth derived from commercial trap monitoring surveys in Shark Bay between 2000 and 2010. ± standard errors are included.

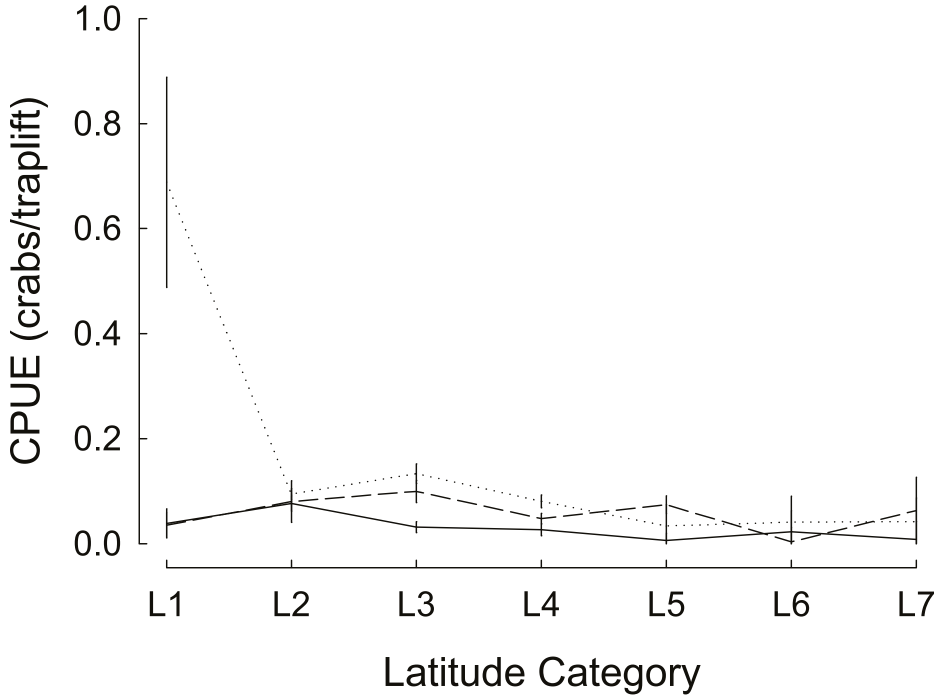

Figure 39. Standardized catch rates of soft-shelled male crabs for Jul/Aug/Sep (—), Oct/Nov/Dec (---) and Mar/Apr/May (····) by latitude derived from commercial trap monitoring surveys in Shark Bay between 2000 and 2010. ± standard errors are included.

3.1.4 Fishery independent trawl surveys

3.1.4.1 November trawl

Catch composition

Catches from the November fishery-independent trawl surveys varied from commercial trap monitoring surveys over the same period. Whereas male crabs dominated the trap catch, the trawl catch was divided evenly between male and female crabs (Fig. 40). Furthermore, 39% of female crabs captured by trawl were berried compared to just 8% in catches from November trap monitoring (Figs 18, 40). The trawl survey also captured many more small crabs compared with the trap monitoring.

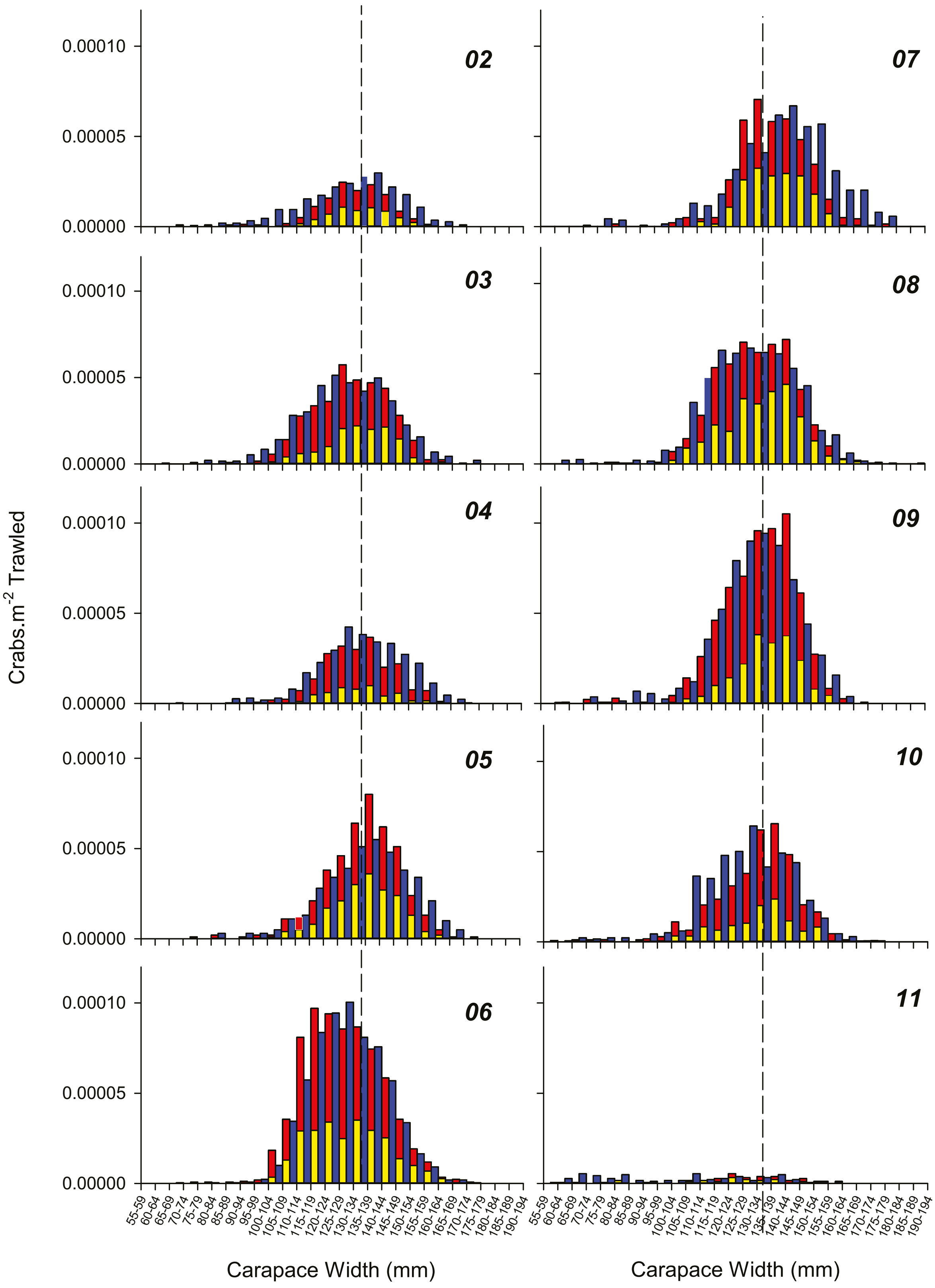

Figure 40. Annual mean length frequency distributions for male (■), female berried (■) and female non-berried (■) blue swimmer crabs captured at standardised sites during the annual November fishery independent trawl survey in Shark Bay between 2002 and 2010.

Annual trends in catch rate

Standardized catch rates of commercial (≥135mm CW) male crabs from annual November fishery-independent trawl surveys in Shark Bay increased from 0.15 crabs/1000m^2 trawled in 2002 to 0.26 crabs/1000m^2 in 2005 (Fig. 41). However, catch rates then steadily declined to 0.16 crabs/1000m^2 by 2010. This trend was replicated for commercial (≥135mm CW and not berried) female crabs, increasing from 0.06 crabs/1000m^2 in 2002 to 0.17 crabs/1000m^2 in 2005, before declining to 0.07 crabs/1000m^2 in 2010 (Fig. 41). Similar trends were apparent for sexually mature sub-legal male (115 – 134mm CW) and sexually mature sub-legal female (93 – 134mm CW), and berried crabs, with catch rates increasing from 2002 to 2006 before a declining trend to 2010 (Figs 41, 42). However, there was no statistically significant difference in annual catch rates between years for both sexually immature male ($F_{7,678} = 1.61$, $p = 0.13$) and female ($F_{7,678} = 0.3$, $p = 0.96$) crabs.

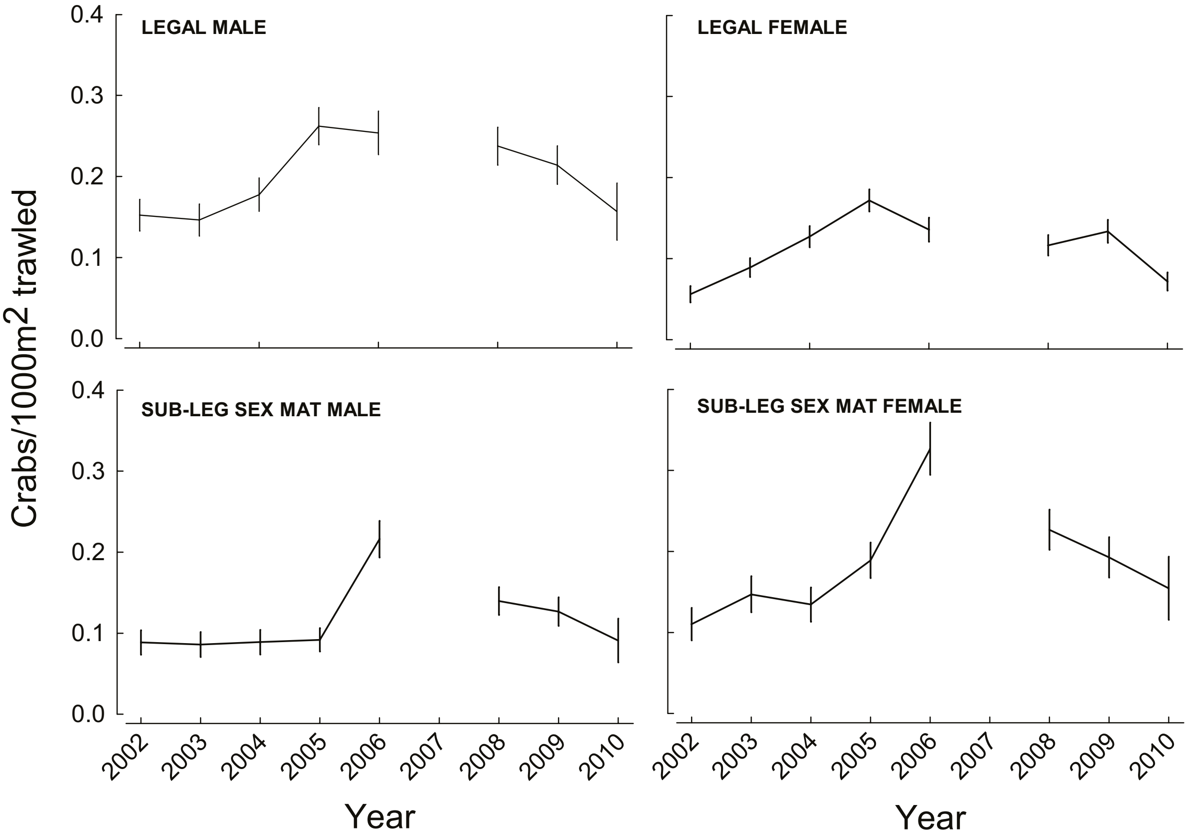

Figure 41. Mean annual standardized catch rates of commercial male, sub-legal sexually mature male, commercial female and sub-legal sexually mature female blue swimmer crabs derived from November fishery-independent trawl surveys in Shark Bay between 2002 and 2010. ± standard errors are included. 2007 survey data not included.

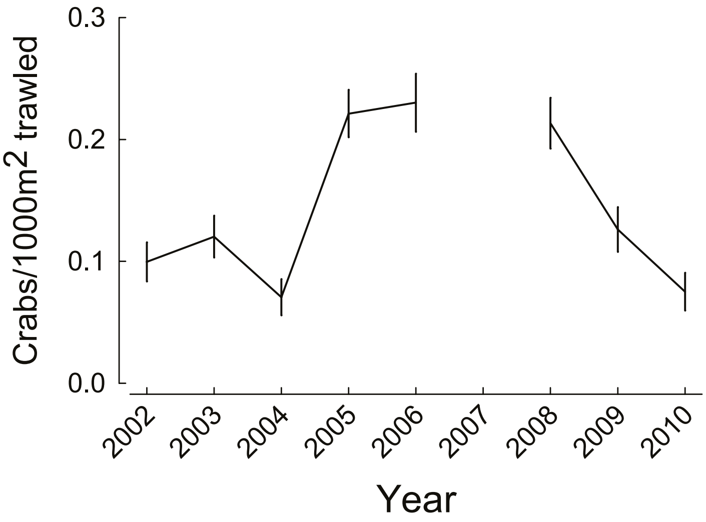

Figure 42. Mean annual standardized catch rates of ovigerous blue swimmer crabs derived from annual November fishery-independent trawl surveys in Shark Bay between 2002 and 2010. ± standard errors are included. 2007 survey data not included.

Depth

Standardised catch rates of commercial male crabs were highest in the deeper water (>17m) ($F_{2,678}$ = 9.63, p <0.01) (Fig. 43). This trend was also evident for both sexually mature sub-legal male and female, and sexually immature male blue swimmer crabs (Fig. 43). However, depth did not have a significant effect on catch rates of commercial non-berried female ($F_{2,678}$ = 0.17, p = 0.84), berried female ($F_{2,678}$ = 1.34, p = 0.26) and sexually immature female ($F_{2,678}$ = 0.41, p = 0.66) crabs.

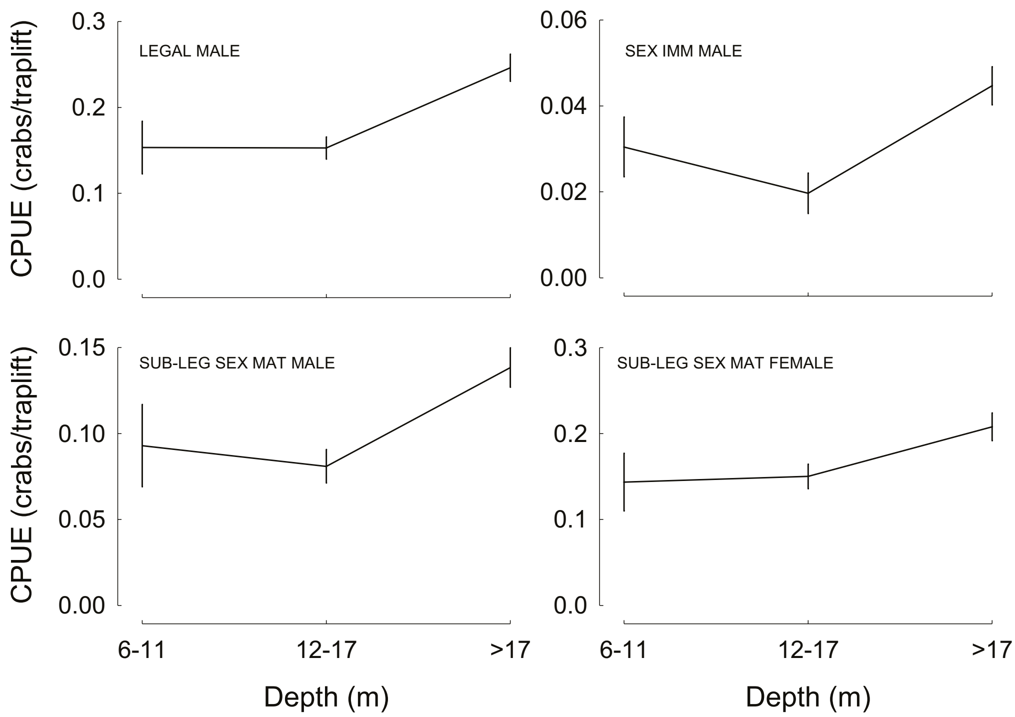

Figure 43. Standardized catch rates of commercial-sized male, sexually immature sub-commercial male, sexually immature sub-legal female, and sexually immature male crabs by depth derived from annual November fishery-independent trawl surveys in Shark Bay between 2002 and 2010. ± standard errors are included.

Location

Standardised catch rates of commercial male crabs were highest in the fishing ground NW Peron (0.55 male crabs/1000m^2 trawled) and to a lesser extent, Red Cliff (0.25 crabs/1000m^2 trawled), and lowest in the Eastern Gulf (0.10 crabs/1000m^2 trawled), Denham Sound (0.07 crabs/1000m^2 trawled), Freycinet Harbour (0.04 crabs/1000m^2 trawled), and the Leads (0.03 crabs/1000m^2 trawled) (Fig. 44a). Highest catch rates of commercial females also occurred at NW Peron (0.23 male crabs/1000m^2 trawled) and Red Cliff (0.21 crabs/1000m^2 trawled), with low catch rates for the other four fishing grounds (Fig. 44d). Catch rates of sub-legal sexually mature males and females were also highest at NW Peron, but there were also high catch rates in the Eastern Gulf (Fig. 44b, e). This trend was even more apparent in catch rates of sexually immature male crabs, which were nearly as high in the Eastern Gulf as NW Peron, and also significant in Freycinet Harbour (Fig. 44c). Standardized catch rates of sexually immature female crabs were highest in the Eastern Gulf (Fig. 44f). Catch rates of berried blue swimmer crabs followed the spatial trends of commercial male and female crabs, with significantly higher catch rates at NW Peron and Red Cliff than the other four fishing grounds (Fig. 45).

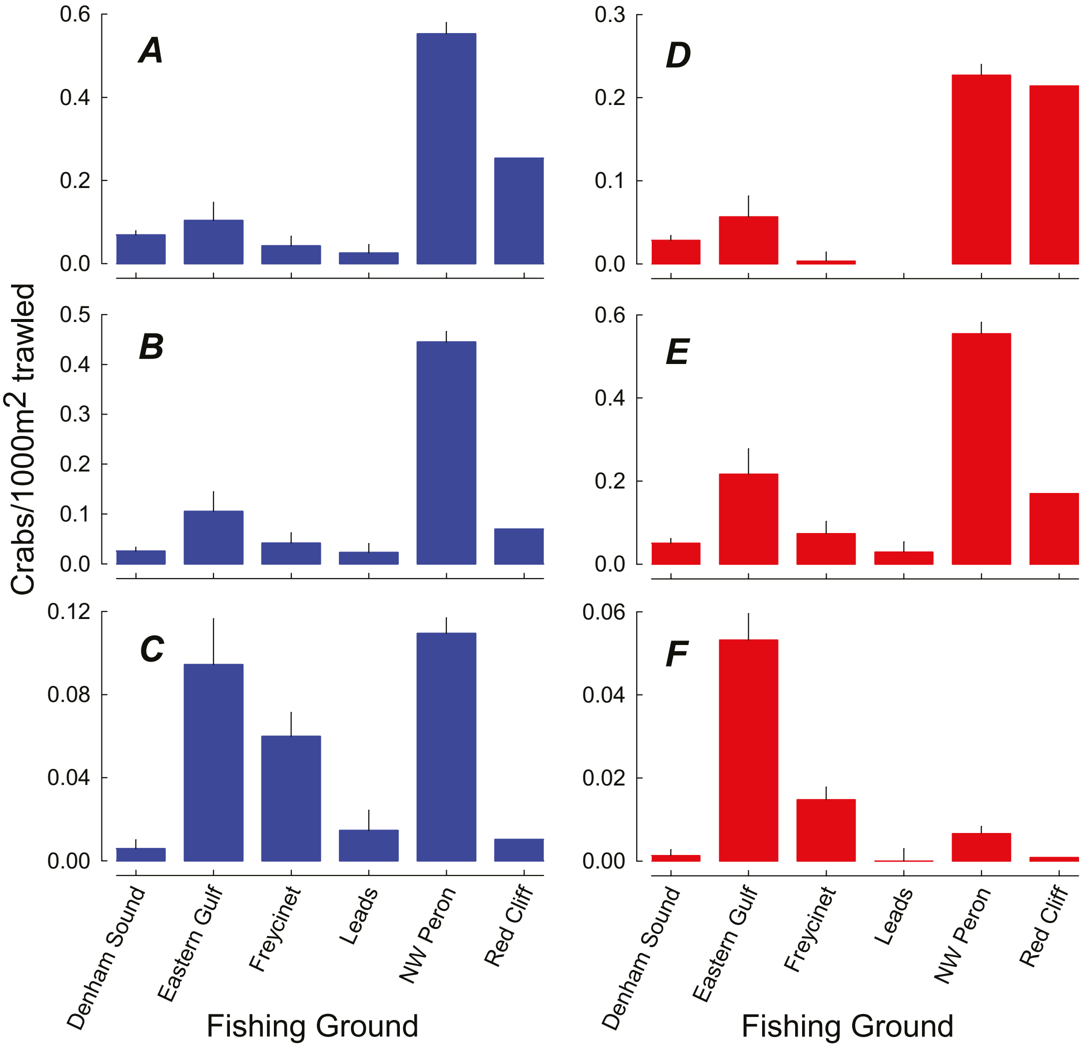

Figure 44. Standardized catch rates of: (***A***) commercial male, (***B***) sub-legal sexually mature male, (***C***) sexually immature male, (***D***) commercial female, (***E***) sub-legal sexually mature female, and (***F***) sexually immature female blue swimmer crabs by fishing ground derived from annual November fishery-independent trawl surveys in Shark Bay between 2002 and 2010. ± standard errors are included.

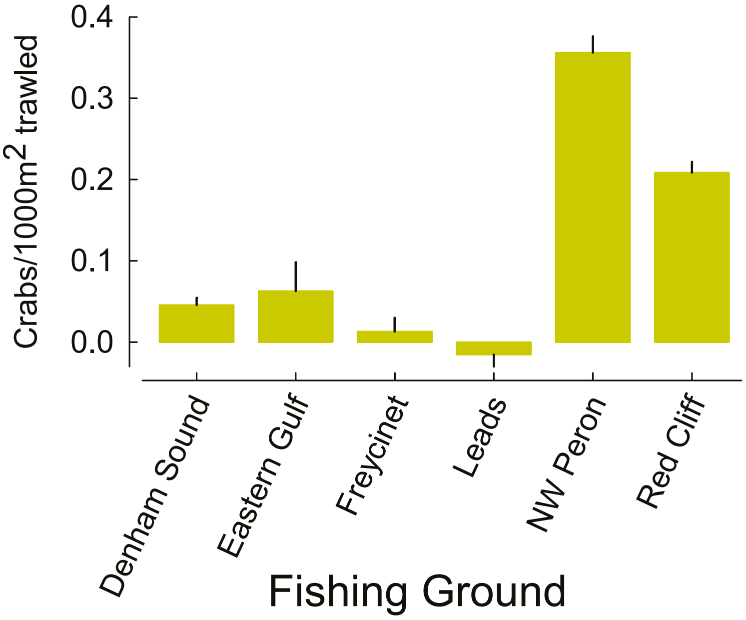

Figure 45. Standardized catch rates of ovigerous female blue swimmer crabs by fishing ground derived from annual November fishery-independent trawl surveys in Shark Bay between 2002 and 2010. ± standard errors are included.

Size

Crabs captured by trawl in Shark Bay were on average smaller than animals caught in commercial traps. Male crabs captured during the 2004, 2009 and 2010 November fishery-independent trawl surveys had mean carapace widths of 135mm, 129mm and 133mm, respectively (Fig. 46). By comparison, males captured during November commercial trap monitoring surveys in 2004, 2009 and 2010 had mean carapace widths of 148 mm, 145 mm and 142 mm, respectively (Fig. 46).

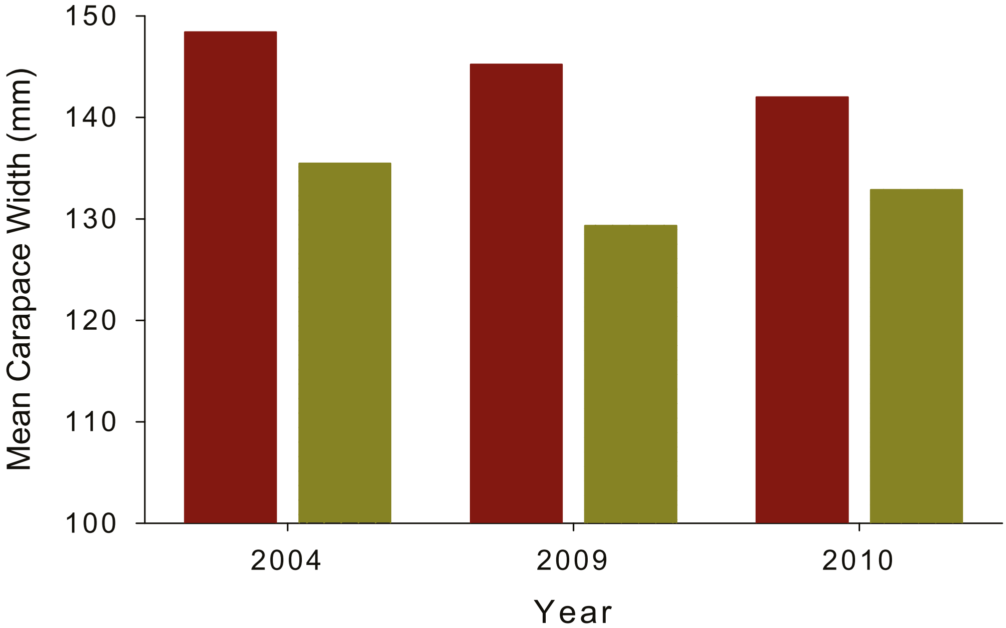

Figure 46. Comparison of mean carapace widths for male blue swimmer crabs captured during November commercial trap monitoring surveys (■) and the annual November fishery-independent trawl survey (■) in Shark Bay, for 2004, 2009 and 2010.

Changes in the size of crabs captured during November trawl surveys in Shark Bay mirrored trends from commercial trap monitoring surveys. There was initially a gradual increase in the mean carapace width of male crabs, from 132 mm in 2002 to a peak of 141 mm in 2005 (Fig. 47). However, a downward trend was evident from this point with male carapace widths decreasing to 129 mm by 2009. Similar trends were observed for non-berried and berried female crabs. Mean non-berried female carapace widths increased from 123 mm in 2002 to 136 mm in 2005 before decreasing to 129 mm by 2009, while berried females increased from 134 mm to 138 mm in 2005 before dropping to 133 mm in 2010 (Fig. 47).

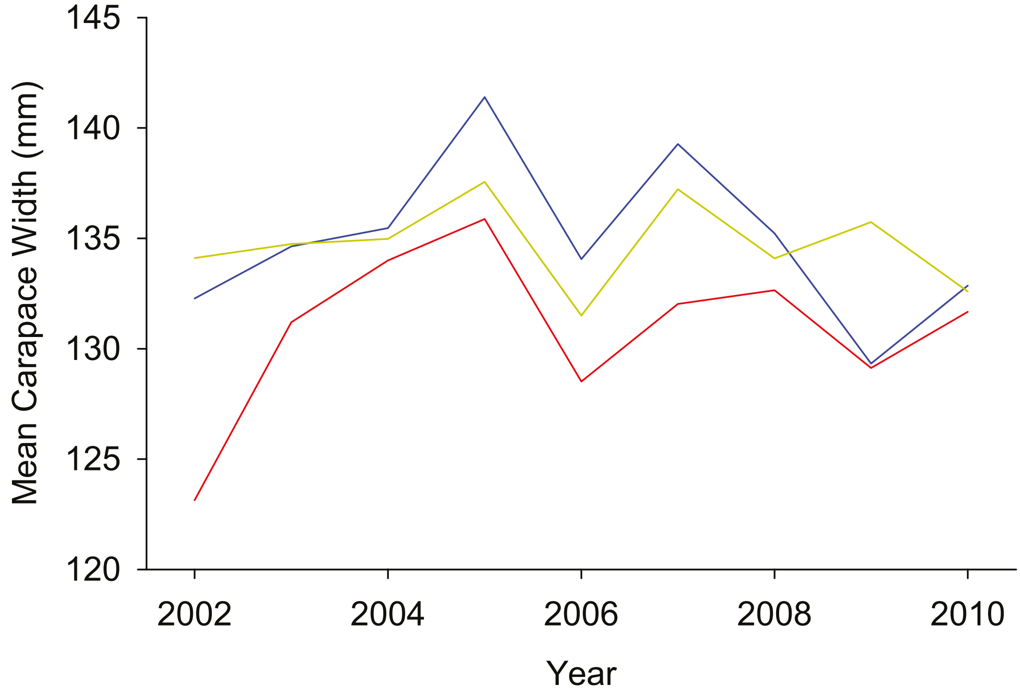

Figure 47. Mean annual carapace widths for male (—), female berried (—) and female non-berried (—) blue swimmer crabs captured during the annual November fishery-independent trawl survey in Shark Bay between 2002 and 2010.

3.1.4.2 Pilot sampling in eastern Shark Bay (ENA)

Preliminary analysis of the crab abundance data indicates that catch rates were lower overall in November than in March or April (Table 5), but catch rates in March 2011 were much higher than observed in April 2010 (Fig. 48). The northern part of the ENA had the lowest catch rates in any one time period with the other two regions (central and south) not showing a consistent trend between years or sites (Table 5). In November 2010, southern sites had highest numbers of crabs (Fig. 49). The size composition data is yet to be analysed.

Table 5. Mean number of blue swimmer crabs/nm trawled captured at each sampling site during trawl surveys in the Extended Nursery Area of the Shark Bay Prawn Managed Fishery in April and November 2010, and March 2011.

Area	Site No	Apr 10	Nov 10	Mar 11
NORTH	27	77	54	49
	28	NS	34	88
	29	118	42	104
	1	13	31	98
CENTRAL	4	141	15	116
	5	149	42	65
	30	210	126	386
	6	99	90	158
	7	15	103	491
	8	291	207	30
	9	201	175	407
SOUTH	11	63	118	120
	12	20	477	199
	14	30	NS	528
	15	126	620	131
	17	NS	102	241
	18	19	317	283
SURVEY MEAN (± s.e.)		**110±23**	**160±46**	**188±39**

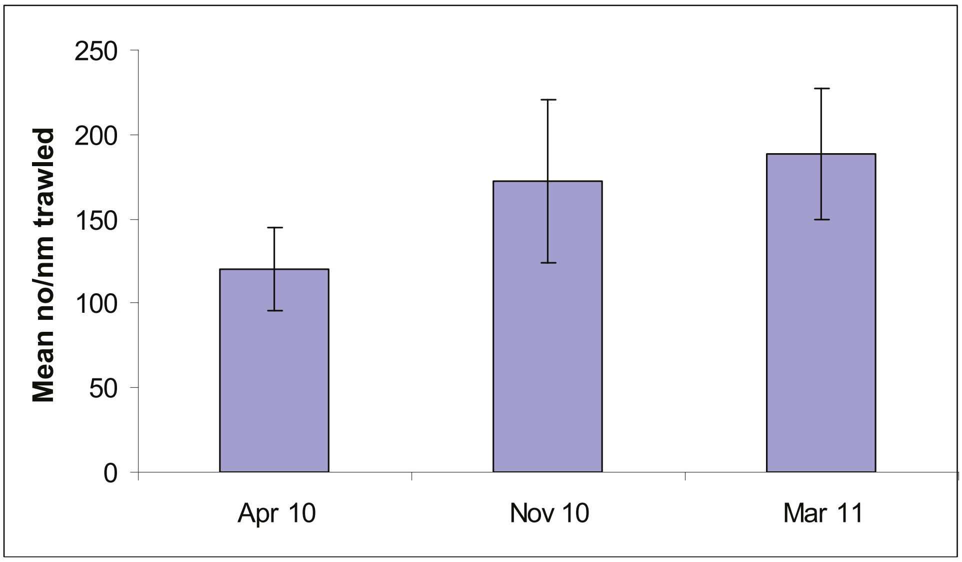

Figure 48. Mean number of crabs/nm trawled during ENA surveys in April and November 2010 and March 2011 (adjusted to twin 6 fathom nets).

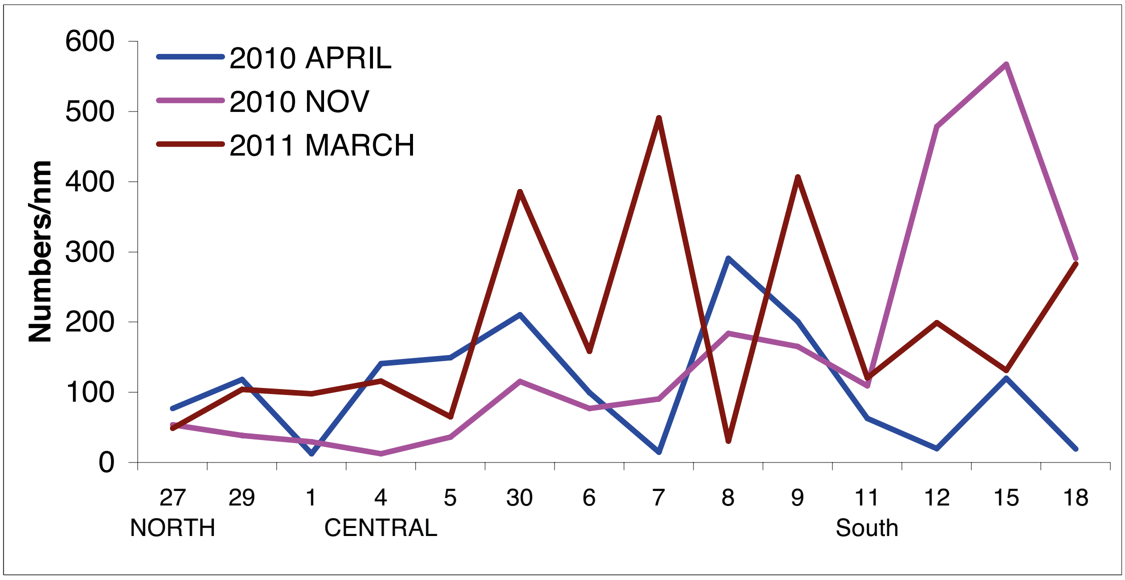

Figure 49. Mean number of crabs/nm trawled at each site during ENA surveys in April and November 2010 and March 2011 (adjusted to twin 6 fathom nets).

3.1.5 Daily research logbook data

3.1.5.1 Trap

Despite covering an area of 13,000km^2, only 20 – 30% of the waters of Shark Bay are exploited by commercial crab trap fishers, primarily in the oceanic waters north of Cape Inscription. Almost 90% of the fleet's catch came from these northern grounds at a mean CPUE of 1.6 kg/potlift, compared with 8% from the Eastern Gulf (1.3 kg/potlift) and just 5% from the Western Gulf (1.2 kg/potlift). Fishing activity in the northern grounds was centered on two main areas: from Cape Peron north-west to Koks Island, and along the eastern coast from north of Carnarvon to Bush Bay up to 30km from land (Fig. 50). While catches were highest in specific areas, the mean annual catch rate was relatively consistent across all areas fished in the northern grounds, with only slightly higher catch rates north of Cape Peron, east of Koks Island, and 20km south west of Carnarvon (Fig. 50). Spatial distribution between male and female crabs was homogenous across these fishing areas, other than the ground northwest of Peron, which produced significant quantities of male crabs but fewer females (Fig. 51). It must be noted, however, that the areas north of Cape Inscription that can be accessed by trap fishers are restricted for parts of the year by the operations of the Shark Bay prawn and scallop fleets. The prawn fleet operates each year from April through October, while the scallop fleet commences around April and can fish from 3 weeks to 6 months depending on the strength of scallop stocks. During these periods, trap fishers stay out of the areas open to trawlers (Fig. 2) to avoid their traps fouling the trawlers' nets (Fig. 52).

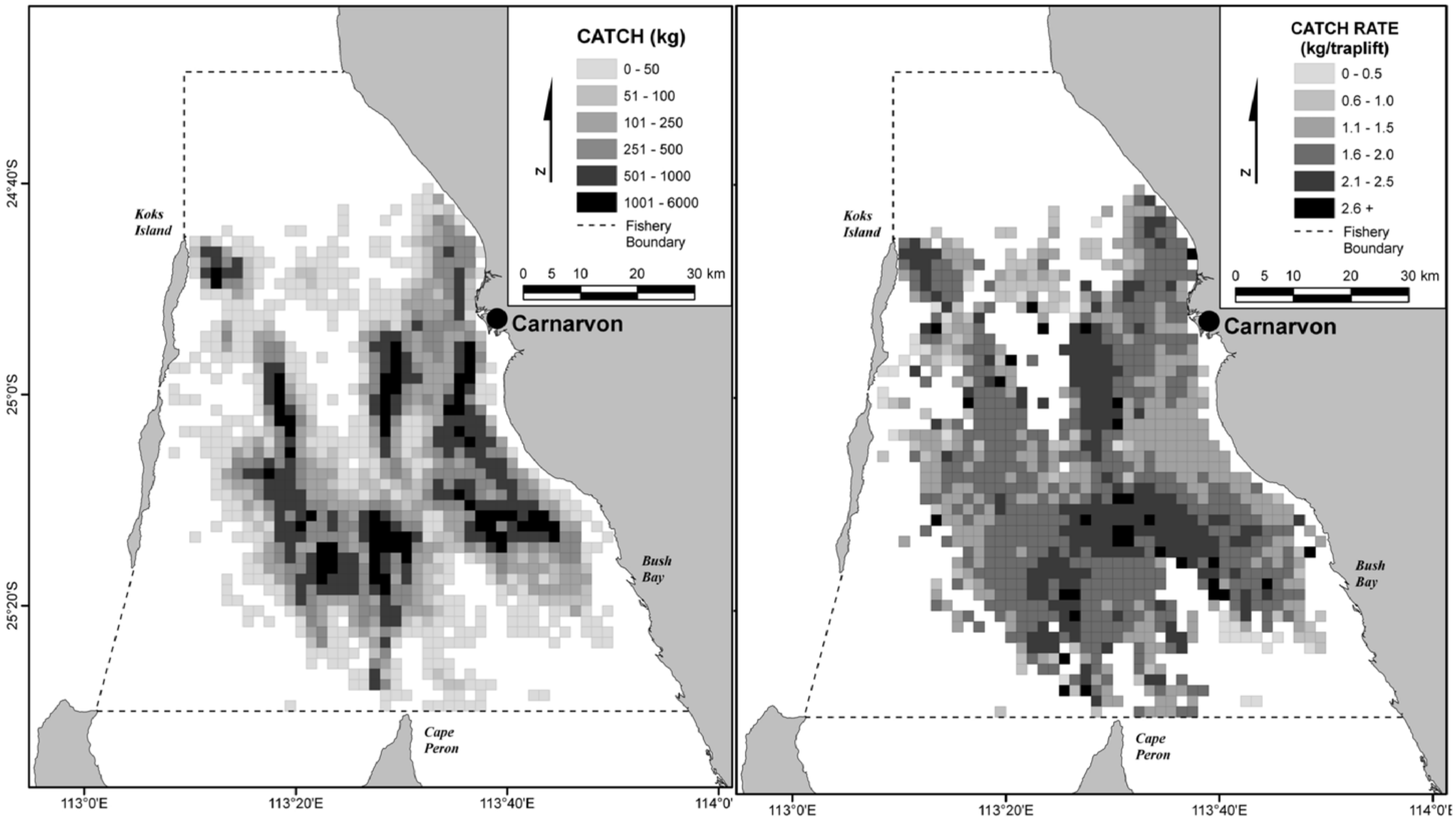

Figure 50. Spatial distribution of mean annual commercial trap crab catch (kg) and catch rate (kg/traplift) between 2003 and 2008 in the waters of Shark Bay north of Cape Inscription, derived from daily blue swimmer crab research logbook data.

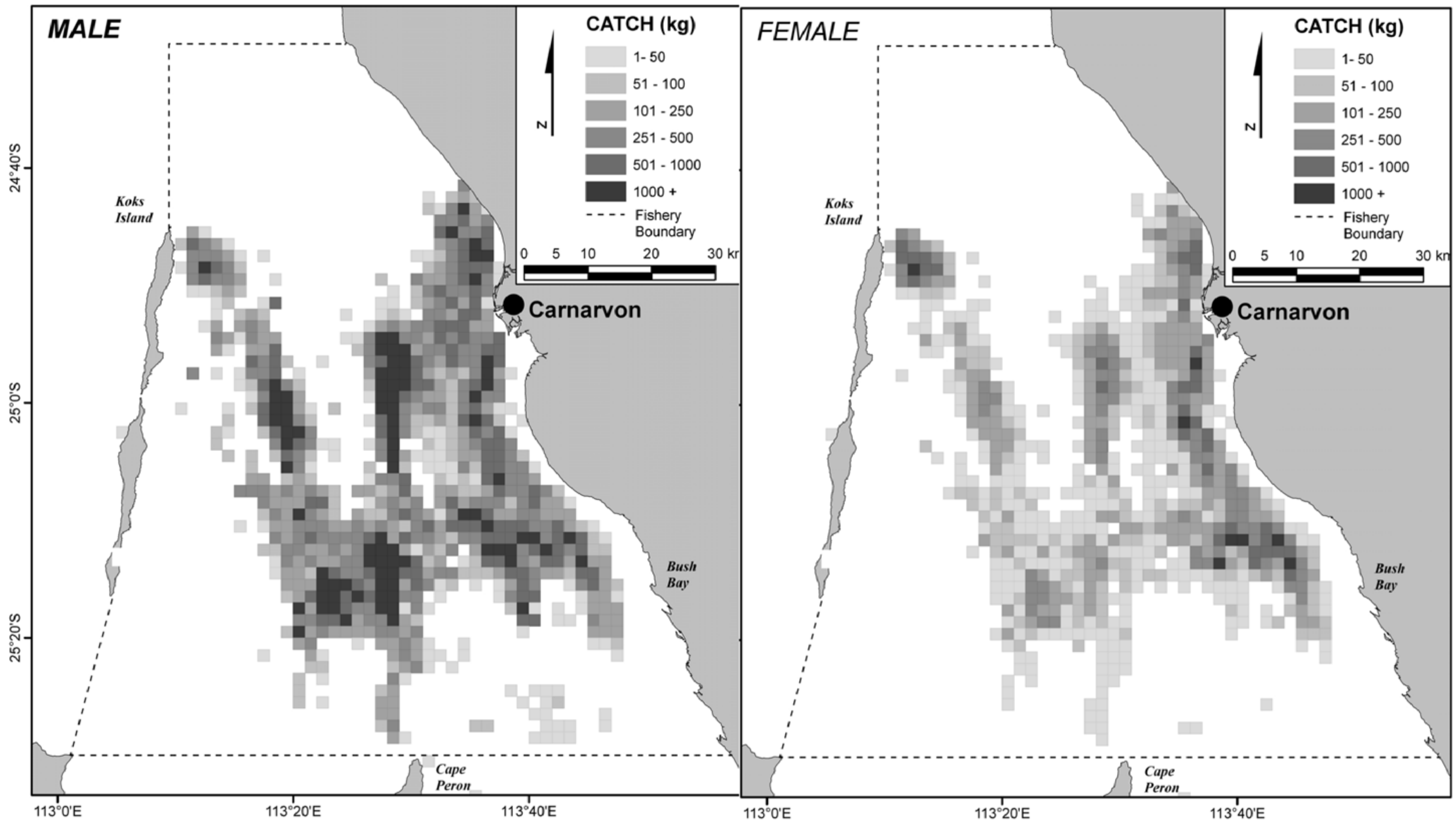

Figure 51. Spatial distribution of mean annual commercial male and female trap catch (kg) between 2003 and 2008 in the waters of Shark Bay north of Cape Inscription, derived from daily blue swimmer crab research logbook data.

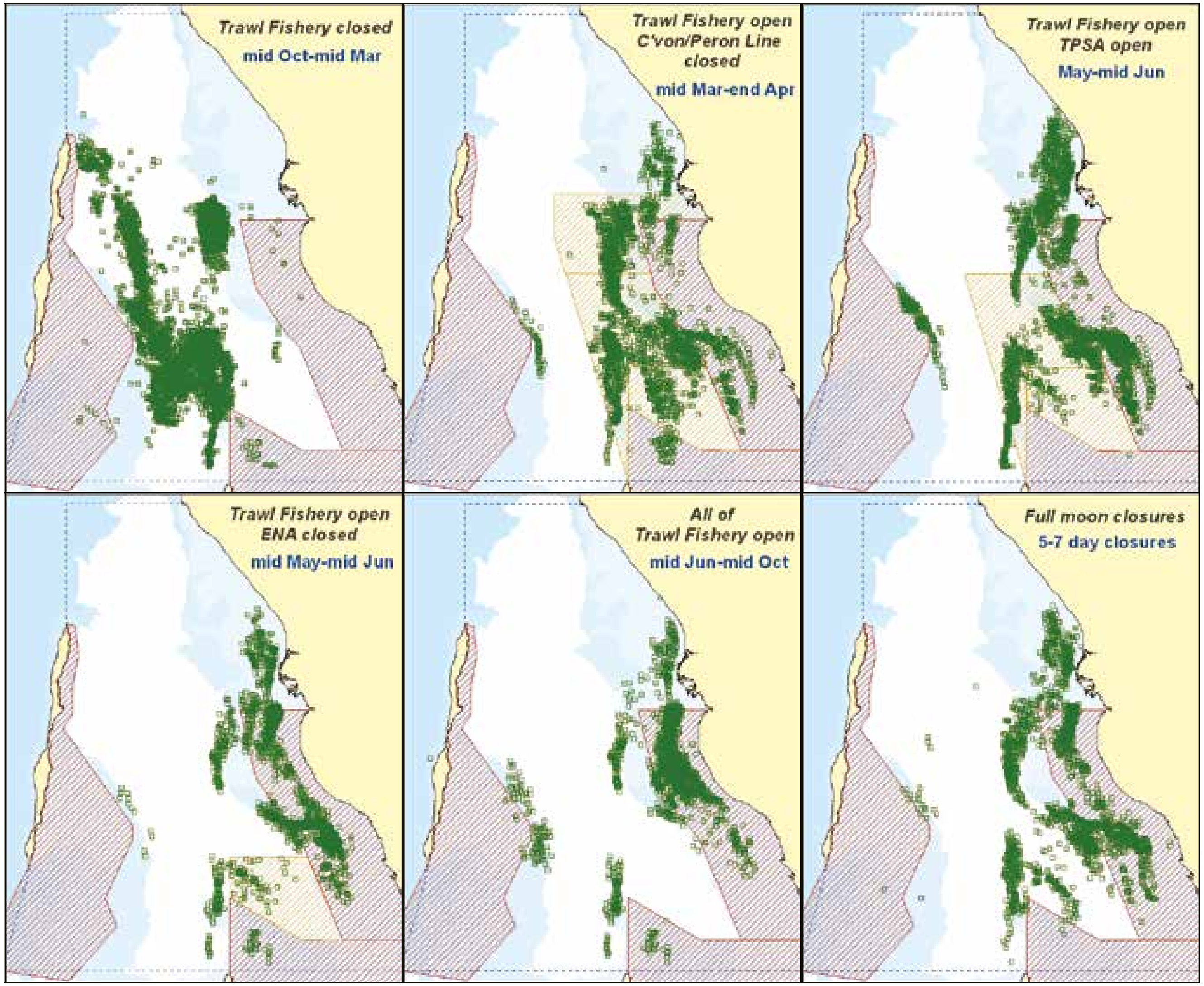

Figure 52. Spatial distribution of commercial trap effort (□) during different phases of the trawl fishing season in the waters of Shark Bay north of Cape Inscription between 2007 and 2010. Data is derived from voluntary Department of Fisheries Daily Research Logbooks submitted by the Shark Bay trap fleet. (///) denotes areas permanently closed to trawling; (///) denotes temporal trawl closures; □ denotes area actually fished by trawlers.

3.1.5.2 Trawl

Catch

Records of crab landings for the trawl sector commenced in 1989 and these were via monthly CAES records. Low landings, between 3 and 12 t of crabs were recorded as retained catch for the first four years (1989 to 1992). From 1993 to 2001 inclusive the crab annual landings increased, ranging from 25 to 89 t with an average of 51 t. Reporting of byproduct landings by the trawl fleet using logbooks and validation through processor unloads commenced in 1997. Historical logbooks did not record byproduct because the focus of recording was the target species. Between 1978 and 1996 the statutory reporting of byproduct was through monthly CAES records and the accuracy of the reported crab catches cannot be validated. Low annual crab catches were reported in these early years with reporting improving by the mid 1990's. It is likely there was under-reporting of byproduct landings, including crabs, between 1978 and 1996.

In 2002 there was a significant increase in the retention of crabs by the prawn boats. From 2002 to 2010 the total landings of crabs from the prawn boats were in excess of 100 t with an average annual catch of 190 t. (Table 4). The annual landings were approximately 250 t of crabs in 2007 and 2009 and peaking in 2010 at 338 t. Scallop boats retain a very small amount of crab and the annual total landings are in the order of 10 t.

In the years 1998 to 2005 inclusive most of the crabs were retained in the early part of the season, whereas from 2006 most crab numbers were retained in the middle of the season May to August (Fig. 10). This tends to fit the delayed prawn fishing strategy by opening the eastern part of the fishery later and rolling opening of areas where crabs are mostly abundant in the early part of the season.

Effort

The trawl fishery in Shark Bay commenced with 4 boats fishing a total of 2420 hrs in 1962. Fishing boat numbers increased and peaked at 35 in 1975. Fishing effort increased rapidly and peaked at 70,000 hours in 1981, but that was an exceptionally high year for total prawn landings and the nominal effort range was between 55,000 and 66,000 hours. The nominal effort remained stable around 60,000 hours until a reduction of boat numbers from 35 to 27 boats in 1990 occurred. The boats towed twin gear (16 fathoms headrope length). Fleet rationalisation to increase fleet efficiency commenced in 2005 and reduced boat numbers from 27 to 18 with those boats remaining towing quad gear (22 fathoms). Although boat numbers were reduced by 33% the total net headrope length was only reduced by 8%. Because of rising costs of fishing and a decline in prawn prices since the mid 1980s fishing effort has also decreased to gain efficiency and maintain profits. The comparable effort since 2005 is around 39,000 hours and the annual nights fished have reduced from a high of 226 to around 170.

Crab retention

Retention of crabs from individual prawn boats varies, with annual landings of blue swimmer crabs ranging from 3 to 28 t. From a total landed catch of 251 t in 2009, eight trawlers averaged 20 t, whereas the other ten boats averaged only 9 t. The total crab landing for the 2010 fishing season increased to 338 t (Table 4; Fig. 7), demonstrating the potential for higher trawl crab catches if all boats retained crabs at the higher retention rates.

3.1.6 Recreational Sector

A 12-month survey of recreational boat-based and shore-based fishing covering the Gascoyne bioregion (Shark Bay to Exmouth Gulf) between April 1998 and March 1999 (Sumner *et al.*, 2002) estimated the retained recreational blue swimmer catch to be 3,870 (SE±1154) crabs (Table 6). This catch represents ~1 t of blue swimmer crabs, or less than 1% of the commercial catch over the same period for the Gascoyne bioregion of 147 t (Table 7). A further 2,892 crabs were caught but returned to the water because they were either female crabs bearing eggs or under the legal recreational size (127 mm CW). All of the recreational catch was taken using drop nets by people fishing from a boat. An estimate of recreational crab catch for Shark Bay alone was not included in the analysis. A repeat of the recreational fishing survey was conducted in the Gascoyne bioregion between March 2007 and March 2008. Analysis of the collected data is expected to occur in the near future.

Table 6. Annual estimates of numbers of retained and released blue swimmer crabs by recreational fishers in Shark Bay from creel surveys in the Gascoyne bioregion in 1998-99, and in the lower gulfs of Shark Bay in 2000/01, 2001/02, 2005/06, 2006/07 and 2007/08, and catch composition of samples of the recreational catch from the eastern gulf of Shark Bay for the 2005/06, 2006/07 and 2007/08 surveys.

Year	Region	Retained				Released			Length freq. samples				
		Rep.	Est.	SE	Approx. wght (t)	Rep.	Est.	SE	Cohort	*n*	Mean CW	SE	Cohort prop'n
1998/99	Gascoyne	-	3870	1154	1	-	2892	-	-	-	-	-	-
2000/01	Lower gulfs	-	5995	1340	1.2	-	1068	-	-	-	-	-	-
2001/02	Lower gulfs	-	1487	668	0.3	-	622	-	-	-	-	-	-
2005/06	Eastern gulf	204	3266	1132	0.8	57	805	302	1	18	139	1.1	
2006/07	Eastern gulf	368	7269	1595	1.9	70	1594	481	1	9	139	1.5	
2007/08	Eastern gulf	162	3789	1456	1	50	805	344	1	9	135	0.8	14%
									2	55	158	1.5	86%
	Western gulf	27	401	321	0.1	8	119	126	-	-	-	-	-

Table 7. Comparison of recreational versus commercial blue swimmer crab catch for the Gascoyne bioregion in 1998 – 99, and in the lower gulfs of Shark Bay in 2000/01, 2001/02, 2005/06, 2006/07 and 2007/08.

Year	Recreational		Commercial	
	Catch (t)	Prop'n (%)	Catch (t)	Prop'n (%)
1998/99	1	< 1	147	> 99
2000/01	1.2	3	36	97
2001/02	0.3	< 1	53	> 99
2005/06	0.8	1	78	99
2006/07	1.9	4	43	96
2007/08	1.1	3	34	97

Information on recreational blue swimmer catches in the inner gulfs of Shark Bay has also been extracted from surveys targeting recreational pink snapper fishers. A 12-month creel survey conducted in Shark Bay between May 2000 and April 2001 (Sumner and Malseed, 2002) estimated the total retained recreational catch of blue swimmer crabs from the lower gulfs for the 12-month period to be 5995 ± 1340 crabs (Table 6). This catch equated to ~1.2 t or 3% of the commercial trap catch from the lower gulfs for the same period of 36 t (Table 7). A further 1068 crabs were returned to the water because they were berried female crabs or under the legal size of 127mm CW.

The 12-month recreational pink snapper surveys were repeated in 2001/02, 2005/06, 2006/07 and 2007/08. The first three surveys provided retained recreational crab catch estimates of ~0.3 t, ~0.8 t and ~1.9 t, respectively (Table 6), with all crabs caught in the eastern gulf around Monkey Mia. However, the 2007/08 survey recorded catches from both the eastern gulf around Monkey Mia, and the western gulf around Denham. The retained catch estimate for the eastern gulf in 2007/08 was ~1 t, while the retained catch estimate for the western gulf was 0.1 t. There was also an unusually high catch (~90 t) of blue swimmer crabs taken by the trawl fleet in the Western Gulf during the July, August and September in 2007. The recreational component of the total catch for the lower gulfs of Shark Bay equated to 1% to 4% for the four years (Table 7).

Sub-samples of blue swimmer crabs retained by recreational fishers in the eastern gulf were measured (carapace width) during each of the pink snapper surveys. The 2005 sample (*n* = 18) was uni-modal, with a mean carapace width of 139 ± 1.1mm (Fig. 53, Table 6). A sample of 9 crabs was measured from the eastern gulf during the 2006 survey, again representing a single cohort with a mean carapace width of 139 ± 1.5mm. However, the sample (*n* = 65) of crabs from the 2007 survey was bi-modal. Cohort 1 represented 14% of the sample and had a mean carapace width of 135 ± 1.1mm, while cohort 2 represented 86% of the sample and had a mean carapace width of 158 ± 0.8mm (Fig. 53, Table 6).

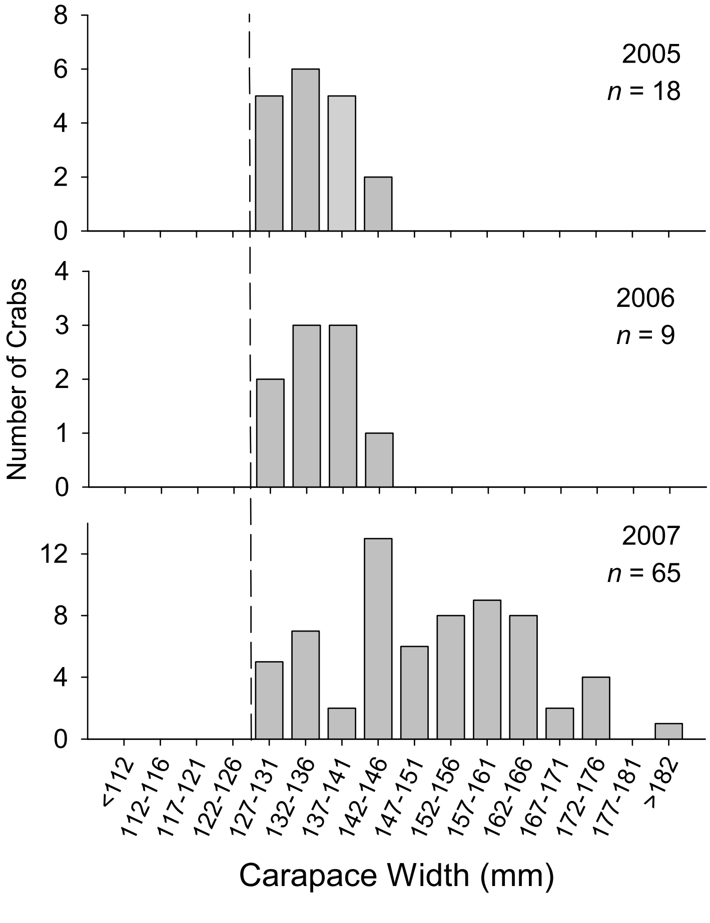

Figure 53. Length frequency distributions of blue swimmer crabs captured by recreational fishers surveyed in the eastern gulf of Shark Bay during pink snapper creel surveys between 2005 and 2007. (– – –) minimum recreational size limit (127mmCW).

4.0 Discussion

4.1 Commercial fishing history

Since the first commercial catches were landed in the 1950s, the Shark Bay crab fishery has developed into the largest blue swimmer crab fishery in Australia.

4.1.1 Trawl

Small quantities (<5 t annually) of blue swimmer crabs were landed by the Shark Bay prawn trawl fleet from the 1950s through to the 1990s (Fig. 7) as the fishery targeted prawns, and to a lesser extent scallops. Markets had yet to develop to make the transport of raw crab product from a remote area like Shark Bay viable, and the boats had limited capacity to process and freeze a high volume of byproduct. However, it should be noted that reported trawl crab landings were likely to have been under-estimated, as there was a level of under-reporting of by-product during this period.

After 2000, the trawl sector began to increase crab retention. Markets developed and crabs increased in value whereas prawn prices were declining in real terms. Larger boats that allowed for additional crew, more processing deck space and larger freezer capacity for storage, replaced smaller prawn boats. Consequently, the trawl crab landings rose steadily from 43 t in 2000 to 338 t in 2010 (Table 4; Fig. 7).

Potential exists for further significant increases in crab landings by the trawl fleet. The high capital cost to fish in the prawn industry, and repayments for fleet restructures to remain viable and profitable, has seen the industry look at increasing retention of crabs. While increases in the trawl crab retention in recent years with lower effort levels has reduced some of the potential for increased crab landings, the comparative increase in crab value to trawlers could see the trawl fleet continue to increase the level of retention of crabs.

4.1.2 Trap

Trap catches remained low following the introduction of purpose-designed crab traps in the 1980s, largely because effort in the fishery was limited to a maximum of 450 traps and trap fishers were faced with the same marketing and logistical obstacles as the trawl fleet. Consequently, the annual trap catch had reached just 31 t by 1997 (Fig. 8).

However, following the implementation of the Carnarvon Experimental Crab Trap Fishery (CECTF) in 1998 the annual trap catch grew rapidly, peaking at 564 t in 2005 (Figs 7, 8). This escalation was due largely to the substantial increase in fishing effort that resulted from the establishment of the CECTF. The two fishers with a prior history of fishing for crabs with traps in Shark Bay were each issued with a formal exemption that permitted them to use a maximum of 200 traps throughout the embayment. In addition, a further three 200-trap exemptions were issued with their use restricted to the waters of Shark Bay north of Cape Inscription. Each of the five Shark Bay trap exemption holders was granted a further 100 traps on a trial basis in 2002, with the provision that the additional traps could only be used north of Cape Inscription. This additional allocation took the trap fishery to its current capacity of 1500 traps (but only a maximum of 400 traps could be used in the Western and Eastern Gulfs below Cape Peron). Consequently, effort increased steadily from a total of 35,000 traplifts in 1997 to 355,000 traplifts in 2005 (Fig. 8). The rapid rise in catch could further be explained by the increase in local fishing knowledge during the developmental phase of the Shark Bay trap fishery. The standardized trap catch rate increased by about 50% over the first three years of the CECTF, representing an increase in fishing efficiency as trappers identified productive crabbing grounds in the waters north of Cape Inscription. Moreover, smaller trap boats were replaced with more powerful, purpose-built vessels, trap design and mesh size were refined and optimal baits identified.

Following the move to interim management in 2005, the annual catch and effort in the Shark Bay trap fishery stabilised between 480 – 540 t from 310,000 – 330,000 traplifts (Fig. 8). Trap fishers have identified the main fishing grounds in the northern waters of Shark Bay and consolidated their fishing operations to the more productive months from November to June (Fig. 10).

These temporal catch trends were reflected in standardized annual commercial trap catch rates. Following the implementation of the CECTF, the catch rate in the northern fishing grounds increased from 1 kg/traplift in 1998/99 to 1.7 kg/traplift in 2000/01 (Fig. 9). The catch rate then fluctuated between 1.3 and 1.6 kg/traplift over the next four years, as fishers continued to explore the northern fishing grounds and experiment with fishing gear and vessel configurations. Following the move to interim management in 2005, the trap catch rate stabilized between 1.4 and 1.5 kg/traplift through to 2009/10. An increase in trap catch rate has occurred in 2010/11, although this trend is preliminary as the data was to December 2010 inclusive (Fig. 9).

Standardised catch rates in the Eastern Gulf initially showed a similar trend to that experienced in the northern fishing grounds. The catch rate fluctuated between 0.8 and 1.3 kg/traplift between 1990/91 and 1997/98, followed by an increasing trend to a peak of 1.6 kg/traplift in 2001/02 (Fig. 9). However, the catch rate has since decreased to just 0.8 kg/traplift in 2010/11. It is unclear whether this decline represents a depletion of the crab stocks in the Eastern Gulf, or is more reflective of a decrease in fishing efficiency.

Monthly standardized catch rates in the northern fishing grounds were highest over the summer and autumn months, with a peak in March, April and May (Fig. 10). However, catch rates in the Eastern Gulf were highest in late winter/spring, peaking in July, August and September. The reasons for this disparity in peak catch periods between fishing areas are currently unclear.

4.2 Commercial catch composition

4.2.1 Trawl

Despite a legislated minimum size of 127 mm CW, the prawn trawl fleet in Shark Bay focuses mainly on large blue swimmer crabs (≥ 135 mm CW). However, different marketing strategies saw one part of the trawl sector taking only large size males (≥ 150 mm CW), while the other tended to retain male and female crabs ≥ 135mm CW. The licensees of boats that retained the smaller size crabs value-add to the product by extracting the meat, therefore presentation and size was less important. A voluntary notch-to-notch crab gauge (equating to ~138 mm CW) was introduced to the trawl fleet in 2009 and adopted with more rigor during the 2010 and 2011 seasons.

4.2.2 Trap

As with many blue swimmer crab trap fisheries, large (>135mm CW) male crabs dominate the commercial trap catch in Shark Bay. Data from factory unloads showed that males accounted for 80 – 90% of the retained catch from the primary fishing grounds north of Cape Inscription over the summer months (November – April), and 60 – 70% during the winter months (May –

October) (Fig. 18).

Male dominance was even more pronounced in commercial trap catches from the Eastern Gulf. Factory unloads showed males accounted for 97 – 99% of the retained catch from September through to May, with small quantities of female crabs (5 – 8%) retained in June, July and August (Fig. 20). Higher proportions of male crabs were also present in commercial trap monitoring surveys in the Eastern Gulf than in the northern fishing grounds (Fig. 20), suggesting that the higher male dominance in commercial trap catches may be a true reflection of crab stocks in this fishing ground, rather than the behaviour of fishers in not retaining female crabs. However, it is also possible that this male dominance results principally from spatial segregation between male and female crabs, trap selectivity or temporal catchability.

The seasonality of sex ratios identified in factory unloads of retained commercial trap catch were supported by statistical analysis of data from commercial trap monitoring, which showed highest catch rates of commercial and sub-legal males to be in Mar/Apr/May, whereas highest catch rates of commercial and sub-legal females were in Jul/Aug/Sep (Fig. 26).

These trends in the sex ratio of commercial trap catches from Shark Bay had previously been identified in the preliminary stock assessment of the CECTF by Bellchambers and Smith (2005), who also reported male-dominated catches in Shark Bay with peaks in the summer months. Similar, although more pronounced patterns of seasonal changes in sex ratio occur in commercial trap catches from southwest WA crab fisheries. Johnston *et al*. (2011) reported that male crabs dominated the commercial trap catch through the summer months (69 – 79%) in Cockburn Sound. However, over a four-week period in late March/early April, the catch switched from predominantly male to mainly non-berried female crabs. This female dominance (63 – 81%) then continued through to the following December. Male dominance in commercial catches over the summer months followed by female dominance from late autumn to late spring has also been documented for commercial crab fisheries in the Peel-Harvey Estuary, the Swan River, Warnbro Sound and Comet Bay (Johnston *et al*. 2011; Johnston *et al*., in press)

Male dominance in retained commercial blue swimmer crab trap catches is common in fisheries around Australia. Dixon *et al.* (2008) reported similar levels of male dominance in annual commercial catch throughout the year from both Spencer Gulf (73 – 89%) and Gulf St Vincent (57 – 89%) in the South Australian crab trap fishery. The dominance of large, male crabs in the trap catch from Shark Bay can be attributed to a range of factors including: prevailing market forces which favour large male crabs (Sumpton *et al*., 2003; Bellchambers and Smith, 2005); the selectivity of hourglass traps for male crabs (Thompson, 1951; Moñtano and Ferrer, 1997; Potter and de Lestang, 2000; Sumpton *et al*., 2003; Bellchambers and de Lestang, 2005); the reduced catchability of female crabs during certain phases of the reproductive and moult cycles (Sumpton *et al*. 1994); and a general trend by fishers to avoid areas with high abundances of female and sub-legal crabs (Sumpton *et al*., 2003).

Berried female crabs were present in catches from all commercial trap monitoring, with highest numbers in July, August and September surveys (Figs 18, 20, 21, 34). This suggests that spawning in Shark Bay may occur all year round, with a peak during the winter/spring months. Potter *et al*. (2001) reported spawning occurring all year round in Shark Bay while undertaking a study to determine data requirements for management regimes of WA blue swimmer crab fisheries, presuming this to reflect the influence of high year round water temperatures. Bellchambers and Smith (2005) reported berried females in all catches from commercial trap-monitoring surveys between 2001 and 2004. Similar trends while undertaking a preliminary stock assessment of the Shark Bay crab stocks. Similar trends have been reported for blue swimmer crab populations in sub-tropical locations comparable to Shark Bay. Sumpton *et al*. (1994, 2003) reported the presence of berried females all year round in trawl samples taken in Moreton Bay, Queensland, with a peak in spawning during the spring providing the bulk of recruits to the fishery. Corazon *et al*. (1987) found breeding activity to be continuous throughout the year in selected coastal waters in Leyte and Vicinity, Philippines. In contrast, the spawning period for blue swimmer crab stocks in the cooler temperate climates of South Western Australia (de Lestang *et al*., 2010; Johnston *et al*., 2011; Johnson *et al*., in press) and South Australia (Kumar *et al*., 2003; Dixon *et al*., 2008) is restricted to a 3 – 4 month period over spring/summer. Various studies have linked increases in water temperature with higher rates of crustacean ovulation and egg development (Pollock, 1995; Kumar *et al.*, 1999; Sumpton *et al.* 2003).

Seasonal changes in the size of male crabs in the commercial trap catch from the northern fishing grounds tended to follow monthly trends in sex ratio for this region. Extra large (150+ mm CW) male crabs accounted for 37 – 51% of the commercial trap catch from factory unloads between October and March, but then steadily decreased to 22% by June. The proportion of extra large males then remained low (24 – 26%) through to September, before a sharp increase to 44% in October (Fig. 17). A decline in the proportion of extra large male crabs through the fishing season was also observed in the retained commercial trap catch from the Eastern Gulf. However, rather than the steep decline/plateau/sharp incline seen in the northern fishing grounds, the proportion of extra large males declined steadily from 65% in February to 33% in August, before a gradual increase to 51% the following January (Fig. 19).

The interpretation of intra-annual trends in the composition of commercial trap catches from the northern fishing grounds is confounded by the trap sector's movement in and out of the central crabbing grounds north of Cape Inscription when the trawl fishery is in operation (mid-March to mid-October, other than monthly 5 – 10 day closures over full moon periods) (Fig. 52). At the start of the trawl season in mid-March, several trawl closures remain in place that allow trap fishers to access a portion of the preferred crabbing grounds. These spatial closures are then opened to trawling in stages as the season progresses, and trap fishers operate closer to the eastern shore, and in a few areas in the southern and western trawl grounds (Fig. 52). Consequently, it is difficult to determine to what extent seasonal trends reflect: 1) the depletion of extra large male crabs over the autumn (March – June) period from targeted fishing pressure by both sectors; 2) seasonal patterns in the catchability of female crabs; and/or 3) the spatial restrictions of the trap fleet reflecting differences in sex ratio and crab size between areas inside and outside of the trawl grounds.

While large male crabs dominate the commercial trap catch, there has been a significant change in the mean size of crabs captured by trap fishers over the past decade. From 1999/00 to 2004/05, the mean carapace width of male crabs increased from 140 mm to 148 mm as trap fishers explored the waters of Shark Bay and identified fishing grounds populated by larger animals. However, since 2004/05 there was a steady decline to 143 mm CW in 2010/11 (Fig. 33). This trend was also evident in the November fishery-independent trawl surveys. There was a gradual increase in the mean carapace width of male crabs, from 132 mm in 2002 to 141 mm in 2005. However, a downward trend was evident from 2005, with male carapace widths decreasing to 133 mm by 2010 (Fig. 47). These changes in size were also reflected in the proportion of extra large (150+ mm CW) male crabs in the commercial trap catch from the main crabbing grounds north of Cape Inscription. Analysis of factory unloads showed a steady increase in the proportion of extra large males during the first half of the decade to 44% in 2007/08. However, there has been a steady decline over the past three years to 21% in 2010/11 (Fig. 17). However, this trend was not evident in the Eastern Gulf, with factory unloads from this area showing that the proportion of extra large male crabs in the commercial trap catch increased slightly from 46% in 2006/07 to 49% in 2009/10 (Fig. 19). This contrast may be indicative of variations in fishing pressure between the two areas, with relatively high fishing pressure in the northern grounds by both the trap, and in recent years the trawl, sectors possibly responsible for the depletion of extra large male crabs experienced over the last four years. However, as the northern fishing grounds account for the bulk of the blue swimmer catch (Fig. 13), the downward trend seen in trap catches in this area should be viewed as representative of the majority of the Shark Bay crab stock if a precautionary approach towards future management is to be taken.

Similar trends were identified in the size of commercial female and berried female crabs captured during commercial trap monitoring in Shark Bay. There was a steady increase in the mean carapace width of commercial females from 133 mm in 2000/01 to 142 mm in 2004/05, followed by a decline to 133 mm in 2010/11. There was also an initial increase in the size of berried female crabs, with standardized carapace widths increasing from 133 mm in 2000/01 to 144 mm in 2007/08. However, the mean carapace width then fell to 135 mm in 2010/11. Similar trends were also evident for commercial female and berried female crabs sampled in recent years during the November fishery-independent trawl surveys. The mean carapace width decreased from 136 mm in 2005 to 131 mm in 2010 for commercial females, and from 138 mm in 2005 to 133 mm in 2010 for berried females (Fig. 47). As brood size for blue swimmer crabs is highly correlated to carapace width (J. Halawa, 2006; Johnston, 2010), a decrease in the mean size of breeding females has the potential to reduce overall egg production for the Shark Bay crab stocks.

Relatively small amounts of sub-legal (<135 mm CW) crabs were captured by commercial trap fishers in Shark Bay. Sub-legal male crabs accounted for a quarter of commercial trap monitoring catches in the fishing grounds north of Cape Inscription in 1999/00. This proportion decreased to just 9% by 2004/05, as fishers identified and avoided areas of high populations of sub-legal crabs and refined the size of mesh used on their traps (to minimise the take of sub-legal crabs while still maximising retention of commercial crabs). In contrast, nearly half (mean: 46±2.7%) of the crabs captured during November fishery-independent trawl surveys were sub-legal. Sumpton *et al*. (2003) reported similar findings in the Moreton Bay crab fishery in Queensland. Very few crabs less than 120 mm CW caught in commercial pots, whereas the majority of catch from commercial trawlers operating in the same fishing grounds was sub-legal (<150 mm CW).

4.3 Spatial/depth trends

The majority (~85%) of the commercial trap catch in Shark Bay is sourced from the northern fishing grounds which cover the oceanic waters from Cape Inscription to Koks Island (Fig. 13). While blue swimmer crabs are averse to fresh water, they also avoid areas of hypersalinity. Romano and Zheng (2006) found that juvenile crab mortality was significantly higher at both low (≤ 15 ppt) and high (≥ 45 ppt) salinities. As the lower reaches of both the western and eastern gulf can approach salinities of 56-70ppt (Logan and Cebulski, 1970), they would not be expected to support significant stocks of blue swimmer crabs. So although fishers having access to all the waters of the lower gulfs, commercial fishing in these regions has been restricted to the upper reaches of the Eastern Gulf, and to a lesser extent, the Western Gulf.

These trends were supported by data from November fishery-independent trawl surveys. Significantly higher standardized catch rates of commercial male and female crabs were recorded north of Cape Inscription (NW Peron and Red Cliff) than in the upper reaches of the Eastern and Western Gulf (Denham Sound), with very small catches recorded in the lower reaches of the Western Gulf (Freycinet Harbour and the Leads) (Fig. 44).

Despite the high proportion of the commercial crab catch that comes from the northern fishing grounds, and the substantial level of exploration by trap fishers in Shark Bay over the past 10 years, little effort has gone into investigating the commercial exploitation of crab stocks in the very northern waters of Shark Bay between Koks Island and Point Quobba.

Statistical analysis of commercial trap monitoring data suggests that commercial female crabs are most prevalent in the deeper waters (>17m) of Shark Bay throughout the year (Fig. 29). In contrast, commercial (>135 mm CW) male crabs were found evenly distributed between all depths during most of the year. However, in Mar/Apr/May they are found in highest numbers in waters deeper than 17m (Fig. 27) as they move into the deeper waters to mate.

Standardized catch rates of sub-legal sexually mature female crabs were found in consistent numbers across all depths in Oct/Nov/Dec and Mar/Apr/May, but were significantly higher at depths >17m during Jul/Aug/Sep as they migrate into the deeper water to spawn (Fig. 30). In contrast, sub-legal male crabs were found in consistent numbers across all depths throughout the year (Fig. 28).

4.4 Reproductive biology/breeding stock

Highest catch rates of soft-shelled male and female crabs captured during commercial trap monitoring surveys occurred in deeper waters (>17m) in the Mar/Apr/May period (Figs 36, 37). Given that spawning is continuous in Shark Bay (de Lestang, 2003), it would be expected that mating also occurs throughout the year, with the higher incidence of moulted female crabs in Mar/Apr/May suggesting a peak period of mating during these months. This timeframe would synchronise with the peak spawning period in the Shark Bay crab stocks that occurs three months later in Jul/Aug/Sep. The months of Mar/Apr/May are consistent with the peak mating period for crab stocks in southwestern Australia, which occurs in the late austral summer – autumn (January to April) in Cockburn Sound (Kangas, 2000; Potter *et al*. 2001; Johnston *et al*., 2011) and the Peel-Harvey Estuary (de Lestang *et al*., 2003a; Johnston *et al*., in prep). Sumpton *et al*. (2003) reported that mating activity in Moreton Bay peaked in May and June, followed by a peak in spawning several months later during the spring.

As previously discussed, berried female crabs were present in the catch from all commercial trap monitoring, with highest numbers during July, August and September, suggesting that spawning in Shark Bay occurs all year round with a peak during the winter/spring months (Figs 18, 20, 21). Statistical analysis of commercial trap monitoring data showed highest catch rates of berried females in Shark Bay during this period were found in the deeper waters (>17m) to the east of Koks Island, (northern-most latitudinal category L1), and in the Eastern Gulf (categories L6 and L7) (Figs 34, 35), suggesting possible spawning grounds in deeper water of these areas.

Confirmation of these areas as principal spawning grounds will need to be determined through fishery-independent trawl surveys.

It should be noted that comparisons between trap catch monitoring surveys and a fishery-independent trawl survey conducted over the same period in Shark Bay suggests that the proportion of berried females in the commercial trap catch is likely to be significantly less than in the overall population. While 8% of female crabs in the trap catch from November surveys were berried, 39% of the female crabs captured by trawl were berried. However, while the use of commercial trap catches to determine spawning levels should be treated with caution, if it is presumed the behaviour of crab trap fishers in avoiding areas of high abundance of berried females is consistent throughout the year, the assumption that the peak in numbers of berried females in commercial trap monitoring catches in the Jul/Aug/Sep period coincides with a peak spawning period in Shark Bay remains valid.

4.5 Life cycle of the blue swimmer crab in Shark Bay

A preliminary life cycle for the blue swimmer crab in Shark Bay is presented (Fig. 54) based on analysis of data collected to date from commercial monitoring and fishery-independent research programs, and factory unload returns from commercial trap fishers.

It must be recognized that while the life cycle presented is based on the peak periods of biological activity in the Shark Bay crab stock, moulting, mating and spawning occur continuously. Consequently, this life cycle is intended to represent the majority of animals in the crab stock.

The peak spawning period in Shark Bay occurs from July to September. Incubation of released eggs takes 10 to 18 days, followed by a larval phase which can extend for up to six weeks. Induced by the warming sub-tropical waters, blue swimmer crabs moult frequently during the juvenile phase in Shark Bay and growth is rapid, with juveniles recruiting to the fishery from November to February. Female crabs undergo a pubertal moult in Shark Bay at around 6-10 months of age, with the peak mating period considered to be between March and May. Mature males moult some weeks before the maturing females, and each male carries a female clasped beneath him for 4 – 10 days until she moults and mating occurs. The mean size at maturity for blue swimmer crabs in Shark Bay is 115.1 mm CW for males and 92.4 mm CW for females; de Lestang *et al*., 2003a). Mature male and female crabs attain commercial size (135 mm CW) in Shark Bay between 10 – 14 months of age, with most animals having died through natural or fishing mortality by the time they are 20 months (Potter *et al*., 2001). However, without fishing pressure blue swimmer crabs in Shark Bay could be expected to live for three to four years.

The assumptions used in the development of this 'straw man' lifecycle will be verified by future research as outlined later in this report.

5.0 Conclusions

5.1 Stock status/sustainability risk

Conflicting evidence exists as to the sustainability of current total harvest levels in the data collected to date in the Shark Bay crab trap fishery.

Plots of nominal and standardized effort against commercial catch for the trawl fleet over the past decade (2000 – 2010) have produced a linear relationship (Figs 14 – 16), suggesting the Shark Bay crab stock is yet to show significant signs of excessive fishing effort, and that fluctuations in catch are largely dependent on changes in effort and environmental conditions. This conclusion is consistent with previous analysis undertaken by Bellchambers and Smith (2005), who also suggested that commercial trap catch levels in Shark Bay at that time were largely dependent on fishing effort.

Following a significant increase from 1998 to 2005, commercial trap catch and effort has been relatively constant (Fig. 8), with the standardized catch rate for the main fishing grounds north of Cape Inscription having stabilized between 1.4 – 1.5 kg/traplift in recent years (Fig. 9). However, the total annual catch from the Shark Bay crab fishery has fluctuated appreciably since 2005, largely in response to the level of retention of crabs by the trawl fleet. There has also been a downward trend in the standardized catch rate in the Eastern Gulf in the past two years, although it is not clear whether this decline reflects a depletion in crab stocks or a decrease in the fishing efficiency of crab fishers operating in this area as previously discussed.

In contrast, several datasets have suggested that a level of depletion has occurred in the Shark Bay crab stocks in recent years. Standardised catch rates of commercial male, commercial female, sub-legal male, sub-legal female and berried female crabs from November fishery-independent trawl surveys have all decreased in the last three years. The decrease in mean standardized carapace widths for male, non-berried female and berried female crabs seen in data from both commercial trap monitoring surveys and the November fishery-independent trawl surveys, is synonymous with a fishery showing signs of high exploitation. In addition, there was also a reduction in the proportion of extra large male crabs in the commercial catch identified in factory unloads from recent years.

Further concern over the sustainability of Shark Bay crab stocks has arisen from a degree of inconsistency between months within recent years. Catch rates in the first half of 2007/08 were well below average, and the season's catch appeared to be well down. However a late run of above average catch rates in March and April of that year saw the annual catch reach a level consistent with previous years. During the 2008/09 season, catch rates were on a par with the average through the first half of the season, but dropped well below average from February onwards.

Since June 2011, catches of blue swimmer crabs in Shark Bay have declined sharply for both trap and trawl sectors, suggesting a significant depletion of the adult (>135 mm CW) population. The mean monthly trap catch rate fell from 2.2 kg/traplift in June, to 1.7 kg/traplift in August, to less than 1 kg/traplift by October. Similarly, the total monthly retained trawl catch declined from over 90 t in April, to around 30 t by July, with just 2 t taken in September. A significant reduction has also been recorded in the abundance of recruits (<85 mm CW) in the fishery. The numbers of recruiting crabs captured during fishery-independent trawl surveys in Shark Bay during November 2010 and March 2011 (~50 crabs/nm) were well within the normal range of

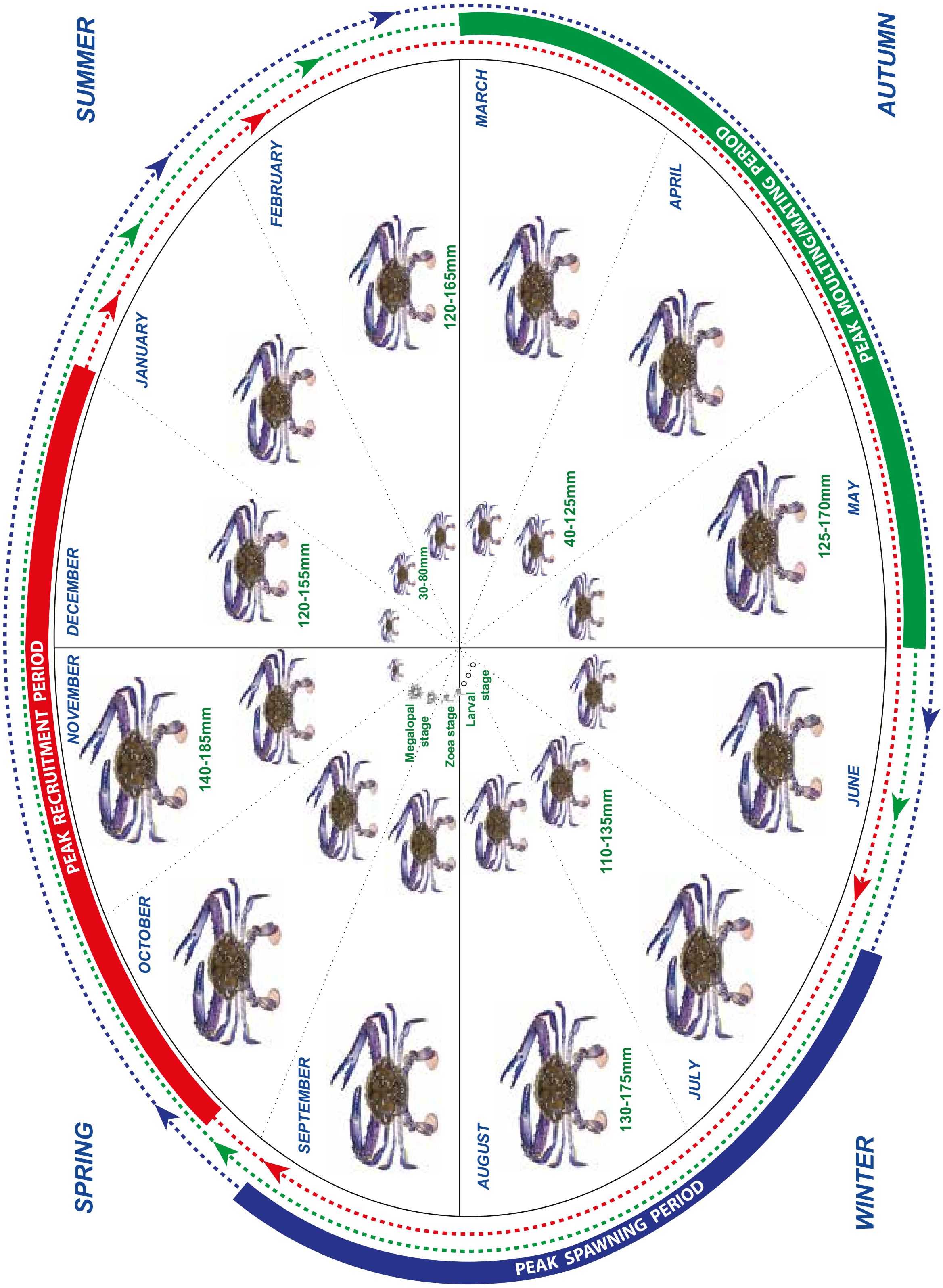

Figure 54. Lifecycle of the blue swimmer crab in Shark Bay

previous surveys. However, by November 2011 numbers in the trawls had declined to ~2 crabs/nm. The reasons for this unexpected and substantial decline are yet to be clearly understood, but it is possibly linked to several adverse extreme environmental events that occurred during the summer of 2010/11 associated with a very strong La Nina event. The possible effect of fishing on the spawning stock will also be examined but preliminary assessment indicates that the spawning stock that led to the low recruitment was within historic ranges. Two major flood events occurred in the Shark Bay region during December 2010 and February 2011, coinciding with a major temperature anomaly that saw sea surface temperatures in Shark Bay at record high levels (3 – 4.5°C above average) between December 2010 and March 2011. These water temperature increases were part of the record increases that were observed for the entire Gascoyne and mid-west region of WA that has been associated with the mortality of a number of invertebrate and fish species (Pearce *et al*., 2011). A similarly dramatic decline in recruitment and adult stock has also been observed in the saucer scallop (*Amusium balloti*) stocks within Shark Bay (E. Sporer, *pers. comm*).

There is also concern over the level of latent effort that exists within both sectors of the Shark Bay crab fishery. Due to variations in fishing pressure between trap fishers, and logistical cost-benefit considerations in operating more traps from a single vessel than can be fished at an optimal level, the trap fishery is currently operating at 70 – 80% of its potential effort. Capacity also exists for further increases in crab landings by the trawl fleet. As trawlers were unlikely to targeted crabs over prawns or scallops, it can be assumed that the amount of crabs caught by trawlers has remained relatively constant over the past decade, with increases in the trawl crab catch in recent years reflecting an increase in the level of crab retention. However, decreases in prawn prices and corresponding increases in crab markets and prices has seen crab become more valuable. Consequently, the price structuring by trawl companies of species to vessels could lead to the trawl fleet continuing to increase the level of retention of crabs caught in trawl nets.

Given the limited commercial monitoring program for both trap and trawl sectors, and the absence of dedicated recruitment and breeding stock surveys, it is not possible to provide a precise estimate of sustainable catch levels for the Shark Bay crab fishery. However, the current catch and effort data may be sufficient to fit a simple biomass dynamics model, such as the Schaefer model, which could provide some indication of potential maximum yield for this fishery. Confounding this approach, however, would be the different contributions from each of the three sectors to the annual catch, and the inability to determine an accurate estimate of effort for the trawl and recreational sectors.

While it is considered that there is sufficient biomass and productivity within the blue swimmer crab stocks in Shark Bay to sustain commercial catches, the current challenge is to manage the risk of increases to the current catch levels and the effect this may have on the future sustainability of the stock. In the absence of more precise information, sustainability risks associated to the crab stock would be reduced if a precautionary approach to commercial fishing was adopted by maintaining the total crab catch from both sectors 10 – 20% below, current levels. Exceeding current catch levels may put the Shark Bay crab stocks under significant pressure, and increase the risk to the sustainability of the stock to an unacceptable level.

The mechanisms required to absorb latent effort in the fishery, while limiting the commercial catch to current levels, will need to be reviewed by the DoF. An independent review of the Shark Bay crab fishery recommended the current data collection and analysis should be continued, with potential indicators that could feed into the management framework including:

- Plots of annual standardized effort versus catch for the trap fleet based on fisher's statutory monthly (CAES) returns;

- Mean annual standardized catch rate for the trap fleet based on fisher's statutory monthly (CAES) returns;
- Annual standardised catch for the trawl fleet based on fisher's statutory daily research logbooks and factory unloads;
- Annual standardized catch rate for male and female crabs for the trap fleet based on commercial monitoring data;
- Annual standardized catch rate for commercial (135 – 149 mm CW) and large (150+ mm CW) male crabs and female crabs for the trap fleet based on factory unloads;
- Trends in mean annual standardized carapace width for male and female non-berried and female berried crabs for the trap fleet based on commercial monitoring data;
- Annual standardized catch rate for male, female non-berried and female berried crabs based on fishery-independent trawl surveys;
- Trends in mean annual standardized carapace width for male, female non-berried and female berried crabs based on fishery-independent trawl surveys.

5.2 Future Research

Significant gaps exist in the scientific knowledge required to manage the Shark Bay crab fishery into the future. Given the large area covered by Shark Bay, the continuous nature of spawning activity in the crab stocks, and the discontinuous nature of the commercial monitoring and fishery-independent trawl programs, the location of the main spawning grounds and the peak periods of spawning activity have proven difficult to identify. Comparison between commercial trap data and fishery-independent trawl data has demonstrated that commercial trap data is biased heavily against berried females so trawling is the recommended method for assessing spawning activity. Regular trawl surveys over a three-year period will be required to adequately define spawning grounds and peak spawning periods. Fishery-independent trawl surveys of crab stocks could be combined with existing surveys of scallop stocks in November in NW Peron and Red Cliff, and with prawn surveys conducted in March/April along the eastern part of SB and July/August for the tiger prawn spawning survey. These trawl surveys would also serve to identify recruit abundance and distribution. Hourglass traps covered with small (2-inch) mesh were used in a preliminary survey to identify areas important to juvenile blue swimmer crabs in Shark Bay. However, while the traps effectively captured juvenile blue swimmer crabs when used in the Peel-Harvey Estuary, they were not successful in catching juveniles in Shark Bay. Trawls using a try net conducted parallel to a line of 10 traps caught juvenile crabs whereas the traps failed to catch any crabs. Therefore, trawling is also recommended over trapping to sample juvenile crabs and measure the crab population as a whole.

Despite the limitations and biases of traps, one cost-effective approach to collect additional information on commercial catch and effort could involve attaching a small-mesh research trap to each line of commercial traps employed by the commercial trap fishers operating in Shark Bay. Fishers would be expected to record the total catch from these traps, along with the depth and latitude and longitude.

Further gaps in our understanding of the dynamics of the Shark Bay crab stock include:

1. Accurate and precise estimates of male and female growth rates;

2. Accurate and precise estimates of natural and fishing mortality;
3. Movement/migration of juvenile and adult crabs throughout Shark Bay.

Monitoring of the commercial crab fishery in Shark Bay needs to continue to determine if catch levels from the combined trap and trawl sectors remain at or below current levels, and that the catch composition and crab size remains relatively constant. A rationalization of the monitoring program will be needed between the trap and trawl sectors, and resource requirements to achieve this rationalization will need to be determined. One proposal involves the development of an electronic logbook to replace the current paper versions for both the trap and trawl sectors, with the intention of increasing the resolution and precision of research data provided by fishers. Increased resources will also be required to complete the comprehensive stock assessment required to adequately determine a sustainable harvest level for the Shark Bay crab stock. Consequently, a three-year project has been funded by FRDC (FRDC 2012/015) to provide biological data on spawning, recruitment, mortality, growth and trophodynamics that will provide a better understanding of Shark Bay crab stock dynamics and their role within the Shark Bay ecosystem. The specific objectives of this project will be to:

1. Examine key drivers of blue swimmer crab recruitment in Shark Bay, particularly environmental factors associated with low recruitment
2. Determine the socio-economic significance of the blue swimmer crab resource to the commercial trap and trawl sectors in Shark Bay
3. Host the Third National Workshop on Blue Swimmer Crab in 2015.

5.3 Management issues for future consideration

A number of management issues that impact on the sustainability of the Shark Bay blue swimmer crab stock have been identified for future consideration:

1. The existing management framework does not provide the statutory ability to effectively manage exploitation of the stock in a holistic manner, thereby increasing the sustainability risk;
2. The absence of explicit catch shares or other management arrangements to share the commercial catch creates the risk of each sector seeking to maximize its share of the crab resource.

The combination of these two factors is considered to have established an unacceptable risk to the sustainability of the crab stock in Shark Bay. The development of an appropriate harvest strategy will need to consider all ecological, social and economic factors, and associated risks and benefits, with the stock exploitation by each of the three sectors.

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7.0 References

Bellchambers, L. and de Lestang, S. 2005. Selectivity of different gear types for sampling the blue swimmer crab, *Portunus pelagicus* L. *Fisheries Research.* **73:1-2**; pp 21 – 27.

Bellchambers, L. and Smith, K. 2005. Stock assessment of blue swimmer crabs, *Portunus pelagicus* in Shark Bay, Western Australia. In, Bellchambers, L., Sumner, N. and Melville-Smith, R. 2005. Development of stock allocation and assessment techniques in western Australia blue swimmer crab fisheries. FRDC Project No. 2001/068. pp 98 – 168

Bellchambers, L.M., Smith, K.D. and Harris, D. 2006. An assessment of the blue swimmer crab fishery in Geographe Bay. Fisheries Research Report No. 158. Department of Fisheries, Western Australia. 38pp.

Campbell, C. 1998. Summary of submissions to Fisheries Management Paper No. 108 - Issues affecting West Australia's inshore crab fishery. Fisheries Management Paper No. 112. Department of Fisheries, Western Australia. 44pp.

de Lestang, S., Bellchambers, L.M., Caputi, N., Thomson, A.W., Pember, M.B., Johnston, D.J., and Harris D.C. 2010. Stock-Recruitment-Environment Relationship in a *Portunus pelagicus* Fishery in Western Australia. In: Kruse, G.H., Eckert, G.L., Foy, R.J., Lipcius, R.N., Sainte-Marie, B., Stram, D.L., and Woodby D. (eds.), Biology and Management of Exploited Crab Populations under Climate Change. Alaska Sea Grant, University of Alaska Fairbanks.

de Lestang, S., Hall, N.G. and Potter. I.C. 2003a. Reproductive biology of the blue swimmer crab, *Portunus pelagicus* (Decapoda: Portunidae) in five water bodies on the west coast of Australia. Fish. Bull. **101**:745–757.

de Lestang, S., Hall, N.G., and Potter, I.C. 2003b. Do the age compositions and growth of the crab Portunus pelagicus in marine embayments and estuaries differ?. Journal of the Marine Biological Association of the UK, 83 , pp 971 – 978

Department of the Environment and Heritage (DEH), 2004, Assessment of the Shark Bay Experimental Crab Fishery, Commonwealth of Australia, Canberra. 27pp.

Dixon, CD, Hooper, GE & Ward, TM (2008). Blue Crab (*Portunus pelagicus*) Fishery 2006/07. Stock Assessment Report to PIRSA Fisheries. SARDI Research Report Series No.290. 56pp.

Edgar, G .J. 1990. Predator-prey interactions in seagrass beds. II. Distribution and diet of the blue manna crab *Portunus pelagicus* Linnaeus at Cliff Head, Western Australia. Journal of Experimental Marine Biology and Ecology. **139**, 23 – 32.

Francesconi, K. and Clayton, D. 1996. Shark Bay: Management Paper for Fish Resources. Fisheries Management Paper No. 91. Department of Fisheries, Western Australia. 118pp.

J. Halawa, Efrizal (2006). Reproductive Biology and Larval Rearing of Blue Swimming Crab, *Portunus pelagicus* (Linnaeus, 1758). PhD thesis, Universiti Putra, Malaysia.

Johnson, D.D., Gray, C.A. and Macbeth, W.G., 2010. Reproductive biology of *Portunus pelagicus* in a south-east Australian estuary. Journal of Crustacean Biology, **30(2)**: 200 – 205.

Johnston, D. and Harris, D. 2011. West Coast blue swimmer crab fishery status report. In, State of the Fisheries Report 2009/10. Eds. W.J. Fletcher and K.Santoro. Department of Fisheries, Western Australia, pp 39 – 45.

Johnston, D., Harris, D., Caputi, N. and Thomson, A. 2011. Decline of a blue swimmer crab (*Portunus pelagicus*) fishery in Western Australia – History, contributing factors and future management strategy. Fish. Res. **109**(1), 119 – 130.

Johnston, D., Harris, D., Caputi, N., de Lestang, S. and Thomson, A. *in press*. Status of the Cockburn Sound Crab Fishery; DIBF Final Report. Fisheries Research Report No. ###. Department of Fisheries, Western Australia. 121pp.

Joll, L.M. and Penn, J.W. (1990) The application of high-resolution navigation systems to Leslie-DeLury depletion experiments fro the measurement of trawl efficiency under open-sea conditions. *Fisheries Research* **9**: 41 – 55.

Kangas, M. I. 2000. Synopsis of the biology and exploitation of the blue swimmer crab, *Portunus pelagicus Linnaeus*, in Western Australia. Department of Fisheries Western Australia Final Report No. 121. 22 pp.

Kailola, P. J. & Fisheries Research and Development Corporation (Australia) & Australian Bureau of Resource Sciences. 1993. Australian fisheries resources. Bureau of Resource Sciences and the Fisheries Research and Development Corporation, Canberra, A.C.T. 442 pp.

Kumar, M. (1997). Proceedings of the First National Workshop on Blue Swimmer Crab *Portunus pelagicus*. *SARDI Research Report Series,* **16**, 129 pp.

Kumar, M. (1998). National Strategy for research programs on the blue swimmer crab, *Portunus pelagicus*. *SARDI Research Report Series,* **29**, 16 pp.

Kumar, M.S., Xiao, Y. and Williams, H. (1999). *Blue Crab.* South Australian Fisheries Assessment Series 99/01. (South Australian Research and Development Institute: Adelaide).

Kumar, M.S., Xiao, Y.S., Venema, S. and Hooper, G. 2003. Reproductive cycle of the blue swimmer crab, *Portunus pelagicus*, off southern Australia. *Journal of the Marine Biological Association of the United Kingdom.* **83** (5): 983 – 994.

Lai, J., Ng, P.K.L and Davie, P.J.F. (2010). A revision of the Portunus pelagicus species complex (Crustacea: Brachyura: Portunidae) with the recognition of four species, Raffles Bulletin of Zoology. **58 (2)**, 199 – 237.

Logan, B. W., and Cebulski, D. E. 1970. Sedimentary environments of Shark Bay, Western Australia. *Mem. Am. Assoc. Petrol. Geol.* **13,** 1 – 37.

Meagher, T.D. (1970). Crab research programme - Leschenault Inlet, Bunbury. *FINS,* **3**: 18 – 27.

Meagher, T.D. (1971). Ecology of the crab *Portunus pelagicus* (Crustacea Portunidae) in southwestern Australia. University of Western Australia. Unpublished PhD thesis, 232 pp.

Montaño Ferrer, O.J. 1997. Effectiveness of two pots and other factors for harvesting hard blue crabs *Callinectes sapidus* in Lake Maracaibo, Venezuela. *Ciencia* 5 (1997) (2), pp. 111 – 118.

Nahas, E. L., Pattiaratchi, C. B. & Ivey, G. N. 2005. Processes controlling the position of frontal systems in Shark Bay, Western Australia. Estuarine, Coastal & Shelf Science **65**: 463:474.

Penn, J.W. 1977. Trawl caught fish and crustaceans from Cockburn Sound. Fisheries Research Report No. 20. Western Australia, Dept. of Fisheries and Wildlife. 24pp + bibliography.

Potter, I.C., Chrystal, P.J. and Loneragan, N.R. (1983) The biology of the blue manna crab *P. pelagicus* in an Australian estuary. *Marine Biology,* **78**: 75 – 85.

Potter, I.C. and de Lestang, S. 2000. The biology of the blue swimmer crab *Portunus pelagicus* in the Leschenault Estuary and Koombana Bay in south-western Australia. *Journal of the Royal Society of Western Australia.* **83**: 443 – 458.

Potter, I. C., de Lestang, S. and Melville-Smith, R. 2001. The collection of biological data required for management of the blue swimmer crab fishery in the central and lower west coasts of Australia. FRDC Project No. 97/137, Canberra. 54 pp + appendices.

Potter, I.C., de Lestang, S. and Young, G.C. 1998. Influence of the Dawesville Channel on the recruitment, distribution and emigration of crustaceans and fish in the Peel-Harvey Estuary. FRDC Final Report, Project 95/042, 61 pp.

Romano, N., and Zeng, C**.** 2006. The effects of salinity on the survival, growth and haemolymph osmolality of early juvenile blue swimmer crabs, *Portunus pelagicus*. *Aquaculture* **260**: 151 – 162.

SAS Institute, Inc. 1989. SAS/STAT user's guide, volume 2, version 6, 4th edition. SAS Institute, Inc., Cary, North Carolina.

Sezmiş, E. 2004. The population genetic structure of *Portunus pelagicus* in Australian waters. PhD thesis, Murdoch University, Western Australia.

Stephenson, W. 1962. The evolution and ecology of portunid crabs, with especial reference to Australian species. In, Leeper, G. W. (Ed.), The evolution of living organisms. Melbourne University Press, Melbourne. 327 pp.

Sumner, N.R. and Malseed, B.E. 2002. Quantification of changes in recreational catch and effort on inner Shark Bay snapper species following implementation of responsive management changes. FRDC report 2000/139.

Sumner , N. R. and Malseed, B. E. 2004. Quantifications of changes in recreational catch and effort on blue swimmer crabs in Cockburn Sound and Geographe Bay. Fisheries Research Report No. 147. Department of Fisheries, Western Australia. 48pp.

Sumner , N. R. and Williamson, P. C. 1999. A 12-month survey of coastal recreational boat fishing between Augusta and Kalbarri on the west coast of Western Australia during 1996 – 97. Fisheries Research Report No. 117. Department of Fisheries, Western Australia. 52pp.

Sumner, N.R., Williamson, P.C. and Malseed, B.E. 2002. A 12-month survey of recreational fishing in the Gascoyne bioregion of WA during 1998/99. Fisheries Research Report No. 139, Department of Fisheries, Western Australia, 54p.

Sumpton W., Gaddes S., McLennan M., Campbell M., Tonks M., Good N., Hagedoorn W. and Skilleter, G. 2003. Fisheries Biology and Assessment of the Blue Swimmer Crab *(Portunus pelagicus)* in Queensland. Industries Project Series, Project no. 98/117. Queensland Department of Primary Industries. 156p.

Sumpton. W.D., Potter, M.A. and Smith G.S. 1994. The biology of the commercial sand crab Portunus pelagicus L. In a subtropical Australian embayment. Asian Fisheries Science. **7**: p 103 – 113.

Thompson, J.M. 1951. Catch composition of the sand crab fishery in Moreton Bay. *Australian Journal of Marine and Freshwater Research*. **2**: 237 – 44.

Walker, D.I. 1989. Seagrass in Shark Bay – the foundations of an ecosystem. In: Seagrasses: A Treatise on the Biology of Seagrass with Special reference to the Australian Region, eds Larkum, A.W.D., McComb, A.J. and Sheperd, S.A. Elsevier, Amsterdam. Pp. 182 – 210.

White, W.T., Platell, M.E. and Potter, I.C. 2004. Comparisons between the diets of four abundant species of elasmobranchs in a subtropical embayment: implications for resource partitioning. *Marine Biology*. **144.**3: 439 – 448.

Williams, M.J. 1982. Natural food and feeding in the commercial sand crab *Portunus pelagicus* Linnaeus, 1766 (Crustacea: Decapoda: Portunidae) in Moreton Bay, Queensland. *Journal of Experimental Marine Biology and Ecology* **59**:165 – 176.