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Assessment of blue swimmer crab recruitment and breeding stock levels in the Peel-Harvey Estuary and status of the Mandurah to Bunbury Developing Crab Fishery

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Executive Summary

Two projects were funded to investigate iconic blue swimmer crab stocks in the Peel-Harvey Estuary and Mandurah to Bunbury Developing Crab Fishery. One was a four year project (2007 – 2011) to undertake the following: i) determine recruitment and spawning stock levels of the crab population in the Peel-Harvey Estuary and whether the status of stocks has changed considerably in the past decade, ii) establish a commercial monitoring program to assess the length frequency and sex ratio of crabs captured by commercial fishers, and iii) develop a commercial monitoring program in the Mandurah to Bunbury Developing Crab Fishery and South West Trawl Managed Fishery. A fishery-independent study was conducted at 15 sites throughout the estuary per month between December 2007 and December 2011. Sites chosen were identical to those surveyed between 1995 and 1998, to allow historical comparisons. Additional trap sites were sampled outside the Peel-Harvey Estuary monthly from August 2008 to December 2011 to understand crab abundance, composition and movement between estuarine and oceanic waters. A second project was a 12-month recreational survey in the Peel-Harvey Estuary between November 2007 and October 2008 to provide an estimate of recreational catch and effort.

Peel-Harvey Commercial Fishery

Substantive commercial fishing for blue swimmer crabs in the Peel-Harvey Estuary began in the 1980s, with fishers using gill nets primarily over summer months. Catch and effort was initially highly variable ranging from 2 t to 75 t. Conversion from gill nets to crab traps in the mid-late 1990s resulted in an increase in catches due to the improved efficiency of traps, with catches fluctuating between 45 t and 104 t. Catch rates have subsequently fluctuated between 0.8 and 1.5 kg/traplift, but have generally remained above 1.2 kg/traplift since 2003/04. Following conversion to traps, there has been increased fishing in autumn/winter, but most (62%) of the catch and highest catch rates are still taken between December – March.

Commercial Monitoring

A comparison between commercial monitoring in the historical period 1998 – 2001 with the current period (2007 – 2011) revealed length frequency distributions have not changed significantly. Males dominated the fishery during summer with female catches increasing from March with highest catch rates (approximately 50% of the catch) between April and June. Over summer fishing focuses on the central areas of the Peel Inlet and Harvey Estuary, whereas in autumn it shifts to the northwest region of the Peel and top end of the Harvey, and around the entrance to the Dawesville Cut in winter. This pattern of fishing has been influenced by the elevated salinities now generated from greater oceanic flushing through the Dawesville Cut with crabs now remaining longer within the estuary during winter. The potential impact of higher winter fishing should be monitored closely as a significant proportion of the catch at this time is mated pre-spawn females that are exiting the estuary to spawn offshore. Significantly higher catch rates of females in July (up to 1 crab/traplift) were recorded between 2007 and 2011 compared to 1998 and 2001 (<0.2 crabs/traplift). The degree of flushing of crabs out of the estuary over the winter period is reflected in the low catch rates of all size classes (<1 crab/traplift) in August – October. The low catch rate of berried females during this period confirms that mated pre-spawn females move out of the estuary to spawn.

There was a significant decline in the catch rate of legal males from 1998/99 (4–5 crabs/traplift) to 2010/11 (2 – 3 crabs/traplift) in both the Peel Inlet and Harvey Estuary. Historical trends also show a significant decrease in the catch rates of sexually mature sub-legal males in the

Peel Inlet from 4 crabs/traplift in 1998/99 to 1.5 crabs/traplift in 2010/11, although catch rates in the Harvey Estuary remained steady. Furthermore, there was a significant decline in catch rate of sexually mature sub-legal and legal males in the Peel Inlet during the recent survey period from 2007/08 to 2010/11, while the catch rate of mature sub-legal females in both the Peel Inlet and Harvey Estuary appears to be increasing. The implications of these trends for future management need to be considered, to ensure sexually mature sub-legal and legal males and females remain at sustainable levels, and will be considered within the proposed harvest strategy for Peel-Harvey.

Fishery-Independent Survey

Fishery-independent crab data for the Peel-Harvey Estuary showed the highest catch rates of males (up to 3 crabs/traplift – all size classes) occurred over summer, while female catch rates were lower overall (<1 crab/traplift), but highest over autumn/winter. Immature crabs <80 mm CW (juveniles) appeared in traps between June and October confirming that recruitment into the estuary occurs over summer, but that crabs are not catchable in traps until much later in the year. Crab abundance patterns differed in the Estuary Channel with equal abundance of males and females throughout the year, with legal female numbers exceeding males in May and June. Catch rates of crabs at the oceanic sites were significantly lower (generally <1 crab/traplift) than inside the estuary and Estuary Channel, with females dominating the catch. This female dominance outside the estuary is consistent with commercial catches in the Mandurah to Bunbury Developing Fishery.

Catch rates of sexually mature females were very high in the Estuary Channel, with sub-legal female numbers peaking in June/July and November/December and legal females in May (4.4 crabs/traplift). Peaks in May – July is most likely due the exiting of mature females from the estuary to spawn, whereas sub-legal females are most likely entering the estuary in November/December as water temperatures start increasing. Highest numbers of berried crabs occurred between November and January which is consistent with the spawning period. Catch rates of berried females were very low in all locations except for the Estuary Channel, which supports the hypothesis that berried females use the Estuary Channel to migrate out of the estuary to spawn.

Female abundance was much higher in all months (except for May) during the recent survey period 2007 – 2011 compared to 1996 – 1997, with berried females caught in November – January, whereas no berried females were caught during 1996 and 1997. There was no clear trend in the abundance of males between the two periods, with male abundance higher in 2008/09, 2009/10, 2010/11 than 1996/97 and 2007/08. The long-term change in the abundance of females is reflected in higher catches of females by commercial fishers and needs to be considered carefully in future management of the Peel-Harvey crab fishery.

Mandurah to Bunbury Developing Crab Fishery

This fishery is divided into Area 1 (Comet Bay) and Area 2 (Mandurah to Bunbury) with fishers operating under exemptions. Catches in Comet Bay have ranged between 2 and 13 t since 1998. Highest catches occur in summer and autumn, with catch rates between 0.7 and 0.8 kg/traplift. Crabs are also retained in relatively low numbers by trawlers operating in the South West Trawl Fishery. Catches in Mandurah to Bunbury have ranged between 0 and 20 t since 1998 with recent catches fluctuating significantly with effort. Fishing has been mainly focused between February and June with catch rates fluctuating between 0.5 and 1.8 kg/traplift. Females dominate the catch in all months increasing from 60% in February to 86% in June. This level of female dominance is consistent with retained catch from other oceanic fisheries in the south-west of Western Australia. The mean annual percent of females in the catch of these oceanic fisheries is 67%, which is much higher than estuarine fisheries at 25% and coastal embayment fisheries at 57%. As there are no closures to protect breeding stock in these oceanic fisheries, additional protection of the females should be considered to ensure that fishing effort in these waters does not increase markedly. Highest risk is on mated pre-spawn females between April and October.

Recreational Survey

The recreational fishery for blue swimmer crabs in the Peel-Harvey Estuary comprises fishers crabbing from boats, shore, bridges and jetties, house boats and private houses along canals. Two recreational surveys carried out almost a decade apart estimated the total recreational catch of blue swimmer crabs in the Peel-Harvey Estuary decreased from 251 – 337 tonnes in 1998 – 99 to 107 – 193 tonnes in 2007 – 08. Marked declines of catch occurred for all catching methods; however the proportion of catch remained 70% boat-based to 30% shore-based catch in both survey periods. Comparison of the recreational kept catch to the commercial catch demonstrates a marked decrease in the recreational proportion of the total catch from 79 – 85% in 1998 – 99 to 54 – 68% in 2007 – 08 with the commercial proportion increasing from 15 – 21% in 1998 – 99 to 32 – 46% in 2007 – 08. A 2010/11 statewide recreational boat-based survey based on the recreational fishing from boats (RFBL) suggests a further decrease in the recreational boat catch and conversely increased commercial proportion of the catch. Future statewide boat-based surveys will provide broad-based estimates of blue swimmer crab catches from boats, however ideally the most efficient method would involve the use of a single survey covering all recreational crab fishing methods based on a common sampling frame of all fishers.

Stock Status

This study has confirmed the life cycle of the blue swimmer crab in the Peel-Harvey Estuary and the close relationship between the stocks inside and outside the estuary. Comparisons between current and historical commercial (CAES and commercial monitoring) and fishery-independent data sets have shown that crab stock abundance appears to have been relatively constant over the past decade, with natural protection of the spawning stock occurring due to their exiting the estuary over winter to spawn in oceanic waters. Consequently, based on a weight of evidence approach, it is believed that current levels of fishing in the Peel-Harvey Estuary are sustainable. Nevertheless, there are a few indicators which suggest that the crab fishery in Peel-Harvey is complex and further analyses may need to be developed to determine appropriate indices that are suitably robust to assess sustainability. In particular, commercial monitoring has shown declining catch rates of sexually mature sub-legal and legal males between 1998/99 and 2010/11 and within the recent survey period between 2007/08 and 2010/11, while the commercial catch rate of sexually mature sub-legal females appears to be increasing. This trend in increasing catch of females was also observed in the recreational surveys with higher numbers of females being caught in the Estuary Channel. These trends, and the focus of commercial fishing opposite the Dawesville Channel in winter indirectly targeting mated pre-spawning females, need to be closely monitored as well as the trends in the offshore fisheries (Comet Bay and Mandurah to Bunbury) where the catch is mainly females. The dominance of the recreational sector in this fishery presents challenges to assessing the impact of each fishing sector on the resource, particularly given there are only two estimates (1998/99 and 2007/08) of recreational catch and effort in the Peel-Harvey Estuary and a state-wide boat based survey carried out in 2011/12.

Proposed Future Sampling Design

Key months of sampling are June to November to provide an estimate of crab abundance as they exit the estuary during autumn/winter and the residual legal biomass after the peak fishing months. This provides indicators of the a) spawning stock for the spring/summer; b) the effects of winter rainfall on the movement of stocks out of the estuary; and c) effects of fishing on legal-sized crabs. The Estuary Channel provided the strongest evidence of stock class structure with the most defined temporal trends and highest catch rates, whereas the oceanic sites will not be included due to poor catch rates. Commercial monitoring will generally focus on November to May to cover the peak fishing period.

Proposed Harvest Strategy

The proposed harvest strategy for the Peel-Harvey Estuary has two key primary performance indicators: commercial catch and CPUE, as these currently provide the longest time series. The indicators were estimated as a 3 year moving average with the threshold reference point set as the lowest recorded catch (53 t) and CPUE (1 kg/traplift) between 1996/97 and 2010/11. The limit was set at 20% below the threshold levels at 42 t and 0.8 kg/traplift. A target catch and catch rate range could potentially be based on the mean value during this period. Secondary performance indicators calculated from the fishery-independent trap surveys were: the abundance of immature crabs (juvenile index); abundance of sexually mature sub-legal and legal crabs (breeding stock index) and abundance of residual legal-sized crabs (legal biomass). A set of control rules has been devised using these indicators.

1.0 General Introduction

D. Johnston

Blue swimmer crabs (*Portunus armatus*) are an iconic species for Western Australia and one the most important recreational species (in terms of community participation rate) in the state. Thus sustainability issues are of high priority and community significance. With the increasing popularity of recreational fishing and the potential for increasing interaction between commercial and recreational fishers, there are concerns that considerable pressure is being placed on the stocks of blue swimmer crabs in some areas of Western Australia (Sumner *et al.* 2000). One such area is the Peel-Harvey Estuary (PHE), which due to its size and proximity to Mandurah and Perth, is the most popular estuary for recreational fishing in the south-west of Western Australia. The blue swimmer crab is the most common species targeted by recreational fishers in the Estuary, which provides much of the state's focus for recreational crabbing (Malseed and Sumner 2001). The blue swimmer crab resource in Peel-Harvey Estuary is exploited by both the recreational sector, which takes the majority of crab catches (63%, 2007/08), and the commercial sector (Area 2 of the West Coast Estuarine Fishery). Recreational and commercial fishing is managed through a series of input and output controls with the principal management tool employed to sustain an adequate breeding stock involving a minimum size limit (127 mm CW) set well above the size at sexual maturity (males = 87.1 mm CW; females = 86.9 mm CW).

1.1 Physical description of Peel-Harvey Estuary

The Peel-Harvey estuarine system, comprising the Peel Inlet and Harvey Estuary, is a single shallow micro-tidal estuary averaging 2.5 m in depth, situated 74 km south of Perth in the south-west of Western Australia (Figure 1.1). The Estuary receives water from three river systems, the Serpentine, the Murray and the Harvey Rivers and their respective river catchments. The Peel-Harvey Estuary is connected to the Indian Ocean via the natural Mandurah Estuary (Entrance) Channel (<3m depth), which is located at the northern end of the Peel Inlet and opens into Comet Bay, and by the artificial Dawesville Cut (Channel) (4 – 6 m depth), which connects the northern end of the Harvey Estuary with the ocean. The Peel Inlet occupies an oval shaped area approximately 75 km^2 whereas the Harvey Estuary is ~ 56 km^2 with Mandurah Estuary Channel approximately 5 km^2 in area. The entire Peel-Harvey combined area occupying ~ 136 km^2 (Potter *et al.* 1998). There are currently 4 spatial closures in the Peel-Harvey Estuary that encompasses the Estuary Channel, Dawesville Cut and river entrances and also no commercial fishing in the oceanic waters adjacent to the PHE.

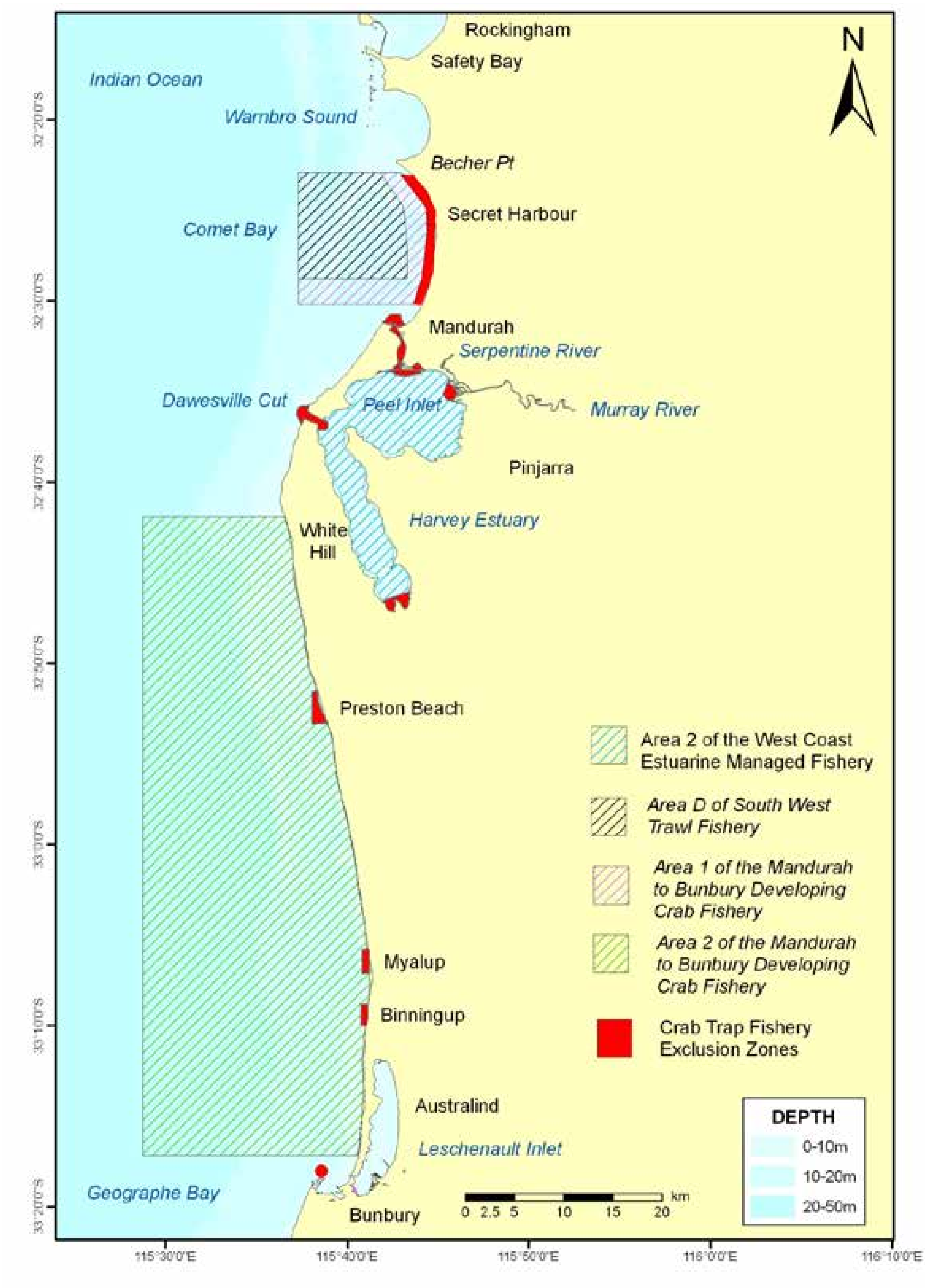

Figure 1.1 Map of Mandurah to Bunbury including Comet Bay, showing extent of Commercial Crab Fishery boundaries and Exclusion Zones.

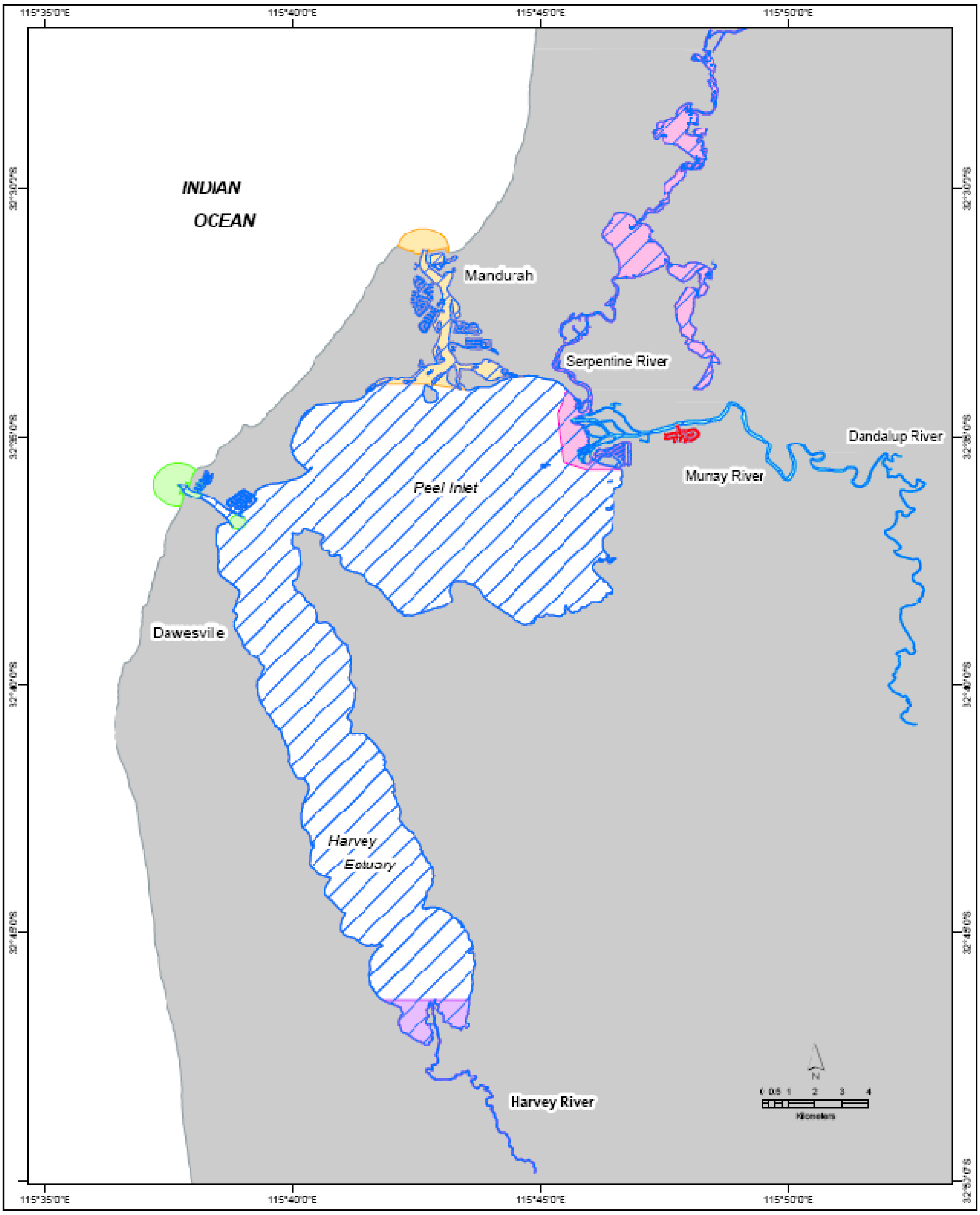

Figure 1.2 Map of Peel-Harvey Estuary region showing spatial closures (areas shaded in green, yellow, red, purple and pink).

1.2 Peel-Harvey Estuary commercial crab fishery

Originally, commercial crab fishers in the Peel-Harvey Estuary used set (gill) nets or drop nets, but along with other crab fisheries in the West Coast bioregion, converted to purpose-designed crab traps in the mid to late 1990s. Following conversion to traps commercial catches increased due to improved fishing efficiency with catches ranging from 46 t to 95 t during the period between 1999/00 and 2010/11. There are currently 11 commercial authorisations (interim managed fishery permits), of which ten permit the use of 42 hourglass traps. There are no restrictions on mesh size but the majority are 3” stretched diamond mesh, with all traps having escape gaps (voluntary) to allow juvenile and undersize crabs to exit freely. Commercial fishing is prohibited on weekends from 0900 h (1 Nov – 31 Mar) or 1000 h (1 Apr – 31 Aug) on Saturday to 0330 h on Monday. There are also localised spatial closures for the Mandurah Entrance Channel, Dawesville Cut and rivers entering the Estuary (Figure 1.2). Interim management measures were introduced in August 2007 to include a seasonal closure to both commercial and recreational fishers in the Peel-Harvey Estuary for the months of September and October to protect pre-spawning female crabs. In 2010 an agreement was made between the recreational and commercial sectors for a voluntary no-take of legal-sized females between November 1st and March 1st by commercial fishers to protect the mated pre-spawned females during this period. Although the minimum legal size is set at 127 mm CW for males and females, some commercial fishers voluntarily prefer to retain females of 130 mm CW and above for marketing and sustainability purposes.

1.3 Peel-Harvey Estuary recreational crab fishery

The majority of recreational fishing for crabs in the Peel-Harvey Estuary occurs from boats, but also occurs from houseboats, bridges, jetties and people scoop netting. Some fishers can also fish directly from private houses along canals within real estate developments. From November 1 2007, the recreational bag limits in the West Coast bioregion were reduced to 10 crabs per person and 20 crabs per boat. To date there have been two assessments of the recreational catch and effort in the Peel-Harvey Estuary. The first was undertaken in 1998 – 99, where the creel survey estimate of recreational crab catch was 251 – 377 t and a more recent creel survey undertaken in 2007 – 08 with an estimated recreational catch of 107 – 193 t. Given these two recreational estimates are almost a decade apart it is not possible to determine if they represent a trend in recreational catches between 1998 – 99 and 2007 – 08, or are only reflective of the survey periods.

1.4 Mandurah to Bunbury Developing Crab Fishery

The Mandurah to Bunbury Developing Crab Fishery operates from waters south of the Shoalwater Islands Marine Park to Point McKenna near Bunbury. The fishery is divided into two zones. A single northern zone (Area 1) 80-pot exemption (valid as at 30 June 2008) authorises crab fishing in a specified area of Comet Bay (Figure 1.1). Historically, four 60-trap exemptions were permitted to operate in the southern zone (Area 2) (in the waters between Cape Bouvard and the southern boundary of the fishery). However, as at 30 June 2008, only two 60-trap exemptions were valid. The area separating the 2 zones is closed to commercial crab fishing (Figure 1.1). The annual trap catch for this fishery has ranged from 2 to 13 t since 1998. Blue swimmer crabs are also retained as by-product by trawlers operating in Comet Bay (Zone D of the South West Trawl Managed Fishery) (Figure 1.1), and occasionally by trawlers operating in the waters from Fremantle to Cape Naturaliste (Zone B of the South West Trawl Managed Fishery). Commercial fishers in the Mandurah to Bunbury Developing Crab Fishery (Area 1 and 2) retain crabs at the minimum legal size of 128 mm CW, however recreational fishers and the commercial trawler in the Zone D of the South West Trawl Managed Fishery retain crabs at 127 mm CW.

1.5 Stock connectivity

Genetic studies have indicated that crab assemblages on the WA coast become more distinct as one moves from north to south of the State, with those in the south-west (Cockburn Sound, Peel-Harvey and Geographe Bay) forming a homogenous but highly distinctive group separate to those stocks in Shark Bay and Exmouth Gulf (Chaplin *et al.*, 2001; Sezmiş, 2004). Sezmiş (2004) found genetic heterogeneity between northern stocks (Broome, Exmouth Gulf, Shark Bay) of *P. armatus* and southern stocks from Port Denison, Cockburn Sound, Peel-Harvey Estuary, and Geographe Bay. The gene flow was greater from Port Denison southwards with stocks between Peel-Harvey Estuary and Geographe Bay homogeneous. Cockburn Sound crab assemblage was more similar to the southern than northern stocks, but still genetically distinct from these southern stocks (Peel-Harvey Estuary and Geographe Bay) despite the short geographic distance, ~50 km. This may be due to the enclosed nature and hydrology of Cockburn Sound and the life cycle generally occurring wholly within the Sound. Sezmiş (2004) suggested that permanent estuaries and sheltered coastal waters which are favoured by crabs was an important vector for larval dispersal, as too the location of spawning, i.e. inside (Shark Bay) vs. outside (Peel-Harvey Estuary) enclosed estuaries.

Given that the Leeuwin Current flows north to south, the greater mixing of stocks among the more closely spaced embayments along the south coast is highly probable. Therefore the crab assemblages of Peel-Harvey Estuary and Areas 1 and 2 of the Mandurah to Bunbury fisheries are highly likely to be part of the same genetic stock where not only is there great mixing of larvae between fishing grounds but the close proximity aided by continuous limestone reef system connecting these regions (Department of Fisheries 2011) will also accommodate movement of adult crabs.

1.6 Concerns for the Peel-Harvey Estuary crab stock

There have recently been concerns about the long-term sustainability of the Peel-Harvey Estuary crab fishery. Recreational fishers have reported that catch rates have declined in the past few years, potentially due to significant population growth in the Mandurah region which has experienced a 45% growth rate between 1996 and 2006 compared with a 14% growth rate for Western Australia (ABS 2006). The possible increase in recreational fishing pressure and its effects on the blue swimmer crab fishery has been unable to be quantified due to a lack of quantitative recreational fishing survey data, with the last survey undertaken in 1998/99 by Malseed and Sumner (2001). Extensive coastal canal developments potentially contributing to environmental degradation in the region have also been thought to negatively impact on the breeding and recruitment potential of crab stocks in the estuary.

Analysis of Volunteer Fisheries Liaison Officers (VFLO) data collected over the past 10 years in the Mandurah region has indicated that recreational catch rates (boat based) declined significantly between 2000 and 2003, with catch rates in 2003 less than half those reported in the 1998/99 recreational survey (Malseed and Sumner, 2001) (Refer to summary of VFLO data Smallwood *et al.* 2010). There was only a slight improvement in VFLO catch rates in 2004 and 2005. Similarly, analysis of shore-based VFLO catch rate data showed a steady decline in catch rates between 1995/96 and 2002/03, with catch rates remaining low in 2004/05 (Smallwood *et al.* 2010). It is not clear whether the declines in VFLO recreational catch rates were due to sharing of the crab resources amongst an increasing number of recreational fishers, or whether there has been a decline in crab stocks. It is clear that these trends need to be validated by expansion of the Volunteer Fisheries Liaison Officer Program and/or another recreational survey in Peel-Harvey Estuary so that the status of recreational fishing can be determined.

Furthermore, the collapse and subsequent closure of the Cockburn Sound blue swimmer crab fishery (Johnston *et al.*, 2011a, 2011b) was thought to have a knock-on effect of increased recreational fishing pressure in the Peel-Harvey Estuary (as well as in Warnbro Sound and Swan River), with the potential shift of its recreational fishers to the Peel-Harvey region. This outcome would further exacerbate the situation in the Peel-Harvey Estuary and surrounding regional fisheries.

In contrast to the VFLO recreational catch rate trends, commercial catches in the Peel-Harvey Estuary had not declined, fluctuating between 46 t and 95 t over the past decade. The different trends between sectors may reflect the different fishing methods used by the two sectors. There is currently no fishery-independent information on the current status of crab populations in the Peel-Harvey Estuary with the last comprehensive study conducted between 1995 – 1998 (de Lestang 2002; de Lestang *et al.* 2003). Given the dramatic population growth, expansion of coastal real estate developments and potential increased recreational fishing pressure, it is likely that considerable changes in crab populations have occurred within the estuary; with crab population data from the late 1990s unlikely to be representative of the current situation. This is to be expected, given that blue swimmer crabs are a short-lived species, dependent on the estuarine and nearshore habitats for spawning and recruitment (Potter *et al.* 1983; de Lestang 2002) and therefore vulnerable to small changes in these environments. To understand the impacts of these changes and the current trends in recreational and commercial catch, it is essential to re-examine the status of the spawning stock and recruitment in the estuary. Without this information it is impossible to adequately assess whether current management of the crab fishery is appropriate and whether management needs to be changed to protect breeding stock and maintain acceptable levels of recruitment.

1.7 Study objectives

A fishery-independent field survey of the crab population in Peel-Harvey Estuary over a period of three years will provide an assessment of crab stocks between 2007 and 2011, and allow a comparison with 1995 – 1998 data (de Lestang 2002) with respect to whether recruitment and the spawning stock have changed. Commercial monitoring of this fishery will provide an understanding of the length frequency and sex ratio of crabs captured by commercial fishers and hence the impact of commercial fishing pressure on the crab population through the year. General environmental conditions will be examined to understand the environmental effects on recruitment and spawning. The objectives of this project were as follows:

1. Fishery-independent monitoring program: determine current recruitment and spawning stock levels of the crab population in the Peel-Harvey Estuary and assess whether the status of stocks has changed considerably in the past decade.
2. Commercial Monitoring program: assess the length frequency and sex ratio of crabs captured by commercial fishers and hence the impact of commercial fishing pressure on the crab population through the year.
3. Develop a commercial catch monitoring program in Area 1 of the Mandurah to Bunbury Developing Crab Fishery and Zone D of the South West Trawl Managed Fishery (Comet Bay) and Area 2 of the Mandurah to Bunbury Developing Crab Fishery.

A second related project was funded to undertake a 12-month recreational survey in the Peel-Harvey Estuary between November 2007 and October 2008 to provide an estimate of total recreational catch and effort. The results of this study are presented in Chapter 5 of this report. An expansion of the VFLO program was also undertaken during the 2006/07 crabbing season in the Peel-Harvey Estuary and are reported in Smallwood *et al.*, 2010.

2.0 Catch and effort statistics and commercial catch monitoring within Peel-Harvey Estuary: Assessing stock status

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Objective Assess the length frequency and sex ratio of crabs captured by commercial fishers and hence the impact of commercial fishing pressure on the crab population through the year.

2.1 Introduction

Commercial fishing targeting blue swimmer crabs can be traced back to the late 1950s in the Area 2 of the West Coast Estuarine Managed Fishery (hereafter referred to as the Peel-Harvey Estuary (PHE)). Traditionally, most of the historical commercial catch has been taken using gill nets with 152 mm stretch mesh, and licensed fishers were entitled to pull up 1000 m of crab gill net per day. In October 1995, the PHE crab fishery was converted from a gill net to trap-based fishery. Trapping provided many benefits over netting as it was a less time consuming fishing method with boat use restrictions on weekends, produced less bycatch, reduced environmental impact from fishing gear and improved catch quality (Bellchambers *et al.* 2005). Fishers were also able to extend their winter fishing as traps were more effective in winter than gill netting. The current commercial gear is referred to as hourglass traps (Figure 2.1). Since 2000, crab traps have been modified by PHE fishers to include escape gaps, although this is not mandatory or regulated so modifications and the year the gaps were adopted vary among fishers. The intention is to reduce the catch of undersize and juvenile crabs with fishers also adopting voluntary measures of self-imposed size restrictions (130 mm CW and above) to establish premium markets for the fishery. Of the 11 authorisations permitting commercial fishing in the PHE there are currently 10 allowing the take of crabs,with each operator permitted to fish from a vessel using a maximum of 42 traps during the fishing season (1 November – 31 August). In 2007 a fishing closure was introduced between 1 September and 31 October in the PHE for both the commercial and recreational sectors.

A short-term commercial catch monitoring program for the PHE crab fishery was established between 1998 and 2001 to supplement the voluntary logbook that was also in place during these years (Melville-Smith *et al.* 2001). In this chapter we examine the catch trends from data generated from a commercial catch monitoring programme that was re-established and ongoing since 2007. We also compare historical commercial catch trends from the period 1998 – 2001 to current commercial catch trends from 2007 – 2011 to assess the likely impact commercial fishing has had on the crab stock in the PHE noting that the majority of crabs removed from the Estuary is by the recreational sector. We also summarise the catch and effort statistics over the history of the PHE crab fishery.

2.2 Methods

2.2.1 Commercial Catch and Effort Statistics (CAES)

Since 1975 all licensed fishers have been required to complete and submit monthly catch and effort statutory fishing returns to the Department of Fisheries. The information provided through the returns is recorded within the Department's Catch and Effort Statistics (CAES) database.

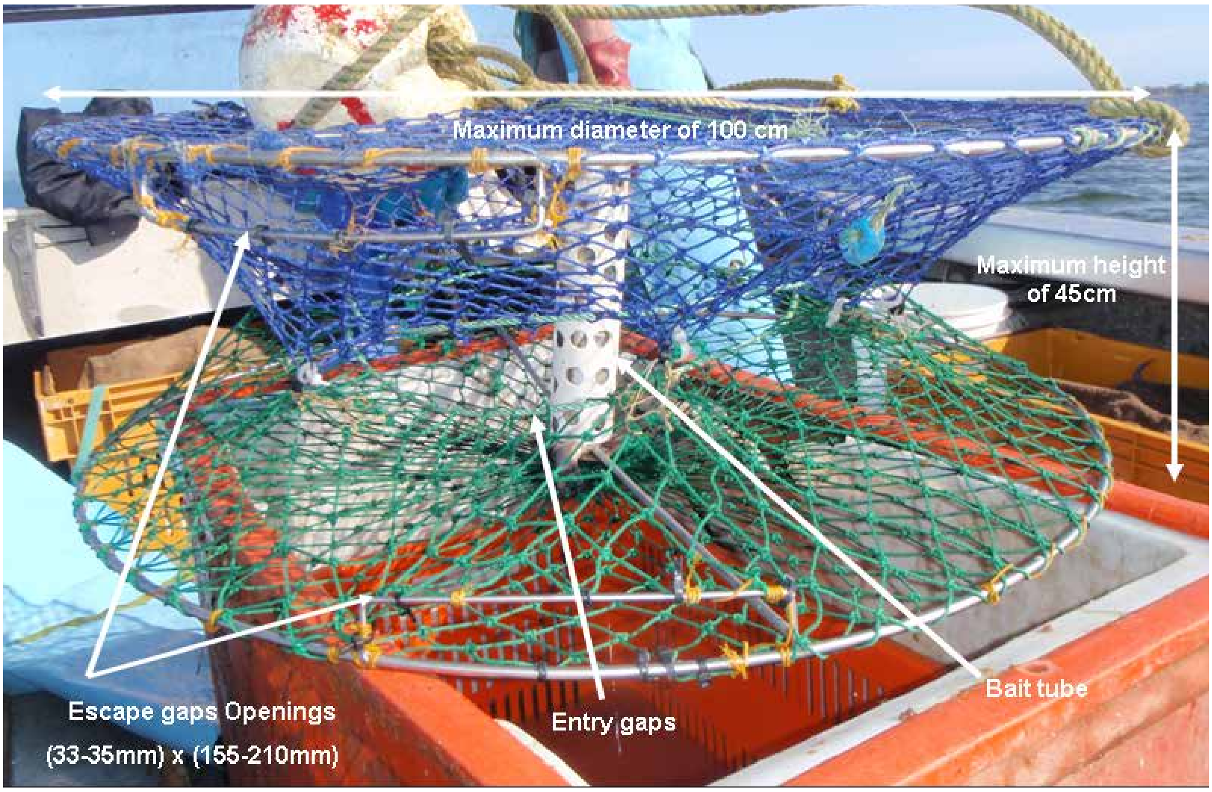

Figure 2.1 Commercial hourglass crab trap used in the current PHE commercial crab fishery. Photo: Chris Marsh

2.2.2 Commercial catch monitoring program

Current commercial monitoring (2007 – 2011)

The current commercial catch monitoring program for the PHE was established in March 2007. Each month Departmental research staff board one commercial fishing vessel operating in the Peel Inlet region and one operating in the Harvey Estuary region (refer to Figure 3.1 from Chapter 3.0). Commercial monitoring continued during the closure months of September and October to determine the potential catch dynamics during this period. Thus commercial crab data was collected from up to 84 traps for each month of sampling (up to 42 in the Peel Inlet and the Harvey Estuary). Baited traps were placed along a "crab-line" (which could vary in the number of traps) over a 24-hr soak duration. From each trap, the carapace width (CW), sex, berried status and shell condition (soft or hard) of each crab were recorded. Determination of soft-shelled condition of crabs was done subjectively by squeezing the top of the carapace. The GPS coordinates of the start location of each crab line was recorded and each trap lift location was determined to be in either the Peel or Harvey region, given the following criteria based on these coordinates:

$$\text{Lat} < (1.54 \times \text{Long} - 145.53) = \text{Peel Inlet}$$

$$\text{Lat} > (1.54 \times \text{Long} - 145.53) = \text{Harvey Estuary}$$

Historical commercial monitoring (1998 – 2001)

The first commercial catch monitoring program for the Peel-Harvey Estuary began in December 1998 and ceased in June 2001 (Melville-Smith *et al.* 2001). The Estuary was sampled twice a month where the crab data (as above) was recorded as well as environmental conditions such as salinity and water temperature at some sites. Fishers recorded fishing location as either Peel or Harvey, or in some instances without distinction as Peel-Harvey. Comparative data analysis with the current commercial monitoring program was restricted to records where either Peel or Harvey was recorded by the fisher.

2.2.3 Statistical Analyses

Current commercial catch monitoring data

Catch rate trends were analysed by ANOVA using the variables fishing year (Nov 2007 – Oct 2008, Nov 2008 – Oct 2009, Nov 2009 – Oct 2010, Nov 2010 – Oct 2011; closure months September and October were also used as sampling was conducted at this time), month (Nov – Oct) and location (Peel Inlet or Harvey Estuary). The crab categories modelled were:

- Legal males (≥ 127 mm CW)
- Legal females (≥127 mm and not berried)
- Berried females (any sized female bearing eggs)
- Sexually mature sub-legal males (87.1 mm ≤ CW < 127 mm)
- Sexually mature sub-legal females (86.9 mm ≤ CW < 127 mm)
- Immature males (< 87.1 mm CW)
- Immature females (< 86.9 mm CW)
- Soft-shelled males (all sizes)
- Soft-shelled females (all sizes)

Estimates by de Lestang (2002) of male and female size at sexual maturity (SOM) for crabs from the Koombana Bay region were used to establish size categories for the current analyses. For detailed explanation see Appendix A – Size at the onset of female maturity estimates.

As there was no data available for some months of 2006/07, this fishing year was omitted from all analyses. Three-way interactions were not included in the analyses due to the dataset not being complete at this level. Catch rates (crabs/traplift) were weighted by the number of traplifts and modelled for the fishery as:

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

where

$y_{i,j,k}$ is the catch rate (animals per traplift) for fishing year i and month j at location k for observation l;

Δ is a constant chosen to give Normal errors;

α_i is fishing year i ϵ (2007/08, 2008/09, 2009/10, 2010/11);

β_j is month j ϵ (November – October);

γ_k is site k ϵ (Peel or Harvey);

$\alpha_i\beta_j$, $\alpha_i\gamma_k$, $\beta_j\gamma_k$ are interactions between the fishing year, month and location.

As the dataset was unbalanced (unequal numbers of crab lines per month) (Table 4) 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 at each factor level.

Historical commercial monitoring

Comparisons of catch rate trends between current and historical and commercial monitoring surveys were analysed by ANOVA. Due to incomplete fishing location and missing monthly data from the historical monitoring data, seasonal catch rate trends of Summer (Nov – Feb), Autumn (Mar – May), Winter (Jun – Aug), Spring (Sep – Oct) were examined for the Peel Inlet and Harvey Estuary sites (Appendix C,Table 5). Only data identifying either the Peel Estuary or Harvey Inlet from the historical (1998 – 2001) dataset were used in the comparative analysis.

Catch rates (crabs/traplift) were weighted by the number of traplifts and modelled for the fishery as:

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

where

$y_{i,j,k}$ is the catch rate (crabs/traplift) for fishing year i and season j at site k

for observation l;

Δ is a constant chosen to give Normal errors;

α_i is fishing year i ϵ (1998/99, 1999/00, 2007/08, 2008/09, 2009/10, 2010/11);

β_j is season j ϵ (Summer, Autumn, Winter, Spring);

γ_k is site k ϵ (Peel or Harvey);

$\alpha_i\beta_j$, $\alpha_i\gamma_k$, $\beta_j\gamma_k$ are interactions between the fishing year, season and site.

All size categories were modelled as before, and environmental covariates were not used in the model as comparative data between both surveys was not available. As the dataset was unbalanced, Type III sums of squares was used and least-square means are presented (SAS Institute Inc. 1989). Back-transformed least-square means have been calculated to obtain standardized estimates for the catch rates at each factor level. Three-way interactions were not included in these analyses due to the dataset not being complete at this level.

2.3 Results

2.3.1 Commercial Catch and Effort data

The earliest records of commercial crab catches from the PHE are from the early 1950s with catches < 1 t up to 1960. Catches rose to 10.4 t during 1962/63 but declined to 1 t by 1966/67. A second peak in catches occurred in 1972/73 with 38 t but again declined towards the end of the 1970s (Figure 2.2). Substantive commercial fishing for blue swimmer crabs in the Peel-Harvey Estuary began in the 1980s, with fishers using gill nets primarily over the summer months. Annual catch and effort was highly variable, fluctuating from less than 2 t (175 fisher days) in 1981/82 to nearly 75 t (1621 fisher days) in 1987/88 (Figure 2.3). The gradual conversion from gill nets to hourglass traps occurred in the mid-late 1990s and resulted in an increase in annual catches, largely due to the increased efficiency of the hourglass traps. Since gear conversion, annual commercial catches have fluctuated between 45 t (896 fisher days) in 2002/03, peaking at 104 t from 1657 fisher days in 2006/07 (Figure 2.3). This increase in tonnage from proportionally less fisher days indicates the increase in fishing efficiency.

Commercial catch for 2007/08 dropped by 13.5% to 90 t with a catch rate of 1.56 kg/traplift. This was followed by a significant 49% decrease in catch to 46 t for the 2008/09 financial year (Figure 2.3).The mean annual catch rate for 2008/09 in the Peel-Harvey Estuary was 0.94 kg/trap lift, the equal lowest mean annual catch-rate since the conversion from gill nets to crab traps. Catch during 2009/10 had increased to 65 t with a CPUE of 1.17 kg/traplift. Since conversion to traps CPUE trends have followed catch with effort in fisher days relatively stable (Figure 2.4).

Since conversion to traps, there has been an increase in the autumn/winter but most of the annual commercial catch is still taken during summer with 62% of the catch taken between December and March (1999/00 – 2010/11) (Figure 2.5). CPUE is also highest over the summer months. Catches decline through autumn to winter before a seasonal closure of the fishery in September and October which was introduced in 2007. The monthly catch trend for gill netting showed an even greater focus on the summer period (Figure 2.5).

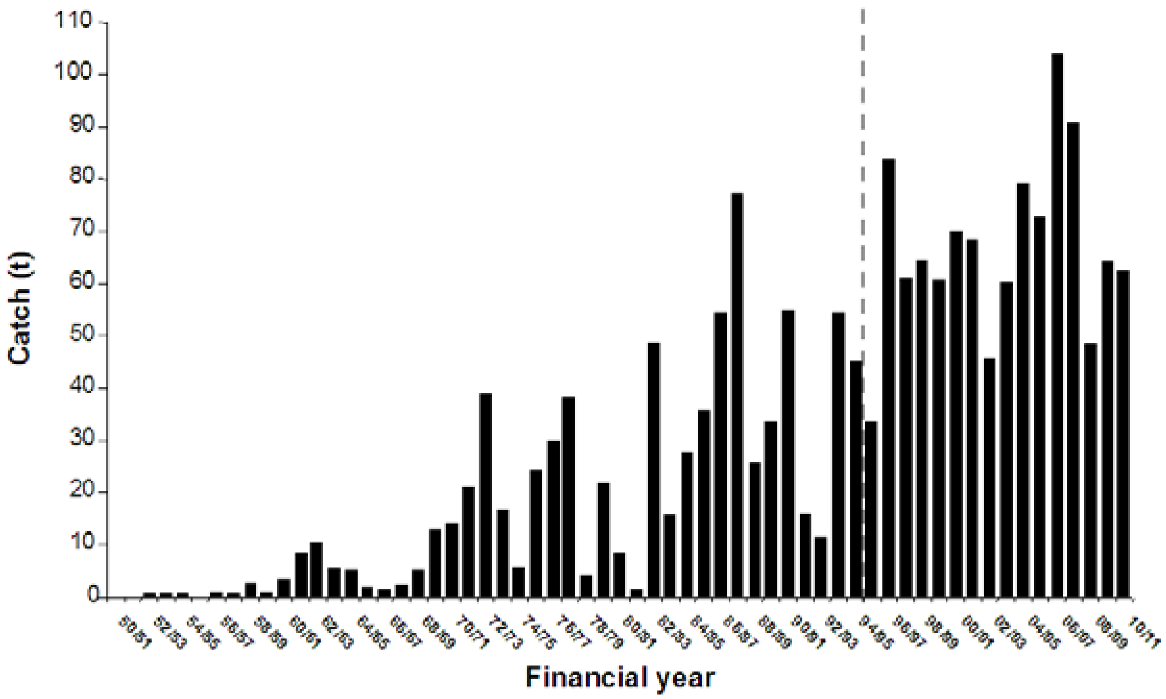

Figure 2.2 Annual commercial blue swimmer crab catch (t) from the PHE crab fishery. The broken line indicates conversion to trapping method from gill netting.

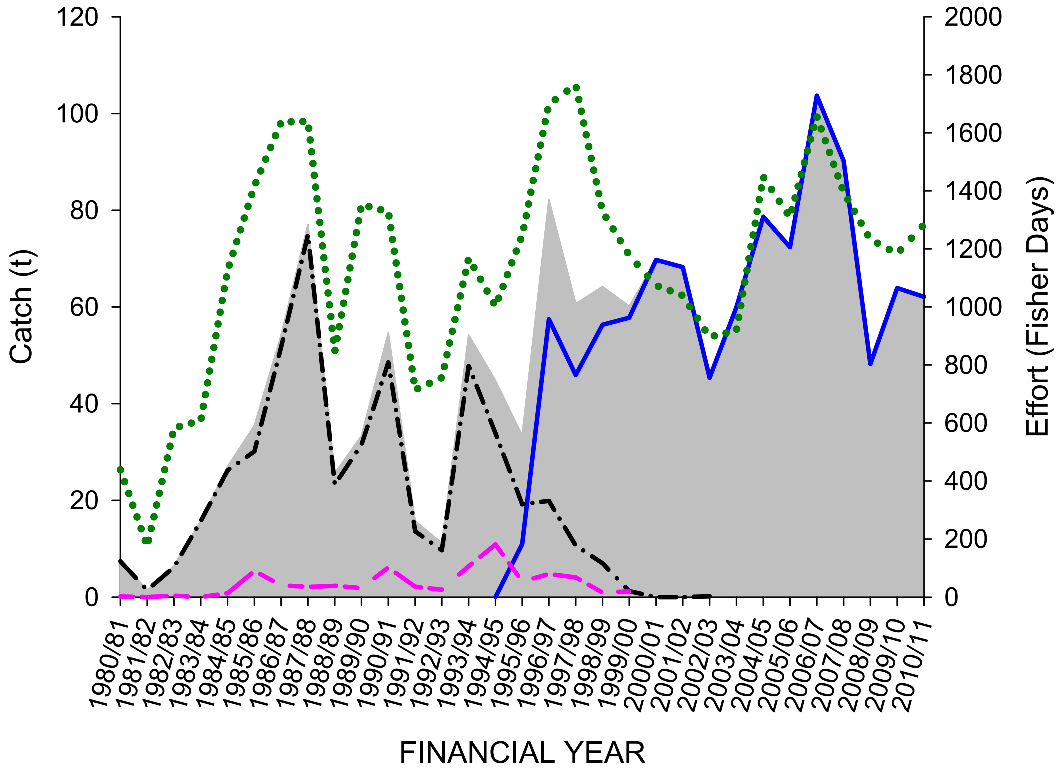

Figure 2.3 Annual commercial blue swimmer crab catch (t) from the PHE crab fishery by fishing method and overall effort (fisher days) irrespective of method. Annual catch is presented by financial year. Total catch (■); gill nets (–·–); crab traps (—); other (– –) and effort in fisher days (••••).

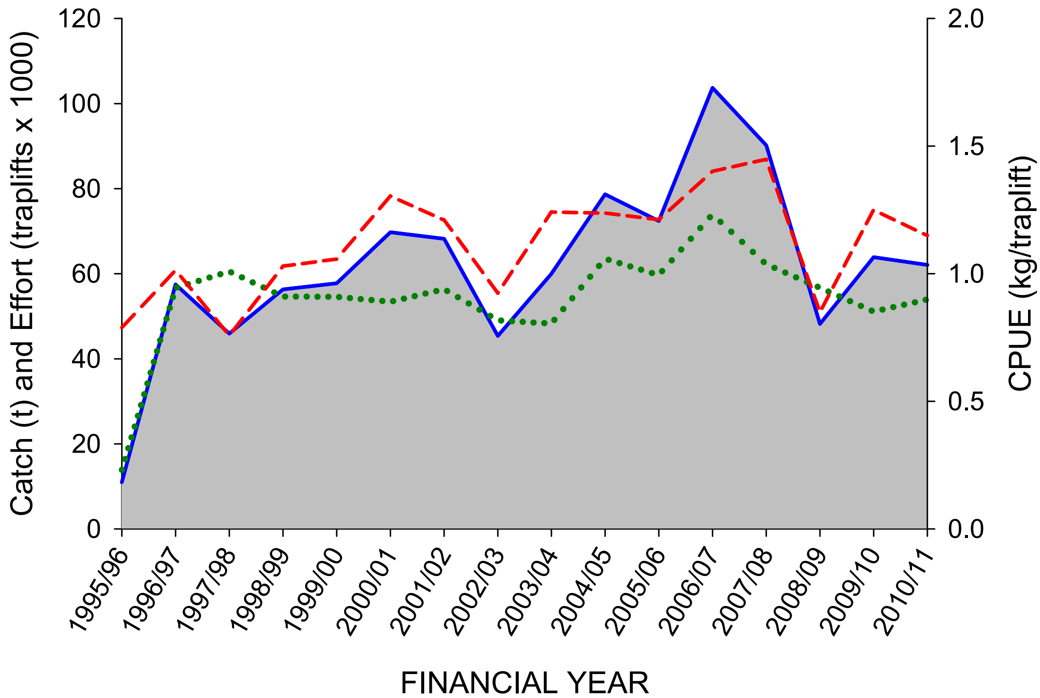

Figure 2.4 Annual commercial blue swimmer crab trap catch (t), effort (trap lifts x 1,000) and catch per unit effort (kg/trap lift) in the PHE crab fishery between 1999/00 and 2010/11. Data is presented by financial year. Total catch (■); crab traps (—); effort (••••) and CPUE (– – –).

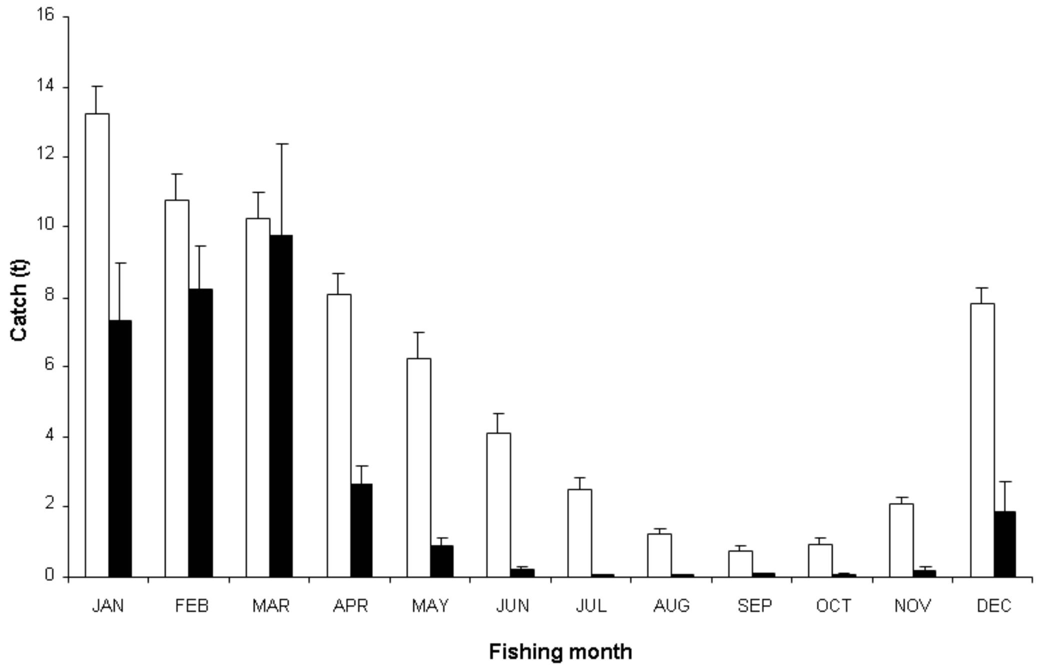

Figure 2.5 Mean (SE) monthly commercial blue swimmer crab catch from the Peel-Harvey Estuary by net (black bars) between 1980/81 and 1995/96 inclusive and by trap (white bars) between 1999/00 and 2010/11 inclusive. Monthly calculations for September and October are based on the fishing years 1999/00 to 2006/07 as these months are closed to fishing from 2007 onwards.

2.3.2 Commercial catch monitoring data

Monthly length frequency distributions of commercial catch are similar between historical and current commercial catch monitoring surveys (Figure 2.6, Figure 2.7). Males dominate the fishery with highest catch rates during summer months (November – March). Female catches increase from March and were approximately 50% of the catch during April, May and June then declining to below 50% until October. July was notably different between the current and historical surveys with female catch rates of up to 1 crab/traplift between 2007 and 2011 compared with < 0.2 crabs/traplift between 1998 and 2001. This may be due to the timing of female migration out of the estuary driven by changes in rainfall patterns over the last decade. Overall catch rates decline to < 1 crab/traplift for all size classes during August, September and October as most crabs have moved out of the estuary at this time. The catch rates of berried females were very low for both time series as berried females usually leave the estuary to spawn offshore. During the 2007 – 11 period some berried females were present during October, November and January while during the 1998 – 01 period a few berried females appeared in December.

Spatial fishing distribution

There were clear seasonal changes in the spatial patterns of commercial fishing within the Peel-Harvey Estuary (Figure 2.8). Fishing during the summer months (November – March) focused on the central regions of the Peel Inlet and Harvey Estuary. During autumn, fishing shifted towards the north-west region of the Peel Inlet and top end of the Harvey Estuary and by winter fishing was largely concentrated around the entrance to the Dawesville Cut. Fleet distribution during spring shows greater spatial diffusion of Harvey and Peel although this is an artefact of sampling during the season closure months of September and October. Both the lower region of the Harvey and the south-east region of the Peel Inlet had no fishing activity during all seasons and this may be due to unsuitable trapping grounds and/or to avoid interaction with recreational fishers.

Current commercial monitoring catch rate trends

Sexually immature crabs: Standardized catch rates of sexually immature male and female crabs were very low (<0.02 crabs/traplift) (due to presence of escape gaps on commercial traps) and highly variable across all months (Figure 2.9). There were no significant effects of fishing year, month or site ($p > 0.05$) on the catch rate of immature females (Figure 2.9b,d,f). For immature males, there were significant interactions between site and month ($p < 0.001$) where catch rates in the Peel were higher than Harvey during June and from August to October (Figure 2.9a). There was also a significant interaction between site and fishing year ($p < 0.01$) where catch rates of immature males in the Peel were higher than Harvey for all years except during 2008/09 (Figure 2.9e) (Appendix D – ANOVA Tables from commercial catch monitoring analyses from current fishing years.).

Sexually mature sub-legal crabs: There were significant month, site and fishing year effects on the catch rates of sexually mature sub-legal crabs (Appendix D – ANOVA Tables from commercial catch monitoring analyses from current fishing years., Table 10 & Table 11). For females, there were significant interactions between site and month (Figure 2.10b), and between fishing year and month (Figure 2.10d) with highest catch rates of mature sub-legal females between May and August. The 2008/09 fishing year shows an unusually high catch rate of > 3 crabs/traplift during May (Figure 2.10d) and predominantly from the Peel Inlet. For males, monthly catch rate trends between 2007/08 and 2008/09 were similar except during November 2007 where catch rate peaked at 6.9 crabs/traplift. Likewise catch rates trends between 2009/10 and 2010/11 were similar and the dip in catches during January and May that was observed for 2007/08 and 2008/09 did not occur for 2009/10 and 2010/11 fishing years (Figure 2.10c). These differences in catch trends may be due to movement of crabs in and out of the estuary and/or timing of moulting. There is a declining trend in the catch rate of mature sub-legal males in the Peel Inlet from 2007/08 to 2010/11 (Figure 2.10e), while catch rate of mature sub-legal females in the Peel and Harvey region appears to be increasing (Figure 2.10f).

Legal-sized crabs: Catch rate of legal crabs showed significant effects of fishing year, month and site (Appendix D – ANOVA Tables from commercial catch monitoring analyses from current fishing years., Table 12 & Table 13). Catch rate of legal-sized males increased from November to January then gradually declined in the following months in both Peel and Harvey regions (Figure 2.11a). For legal females, highest catch rates were recorded from April to July (Figure 2.11b), and highest catches during 2010/11 and lowest during 2008/09. Catch rate of legal males were generally similar between all fishing years, except 2008/09 where January and February catch rates were significantly lower than other years (Figure 2.11c).

Berried Females: There were significant interactions between month, fishing year and site on the catch rate of berried females ($p < 0.05$) (Figure 2.12) (Appendix D – ANOVA Tables from commercial catch monitoring analyses from current fishing years., Table 14). Catch rates were generally very low except for October – November (Figure 2.12a). Catch rates peaked in November in all years except 2010/11 when it peaked earlier in October (Figure 2.12b). Highest catches of berried females occurred in Harvey Inlet in November with numbers of berried females highest in the Harvey Inlet in all years except 2010/11.

Soft-shelled crabs: There were significant interactions between month, fishing year and site on the catch rates of soft-shelled male and female crabs ($p < 0.05$) where the effect of month was most influential (Appendix D – ANOVA Tables from commercial catch monitoring analyses from current fishing years., Table 15 & Table 16) (Figure 2.13). Highest catch rates of soft males occurred between November and January and during April with lower catch rates between July and August (Figure 2.13a). For soft-shelled females, peak catch rates occurred during April (Figure 2.13b). For both sexes, catch rates of soft crabs varied significantly between fishing years. For example, during the 2008/09 fishing year the catch rate of soft females in April was 4 times greater than 2007/08, whereas in 2009/10 and 2010/11 there were almost nil catch of soft females during April (Figure 2.13d). Likewise for males, the catch rate during January 2008/09 was 8 fold higher than the other fishing years, while during April of 2007/08 and 2008/09 fishing years, catch rates of soft males were higher than the nil catches recorded for 2009/10 and 2010/11 (Figure 2.13c).

Current vs historical commercial catch trends

Historical catch rate trends in 1998/98 and 1999/2000 were generally within the range of current fishing years for immature males and females (Figure 2.14), sexually mature sub-legal females (Figure 2.15b, d, f), legal-sized females (Figure 2.16b, d, f), berried females (Figure 2.17) and soft-shelled crabs (Figure 2.18) (Appendix E – ANOVA Tables from commercial catch monitoring analyses from historical and current fishing years., Table 17 – Table 25). Catch rate of legal males shows a notable decreasing trend from 1998/99 (4 – 5 crabs/traplift) to 2010/11 (2 – 3 crabs/traplift) in both Peel Inlet and Harvey Estuary (Figure 2.16e). Similarly, historical catch rate of sexually mature sub-legal males in the Peel Inlet catch rates show a decreasing trend from 4 crabs/traplift in 1998/99 to 1.5 crabs/traplift in 2010/11 (Figure 2.15e) but catch rates were steady in the Harvey region.

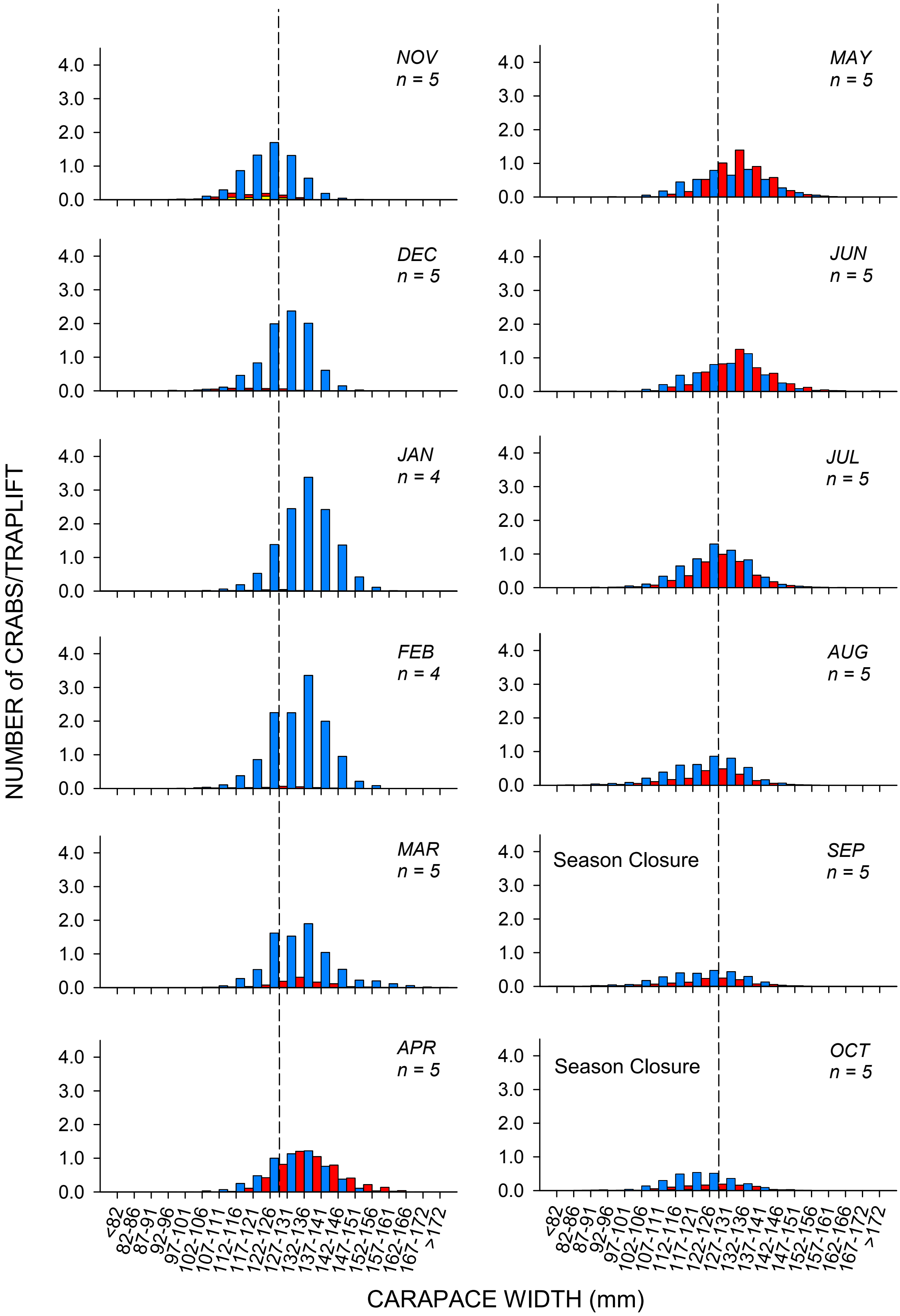

Figure 2.6 Mean monthly length frequency distributions of male (■), female (■), and ovigerous female (■) blue swimmer crabs from commercial catch monitoring surveys aboard commercial crab vessels in the Peel-Harvey Estuary between March 2007 and December 2011 inclusive. Minimum commercial size limit of 127 mm CW (- - -). *n* = number of years sampled.

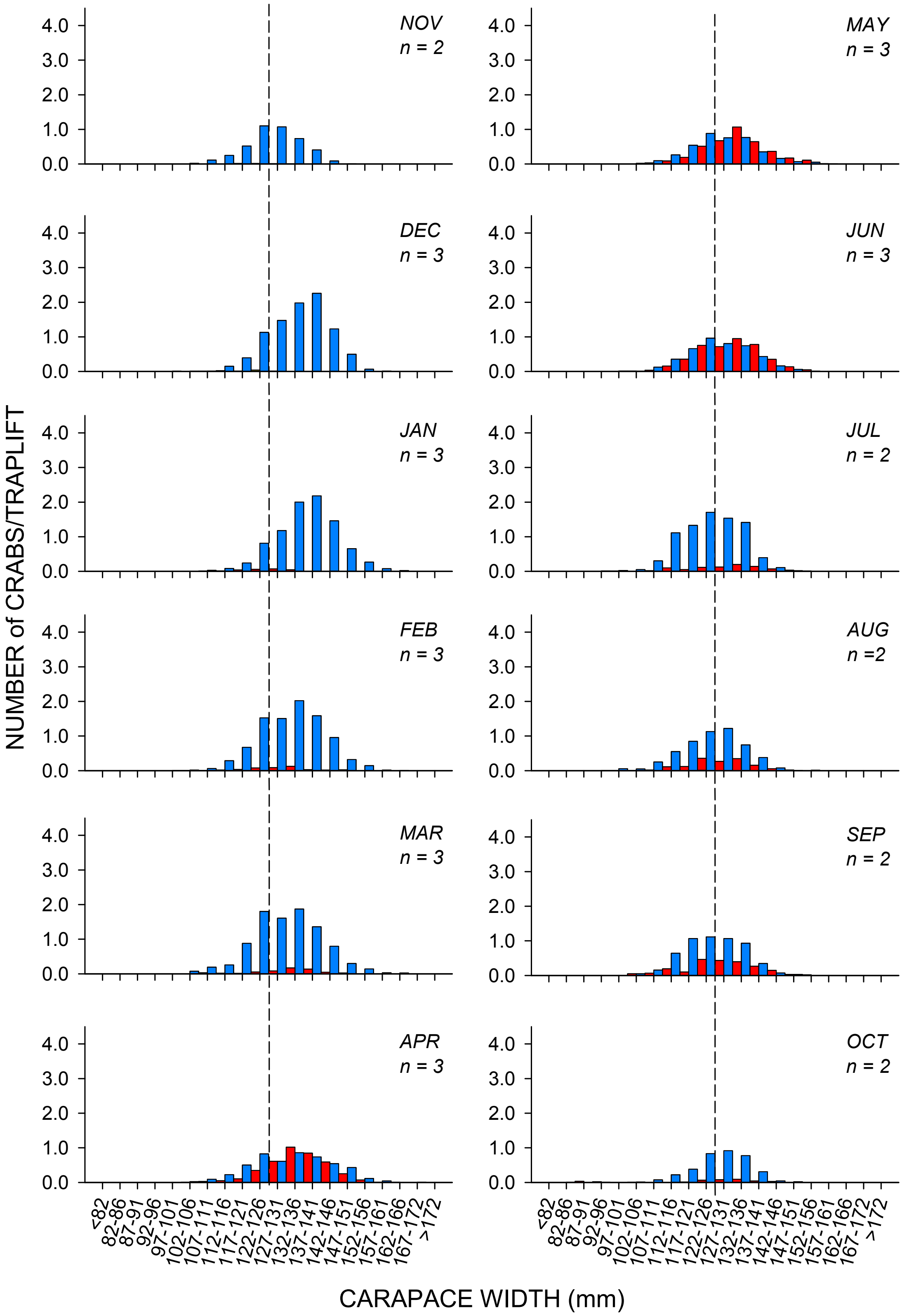

Figure 2.7 Mean monthly length frequency distributions of male (■), female (■), and ovigerous female (■) blue swimmer crabs from commercial catch monitoring surveys aboard commercial crab vessels in the Peel-Harvey Estuary between December 1998 and June 2001 inclusive (Melville-Smith *et al.* 2001). Minimum commercial size limit of 127mm CW (- - -). *n* = number of years sampled.

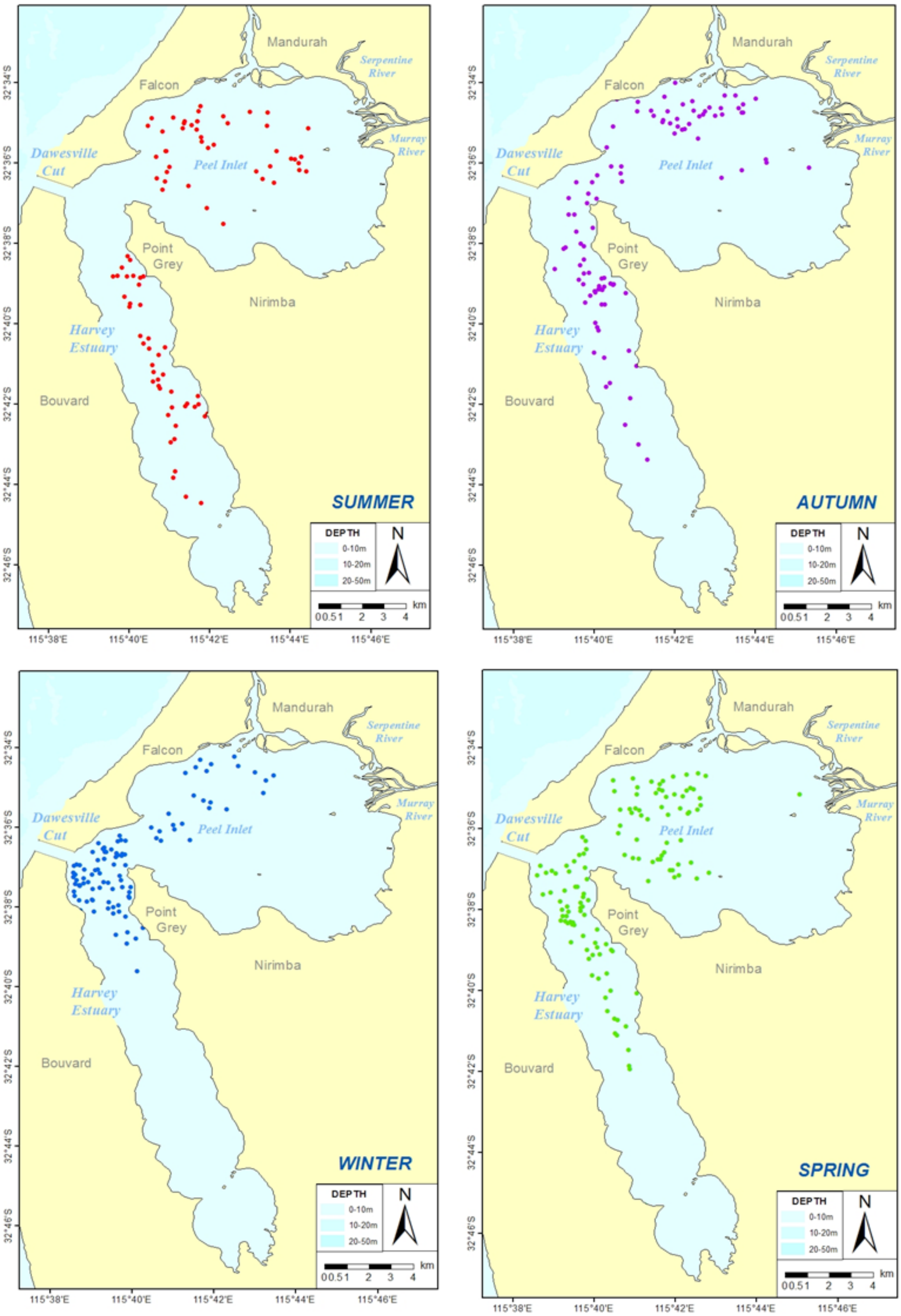

Figure 2.8 Seasonal plots showing start locations (dot) of trap lines sampled during commercial catch monitoring surveys aboard commercial vessels in the Peel-Harvey Estuary between May 2007 and December 2011. Summer (December – February), Autumn (March – May), Winter (June – August), Spring (September – November).

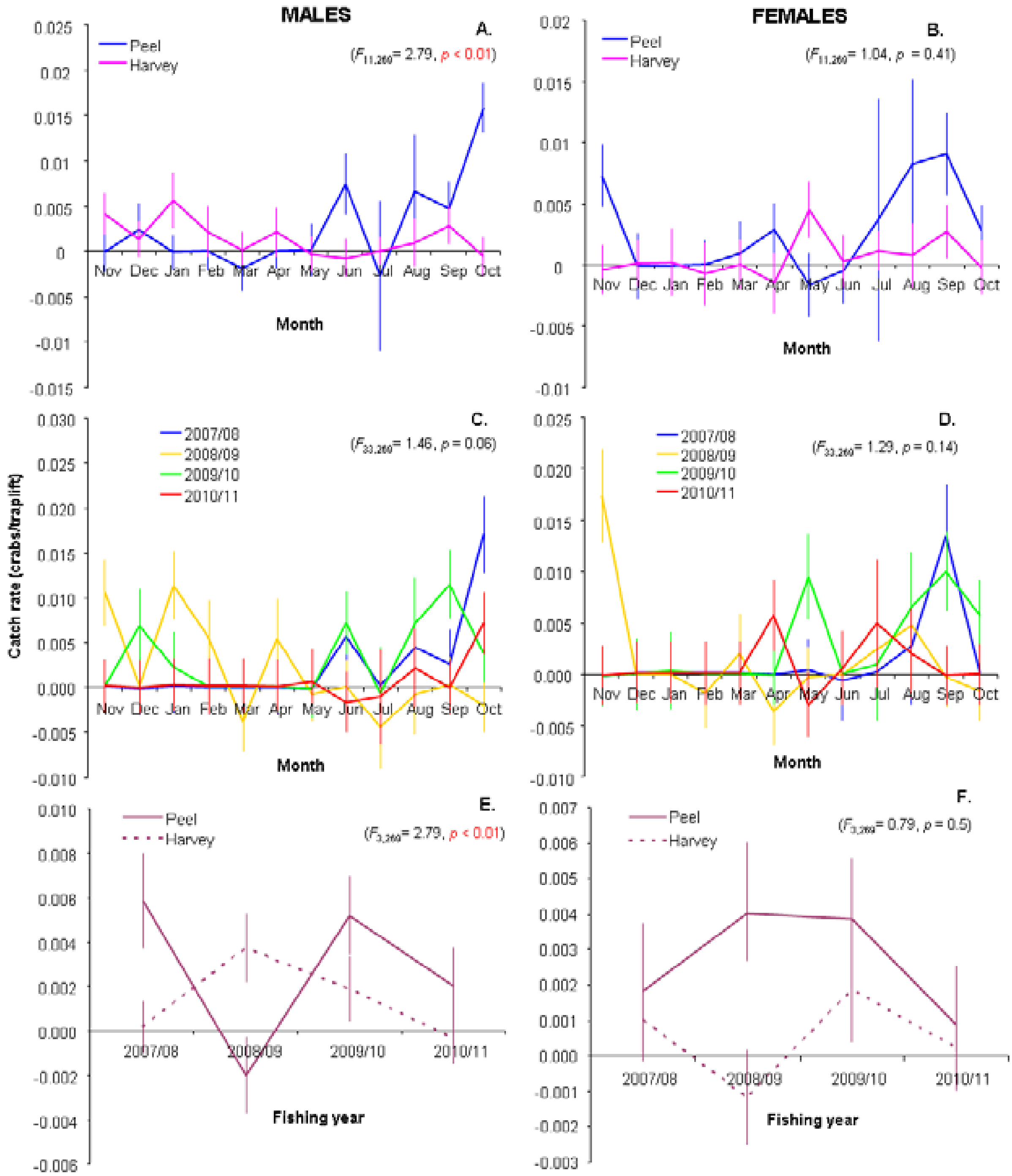

Figure 2.9 Monthly mean (± SE) standardised catch rates of immature males (<87.1 mm CW) and females (<86.9 mm CW) from commercial catch monitoring surveys plotted by interactions of Month (November – October) vs. Site (Peel and Harvey) (A, B), Fishing year (2007/08 – 2010/2011) vs. Month (C, D), and Site vs. Fishing year (E, F).

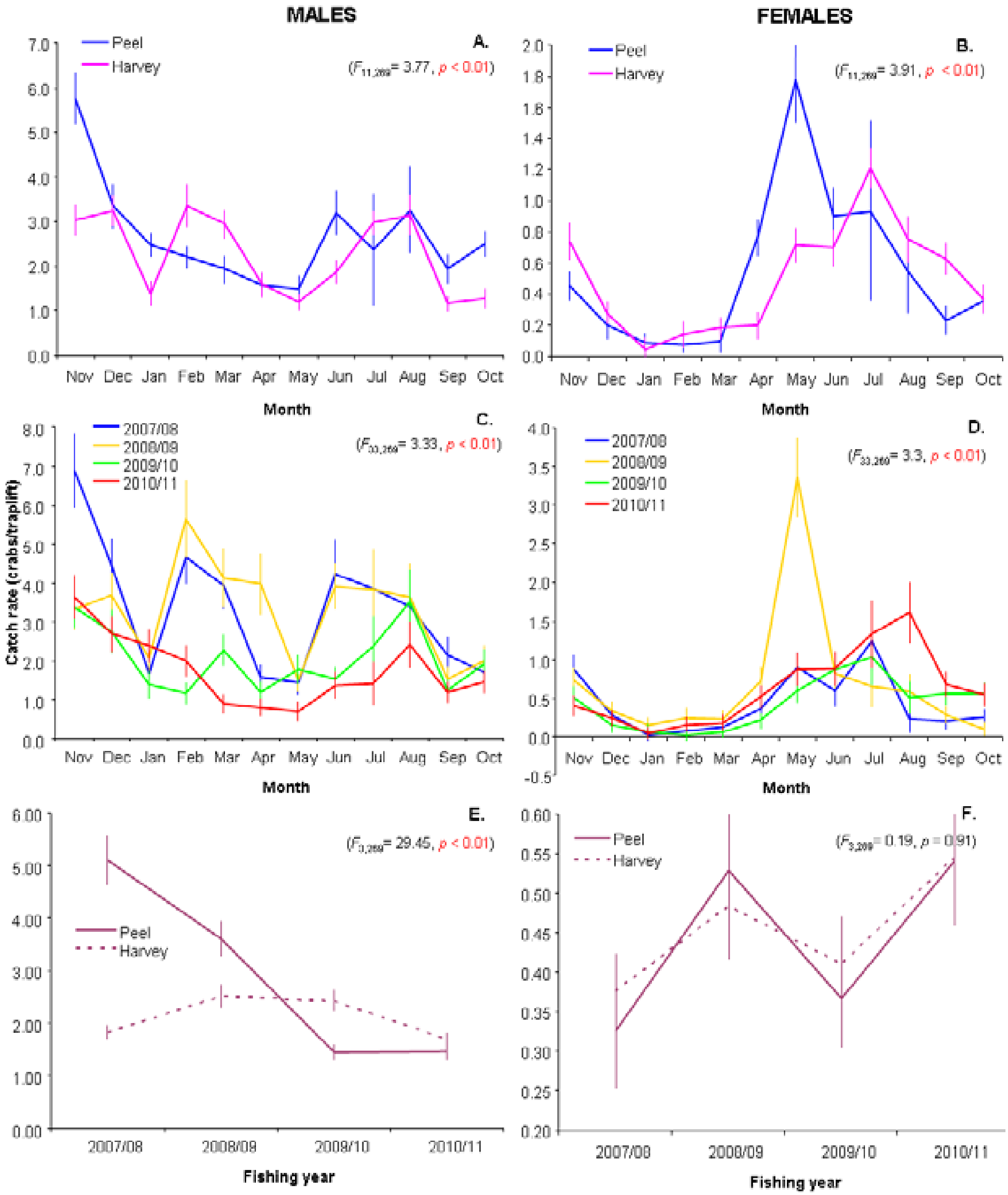

Figure 2.10 Standardised catch rates (mean ± SE) of sexually mature sub-legal males (87.1<CW<127 mm) and females (86.9<CW<127 mm) from commercial catch monitoring surveys plotted by interactions of Month (November – October) vs. Site (Peel and Harvey) (A, B), Fishing year (2007/08 – 2010/2011) vs. Month (C, D), and Site vs. Fishing year (E, F).

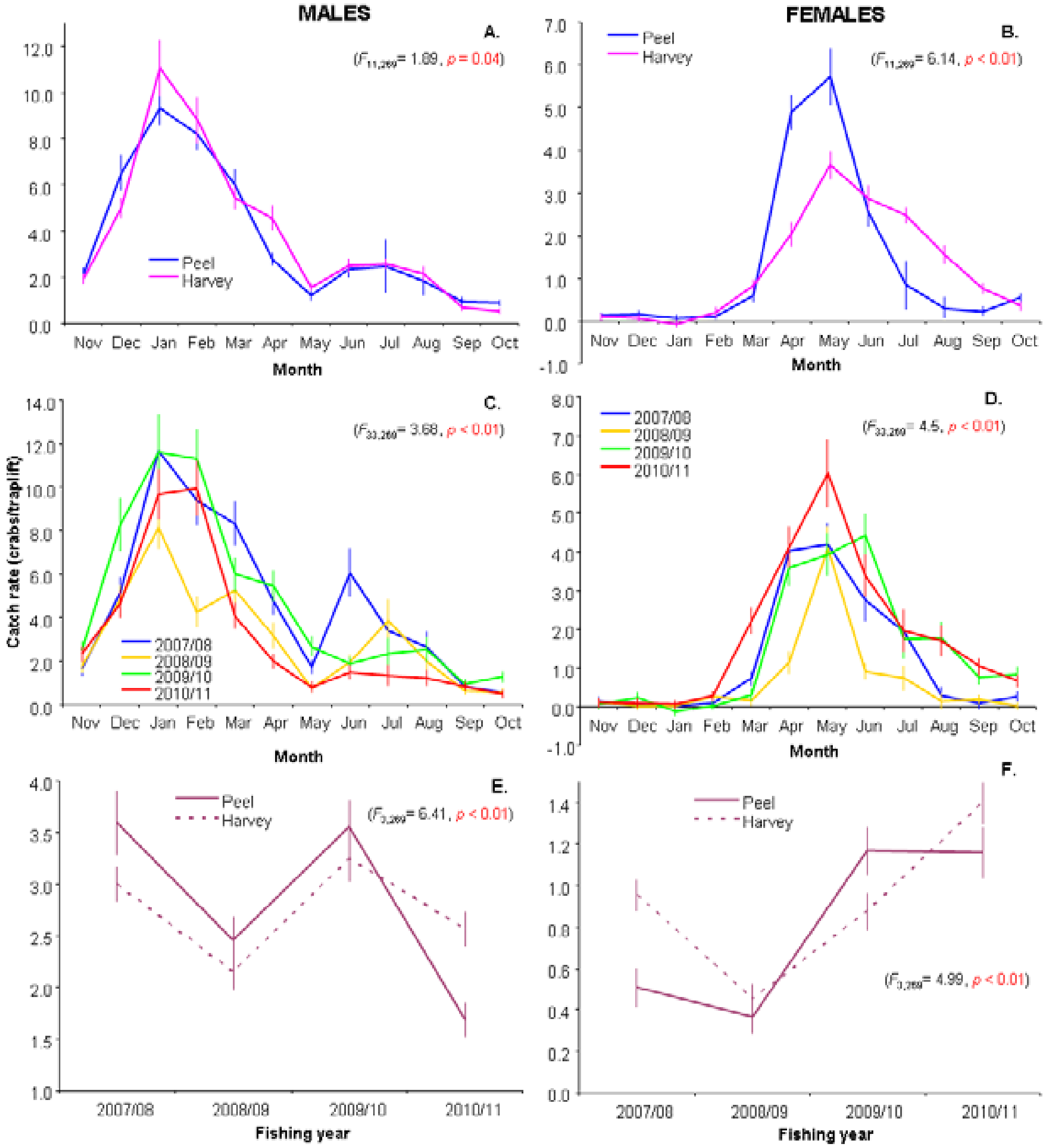

Figure 2.11 Monthly mean (± SE) standardised catch rates of legal-sized (>127 mm CW) males and females from commercial catch monitoring surveys plotted by interactions of Month (November – October) vs. Site (Peel and Harvey) (A, B), Fishing year (2007/08 – 2010/2011) vs. Month (C, D), and Site vs. Fishing year (E, F).

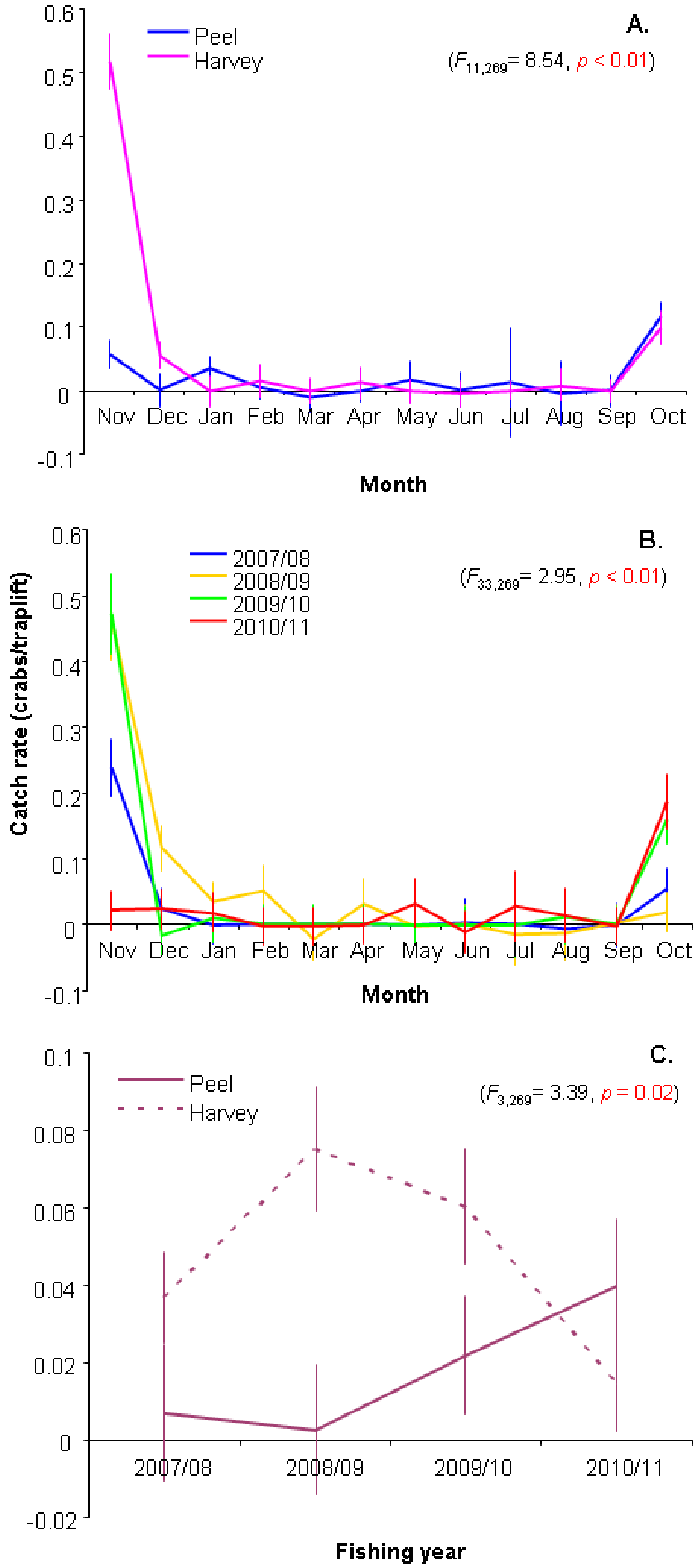

Figure 2.12 Monthly mean (± SE) standardised catch rates of berried (ovigerous) females from commercial catch monitoring surveys plotted by interactions of Month (November – October) vs. Site (Peel and Harvey) (A), Fishing year (2007/08 – 2010/2011) vs. Month (B), and Site vs. Fishing year (C).

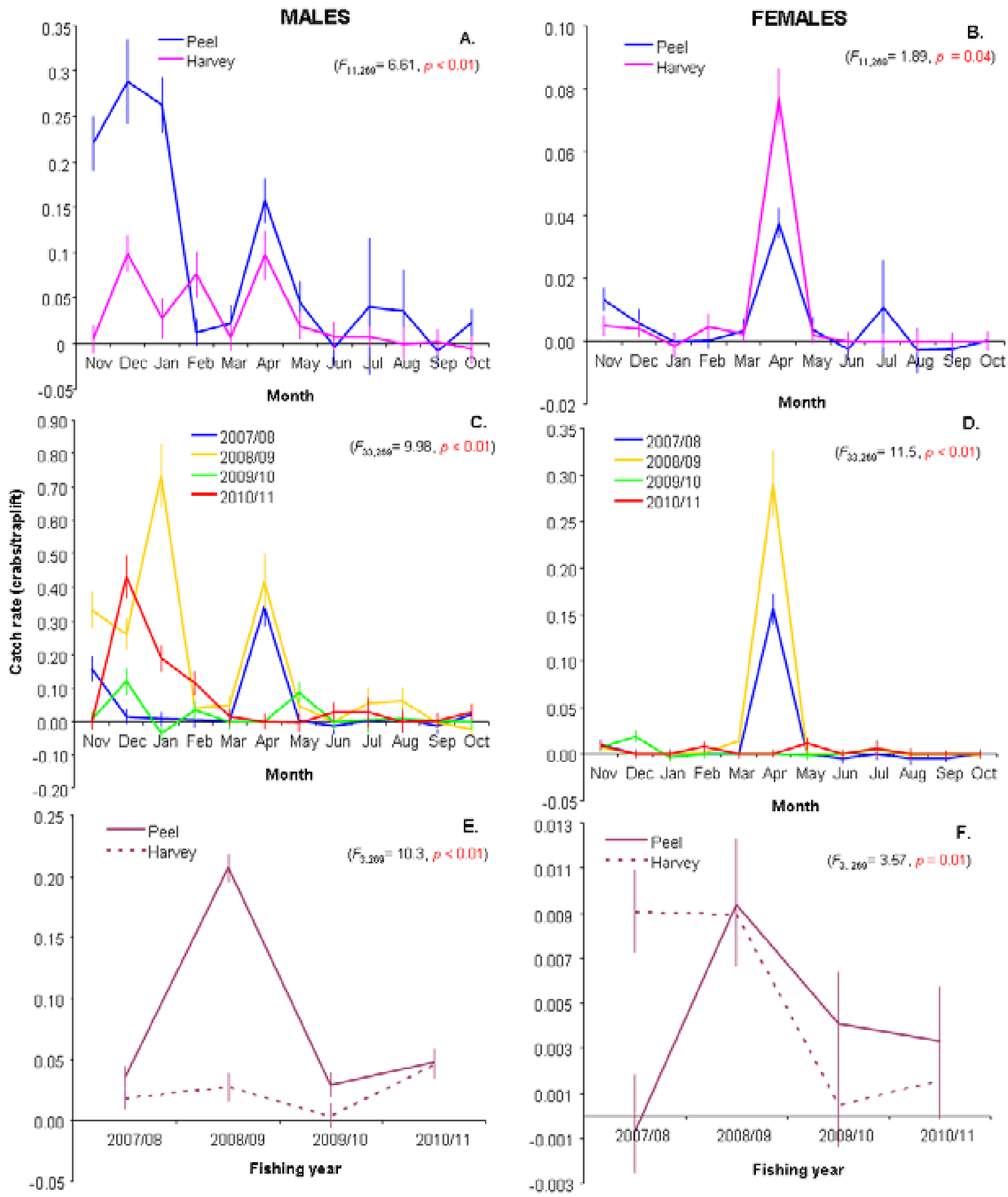

Figure 2.13 Standardised catch rates (mean ± SE) of soft-shelled males and females from commercial catch monitoring surveys plotted by interactions of Month (November – October) vs. Site (Peel and Harvey) (A, B), Fishing year (2007/08 – 2010/2011) vs. Month (C, D), and Site vs. Fishing year (E, F).

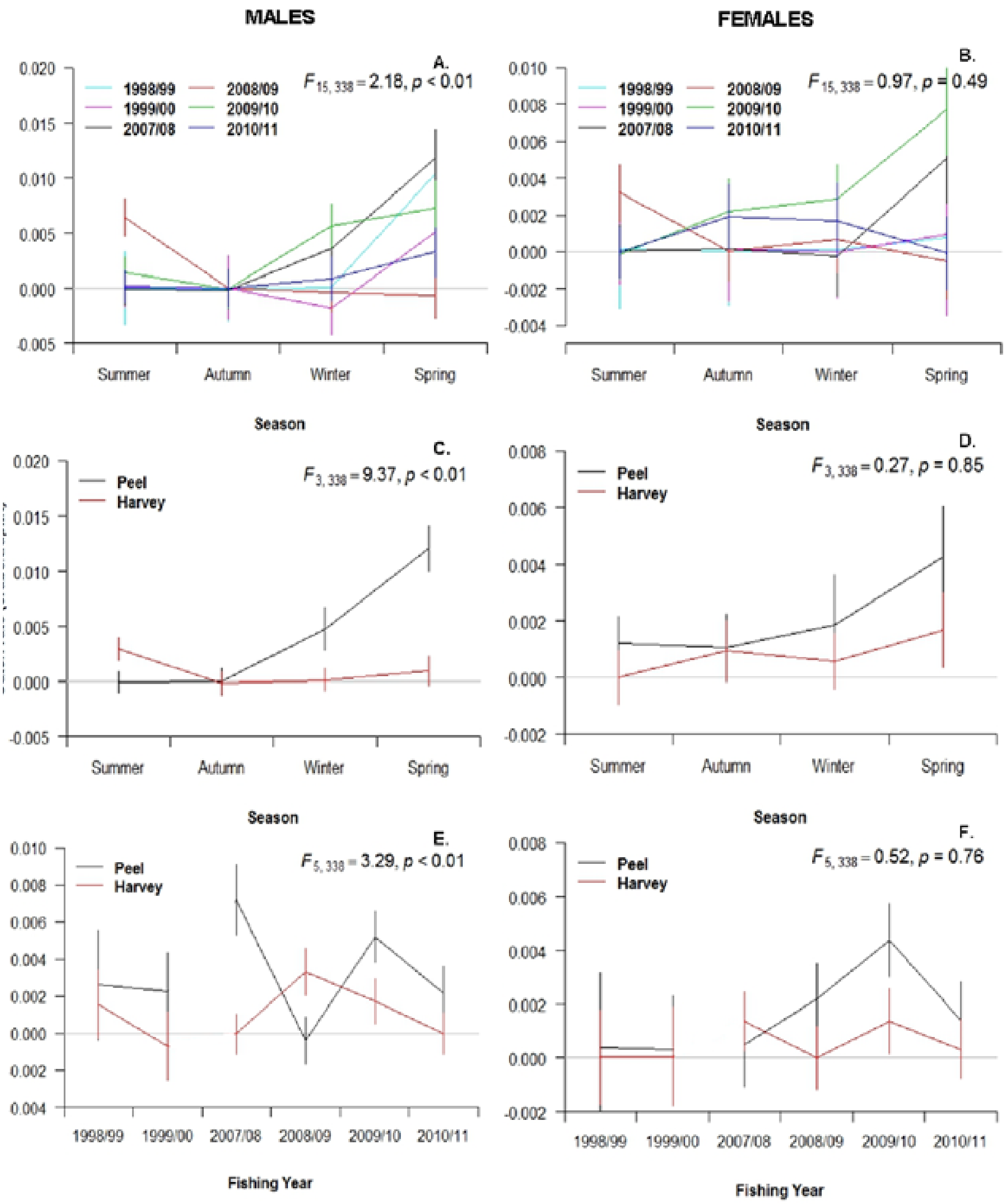

Figure 2.14 Monthly mean (± SE) standardised catch rates of immature males (<87.1 mm CW) and females (<86.9 mm CW) from historical (1998/99, 1999/00) and current (2007/08 – 2010/11) commercial catch monitoring surveys plotted by interactions of Fishing year vs. Season (A,B), Site vs. Season (C,D), and Site vs. Fishing year (E,F).

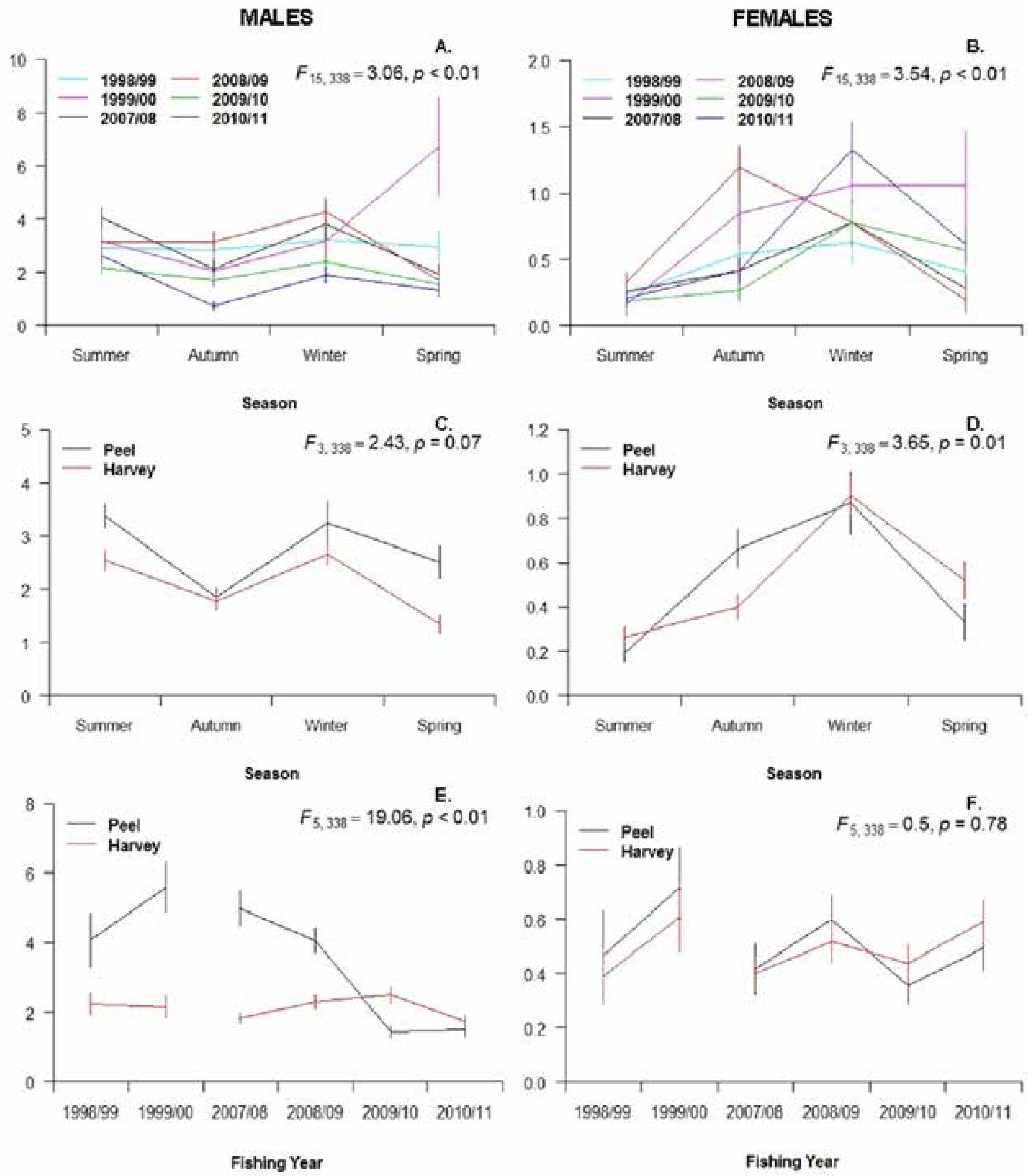

Figure 2.15 Standardised catch rates (mean ± SE) of sexually mature sub-legal males (87.1<CW<127 mm) and females (86.9<CW<127 mm) from historical (1998/99, 1999/00) and current (2007/08 – 2010/11) commercial catch monitoring surveys plotted by interactions of Fishing year vs. Season (A,B), Site vs. Season (C,D), and Site vs. Fishing year (E,F).

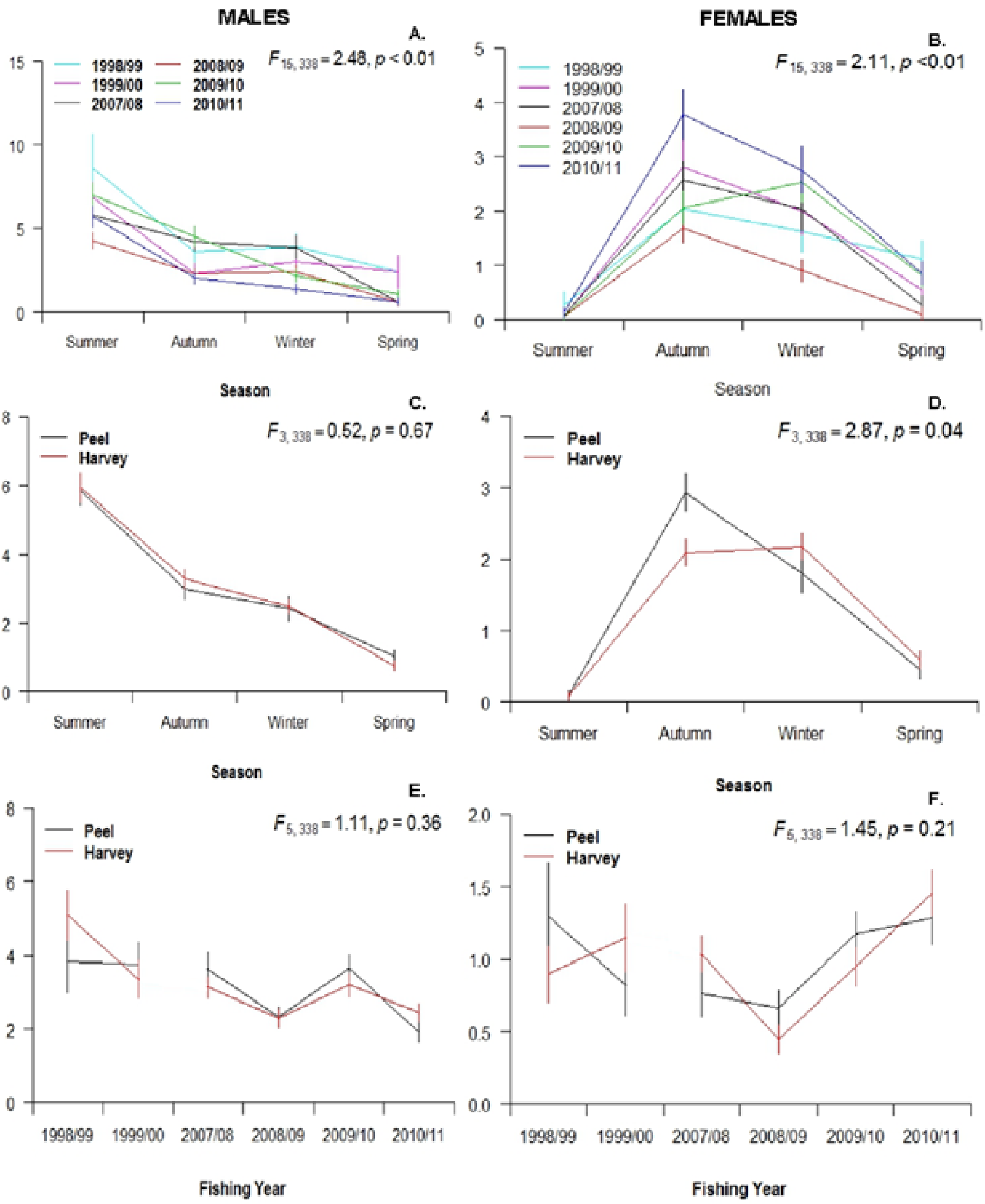

Figure 2.16 Standardised catch rates (mean ± SE) of legal-sized (>127 mm CW) males and females from historical (1998/99, 1999/00) and current (2007/08 – 2010/11) commercial catch monitoring surveys plotted by interactions of Fishing year vs. Season (A,B), Site vs. Season (C,D), and Site vs. Fishing year (E,F).

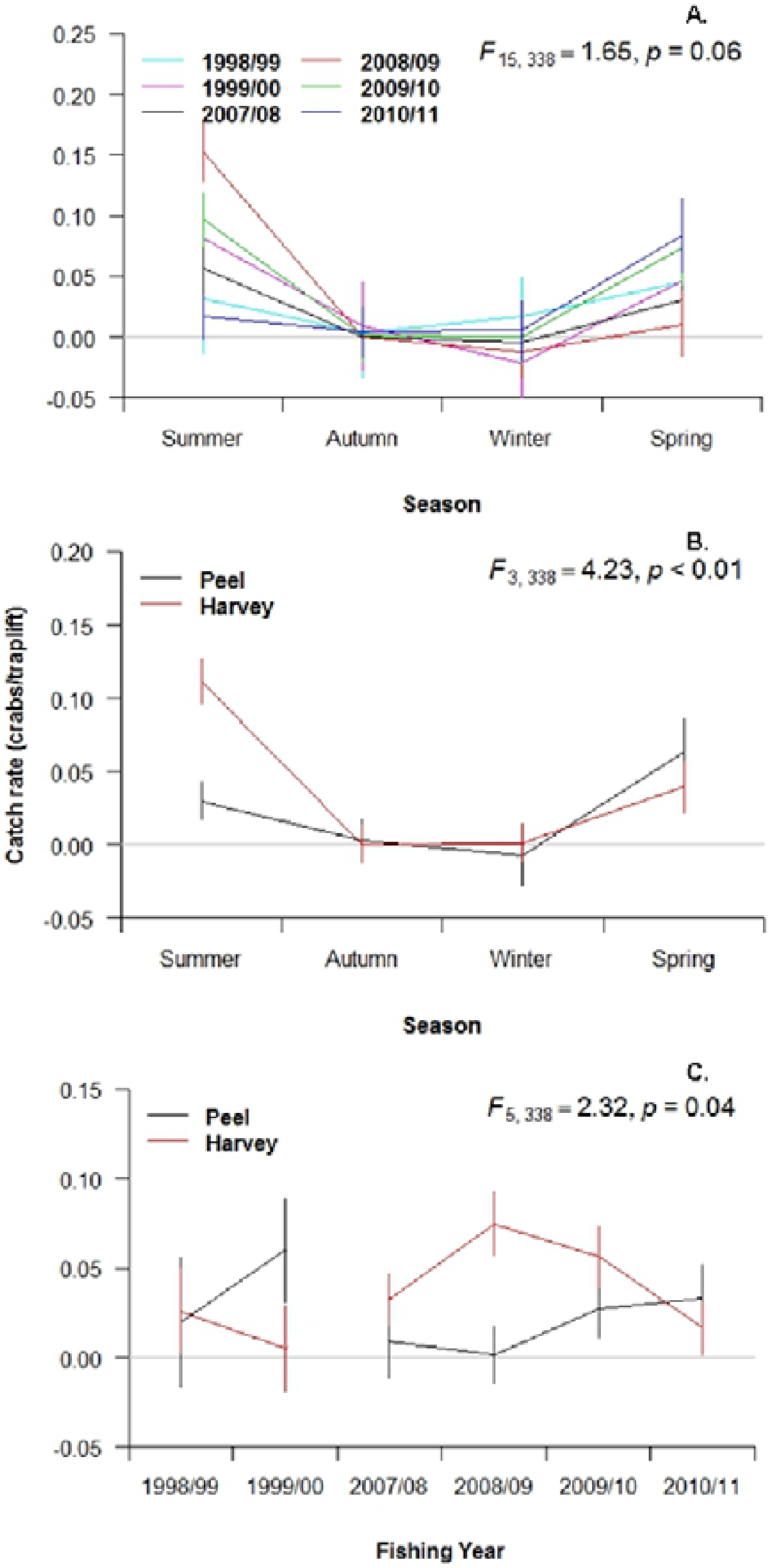

Figure 2.17 Monthly mean (± SE) standardised catch rates of berried (ovigerous) females from historical (1998/99, 1999/00) and current (2007/08 – 2010/11) commercial catch monitoring surveys plotted by interactions of Fishing year vs. Season (A), Site vs. Season (B), and Site vs. Fishing year (C).

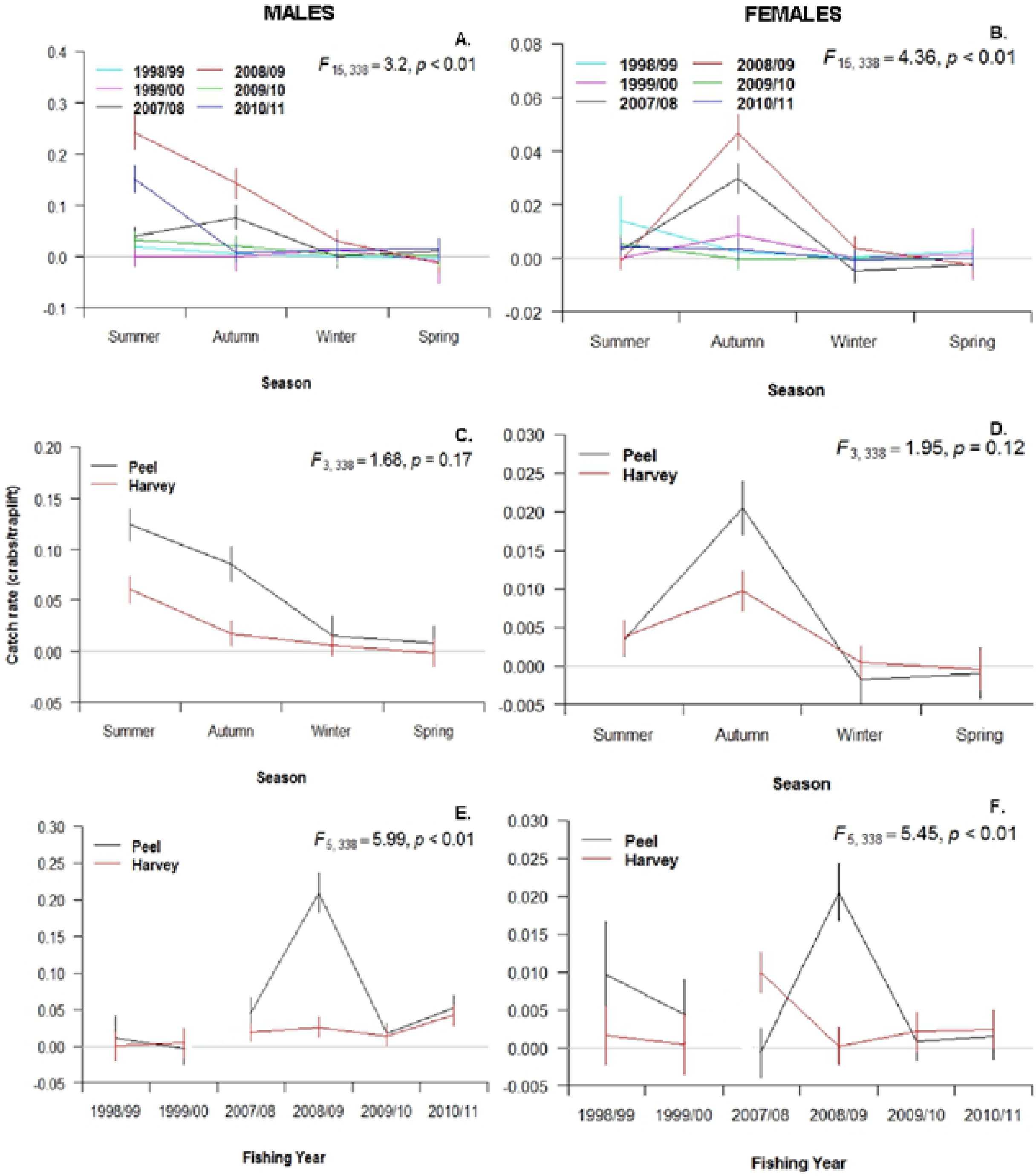

Figure 2.18 Standardised catch rates (mean ± SE) of soft-shelled males and females from historical (1998/99, 1999/00) and current (2007/08 – 2010/11) commercial catch monitoring surveys plotted by interactions of Fishing year vs. Season (A,B), Site vs. Season (C,D), and Site vs. Fishing year (E,F).

3.0 Peel-Harvey Estuary fishery-independent monitoring program: Status of the breeding stock and recruitment

D. Johnston, A. Chandrapavan, C. Marsh, D. Harris, A. Thomson, A. Denham

Objective Fishery-independent monitoring program: determine current recruitment and spawning stock levels of the crab population in the Peel-Harvey Estuary and assess whether the status of stocks has changed considerably in the past decade.

3.1 Introduction

Since the 1980s there have been several intermittent fishery-independent research surveys of the *Portunus armatus* population in the Peel-Harvey Estuary (Potter *et al.* 1983; de Lestang 2002). These surveys differed in their capture methods, study period, and locations, therefore providing only snapshots of the catch composition and distribution in a particular time and location. Collectively the data highlighted critical aspects of life-history traits, stock structure and changes in population dynamics over time.

The first comprehensive population assessment of *P. armatus* was undertaken by Potter *et al.* (1983) when Peel-Harvey Estuary had only one natural entrance channel which opened at the northern end of Peel Inlet (Figure 3.1). Potter *et al.* (1983) sampled the Estuary using a combination of beach seine, gill net and trawl methods and found crab seasonal abundance and distribution related to salinity which was in turn correlated with rainfall patterns. Potter *et al.* (1983) also concluded that crabs reached the minimum legal size (MLS) of 127 mm carapace width (CW) at 12 months of age during summer and migrated out of the Estuary during winter when they are 15 – 20 months old. He also observed greatest abundance of ovigerous females during January and February inside the Estuary.

The eutrophication of the Estuary during the 1970s led to massive blooms of the toxic cyanobacterium *Nodularia spumigena*, which subsequently led to high mortalities amongst benthic fauna including crabs (Potter *et al.* 1983). In an attempt to flush out the excessive build-up of nutrients in the Estuary, a deep artificial entrance channel at Dawesville at the north-western end of the Harvey Estuary was constructed and opened in 1994. The impact of the artificial entrance on the crab population dynamics was investigated by de Lestang (2002). Using a combination of seine net, trawl and trap methods, de Lestang (2002) found the once progressive decline in crab densities from the Estuary Channel to Peel Inlet to Harvey Estuary had changed to more similar densities across the Peel-Harvey Estuary. The extra entrance also created a shorter distance for new recruits to enter the Estuary thus increasing the densities of crabs. The greater intrusion of sea water had led to salinities reaching full sea water strength as early as November (Figure 3.4) which resulted in earlier timing of females becoming ovigerous. Increased tidal water flow and the second entrance may have also provided greater stimulus for ovigerous females to leave the Estuary earlier than previously. Seine netting also allowed the capture of small sized recruits with 3 separate cohorts detected between February and April (Figure 3.17).

In this chapter we examine the current stock dynamics in the Peel-Harvey Estuary and assess any changes that may have occurred since de Lestang's (2002) study. Unlike previous surveys, the current fishery-independent monitoring program extended outside the Estuary to include oceanic sites to supplement data collected from within the Estuary. This is an important aspect of the study given the high mobility of the crab stock in and out of the Estuary. Data on *P. armatus* bycatch from seine netting during 2008 and 2009 (Coulson *et al.* 2010) was also included as it provided a useful comparison with historical seine data collected from de Lestang (2002).

3.2 Methods

3.2.1 Current Fishery-Independent Research Program (2007 – 2011)

Trawl sampling inside the Peel-Harvey Estuary

Initially, this program was designed to use both trawl and trap in order to replicate sites and methods used by de Lestang (2002), and thus produce a comparable dataset. Otter trawl sampling was conducted monthly from February 2007 to January 2009, using the Fisheries Research Vessel Snipe and more recently Fisheries Research Vessel FD 51. Fifteen sites were sampled throughout the Peel-Harvey Estuary; 6 sites in the Harvey Estuary; 6 sites in the Peel Inlet and three sites in the Estuary Channel (Figure 3.1). The otter trawl net had an effective fishing width of 2.6 m (2/3 the head rope length), 0.5 m high with 51 mm mesh in the wings and 25 mm mesh in the cod end. Trawls were conducted during the day, with each shot lasting between 2 – 5 minutes. This equated to a towing speed of approximately 3.5 km h^{-1} for 150 – 300 m during which it sampled an area between 390 and 1300 m^2 (depending on type of substrate and volume of seagrass retained in the net). Unfortunately the increased dominance and abundance of the filamentous green algae *Chaetomorpha* and *Cladophora* (Wilson *et al.* 1995) caused a reduction in trawl net efficiency and prevented successful replication of the trawling program undertaken by de Lestang (2002). The program was therefore only undertaken between February 2007 and January 2009.

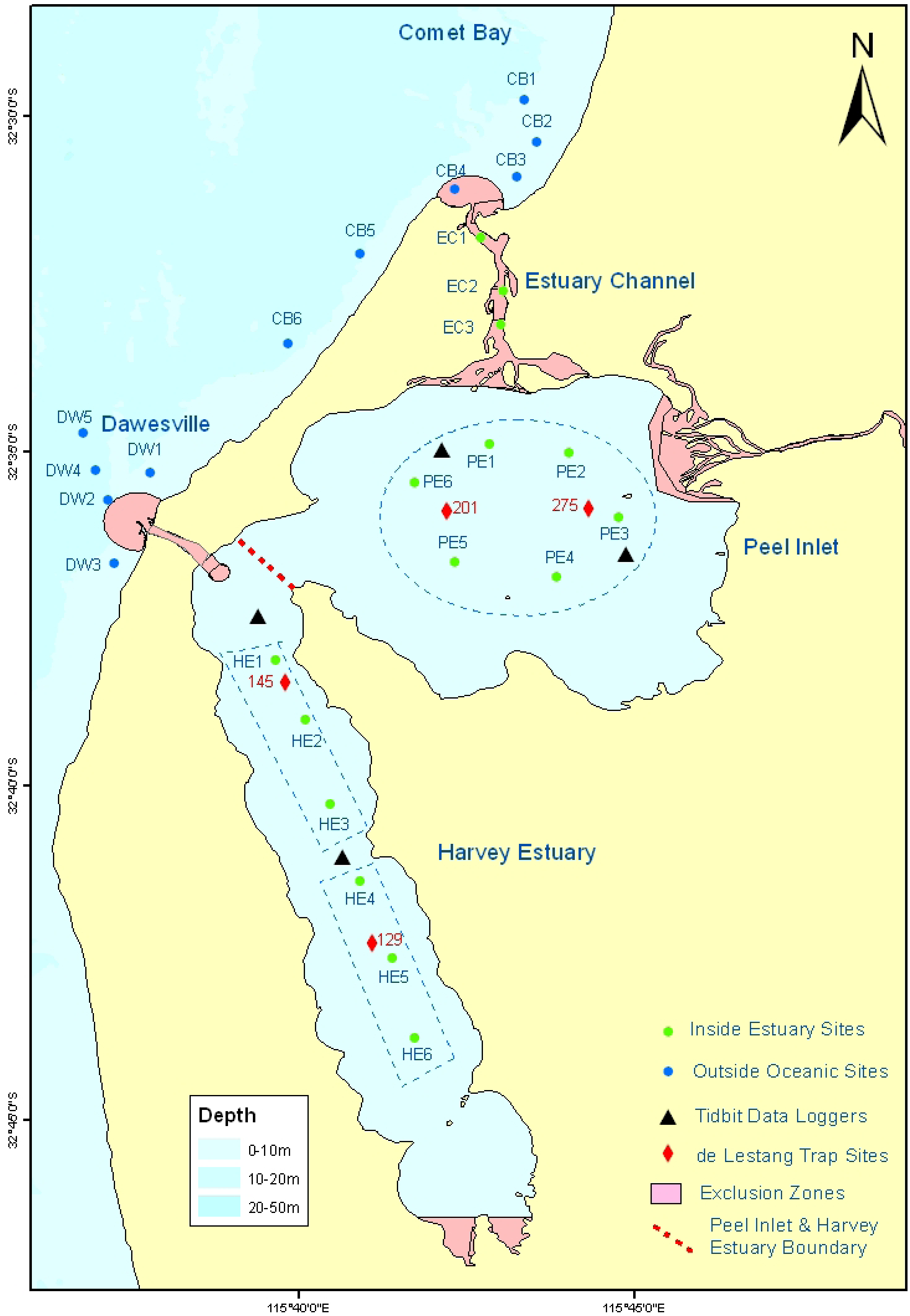

Figure 3.1 Map of Peel-Harvey Estuary detailing fishery-independent research sampling sites inside and outside the Estuary and de Lestang (2002) trap sites. Data from current sampling sites compared to data from de Lestang (2002) sites are indicated by the broken blue line. Sites PE1-6 and 201/275 were compared for Peel region; sites HE1-3 and 145 were compared for Cut-Harvey region; sites HE4-6 and 129 were compared for Deep-Harvey region.

Trap sampling inside Peel-Harvey Estuary

The trap sampling program began in June 2007 with 3 traps being deployed at each of the selected 5 trawl sites (Table 1). From December 2007 to December 2011, 3 traps were set at all 15 PHE trawl sites (Figure 3.1). Individual baited traps on a crab line were deployed 50 m apart with labelled floats for a 24-hour soak duration. These research traps were approximately 116 cm in diameter, 40 – 50 cm extended height and had 2 inch mesh size with no escape gaps so juvenile and sub-legal crabs could be retained (Figure 3.2). Sampling at each site took place once a month and carapace width (CW), sex, berried status and shell condition (soft or hard) were recorded.

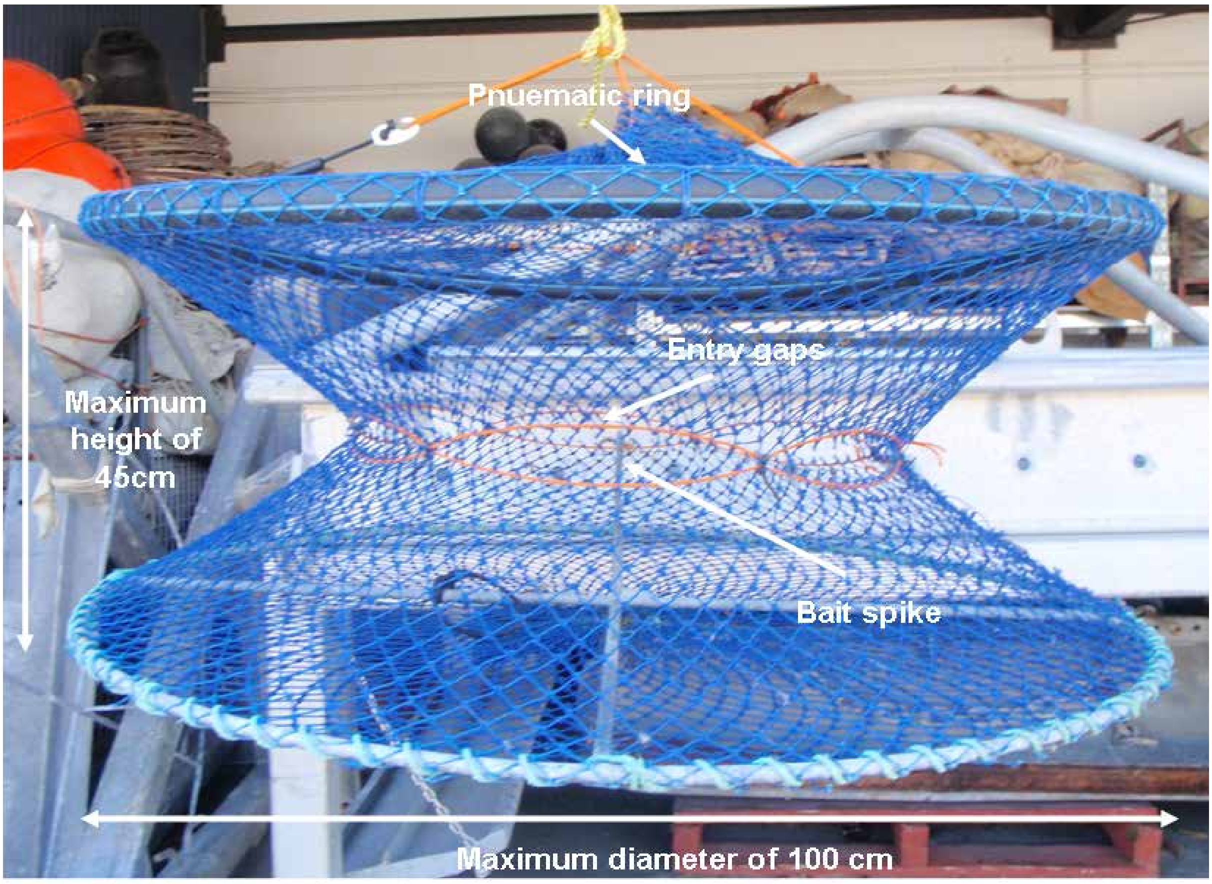

Figure 3.2 An hourglass research crab trap used in the fishery-independent research monitoring surveys. Photo: Chris Marsh

Trap sampling outside Peel-Harvey Estuary

Additional traps were deployed at selected sites outside PHE from August 2008 to December 2011 to understand crab abundance, composition and movement between estuarine and oceanic waters. Initially, there were 6 sites (CB1-6) north of the channel outlet (4 sites within Comet Bay and 2 between the Estuary Channel and Dawesville Cut outlets) and 3 sites close to the Dawesville Cut outlet (DW1-3) which were later expanded to 5 sites (DW4-5) from March 2009 (Figure 3.1, Table 1). At each site, 5 baited traps were deployed ~ 100 m apart with labelled floats for a 24-hour soak duration. Sampling at each site took place once a month at the same time as inside Estuary sites were sampled.

Table 1 Research sampling methods, periods and location for the Peel-Harvey Estuary (PHE) region from February 2007 to December 2011. Refer to Fig 3.1 for site code locations.

Sampling method	Sampling period	Sites sampled
Trawl (~750m)	Feb 2007 – Nov 2007	15 sites (All inside PHE sites)
Trawl (100 – 200m)	Dec 2007 – Jan 2009	4 sites (EC1, EC2, EC3, HE1 only)
Trap	Jun 2007 – Nov 2007	5 sites (3 traps/site) (EC3, HE2, HE5, PE1, PE5 only)
Trap	Dec 2007 – Dec 2011	15 sites (3 traps/site) (PE1-6, HE1-6, EC1-3)
Trap	Aug 2008 – Dec 2011	9 sites outside PHE (CB1-6, DW1-3) (5 traps/site)
Trap	Mar 2009 – Dec 2011	2 sites added outside PHE (DW4-5) (5 traps/site)

3.2.2 Fishery-independent research surveys 1995 – 1998

As part of a study on the biology and stock assessment of *P. armartus* across its main distribution in Western Australia, a short-term fishery-independent research survey program was undertaken by de Lestang (2002) between 1995 and 1998 in the PHE. Greater sampling focus was directed at PHE so as to determine any significant changes to the biological characteristics of *P. armartus* in the Estuary due to the opening of the deep artificial entrance, the Dawesville Channel (referred to as the Dawesville Cut in this report). A combination of seine net, trap and otter trawl fishing methods were used by de Lestang (2002) to sample crabs within the PHE (see Appendix B for a detailed map).

Trapping: A set of 4 lines of 4 baited crab traps (15 m apart) were deployed over 24 hrs in the deeper (2 – 3 m), central region of the Peel Inlet and Harvey Estuary (16 traps per site) (Figure 3.1). Traps were identical to those used by the commercial fishers during this period and were ~63 cm high and 100 cm in diameter and contained 7.6 cm mesh. Trap sampling was conducted monthly (where the size, sex, shell condition and berried status of crabs were recorded) between April 1995 and April 1998, however for some months no trap data was collected for various reasons.

Seine netting: Three different seine nets were used by de Lestang (2002) for sampling in the PHE; a 10.5 m (two 4.5 m wings of 6 mm mesh, 1.5 m pocket of 3 mm mesh), a 21.5 m (two 10 m wings of 9/3 mm mesh and a 1.5 m bunt of 3 mm mesh) and a 102.5 m (2.5 m wings of 25/13 mm mesh and 2.5 m bunt of 9.5 mm mesh). The distance covered by the 10.5 m seine net after 5 min of hauling was 75 – 130 m, while the area covered by the 21.5 m and 102.5 m seine nets were ~116 m^2 and ~1670 m^2 respectively.

Trawling: The otter trawl net was 0.5 m high and 5 m long with an effective fishing width of 2.6 m and consisted of 51 mm mesh in the wings and 25 mm mesh in the bunt (i.e. same as trawl nets used for current surveys). The net was towed at ~3.5 km h^{-1} for 150 – 500 m.

3.2.3 Additional fishery-independent beach seine surveys

Additional information on *P. armatus* in the PHE became available during the course of this study as crabs were caught as bycatch from sampling undertaken in a separate study investigating abundance and distribution of fish fauna in the PHE (WAMSI Node 4.2.1A, Assessment of marine communities and the impact of anthropogenic influences). This data was collected by Peter Coulson and colleagues (Murdoch University) from beach seining of several near-shore sites using a 21.5 m and 102.5 m seine nets to predominantly target small finfish. All captured crabs were sexed and measured from seine netting at selected sites in near-shore, shallow waters of five regions of the PHE, ie. eastern and western Peel Inlet, the northern and southern Harvey Estuary and the Estuary Channel (see A B for a detailed map) during October 2008, January, April, July and October in 2009, January and April 2010. Length-frequency information from this dataset is presented in this report and has not been published elsewhere.

3.2.4 Environmental Monitoring

Environmental parameters such as water temperature, salinity, dissolved oxygen and pH were monitored during the current fishery-independent research surveys. A Hanna meter environmental multi probe (Hanna Instruments Pty Ltd) was used for in situ spot water quality readings at 5 sites (EC2, PE2, PE5, HE2 and HE5) within the Estuary from July 2007 to December 2011 (Figure 3.1). These 5 key sites were used to represent the entire sampling program from the Estuary Channel, through the Peel Inlet and into the Harvey Estuary. Temperature, salinity, dissolved oxygen and pH were recorded, however dissolved oxygen was later ceased due to inaccuracies in the data. From August 2007 Tidbit temperature loggers (OneTemp Pty. Ltd.) were deployed at 2 locations in the Peel Inlet and 2 locations in the Harvey Estuary. The loggers were attached to the static platforms and ski marker beacons in the Peel Inlet and Harvey Estuary. In January 2010 after several loggers were consistently lost from the ski marker beacons due to human interference, the number of loggers was reduced to 2. Statistical analyses suggested there was no significant variation between the 4 initial sites to warrant continuing with 4 loggers. Mean monthly rainfall data was obtained from the Bureau of Meteorology (BOM) for the Peel-Harvey region between 2007 and 2010.

3.2.5 Statistical Analyses

Current Fishery-Independent Research Surveys

Catch rate trends were analysed using ANOVA on the variables fishing year (Nov 2008 – Oct 2009, Nov 2009 – Oct 2010, Nov 2010 – Oct 2011), month (Nov – Oct) and site (Deep-Harvey, Cut-Harvey, Peel, Estuary Channel and Outside (oceanic sites)). The 2007/08 fishing year was omitted from the analyses since outside oceanic sampling did not begin until August 2008, however this year was included when comparing inside estuary sites (Table 1). The crab categories modelled were same as those of the commercial monitoring except soft-shelled crabs due to insufficient data. The environmental variables of water temperature and salinity at the time of sampling at each site were initially used as covariates in the model. However they were found to be not significant and were therefore dropped from the model in the final analysis. Catch rates (crabs/traplift) were weighted by the number of traplifts and modelled for the fishery as:

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

where

$y_{i,j,k}$ is the catch rate (crabs/traplift) for fishing year i and month j at site k for observation l;

Δ is a constant chosen to give Normal errors;

α_i is fishing year i ϵ (2008/09, 2009/10, 2010/11);

β_j is month j ϵ (November – October);

γ_k is site k ϵ (Deep-Harvey, Cut-Harvey, Peel, Estuary Channel, Outside);

$\alpha i\beta_j$, $\alpha i\gamma_k$, $\beta_j\gamma_k$ are interactions between the fishing year, month and site.

As the dataset was unbalanced, Type III sums of squares was used and least-square means are presented (SAS Institute Inc. 1989). Back-transformed least-square means have been calculated to obtain standardized estimates for the catch rates at each factor level. Three-way interactions were not included in these analyses due to the dataset not being complete at this level.

Comparison of current and historical fishery-independent surveys

Catch rate trends from current fishery-independent research surveys were analysed together with de Lestang (2002) surveys using ANOVA. Since de Lestang (2002) did not sample every month using the trapping method, seasonal trends of summer (Dec – Feb), autumn (Mar – May), winter (Jun – Aug), spring (Sep – Nov) were examined. There were only four sites within the Peel-Harvey Estuary (no sampling in the Estuary Channel or outside oceanic waters) where trap sampling was undertaken by de Lestang (2002) and thus sites from the current surveys that were closest to de Lestang's (2002) sites were condensed and re-classified as Cut-Harvey, Deep-Harvey and Peel (Figure 3.1). Since only the inside PHE sites were included in these analyses, data from the 2007/08 fishing year were included in these statistical analyses.

Catch rates (crabs/traplift) were weighted by the number of traplifts and modelled for the fishery as:

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

where

$y_{i,j,k}$ is the catch rate (crabs/traplift) for fishing year i and season j at site k for observation l;

Δ is a constant chosen to give Normal errors;

α_i is fishing year i ϵ (1996/97, 2007/08, 2008/09, 2009/10, 2010/11);

γ_k is season j ϵ (Summer, Autumn, Winter, Spring);

γ_k is site k ϵ (Peel, Cut-Harvey, Deep-Harvey);

$\alpha_i\beta_j$, $\alpha_i\gamma_k$, $\beta_j\gamma_k$ are interactions between the fishing year, season and site.

All size categories were modelled as before, however due to missing data relating to ovigerous females and soft-shelled crabs from de Lestang's (2002) surveys, these categories were excluded from analyses. Environmental covariates were not used in the model. As the dataset was unbalanced, Type III sums of squares was used and least-square means are presented (SAS Institute Inc. 1989). Back-transformed least-square means have been calculated to obtain standardized estimates for the catch rates at each factor level. Three-way interactions where possible were included in these analyses.

3.3 Results

3.3.1 Environmental monitoring

Annual rainfall patterns for the 2007 – 11 time series shows a trend of increasing rainfall from April onwards with maximum occurring during the winter months followed by a highly variable decline towards summer months (Figure 3.3). Exceptions to this pattern were 2008 which showed high rainfall of 140 – 160 mm recorded much earlier in April followed by a drastic drop to 20 mm in August, and an unusual peak of ~100 mm in November rainfall during 2011. The current mean monthly water temperature for the summer months appear to be lower than a decade ago, while winter temperatures are slightly higher than the 1995 – 1998 time series (Figure 3.4a). Mean monthly salinities are similar across all three time series in the Estuary Channel (Figure 3.4b), however in the Peel and Harvey there is a clear increase in mean salinities between June and October 1980 – 1981 to current years 2007 – 2011 (Figure 3.4c,d), probably as a result of the Dawesville Cut.

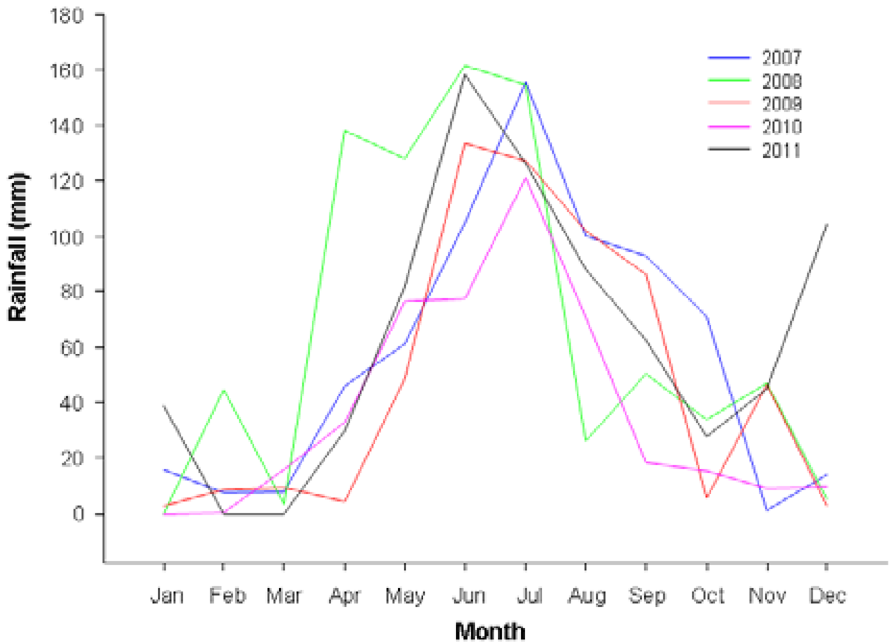

Figure 3.3 Mean monthly rainfall data for the Peel-Harvey region (Sourced from Bureau of Meteorology).

3.3.2 Current fishery-independent trap survey

Length frequency distributions of catches from fishery-independent research surveys were generally unimodal although there were distinct differences in sex ratios and size categories for corresponding months between the inside PHE sites, the Estuary Channel sites and the outside oceanic sites (Figure 3.5 – Figure 3.7). A large proportion of captured crabs from inside the Peel-Harvey and Channel sites were sub-legal (<127 mm). Catches inside PHE were male dominated for most of the year with highest catch rate of 3.0 crabs/traplift for any size-class during summer months, while female (non-berried) catch rate was highly variable and generally less than 1.0 crabs/traplift (Figure 3.5). The very small-sized crabs were apparent during June to October. In contrast, the catch composition from the Estuary Channel sites showed equal sex ratios for most size classes, with catch rates reaching 2.5 crabs/traplift per for some size classes (Figure 3.6). Notably the catch rate of legal-sized females exceeded males in May and June. New recruits were again present after June.

The length frequency distributions from the outside oceanic sites showed catch rates of crabs generally below 1.0 crab/traplift for all size classes. Females dominate the catch composition throughout the year with an increasing trend of legal-sized females from April to September (Figure 3.7). Catch rate of ovigerous females were not detectable from the inside PHE sites but higher catch rates were recorded between October and January from the Estuary Channel sites and the outside oceanic sites.

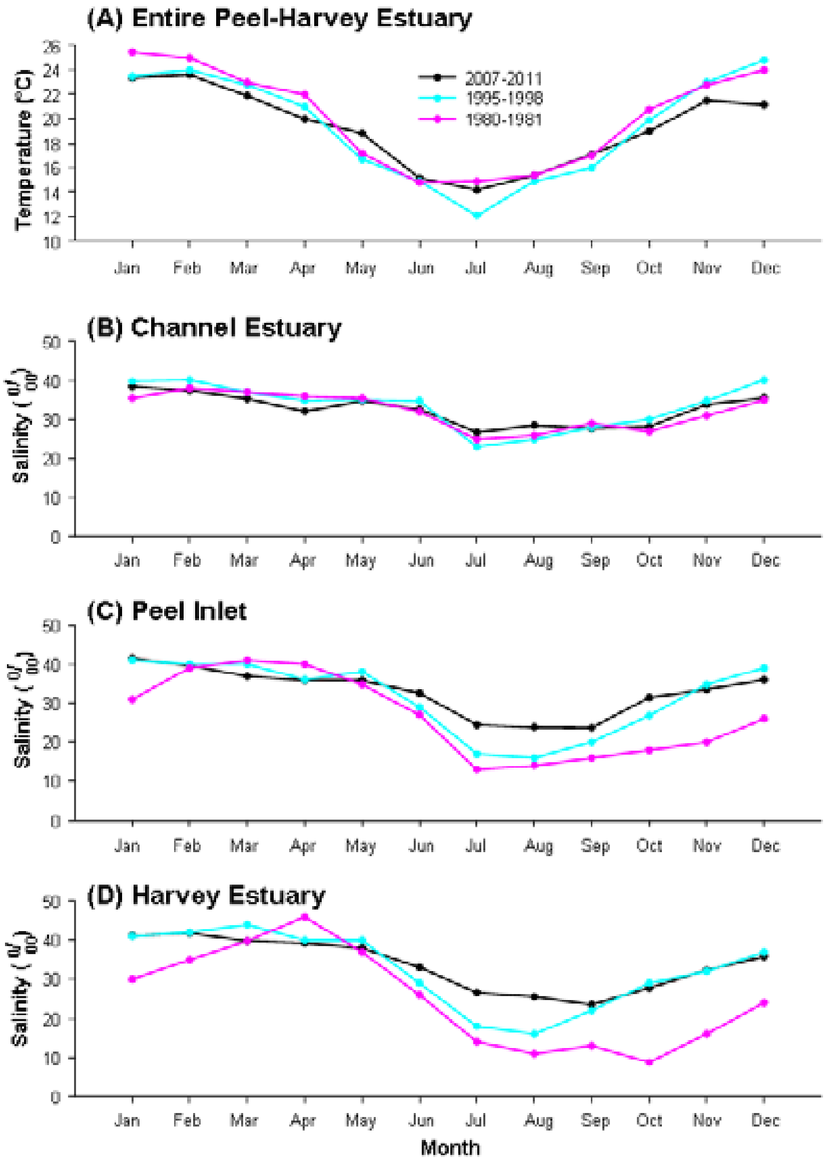

Figure 3.4 Mean monthly water temperature in the Peel-Harvey Estuary and mean monthly salinities in different regions of the Peel-Harvey Estuary during the Pre-Dawesville Channel period (1980 – 1981)(Potter 1983), Post-Dawesville Channel Period (1995 – 1998)(de Lestang 2002) and during the fishery-independent research surveys (2007 – 2011).

Immature crabs: There were significant effects of fishing year, month and site on the catch rates of immature crabs (Appendix F – ANOVA Tables from fishery-independent research survey analyses, Table 26 & Table 27). The catch rate of immature males increased from < 0.2 crabs/traplift between January and May to > 0.5 crabs/traplift between June and December (Figure 3.8a), with highest catches from the Estuary Channel followed by the Peel, Harvey and outside sites. Similarly the catch rate of immature females was higher than average between June and October and highest catch rates were recorded at the Estuary Channel site (Figure 3.8b). Catch rate of immature crabs during 2008/09 were less than 2009/10 between March and October (Figure 3.8c, d), and higher catch rates from the Peel and Estuary Channel sites for males and females in 2009/10 (Figure 3.8e, f).

Sexually mature sub-legal crabs: The sub-legal mature size class recorded the highest catch rates among all the size categories retained by the research traps with catch rates reaching 15 crabs/traplift for males. There were significant effects of site, month and fishing year on the catch rates of males and females (Appendix F – ANOVA Tables from fishery-independent research survey analyses, Highest catch rates of sub-legal males were recorded at the Deep-Harvey site at ~15 crabs/traplift between November and January which then steadily decreased to ~ 5 crabs/traplift in April. This temporal trend was similar for the Cut-Harvey and Peel, with the Channel sites having a more consistent catch rate of 5 – 10 crabs per traplift with peaks in December and July (Figure 3.9a). Low catch rates were obtained during April and May, and as crabs leave the Estuary in the following two months, catch rates increase in the Estuary Channel and Cut-Harvey sites. For sexually mature sub-legal females, the monthly catch rate of < 2 crabs/traplift were observed for most sites across all months with the exception of the Estuary Channel site where catch rates were generally 2 – 8 crabs/traplift with peaks in January and June (Figure 3.9b). Catch rates of males and females from the outside sites were generally < 2 crabs/traplift with no clear temporal patterns present.

Temporal monthly trends were generally similar across the three fishing years for both sexes (Figure 3.9c,d), with the exception of males between November and April where catch rates from 2008/09 were much higher than other fishing years (Figure 3.9c). Unlike males where catch rates from the oceanic site were the lowest across all sites (Figure 3.9e), female catch rates from the oceanic site were similar to Peel and Harvey and all significantly lower than the Estuary Channel (Figure 3.9f).

Legal crabs: There was a significant interaction between site and month on the catch rate of legal males and females (Appendix F – ANOVA Tables from fishery-independent research survey analyses). The spatio-temporal catch rate trends for legal males showed highest catches during January across all sites, and catch rates from the Harvey sites were almost two-fold higher than the Peel and Estuary Channel sites (Figure 3.10a). Highest catch rates of legal females were recorded during May (4.4 crabs/traplift) from the Estuary Channel site (Figure 3.10b) and for other sites peak catches generally occurred during April. Between July and October, catch rates of legal females were highest from the Estuary Channel and outside oceanic sites, which is most likely due to the movement of crabs out of the Estuary. Catch rates of legal male and female crabs were lowest during 2008/09 across most months (Figure 3.10c, d) and all sites (Figure 3.10e, f).

Berried females: Highest catch rate of berried females occurred between November and January across all sites and was almost nil between March and August (Figure 3.11a). The higher catch rates of berried females from the Estuary Channel site and to some extent the outside oceanic sites supports the hypothesis that female crabs probably migrate out of the Estuary in winter to spawn during the summer months. Interactions between fishing year and month (Figure 3.11b) and site (Figure 3.11c) were not significant (Appendix F – ANOVA Tables from fishery-independent research survey analyses).

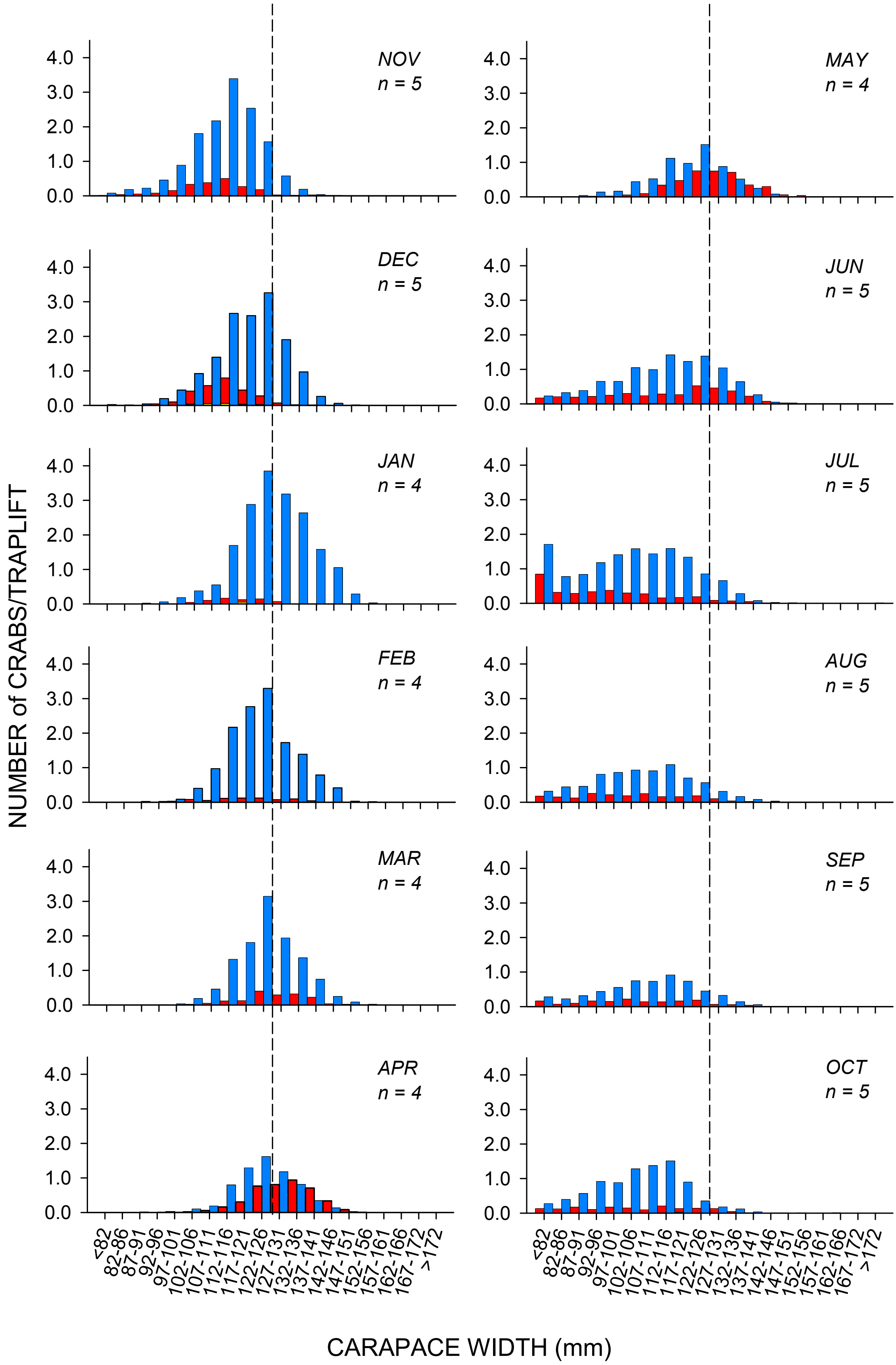

Figure 3.5 Mean monthly length frequency distributions of male (■), female (■), and ovigerous female (■) blue swimmer crabs from fishery-independent research trap surveys in the Peel-Harvey Estuary (excluding Estuary Channel and oceanic sites) between June 2007 and December 2011 inclusive. Minimum commercial size limit of 127 mm CW (- - -). *n* = number of years sampled.

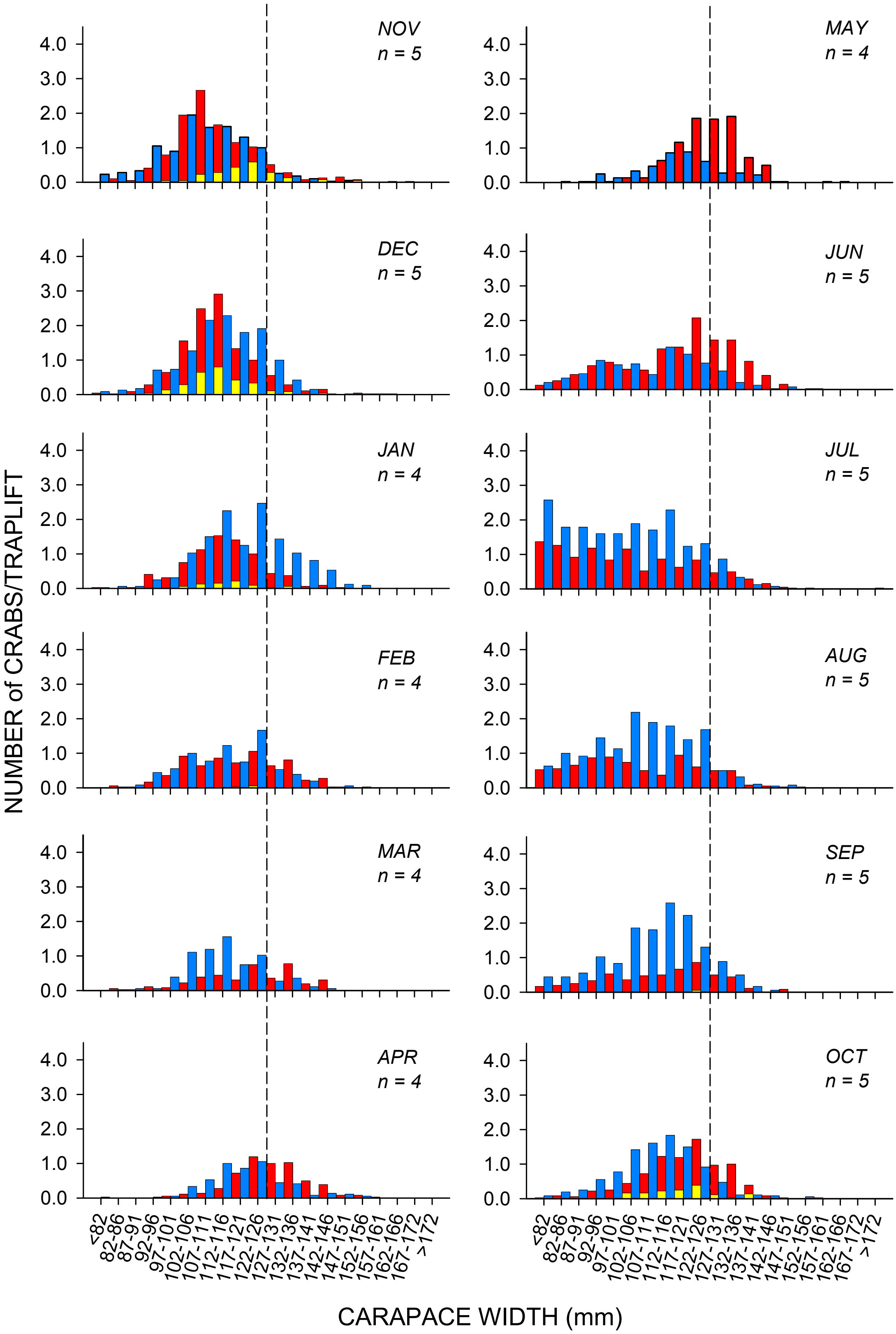

Figure 3.6 Mean monthly length frequency distributions of male (■), female (■), and ovigerous female (■) blue swimmer crabs captured during fishery-independent trap surveys in the Estuary Channel of the Peel-Harvey Estuary between June 2007 and December 2011 inclusive. Minimum commercial size limit of 127 mm CW (- - -). Note the Estuary Channel is a no fishing zone. *n* = number of years sampled.

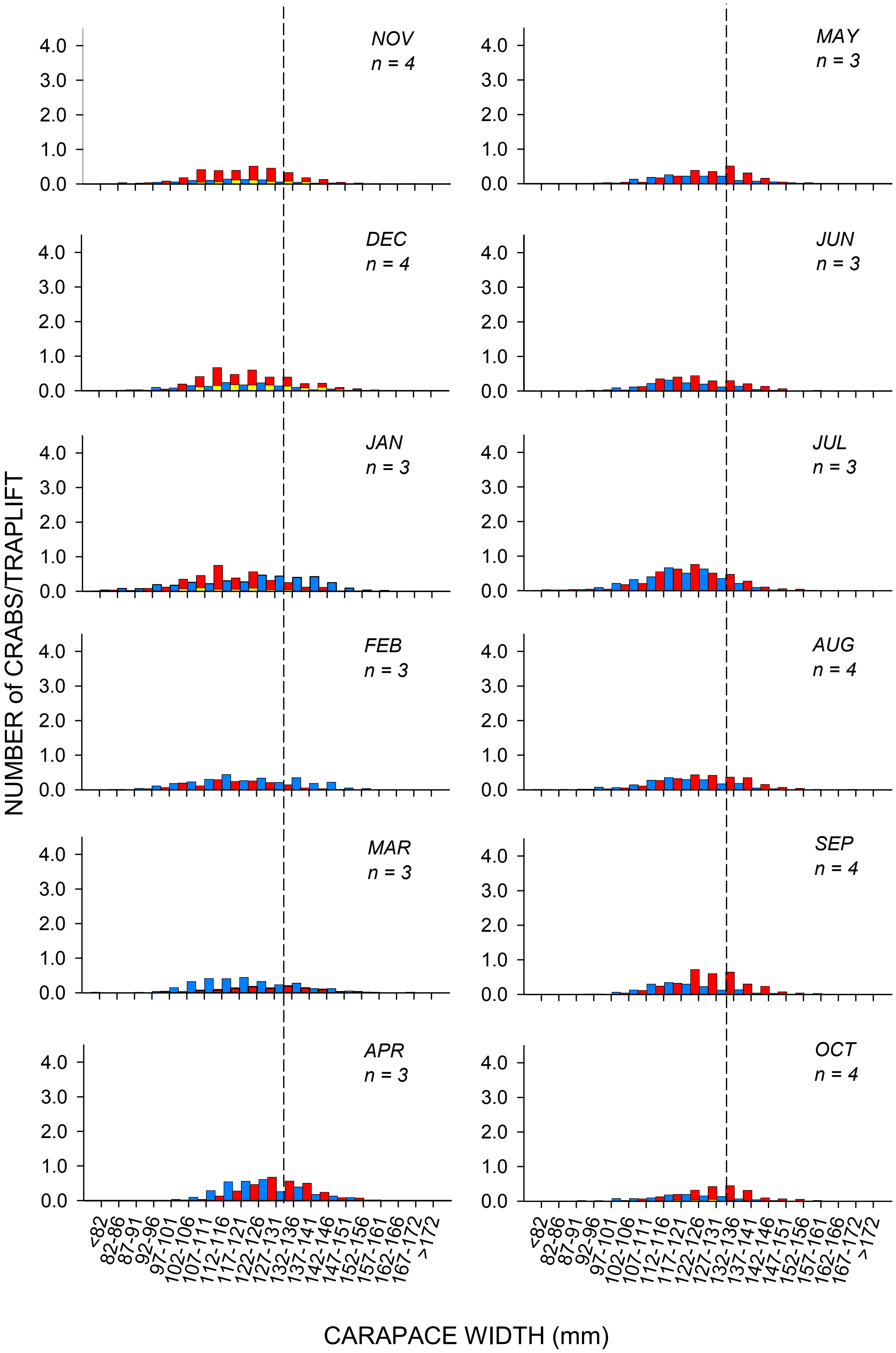

Figure 3.7 Mean monthly length frequency distributions of male (■), female (■), and ovigerous female (■) blue swimmer crabs captured during fishery-independent trap surveys in the oceanic waters immediately outside of the Peel-Harvey Estuary between August 2008 and December 2011 inclusive. Minimum commercial size limit of 127 mm CW (- - -). *n* = number of years sampled.

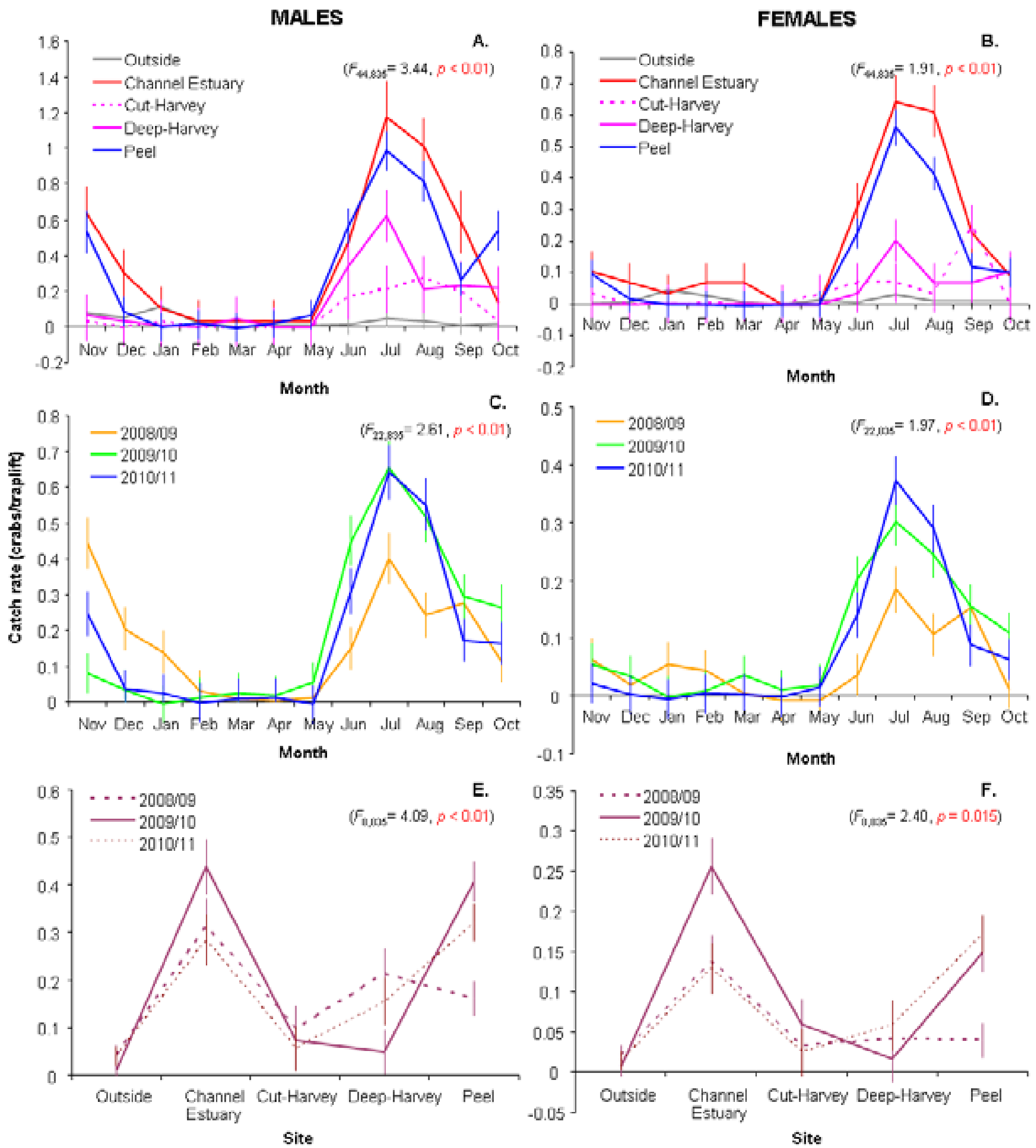

Figure 3.8 Catch rates (mean ± SE) of immature males (<87.1 mm CW) and females (<86.9 mm CW) from fishery-independent research surveys plotted by their interactions of Month (Nov – Oct) vs. Site (Outside, Estuary Channel, Cut-Harvey, Deep-Harvey and Peel) (A, B), Fishing year (2008/09 – 2010/11) vs. Month (C, D), and Fishing year vs. Site (E, F).

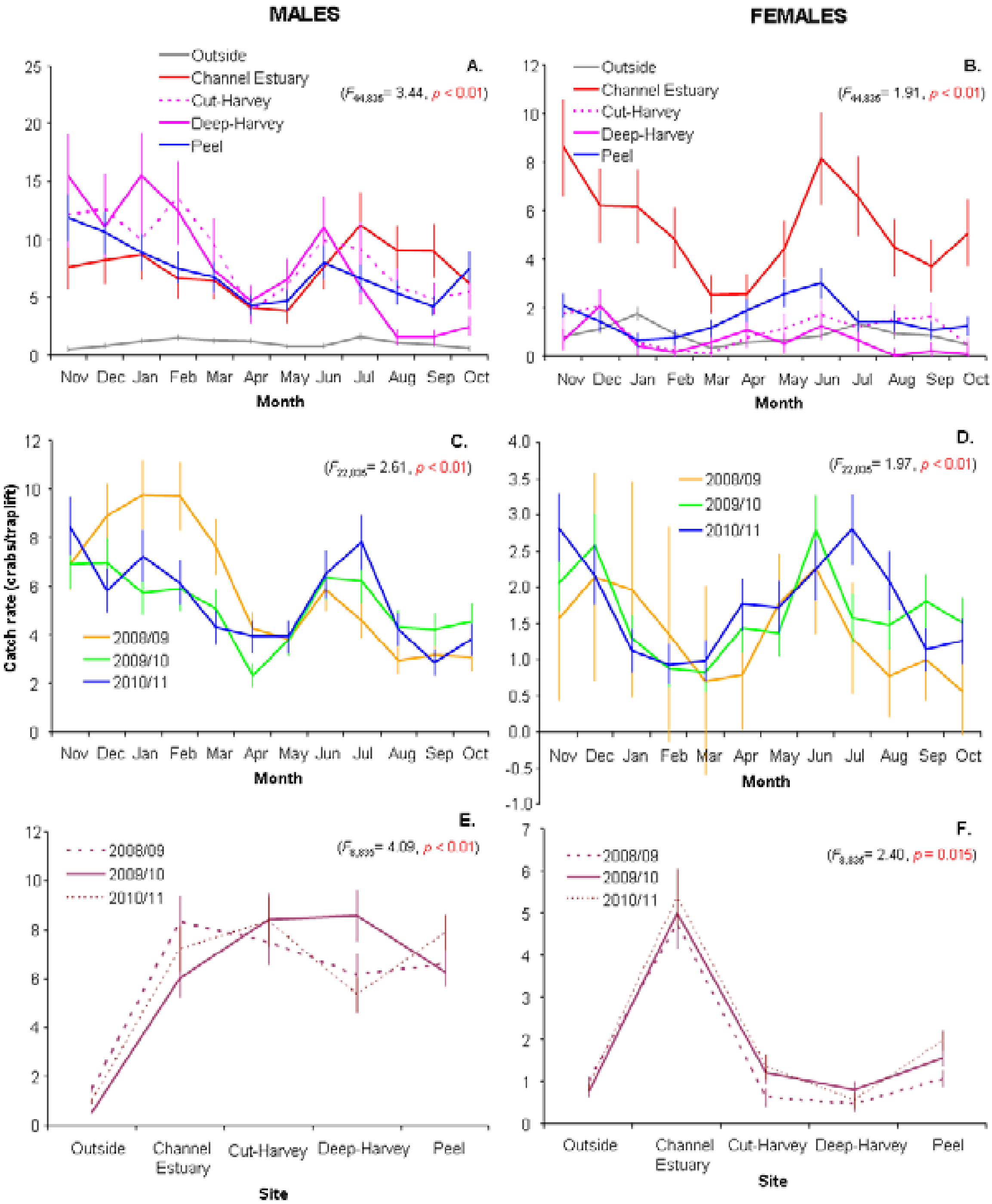

Figure 3.9 Catch rates (mean ± SE) of sexually mature sub-legal males (87.1<CW<127 mm) and females (86.9<CW<127 mm) from fishery-independent research surveys plotted by their interactions of Month (Nov – Oct) vs. Site (Outside, Estuary Channel, Cut-Harvey, Deep-Harvey and Peel) (A, B), Fishing year (2008/09 – 2010/11) vs. Month (C, D), and Fishing year vs. Site (E, F).

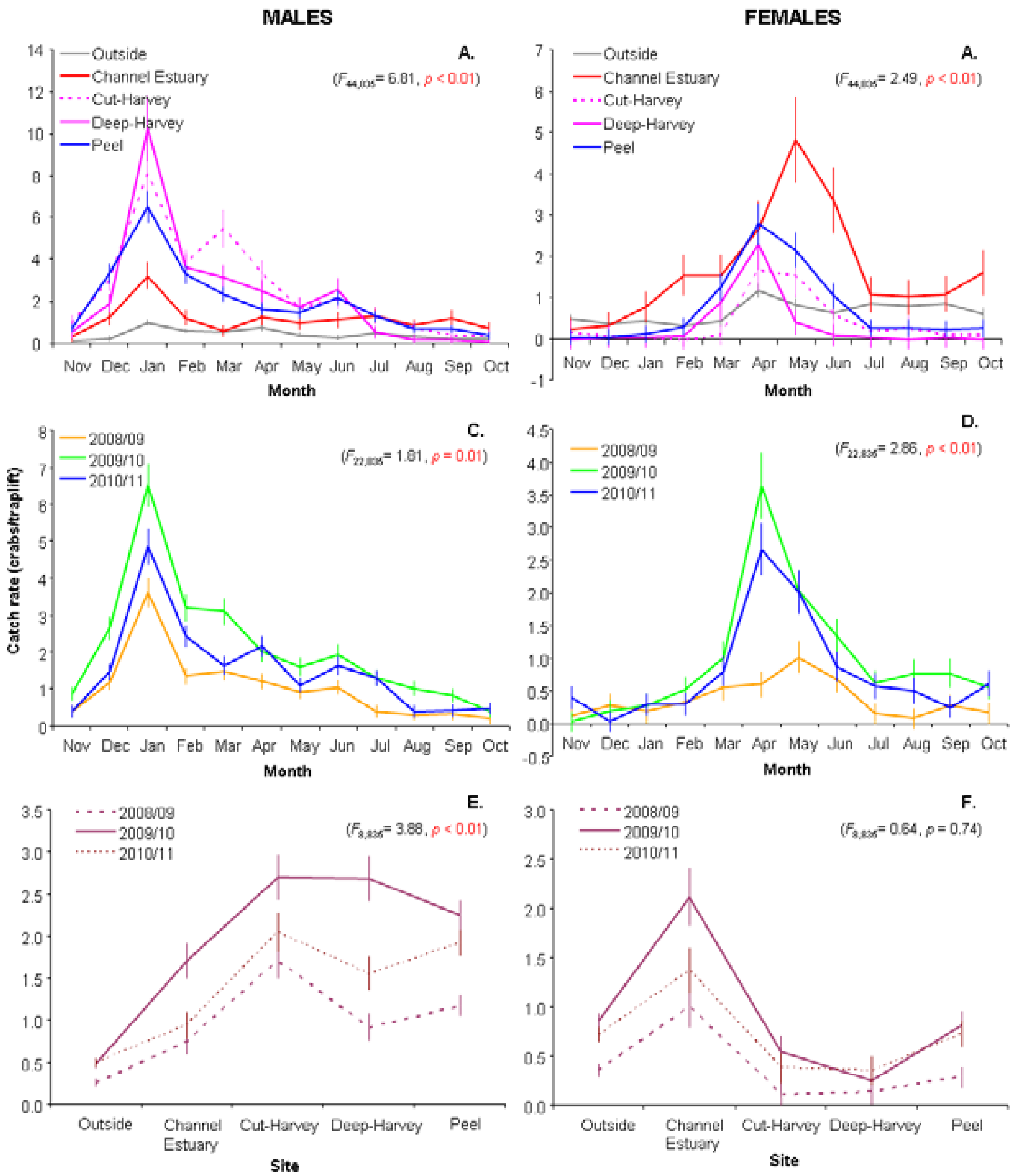

Figure 3.10 Catch rates (mean ± SE) of legal-sized (>127 mm CW) males and females from fishery-independent research surveys plotted by their interactions of Month (Nov – Oct) vs. Site (Outside, Estuary Channel, Cut-Harvey, Deep-Harvey and Peel) (A, B), Fishing year (2008/09 – 2010/11) vs. Month (C, D), and Fishing year vs. Site (E,F).

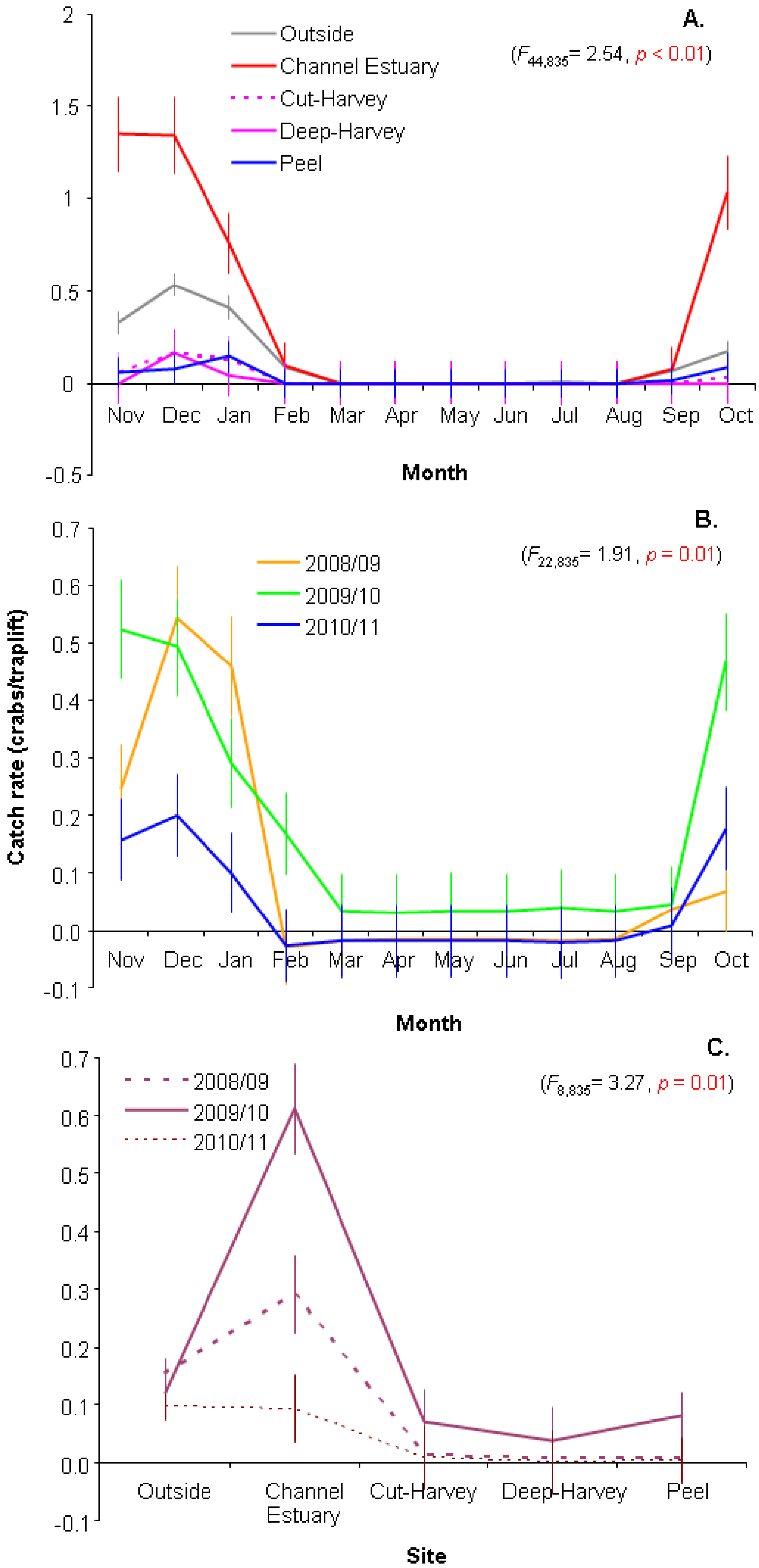

Figure 3.11 Catch rates (mean ± SE) of berried (ovigerous) females from fishery-independent research surveys plotted by their interactions of Month (Nov – Oct) vs. Site (Outside, Estuary Channel, Cut-Harvey, Deep-Harvey and Peel) (A), Fishing year (2008/09 – 2010/11) vs. Month (B), and Fishing year vs. Site (C).

3.3.3 Comparison of current and historical fishery-independent trap surveys

Trapping by de Lestang (2002) during 1996 and 1997 showed a similar pattern of male dominance in the Estuary over the summer with females increasing in numbers in April, making up 50% of the catch in May (Figure 3.12). However, the numbers of females in the Estuary was much lower in all months except May during this time period. Catch did not contain any berried females, particularly between November – January when small catches of berried females were evident from the current time series (2007 – 11) surveys (refer to Figure 3.5).

Immature crabs: There was a significant interaction between fishing year and season on the catch rate of immature crabs (Appendix G – ANOVA Tables from fishery-independent research survey analyses from historical and current fishing years). Catch rate of immature males and females were significantly higher during winter and spring of 2007/08 compared to other years (Figure 3.13a, b) and this may be due to the high winter rainfall early in the year during April – May 2008 (refer to Figure 3.3). There were no significant interactions between fishing year and site on the catch rate of immature males and females, and across all sites catches were lowest during 1996/97 and most similar to catches from the 2008/09 fishing year (Figure 3.13c, d).

Sexually mature sub-legal crabs: There were significant effects of fishing year, season and site on the catch rate of sexually mature sub-legal crabs (Appendix G – ANOVA Tables from fishery-independent research survey analyses from historical and current fishing years). The seasonal catch rate of mature sub-legal males were relatively stable for all fishing years except 2008/09 where catch rates declined from ~16 crabs/traplift during summer to 2 crabs/traplift in spring (Figure 3.14a). Seasonal catch trends of sub-legal females (across all fishing years) decreased from summer to autumn, then increased again during winter before dropping down in spring (Figure 3.14b). For both males and females the catch trends from 1996/97 were most similar to the 2007/08 fishing year. There was a significant interaction between fishing year and site on the catch rate of sub-legal males where catches from 2008/09, 2009/10 and 2010/11 were significantly higher (>6 crabs/traplift) than those from 1996/97 and 2007/08, particularly from the Harvey sites (Figure 3.14c). Catch rate of sub-legal females generally decreased from Peel, to Cut-Harvey, to Deep-Harvey where catches from 1996/97 were again the lowest overall (Figure 3.14d).

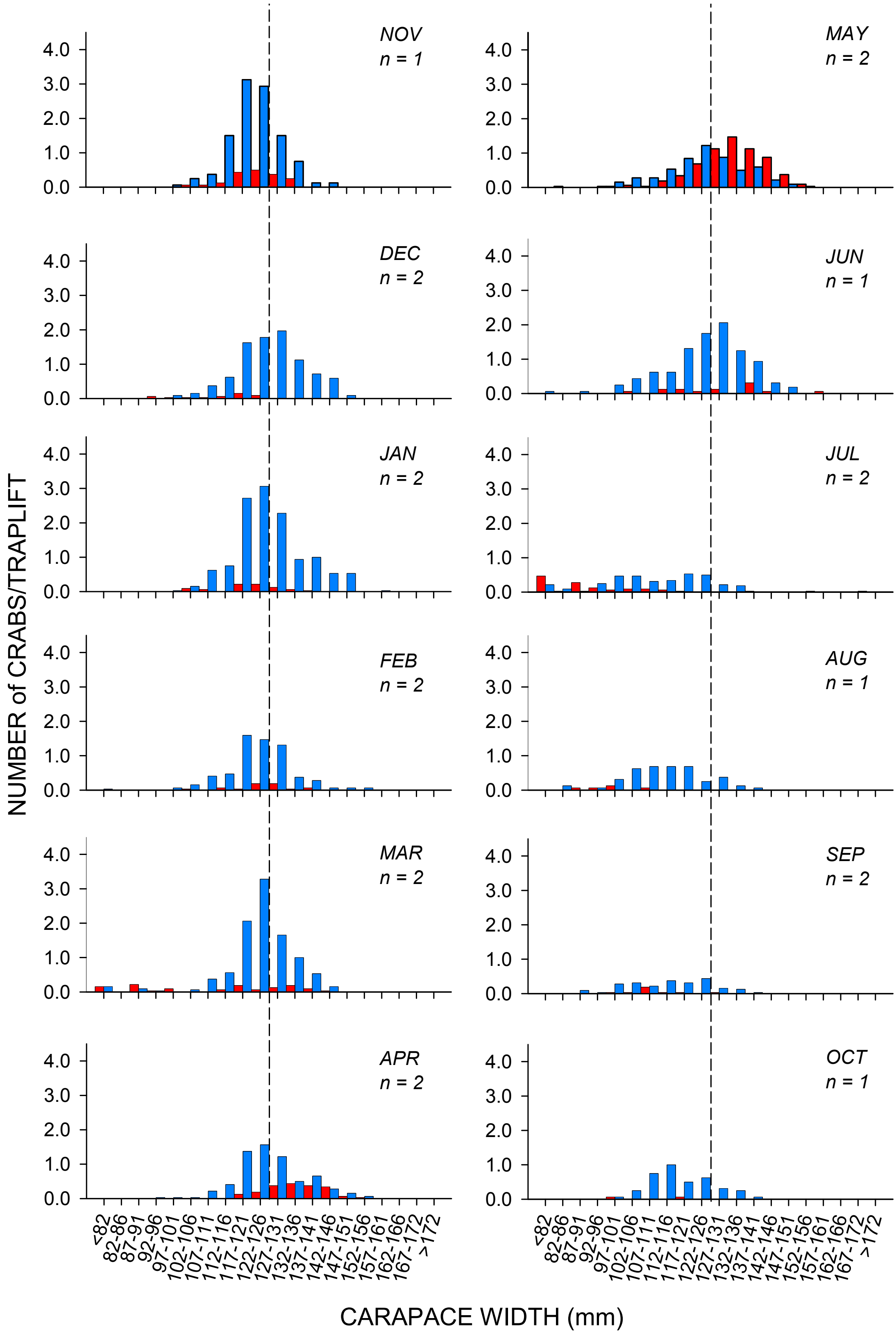

Figure 3.12 Mean monthly length frequency distributions of male (■) and female (■) blue swimmer crabs from fishery-independent research surveys using traps inside the Peel-Harvey Estuary (excluding Estuary Channel) between January 1996 and December 1997 inclusive by de Lestang (2002). Minimum commercial size limit of 127 mm CW (- - -). Note there was fishing during September and October during this period. *n* = number of years sampled.

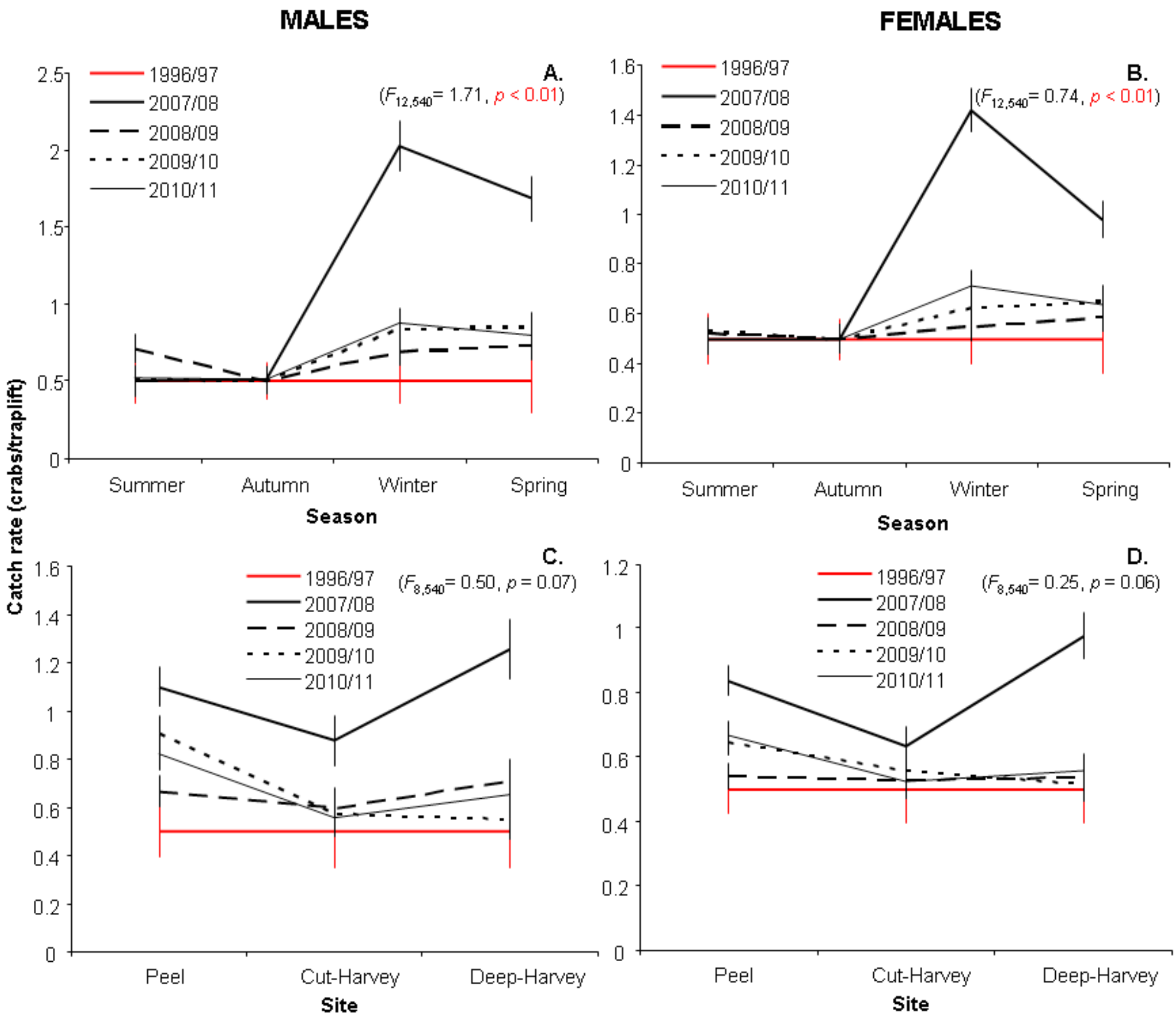

Figure 3.13 Catch rates (mean ± SE) of immature males (<87.1 mm CW) and females (<86.9 mm CW) from historical (1996/97) and current (2007/08 – 2010/11) fishery-independent research surveys plotted by their interactions of Fishing year vs. Season (A, B) and Fishing year vs. Site (C, D).

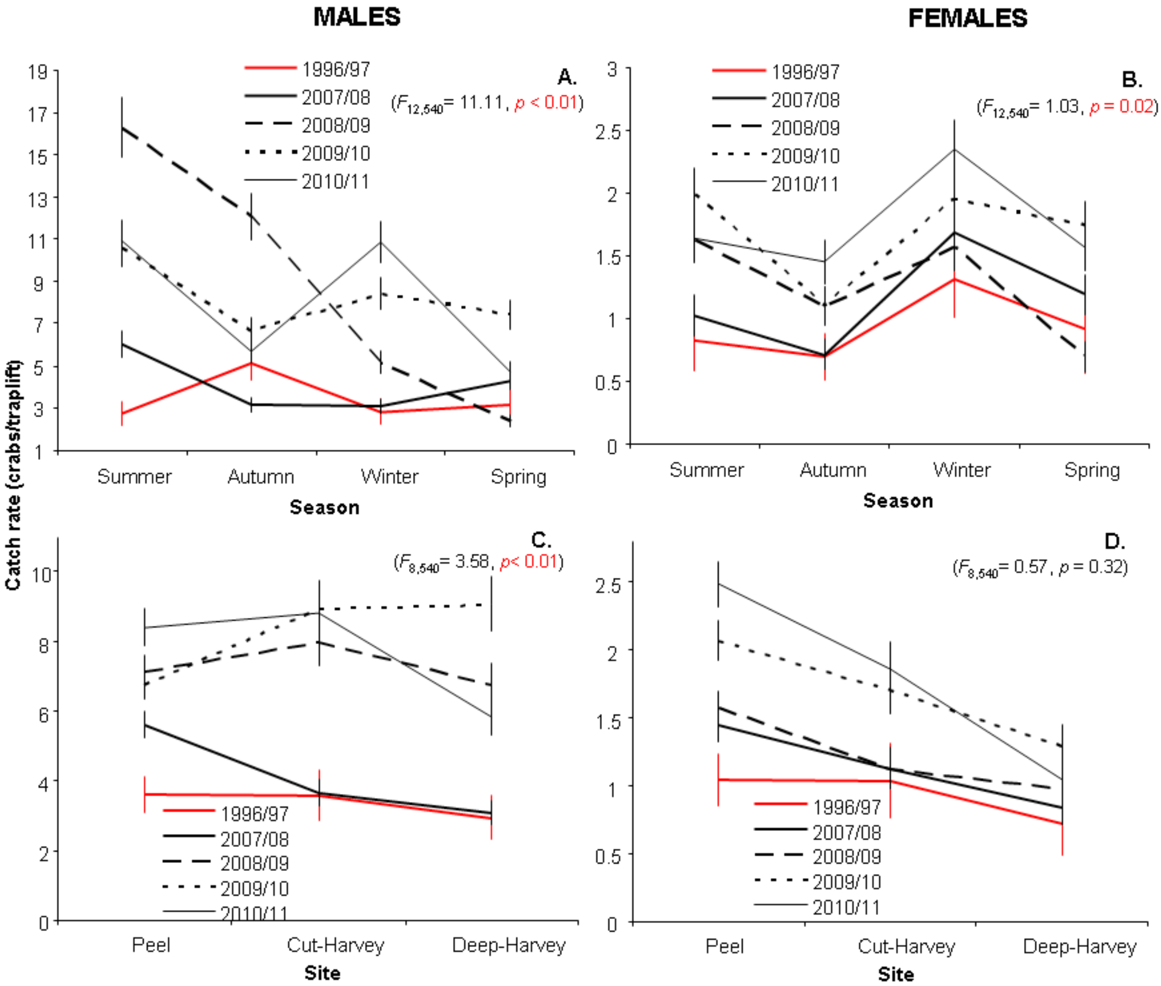

Figure 3.14 Catch rates (mean ± SE) of sexually mature sub-legal males (87.1<CW<127 mm) and females (86.9<CW<127 mm) from historical (1996/97) and current (2007/08 – 2010/11) fishery-independent research surveys plotted by their interactions of Fishing year vs. Season (A, B) and Fishing year vs. Site (C, D).

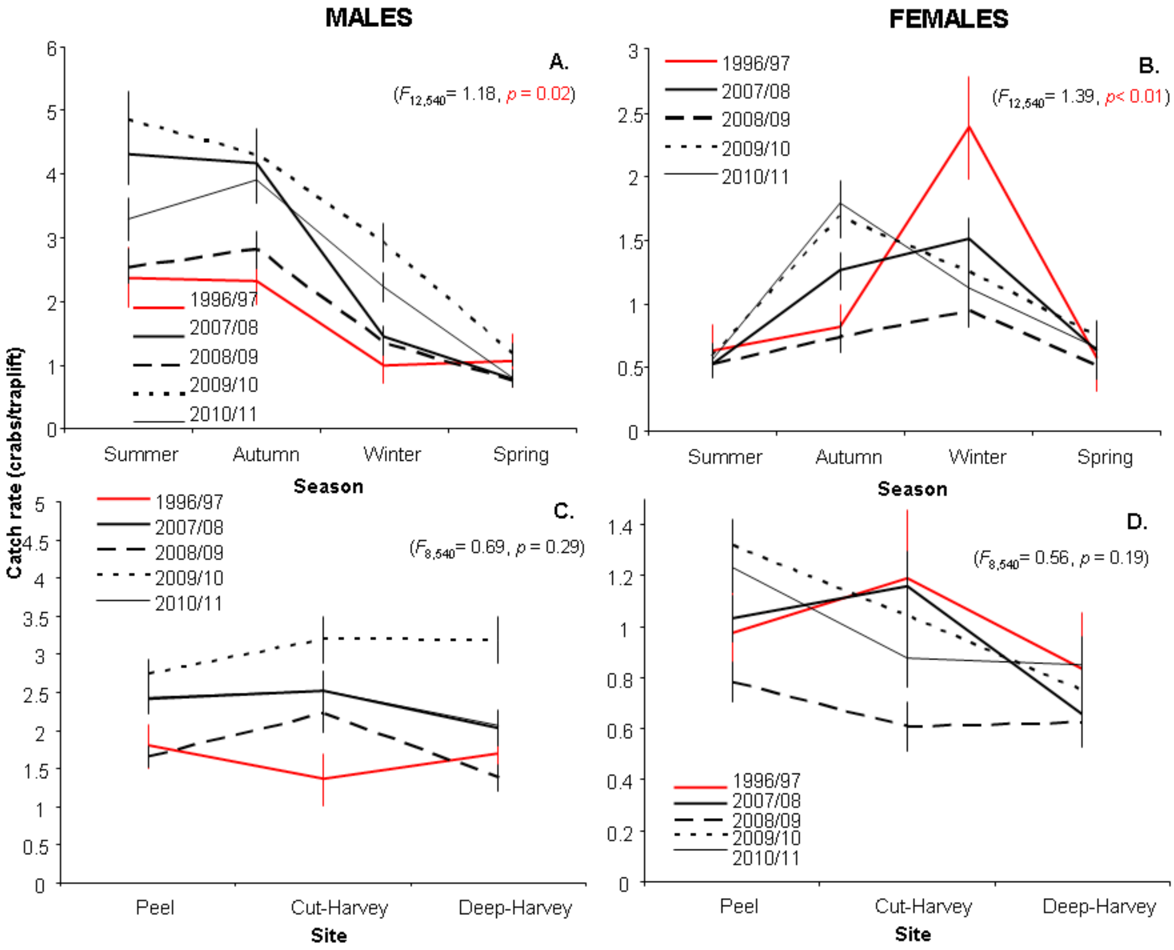

Figure 3.15 Catch rates (mean ± SE) of legal-sized (>127 mm CW) males and females from historical (1996/97) and current (2007/08 – 2010/11) fishery-independent research surveys plotted by their interactions of Fishing year vs. Season (A, B) and Fishing year vs. Site (C, D).

Legal crabs: There was a significant interaction between fishing year and season on the catch rate of legal-sized crabs in the Peel-Harvey Estuary (Appendix G – ANOVA Tables from fishery-independent research survey analyses from historical and current fishing years). Catch rate of legal males were highest during summer (>2 crabs/traplift) across all fishing years and then declined towards spring. Catches from 1996/97 were lowest compared with the current time series (Figure 3.15a). For legal females however, catch rates peaked during winter of all fishing years except 2009/10 and 2010/11 which showed a peak in autumn (Figure 3.15b). The catch rate of legal females was highest overall from 1996/97 and lowest during 2008/09 which reflects the poor commercial catches from that fishing season. There were no significant interactions between fishing year and site on the catch rate of legal crabs (Figure 3.15c, d).

3.3.4 Seine netting and trawl length frequency

The length frequency data from seine netting and trawling methods provided a greater coverage of the stock in terms of revealing the sex and size ranges of small sized crabs (<80 mm CW) that was largely absent from the trapping surveys. In comparing the trawl surveys, the length frequency distributions were very similar between the more recent surveys (2007 – 2009) and those in 1995 – 1998 by de Lestang (2002) except during February where there was less overlap in distributions (Figure 3.16). The trawl data showed unimodal distributions for all months except between February and April when an additional cohort was present (Figure 3.16)

The length frequencies from the seine netting data provided crabs from <20 mm to >150 mm CW size ranges but given the restricted months sampled from Coulson *et al.* (2010), it's unclear how these trends had changed over the last decade (Figure 3.17). From all datasets combined, recruitment of 0+ crabs (<50 mm) was first detected in January where the catches increase until July, then decrease and migrate from the Estuary. The second or middle cohort (50 to 90 mm) was barely detectable for most months probably due to the fast growth of these crabs as they reach sexual maturity. The cohort of mature sub-legal crabs (>90 mm) dominated the catch composition across all months although only a small proportion are seen in the legal size categories between December and May (Figure 3.17).

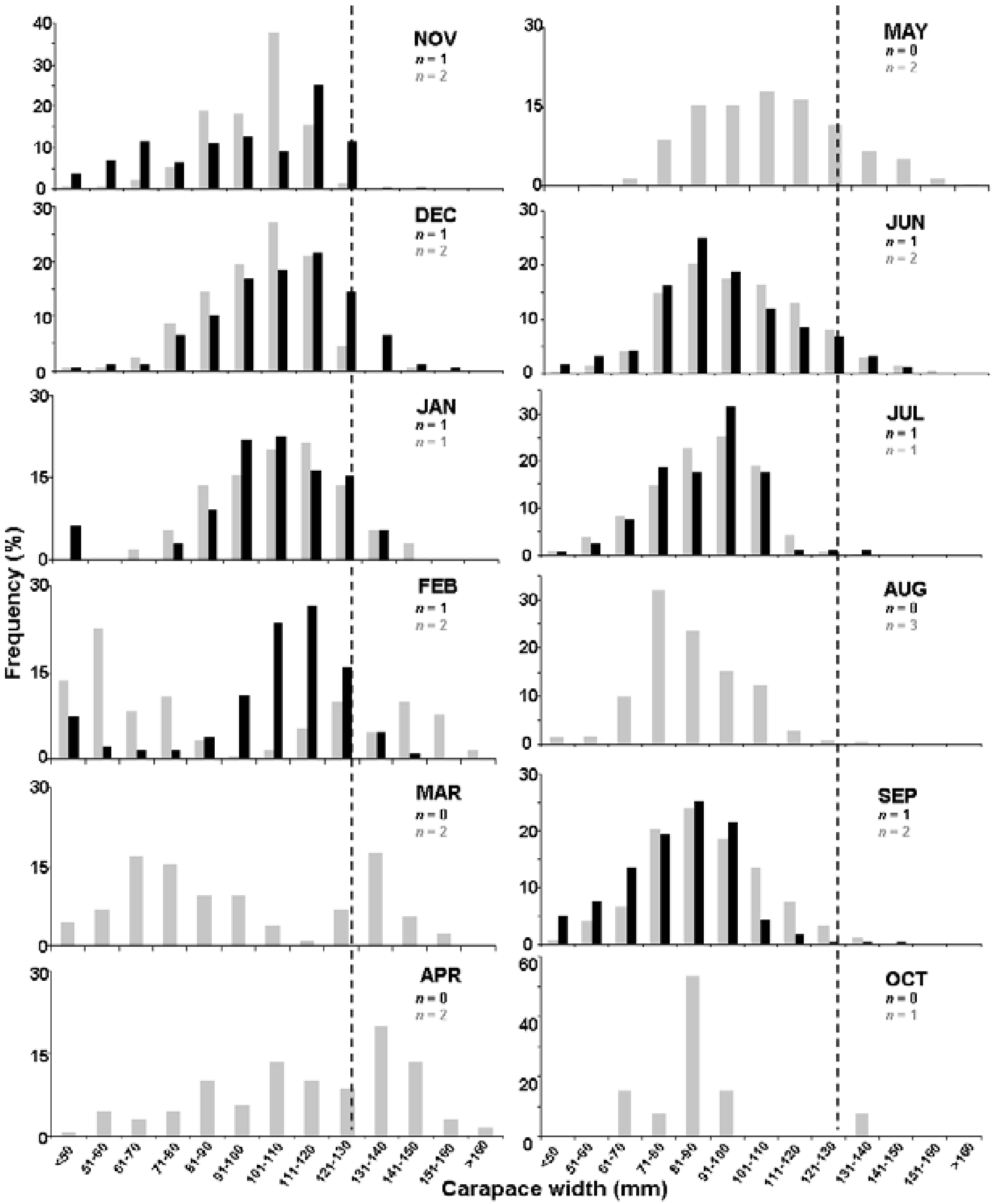

Figure 3.16 Monthly length frequency distributions of blue swimmer crabs (males and females) captured from otter trawl surveys between April 1995 – April 1998 (trawl data not available for some months) by de Lestang (2002) (black bars), and from the current fishery-independent research trawl surveys between February 2007 and January 2009 inclusive (grey bars). Minimum commercial size limit of 127 mm CW (- - -). *N* = number of years sampled.

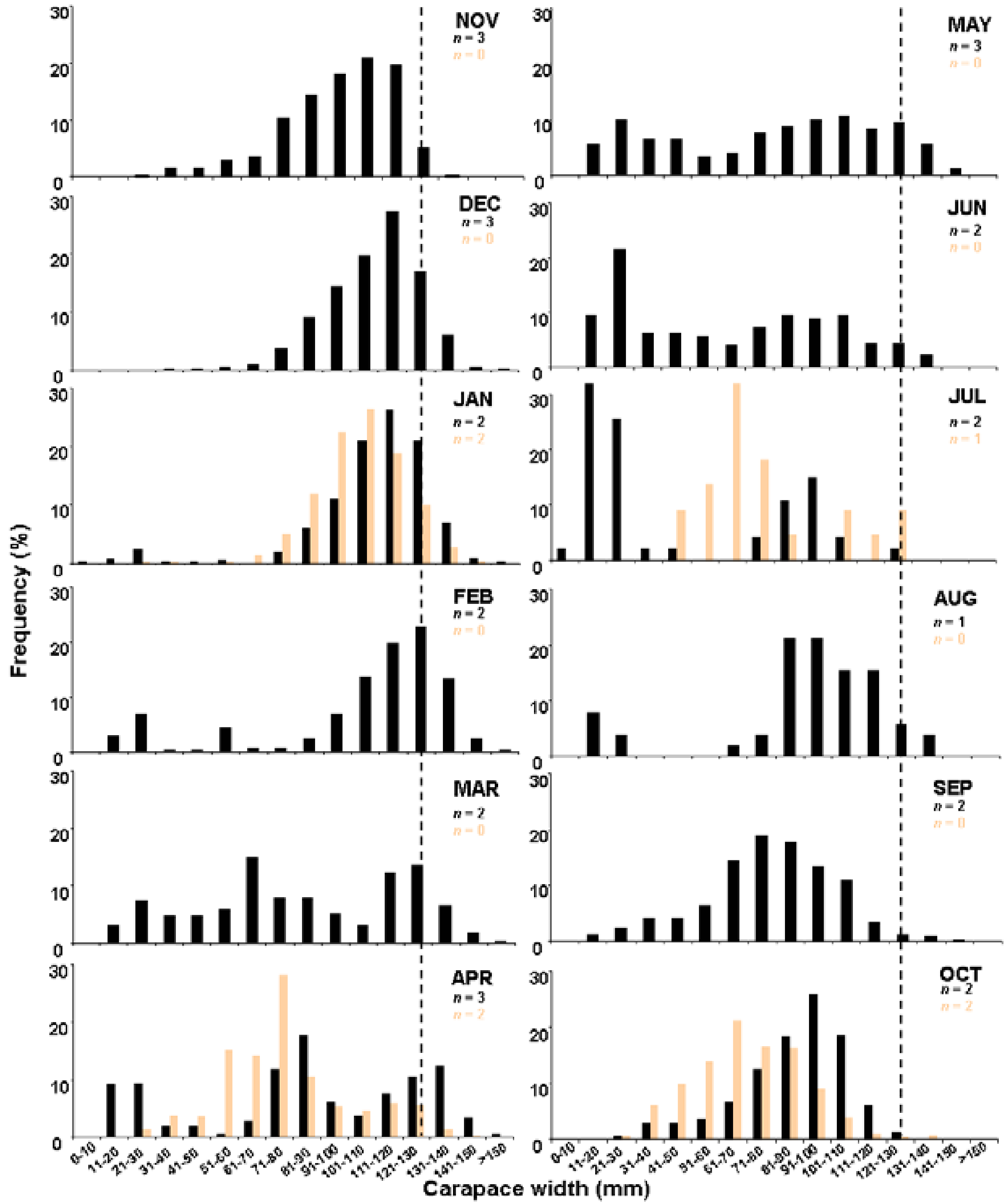

Figure 3.17 Monthly length frequency distributions of blue swimmer crabs (males and females) captured from seine netting surveys between April 1995 – April 1998 by de Lestang (2002) (black bars), and from current seine netting surveys between October 2008 and April 2010 by Coulson *et al.* (2010) (brown bars) (seine data not available for some months). Minimum commercial size limit of 127 mm CW (- - -). *N* = number of years sampled.

4.0 Mandurah to Bunbury Developing Crab Fishery

D. Johnston, A. Chandrapavan, C. Marsh, D. Harris

Objective Develop a commercial catch monitoring program in Area 1 of the Mandurah to Bunbury Developing Crab Fishery and Zone D of the South West Trawl Managed Fishery (Comet Bay) and Area 2 of the Mandurah to Bunbury Developing Crab Fishery.

4.1 Introduction

The Mandurah to Bunbury Developing Crab Fishery was established through an initiative to expand commercial blue swimmer crab fishing into previously unexploited areas of the Western Australian coast. It is made up of two areas, Comet Bay (Area 1) and Mandurah to Bunbury (Area 2). There are currently two fishers operating under exemption in this developing fishery; one in Comet Bay (Area 1) with a total allocation of 80 units (traps) and one in Mandurah to Bunbury (Area 2) with a total allocation of 120 units (traps) (Table 2).

Areas 1 (Comet Bay) and 2 of the Mandurah to Bunbury Developing Crab Fishery are trap fisheries in oceanic waters outside of the Peel-Harvey Estuary (see Figure 1.1). Comet Bay (32° 27′S, 115° 43′E) is an open marine embayment located 43 km south of Fremantle, Western Australia (see Figure 1.1). The embayment is approximately 16 km long by 4 km wide, with the majority of this area being 8 to 10 m in depth. Comet Bay is partially protected from open ocean wind and wave energy by Five Fathom Bank (~10 m in depth) which runs parallel to the coast approximately 13 km offshore, the Murray Reefs (0.3 – 7 m depth) approximately 8 km offshore, and Robert Point at the south-western end of the bay.

Area 2 of the Mandurah to Bunbury Developing Crab Fishery spans a 68 km stretch of coastline from White Hill (8 km south of the Dawesville Cut), south to Bunbury, and west to 1150 30′E longitude (see Figure 1.1). The near-shore coastal topography is dominated by a narrow beach and extensive dune system devoid of outcrops or headlands (Jennings 2008). The narrow beach of sand over limestone extends to a shallow sandy near-shore bathymetry, with the benthic substrate consisting of mainly unconsolidated sand with some seagrass beds and shallow sediment over rock further offshore (Jennings 2008). In the southern part of the fishery, depths are consistent to around 8 m for up to a kilometre offshore, and range from 10 – 12 m up to 10 km offshore. In the northern half of the fishery, shallow banks (2 – 4 m) running parallel to the coastline 6 km from shore form an interior basin with depth ranging from 5 – 8 m.

A commercial catch monitoring program was developed to assess the stock structure and fishery performance and the interaction of the crab stock with the PHE and therefore to help inform future management of all fisheries in the region.

Zone D of the South West Trawl Managed Fishery is a subset of the Comet Bay crab grounds and as a multi-species fishery with blue swimmer crabs retained as by-product. Operator uses twin rigged otter trawl gear (maximum head rope length of 29.25 m) fitted with 50 mm diamond mesh cod end to predominantly target king prawns (no bycatch reduction devices). Trawl fishing is open all year round with a minimum legal size of 127 mm CW (Table 2).

Table 2 Commercial fishing controls for the Mandurah to Mandurah to Bunbury Developing Crab Fishery and Zone D of the South West Trawl Managed Fishery.

Control	Mandurah to Bunbury Developing Crab Fishery Commercial Controls	South West Trawl Managed Fishery Commercial Controls (Zone D)
Minimum legal size	128 mm CW	127 mm CW
Catch Limit	None	None
Fishing Season	All year round	All year round
Daily Fishing Time	September – March 0430 – 1930 April – August 0600 – 1800	
Gear Type	Crab trap	Otter trawl net
Gear Numbers	Area 1 ≤ 80 traps Area 2 ≤ 120 traps	D licences entitled 6 units
Licences	2 fishers operating under exemption	Zone D-3

4.2 Methods

4.2.1 Commercial catch and effort data

All commercial fishers operating in Western Australian waters submit statutory monthly returns that report total catch of all retained species and an estimate of fishing effort. Annual commercial catch and effort for both Comet Bay trawlers and the Mandurah to Bunbury Developing Crab Fishery is presented by calendar year.

There is only a single operator using crab traps and gill nets that has been endorsed to fish commercially for blue swimmer crabs since 1993 in Comet Bay. The operator has fished exclusively with traps, except for a short period of time between July 1995 and December 1997 when gill nets were trialled. With regard to the trawl licenses, one finished operating in 2005, another ceased fishing in 2009, with only one currently remaining.

Historically there have been 3 licenses issued in Zone D of the South West Trawl Managed Fishery operating in Comet Bay since 1980. Two of these licenses operating consistently up until recently, while the other operated sporadically over this period. Currently all three licences are owned and operated by a single fisher.

4.2.2 Commercial monitoring data

Monitoring of commercial blue swimmer crab trap catch and effort in Area 1 and Area 2 of the Mandurah to Bunbury Developing Crab Fishery began in March 2007 and October 2006 respectively, while monitoring of commercial trawl catch and effort in Comet Bay commenced in April 2009. Once a month (in each month that fishing occurred), research staff accompanied commercial fishers during daily fishing operations and recorded the day's catch and effort. Given the limited opportunities to monitor, the trawl fleet in Comet Bay was only monitored in April 2009, January and March 2010. Fishers in Area 2 of the Mandurah to Bunbury inshore crab fishery deployed 120 hourglass traps per day, while the Comet Bay fisher deployed 80 traps per day. Monitoring was undertaken on a randomized day during each month. Size (CW), sex, shell condition, female breeding condition, the number of traps in the line, soak duration and the latitude, longitude and depth were recorded for each trap line.

Limited opportunities were available for commercial monitoring aboard trawlers operating in Zone D of the South West Trawl Managed Fishery (Comet Bay). Monitoring began in April 2009 with one survey recorded for the year and 1 survey recorded in January and March 2010. The vessel operated almost exclusively over just the summer months.

4.3 Results

4.3.1 Area 1 – Comet Bay

The annual trap catch has ranged from 2 to 13 t since 1998 with highest catches in 2004 at 13 t from 205 fisher days and lowest in 2008 at 2 t from 45 fisher days (Figure 4.1, Figure 4.2). Trap catch and effort has remained relatively steady, with a slight decline after the peak in 2004 and an increase in 2010 and 2011 (Figure 4.2). Mean monthly commercial trap catches were highest in summer and autumn between November and May, with 77% of annual catch being taken in this period (Figure 4.3).

The locations of catch monitoring surveys aboard commercial vessels (trawl and trap) in Comet Bay are illustrated in Figure 4.4. During this period, the main concentration of fishing was to the northern region of the shallow fishing grounds around Secret Harbour and Singleton, while no fishing took place at the southern end of the fishing boundary. No clear spatial trends were evident from the trawl grounds largely due to lack of data.

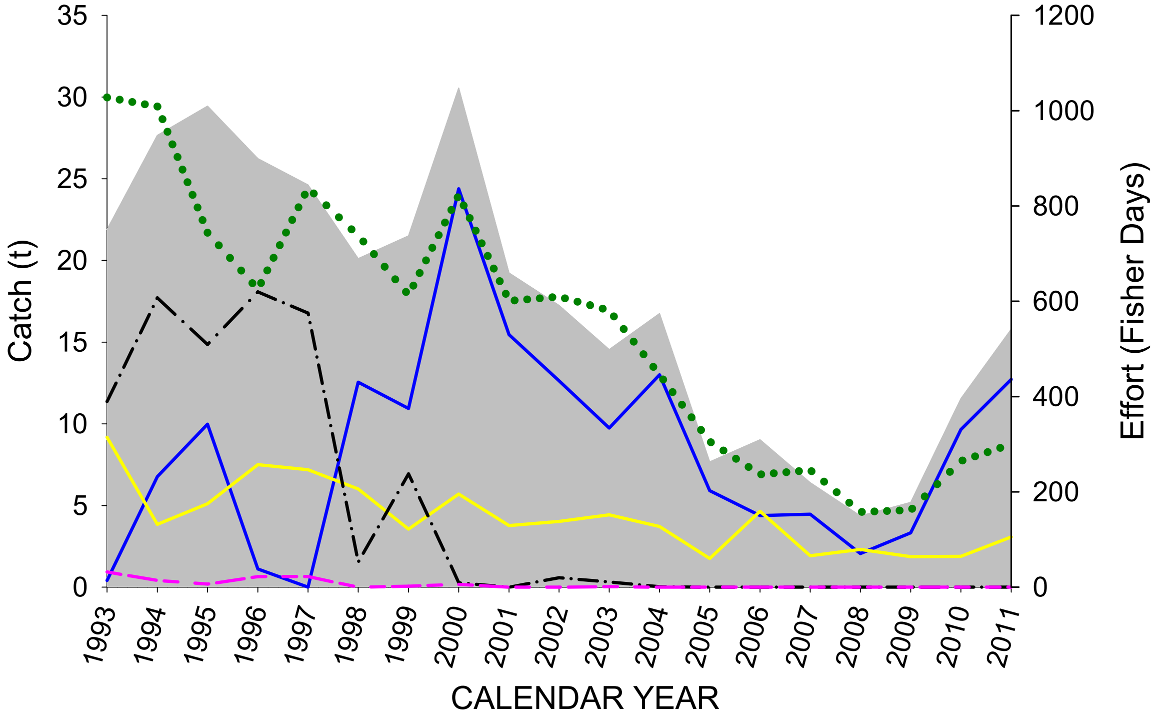

Figure 4.1 Annual commercial blue swimmer crab catch (t) from Comet Bay by fishing method by calendar year. Total catch of trawl and trap (■); trawl (—); crab traps (—); gill nets (–·–·); other (– – –) and effort (fisher days) (••••)

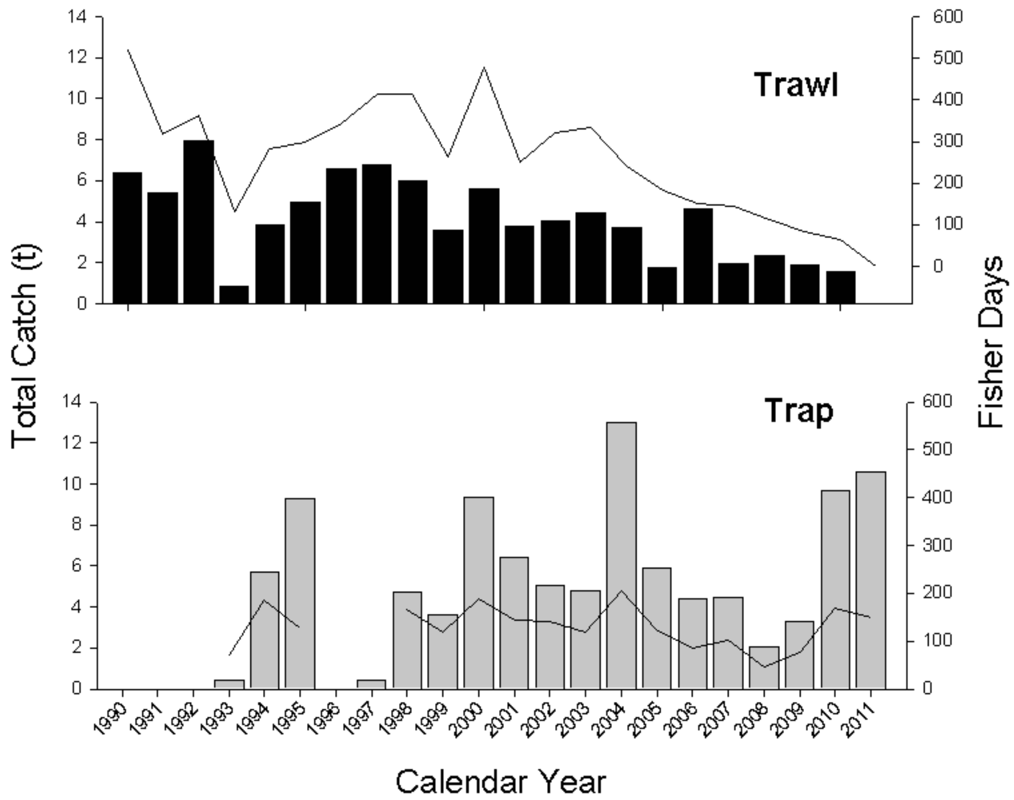

Figure 4.2 Annual commercial blue swimmer crab catch (t) from Comet Bay using hourglass traps (■ ; 1993 – 2011) and trawling (■ ; 1990 – 2010) with fishing effort (fisher days).

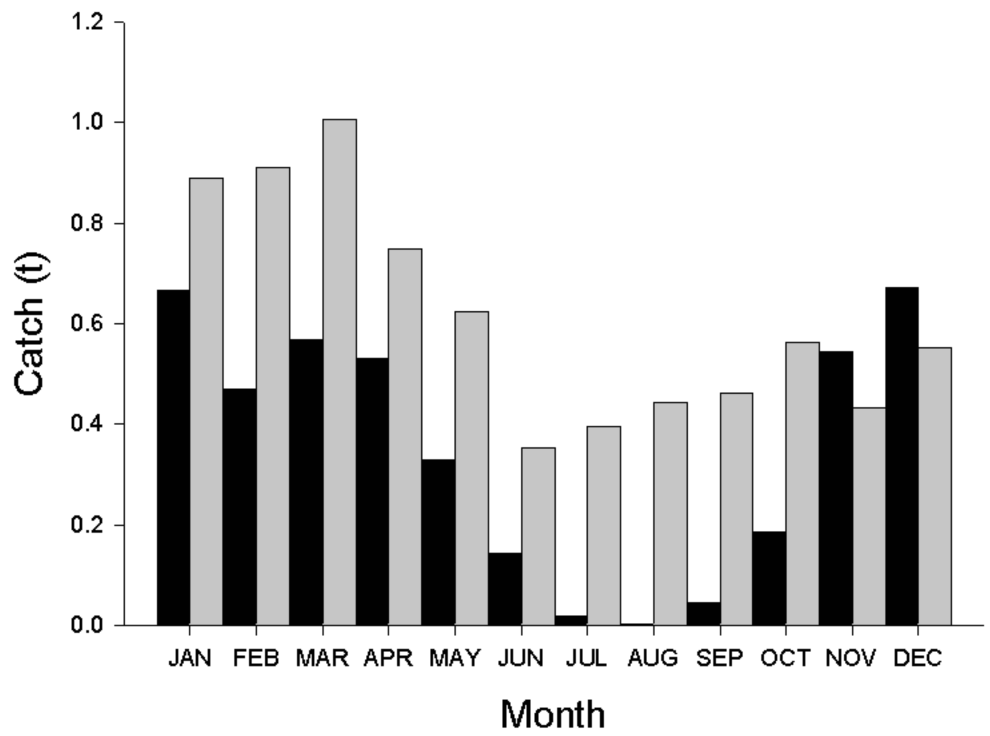

Figure 4.3 Mean monthly commercial blue swimmer crab catch (t) from Comet Bay using hourglass traps (■ ; 1993 – 2010) and trawl (■ ; 1990 – 2010).

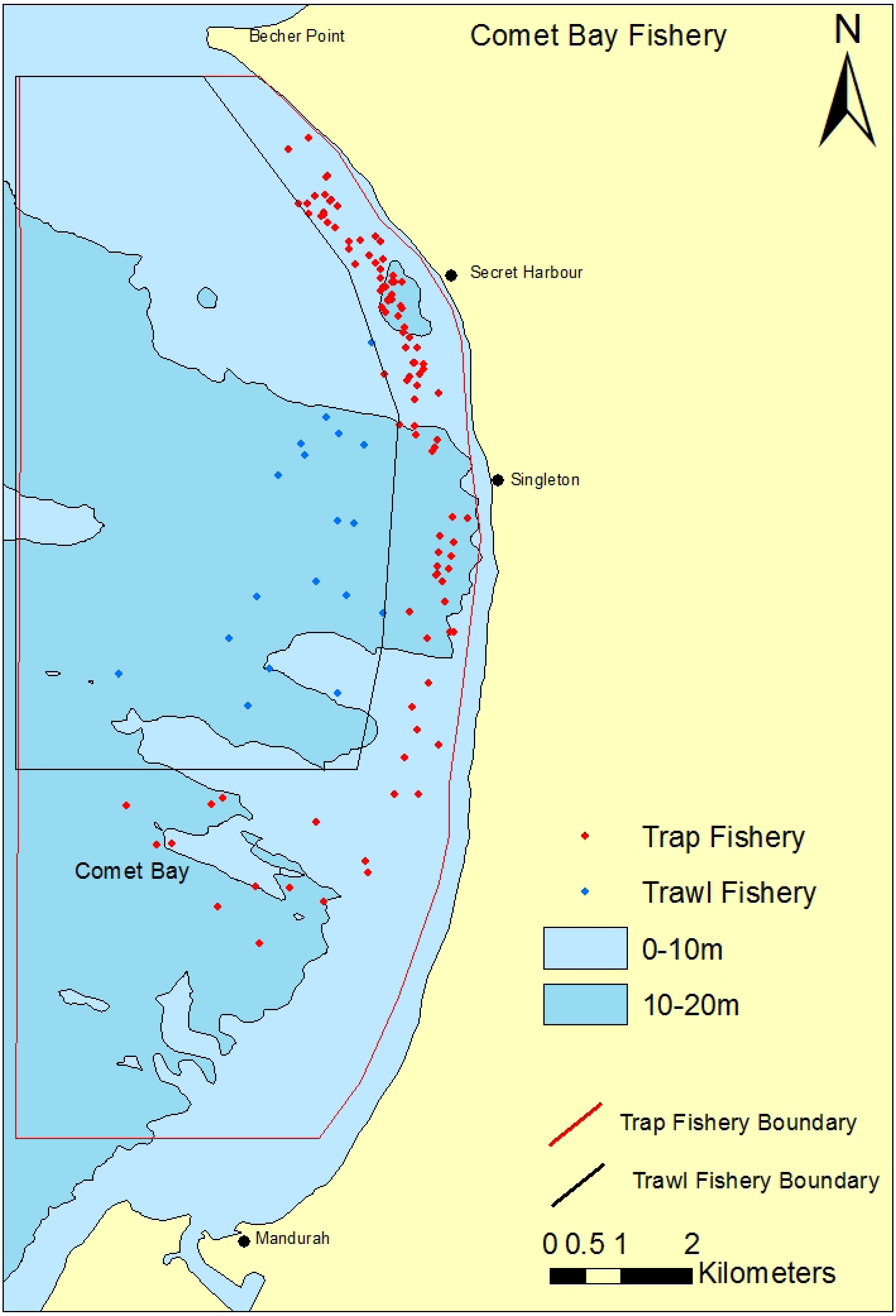

Figure 4.4 Locations of catch monitoring surveys aboard commercial vessels in Comet Bay. Trap fishing (●)(March 2007 – December 2011), Trawl Fishing (●)(April 2009, January 2010, March 2010), Area 1 of the Mandurah to Bunbury Developing Crab Fishery (—) Zone D of the South West Trawl Managed Fishery (—).

Catch monitoring from March 2007 show that trap catches were male dominated over the summer months between January and March, with catches changing to equal proportions of males and females in April (Figure 4.5). Catches are then dominated by females until December with berried females present in catches between October and January. Significant numbers of berried females are present in December and January although most are of sub-legal sizes (<128 mm) (Figure 4.5).

4.3.2 Zone D – South West Trawl Managed Fishery (SWTMF)

The annual trawl catch and effort in Zone D (Figure 4.4) peaked in 1992 at 7.9 t for 364 fisher days, dropping to 1.2 t the following year for 130 fisher days (Figure 4.2). Trawl catch and effort has followed a gradual decline to the present day after a slight resurge in the 1990s (Figure 4.1, Figure 4.2). Mean monthly commercial trawl catch was highest during the summer and autumn months (November to April) with 74% of the annual catch being taken in this period (Figure 4.3).

Data recorded from monitoring aboard the trawler revealed a female dominated catch of predominantly sub-legal size animals (Figure 4.6). March 2010 in particular contained a notable catch of small crabs (<83 mm) with approximately 29% of the catch between 55 mm and 74 mm CW (Figure 4.6).

4.3.3 Area 2 – Mandurah to Bunbury Developing Crab Fishery

Crab traps have been used to land blue swimmer crabs by exemption in Area 2 of the Mandurah to Bunbury Developing Crab Fishery since 2002. Following initial exploratory fishing, annual commercial blue swimmer crab catches were reasonably stable (around 10 t) from 2004 to 2007. Subsequent annual catches, however, have tended to fluctuate with fishing effort, ranging from 7 t in 2009 to 20 t in 2010 (Figure 4.7). Prior to 2006, the fisher operated other commercial fishing endorsements during the summer and autumn months, before undertaking moderate levels of crabbing (mean of 11.3 days per month) during winter. Post 2006, the fisher increased crabbing intensity (19.5 days per month) and focussed on the months between February and June (Figure 4.8). Stock depletion during each fishing season was evident, with catch rates (CPUE, kg/traplift) falling as fishing continued over all time periods (Figure 4.8).

Despite the large area of the fishery, only a small proportion of the available waters are fished. During commercial monitoring between 2006 and 2010, commercial effort was restricted to a narrow strip along shore, from just south of Binningup, north to a point 8 km from the northern fishery boundary. All fishing took place within 1000 m of the waterline, to depths of around 8 m (Figure 4.9).

Retained catch in Area 2 of the fishery was predominantly female in all fished months, increasing from 60% of the catch in February to 86% of the catch by June (Figure 4.10). Ovigerous females, however, were only caught during the single October monitoring survey in 2006 (Figure 4.10). This level of female dominance was consistent with monthly proportions of females in the retained catch from other oceanic fisheries on the south west coastline of Western Australia (Table 3).

The mean annual percentage of females in commercial crab catches in oceanic south-west fisheries (Comet Bay, Mandurah to Bunbury and Warnbro Sound) is 67% and higher compared with estuarine fisheries (Peel-Harvey and Swan River) at 25% and coastal embayment at 57% (Cockburn Sound) (Table 3). For the estuarine fisheries in particular, mean monthly proportions of females were also highly variable (1 – 67%), possible due to the winter rain flushing, moult timing which may affect catchability, and seasonal changes in fishing pressure. The lack of data for some of these fisheries suggests caution is needed in the interpretation of these data. Nevertheless there remains a clear trend of female dominance in crab catches from the Comet Bay, Mandurah to Bunbury and Warnbro Sound crab fisheries.

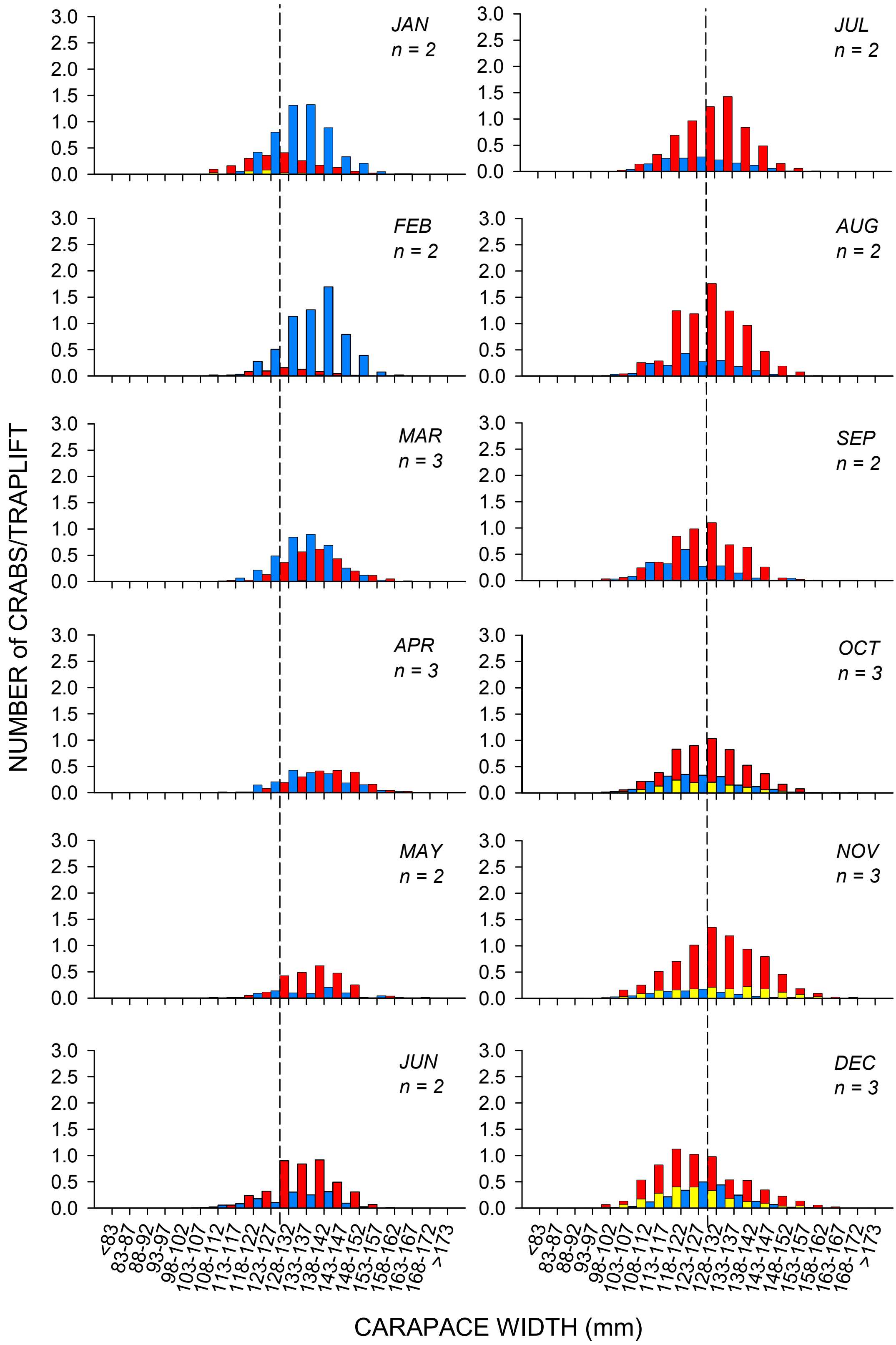

Figure 4.5 Mean monthly length frequency distributions of male (■), female (■), and ovigerous female (■) blue swimmer crabs by month from catch monitoring surveys aboard a commercial trap operator in Comet Bay between March 2007 and October 2011. Minimum commercial size limit (128 mm CW) (- - -). *n* = number of years sampled.

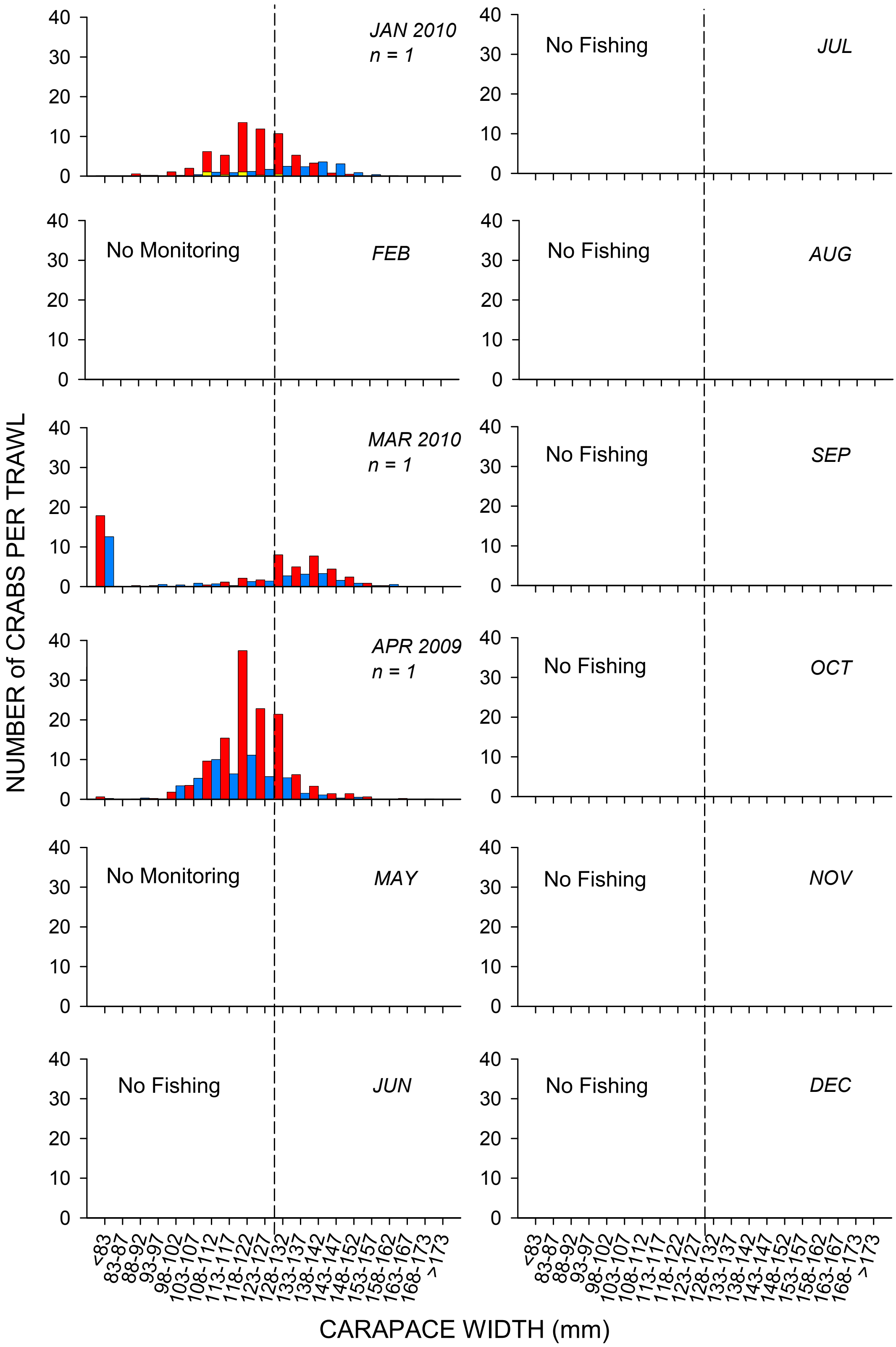

Figure 4.6 Combined length frequency distributions of male (■), female (■), and ovigerous female (■) blue swimmer crabs by month from catch monitoring surveys aboard a commercial trawl operator in Comet Bay between April 2009 and March 2010 inclusive. Minimum commercial size limit (128 mm CW) (- -). *n* = sampling night and is defined as a total of 10 trawl shots of 60 min trawl duration each.

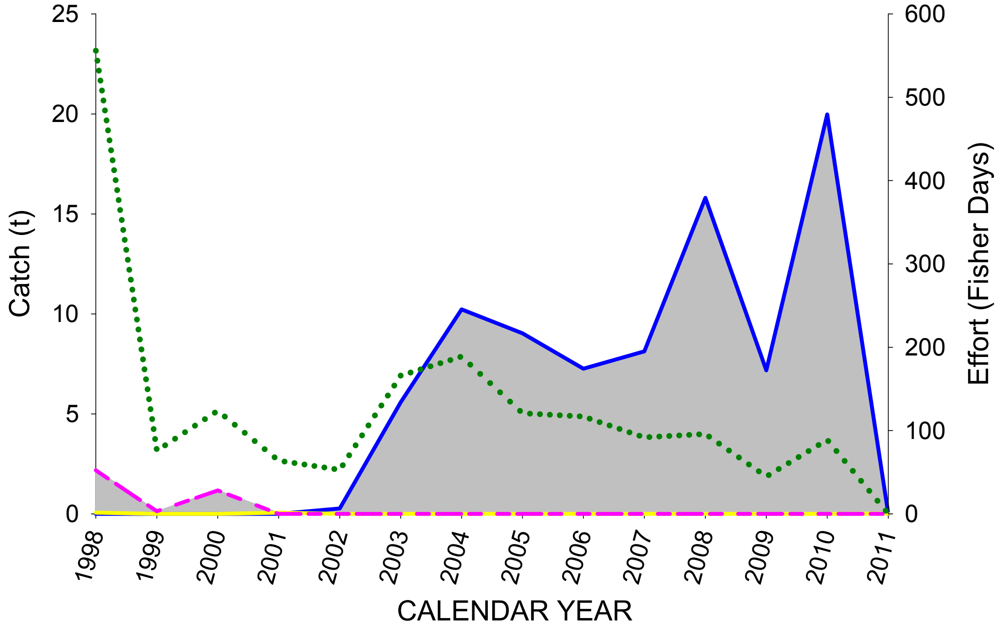

Figure 4.7 Annual commercial blue swimmer crab catch (■); trap (——); trawl (——); other (– – –) and effort (fisher days) (••••) from Area 2 of the Mandurah to Bunbury Developing Crab Fishery from 2002 to 2011. No fishing occurred during 2011.

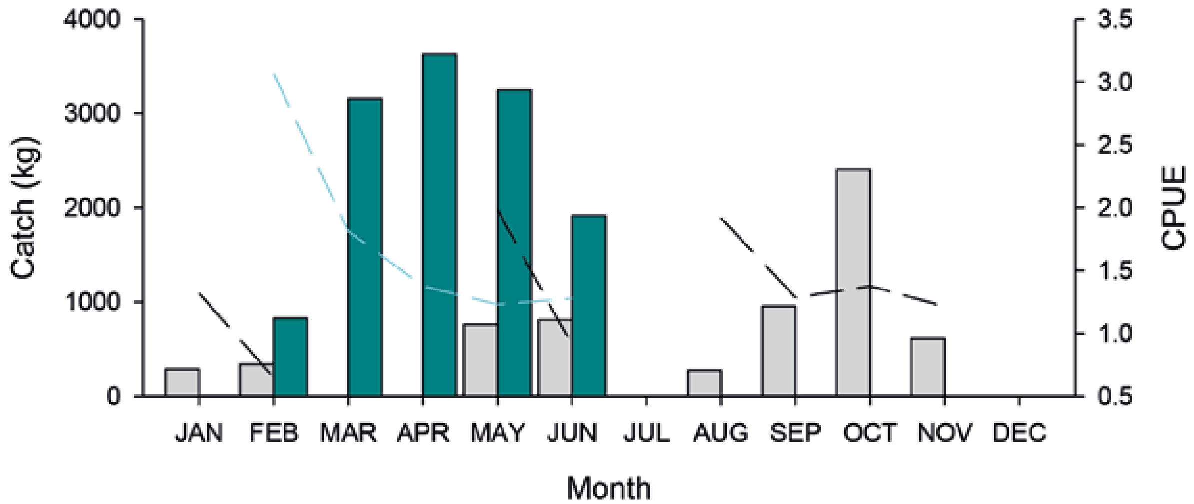

Figure 4.8 Mean monthly commercial blue swimmer crab catch (kg) and catch per unit effort (CPUE, kg/traplift) from Area 2 of the Mandurah to Bunbury Developing Crab Fishery from 2002 – 2007 (Catch: ■ ; CPUE: ----); and from 2006 to 2010 (Catch: ■ ; CPUE: ----);. No fishing occurred during 2011.

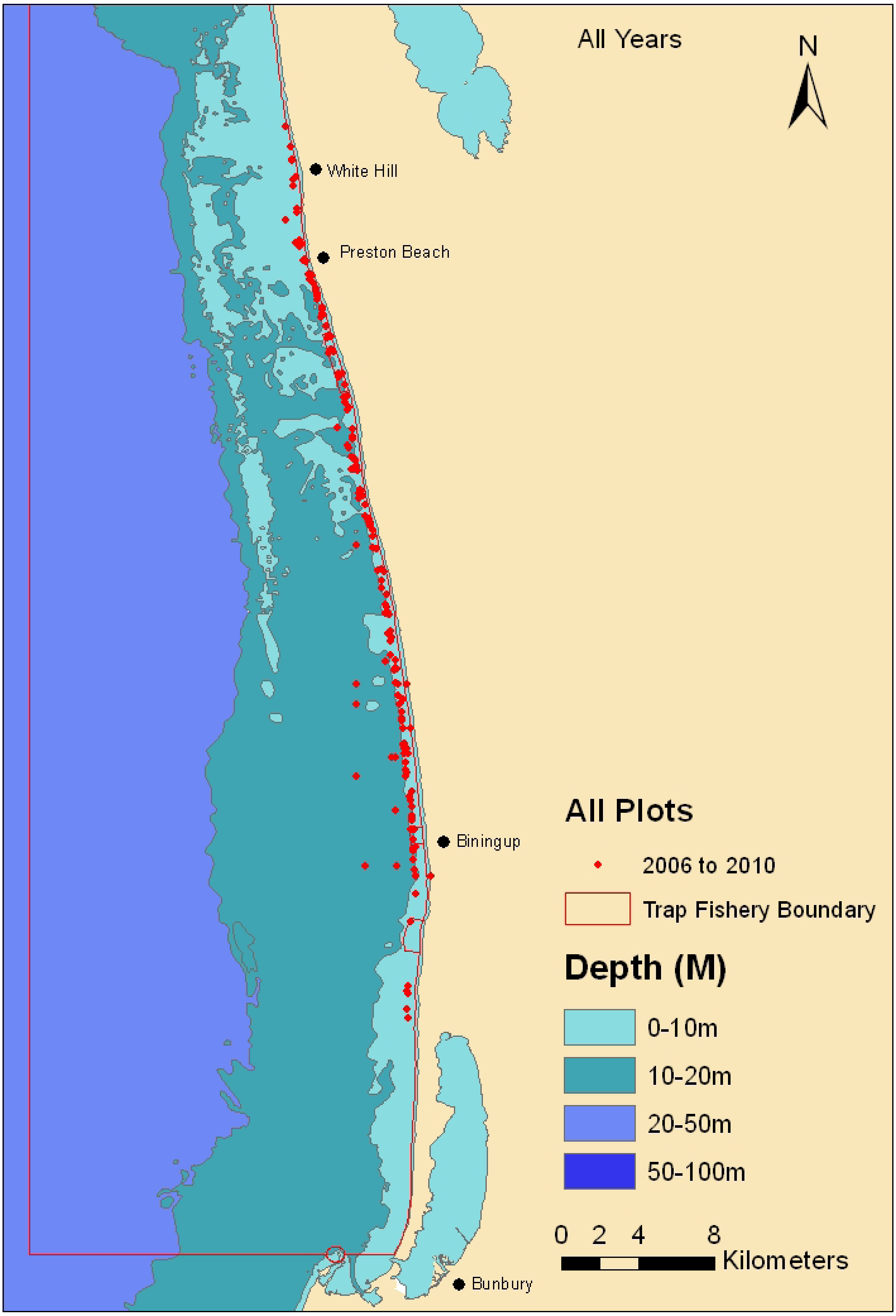

Figure 4.9 Locations (●) of catch monitoring aboard commercial trap vessels in Area 2 of the Mandurah to Bunbury Developing Crab Fishery between October 2006 and May 2010 inclusive. No fishing occurred during 2011.

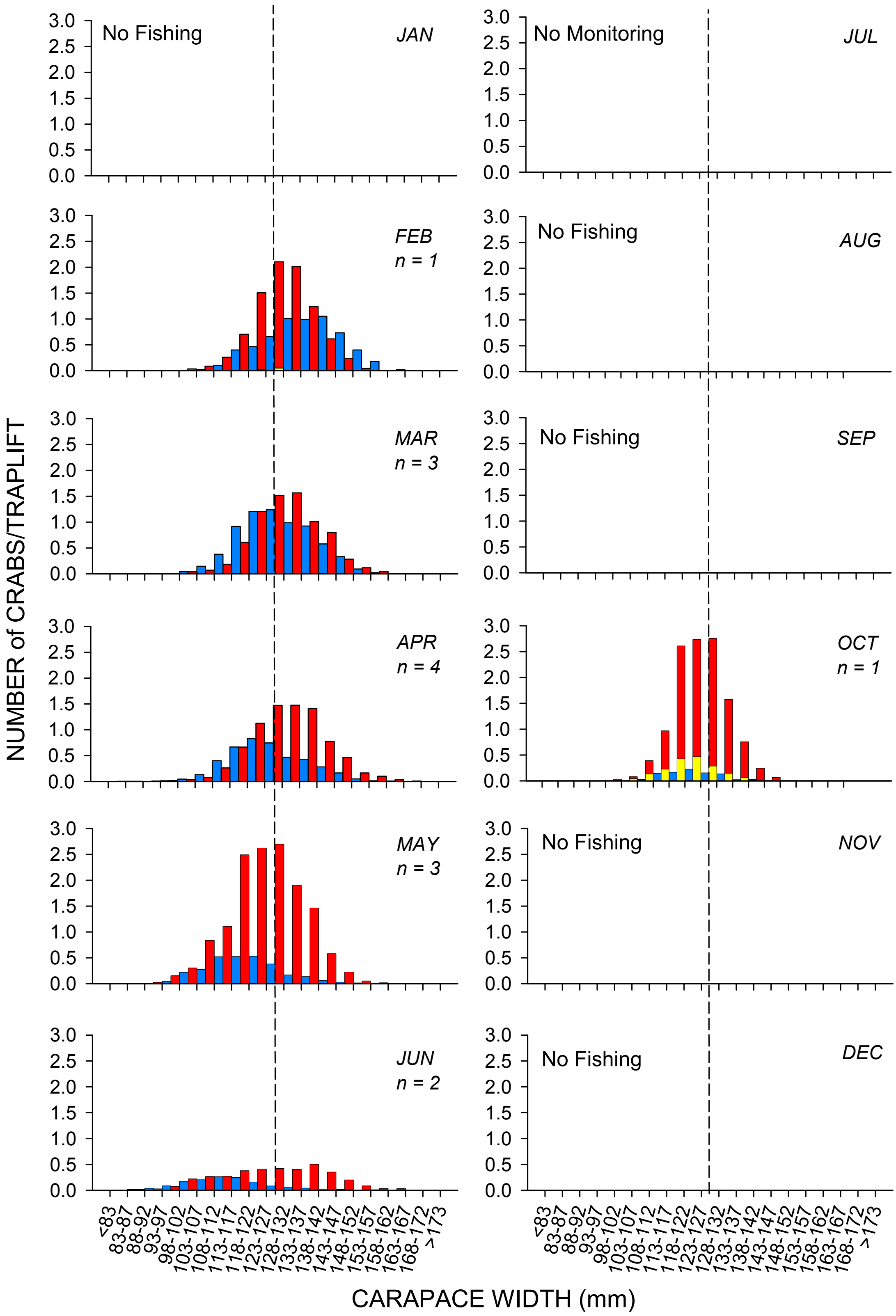

Figure 4.10 Pooled length frequency distributions of male (■), female (■), and ovigerous female (■) blue swimmer crabs by month from catch monitoring surveys aboard commercial vessels in Area 2 of the Mandurah to Bunbury Developing Crab Fishery between October 2006 and May 2010 inclusive. Minimum commercial size limit 128 mm CW (- - -). No fishing during 2011. *N* = number of years sampled.

Table 3 Comparison of the mean monthly and mean annual proportion (%) of females in commercial crab catches sampled during commercial monitoring surveys in south-west crab fisheries between March 2007 and November 2011.

Month	ESTUARINE			EMBAYMENT	OCEANIC				
	Swan River	PH Estuary	MEAN	Cockburn Sound	Warnbro Sound	Comet Bay Trap	Comet Bay Trawl	Mand to Bunbury	MEAN
Jan	3	1	2	25	46	40	77	NA	54
Feb	6	3	5	17	18	19	NA	60	32
Mar	9	9	9	36	42	55	63	55	54
Apr	6	46	26	59	54	68	71	69	65
May	49	55	52	59	64	80	NA	82	75
Jun	65	48	57	64	71	79	NA	77	76
Jul	52	37	45	70	70	81	NA	NA	76
Aug	64	31	48	74	82	82	NA	NA	82
Sep	0	28	14	77		76	NA	NA	76
Oct	23	23	23	70	NA	88	NA	93	90
Nov	8	10	9	66	NA	76	NA	NA	76
Dec	10	8	9	66	71	75	NA	NA	73
MEAN	**25**	**25**	**25**	**57**	**58**	**68**	**70**	**73**	**67**

5.0 Recreational surveys of catch and effort for blue swimmer crabs in the Peel-Harvey Estuary

Eva Lai, Norm Hall, Carli Telfer, John Eyres, Brent Wise

5.1 Introduction

The Peel-Harvey Estuary is a popular location for recreational fishing in the south-west of Western Australia, and within this estuary, the blue swimmer crab is the most common species targeted by recreational fishers. Because of its importance to these fishers, a survey of the recreational fishery in the Peel-Harvey Estuary was undertaken from November 2007 to October 2008 to estimate the total recreational catch and fishing effort for blue swimmer crabs and ascertain whether catches of this species and/or fishing effort had changed from the values estimated from a survey undertaken in 1998 – 99 (Malseed and Summer, 2001).

The recreational blue swimmer crab fishery in the Peel-Harvey Estuary comprises fishers crabbing from boats, bridges & jetties, scoop netting areas along the shore of the estuary, private houses along canals and hire houseboats. While boat-based recreational fishers typically use drop (crab) nets when fishing for crabs, shore-based fishers use both drop and scoop nets. Because of the different modes of operation, different survey approaches are required for each component. Thus, fishers crabbing from boats were interviewed at the conclusion of fishing on return to boat ramps, fishers at bridges & jetties and at scoop netting areas were interviewed while fishing by interviewers who progressively traversed the bridge, jetty or shoreline from which fishers were crabbing, and log books were issued to fishers crabbing from their private houses along canals and hire houseboats.

As the particular focus of this study was the blue swimmer crab, this report concentrates on the recreational fishing activity directed towards crab fishing and the catches of blue swimmer crabs taken by recreational fishers. Data on angling and the catches of fish species caught by recreational anglers, which were also obtained in the course of the study, are not presented.

5.2 Methods

The design used for the 2007 – 08 recreational survey was a refinement of that employed for the earlier 1998 – 99 survey. Thus, it extended over a greater period within each survey day and, although still stratified to provide greater precision during the peak fishing period, covered the full year for the shore-based fishing component rather than the restricted period surveyed in 1998 – 99. It should be noted, however, that the area was closed to blue swimmer crab fishing in the last two months of the 2007 – 08 survey, i.e. September and October. Thus, although angling activity was still recorded, no crabbing activity was observed and no catches of blue swimmer crab were made during the closure months. While the 2007 – 08 survey period overlapped a daylight saving trial (from 28 Oct 2007 to 30 March 2008, and 26 October 2008 to 29 March 2009), with the survey schedule shifting automatically to daylight-savings times, the impact of this trial and fishers' fishing activity is unknown.

In 1998 – 99, the boat-based and hire houseboat surveys extended from August 1998 to July 1999, the scoop netting survey from December 1998 to April 1999, and the bridge and jetty survey ran from November 1998 to April 1999. In contrast, the 2007 – 08 surveys of boat-based fishing, and fishing from bridges/jetties, scoop netting areas, private houses along canals and hire houseboats ran from November 2007 to October 2008.

Estimates of catch (retained and released) and effort within each of these separate components of the recreational fishery were calculated. The methods used for the analysis, which are described in greater detail below, were modified from those employed for the 1998 – 99 survey to accommodate the outcomes of the Steffe (2009) review of the survey methods used in Fisheries Research Report 177 (Sumner *et al.*, 2008) and the advice resulting from a recreational survey workshop held at the Research Division at Hillarys from 22 – 26 February 2010 involving both national and international experts (Wise and Fletcher 2013). Thus, greater attention was given to the calculation of estimates of uncertainty and statistical analyses were extended to explore the consequences of alternative, albeit equally viable, methods yielding slightly different estimates of catch and fishing effort, the results of which are reported below. For consistency and to facilitate comparison with the results of the 2007 – 08 survey, the results of the 1998 – 99 survey were re-analysed using the modified approaches.

5.2.1 2007 – 08 Survey Design

The survey designs for the 1998 – 99 survey are described in Malseed and Summer (2001). The 2007 – 08 survey designs are described below.

Boat ramp-based recreational surveys

Boat-ramp based creel surveys are often used to collect recreational fishing data from boat-based fishers of just-completed fishing trips at a number of defined boat ramps (Pollock *et al.*, 1994). The bus route method (Robson and Jones, 1989; Jones *et al.*, 1990) was used to estimate the total catch and fishing effort for persons crabbing from recreational boats launched at these boat ramps. In this method, each of the boat ramps included in the "bus route" is visited during a scheduled survey shift. At the boat ramps, the survey interviewers count the number of trailers and conduct interviews with fishers coming off the water. The boat ramp shifts for the 2007 – 08 boat-ramp based surveys are listed in Table 5.1.

Table 5.1. Start time and duration of survey shifts in the 2007 – 08 survey of boat-based recreational fishing.

Year	Month	Start time (Morning/Afternoon)	Duration (hours)
2007	11	7:00 am / 2:00 pm	7
	12	7:00 am / 2:00 pm	7
2008	1	7:00 am / 2:00 pm	7
	2	7:00 am / 2:00 pm	7
	3	7:00 am / 2:00 pm	7
	4	8:00 am / 1:00 pm	5
	5	8:00 am / 1:00 pm	5
	6	8:00 am / 1:00 pm	5
	7	8:00 am / 1:00 pm	5
	8	8:00 am / 1:00 pm	5
	9	8:00 am / 1:00 pm	5
	10	8:00 am / 1:00 pm	5

Two bus routes were set up in the Peel-Harvey Estuary and referred to as "eastern" and "western". In the 1998 – 99 study, each bus route comprised eight boat ramps, which were visited during each scheduled survey shift. In the 2007 – 08 study, the "western" route was reduced to seven boat ramps (Figure 5.1). The surveys were stratified by season (spring, summer, autumn or winter), time of day (morning or afternoon), weekdays or weekends (including public holidays) and area (eastern or western ramps). The number of shifts conducted per month varied and more shifts were allocated to the months where most effort occurred, based on prior information on recreational fishing patterns. Table 5.2 shows the allocation of survey shifts and Table 5.3 the actual allocation within the survey period.

Table 5.2. Number of weekday and weekend days sampled within each calendar month during the 2007 – 08 surveys of boat-based recreational fishing.

Year	Month	East		West	
		Weekday	Weekend	Weekday	Weekend
2007	11	4	4	8	8
	12	4	4	8	8
2008	1	4	4	8	8
	2	4	4	8	8
	3	4	4	8	8
	4	4	4	8	8
	5	4	4	4	4
	6	4	4	4	4
	7	4	4	4	4
	8	4	4	4	4
	9	4	4	4	4
	10	4	4	4	4

Table 5.3. Actual number of daily samples taken during the 2007 – 08 survey within each morning and afternoon shift during each month.

Year	Month	East				West			
		Weekday		Weekend		Weekday		Weekend	
		AM	PM	AM	PM	AM	PM	AM	PM
2007	11	2	2	2	2	4	4	4	4
	12	2	2	2	2	4	4	4	4
2008	1	2	2	2	2	4	4	4	4
	2	2	2	2	2	4	4	4	4
	3	2	2	2	2	4	4	4	4
	4	2	2	2	2	4	4	4	4
	5	2	2	2	2	2	2	2	2
	6	2	2	2	2	3	2	2	1
	7	2	2	2	2	2	2	2	2
	8	2	2	2	2	2	2	2	2
	9	2	2	2	2	2	2	2	2
	10	2	2	2	2	2	2	2	2

Figure 5.1. Locations surveyed during the 2007 – 08 survey of recreational fishing of the Peel-Harvey Estuary.

Shore-based recreational fishing surveys

In the 2007 – 08 study, while the area covered by the bridges/jetties survey remained unchanged from that covered by the 1998 – 99 survey, a slight modification was made to the areas covered by the scoop-netting survey. The three scoop netting areas, i.e. Peel/Harvey, Coodanup, and Harvey, were designated in the 2007 – 08 survey as areas 1, 2, and 3, respectively, and the regions represented by these names were modified from the regions that they had previously represented. In the later survey, Area 1 extended northward from Dawesville South (excluding the Dawesville Channel) to the Bypass Bridge on the western shore, Area 2 included the area on the northern, eastern and southern shores of Peel Inlet from the Bypass Bridge to the west of the promontory opposite the opening to the Dawesville Channel, and Area 3 ranged southward from Dawesville South along the western, then southern and eastern shores of Harvey Estuary to the western point of the promontory opposite the Dawesville Channel (Figure 2).

The 1998 – 99 bridge and jetty survey ran from November 1998 to April 1999, while the scoop-netting survey was conducted between December 1998 and April 1999. The selection by Malseed and Sumner (2001) of these survey periods was based on the assumption that there was little activity at bridges & jetties outside the November to April period and the scoop netting survey covered the period when legal-sized blue swimmer crabs are most abundant in the Peel-Harvey Estuary (Potter *et al.*, 1983; 1998). The 2007 – 08 survey was undertaken between November 2007 and October 2008, with the intention of covering the full year.

The primary stratum used when designing both the 1998 – 99 and 2007 – 08 surveys was the calendar month. The secondary stratum was day type, i.e. week or weekend day, with public holidays classified as weekend days. A third stratum, i.e. sampling shift, was included when designing the survey to ensure that sampling was well distributed throughout the daily survey period. Approximately equal numbers of days of each day type were sampled in the 1998 – 99 survey. For the 2007 – 08 survey, however, while sampling occurred in each calendar month, a greater intensity of sampling was allocated to the peak fishing period (November to April) than to the off-peak period (May to October) (Table 5.4).

Table 5.4. Number of weekday and weekend days sampled within each calendar month during the 2007 – 08 surveys of shore-based recreational fishing.

Year	Month	Bridges		Scoop netting	
		Weekday	Weekend	Weekday	Weekend
2007	11	7	5	5	5
	12	6	6	5	4
2008	1	7	4	6	4
	2	6	6	6	6
	3	7	5	5	5
	4	7	5	4	6
	5	3	3	3	3
	6	3	3	3	3
	7	3	3	3	3
	8	2	3	3	3
	9	3	3	3	3
	10	3	3	3	3

The recreational surveys were undertaken on randomly-selected days, within the set of all possible survey days of the same day type (weekend or weekday) within each monthly stratum during the surveyed period. Malseed and Sumner (2001) report that the 1998 – 99 surveys were restricted to daylight hours as (a) resources were insufficient to support more extended coverage, and (b) the personal safety of the interviewers needed to be ensured. They also report that, from anecdotal information obtained from Fisheries Officers and local recreational fishers, "although night fishing occurred at certain times of year, the catch and fishing effort was insignificant".

For each survey, after choosing a random survey day of the specific day type for the stratum, a random starting location and a random direction of traversal of the bridges/jetties were selected.

Although no details of the within-day temporal strata of the bridge/jetty survey times for the 1998 – 99 survey were reported by Malseed and Sumner (2001), analysis of the data indicates that the daily survey period was divided into five two-and-a-quarter-hour periods from 9:00 – 11:15 a.m., 11:15 – 13:30 p.m., 13:30 – 15:45 p.m., 15:45 – 18:00 p.m., and 18:00 – 20:15 p.m. For the scoop-netting areas, Malseed and Sumner (2001) advise that the daily survey period was divided into a morning (7:00 a.m. to 12:30 p.m.) and afternoon shift (12:30 p.m. to 6:00 p.m.), which was randomly selected, following which a starting time within this survey period, which allowed for a maximum survey time at the scoop netting site of 4.5 hours, was also randomly selected. The interviewer terminated the visit to the scoop-netting area either when the 4.5-hour period was completed or, if the interviews required less time than the 4.5 hours that had been allocated, when those interviews were completed.

For the 2007 – 08 survey of the bridges & jetties, the daily survey period extended from 9:00 a.m. to 22:30 p.m., while, for the survey of scoop-netting areas, it extended from 6:00 a.m. to 20:00 p.m. The day for the 2007 – 08 bridges & jetties survey was divided into six two-and-a-quarter-hour periods from 9:00 – 11:15 a.m., 11:15 – 13:30 p.m., 13:30 – 15:45 p.m., 15:45 – 18:00 p.m., 18:00 – 20:15 p.m., and 20:15 – 22:30 p.m., and the shift for the interviewers was specified to be of two hours duration. For the scoop-netting survey in 2007 – 08, the survey day was divided into two shifts, i.e. a morning shift from 6:00 a.m. to 12 noon, and an afternoon shift from 12 noon to 8:00 p.m. Although the 2007 – 08 survey overlapped with the daylight savings trial that was conducted in Western Australia between 2006 and 2009, planned schedules for survey visits between 28 October, 2007, and 30 March, 2008, adhered to daylight savings time and were otherwise unaffected.

Analysis of the data suggests that the survey design for the 2007 – 08 survey was as shown in Tables 5.5 and 5.6. Details of the actual numbers of days on which each location was surveyed within each period are presented in Tables 5.7 and 5.8. For the bridges & jetties survey, the starting time, location and direction of travel were randomly selected, with the interviewer moving from one location to the next during the survey period. On each visit, the scoop-netting locations were each visited for a period not exceeding 4 hours, starting at a randomly selected time within either the morning or afternoon survey period.

Table 5.5. Survey design for the 2007 – 08 survey of recreational fishing at the bridges & jetties.

Date of survey	Number of Weekday (Y) and Weekend (D) shifts	Shift duration (Hours)	Number of times each time period was sampled each month	Survey period
Nov – 07	2Y 2D	2	2	1. 9:00am – 11:15am
Dec – 07	2Y 2D	2	2	2. 11.15am – 13:30pm
Jan – 08	2Y 2D	2	2	3. 13:30pm – 15:45pm
Feb – 08	2Y 2D	2	2	4. 15:45pm – 18:00pm
Mar – 08	2Y 2D	2	2	5. 18:00pm – 20.15pm
Apr – 08	2Y 2D	2	2	6. 20.15pm – 22:30pm
May – 08	1Y 1D	2	1	1. 9:00am – 11:15am
Jun – 08	1Y 1D	2	1	2. 11.15am – 13:30pm
Jul – 08	1Y 1D	2	1	3. 13:30pm – 15:45pm
Aug – 08	1Y 1D	2	1	4. 15:45pm – 18:00pm
Sep – 08	1Y 1D	2	1	5. 18:00pm – 20.15pm
Oct – 08	1Y 1D	2	1	6. 20.15pm – 22:30pm

Table 5.6. Survey design for the 2007 – 08 survey of recreational fishing at scoop netting locations.

Date of survey	Number of morning (M) & afternoon (A) shifts	Number of Weekday (Y) and Weekend (D) shifts	Number of shifts in each zone	Shift duration (Hours)
Nov – 07	2M 2A	2Y 2D	4	4
Dec – 07	2M 2A	2Y 2D	4	4
Jan – 08	2M 2A	2Y 2D	4	4
Feb – 08	2M 2A	2Y 2D	4	4
Mar – 08	2M 2A	2Y 2D	4	4
Apr – 08	2M 2A	2Y 2D	4	4
May – 08	1M 1A	1Y 1D	2	4
Jun – 08	1M 1A	1Y 1D	2	4
Jul – 08	1M 1A	1Y 1D	2	4
Aug – 08	1M 1A	1Y 1D	2	4
Sep – 08	1M 1A	1Y 1D	2	4
Oct – 08	1M 1A	1Y 1D	2	4

Table 5.7. Actual number of daily samples at bridges & jetties during 2007 – 08 survey within each 2.5 hour period during each month, where period 0 = <9:00 a.m., 1 = 9:00 – 11:15 a.m., 2 = 11:15 – 13:30 p.m., 3 = 13:30 – 15:45 p.m., 4 = 15:45 – 18:00 p.m., 5 = 18:00 – 20:15 p.m., and 6 = 20:15 – 22:30 p.m.

Year	Month	Bypass Bridge						Mandurah Quay						Mary Street							Old Traffic Bridge						
		Period																									
		1	2	3	4	5	6	1	2	3	4	5	6	0	1	2	3	4	5	6	0	1	2	3	4	5	6
Weekday																											
2007	11	2	2	1		1	1	3	2		1		1		2	2	1	1	1			3	1	1		2	
	12	1	1	1	1	1	1	1	2	1	1		1		1	1	2	1	1			2		2	1	1	
2008	1	3		1	2	1		2	2	1		2			2	1	2		2			2	1	2	1		1
	2	2	1	1	2			2		1	2		1	1	1	1	2	1			1	1	1	2		1	
	3	1	2		3		1	1	2	1	2		1		1	1	2	2		1		1	1	2	2	1	
	4	1	1	2	1	1	1	2		2	1	2			1	1	2	1	2			1	2	1	2	1	
	5		1	1		1		1		1		1				1		1	1			0	1		1	1	
	6	1	1			1		1	1		1				1		1	1				1		1		1	
	7	1		1		1		1			1	1		1		1		1					1	1		1	
	8		1		1					1		1				1		1					1		1		
	9	1			1	1			1	1		1			1		1		1			1			1	1	
	10	1	1		1			1		1	1				1		1		1			1		1		1	
Weekend																											
2007	11			2	2	1				3	1	1					2	1	2				1		2		1
	12	1	2	1	1	1		1	1	2	1	1			1	1	1	2	1			2			1	1	
2008	1	1	1	2				1	2	1					1	1	2					2					
	2	1	2	1	1	1		1	3			2			1	2	1	1	1			2	1		1	1	
	3	1	1	1	1	1		1	2		1	1			1	1	1		2			1	1		1	1	
	4	1	1	1	1	1		2		1		2			1	2			2			1	1		1	1	
	5	1	1			1		1	1			1			1	1			1			1	1		1		
	6		1		1	1			1	1		1			1		1		1				1		1	1	
	7	1	1			1		1		1		1			1		1	1				1			1		
	8	1		1		1			1	1		1				1	1		1				1			1	
	9	1		1		1		1		1	1				1		1	1	0			1	1		1		
	10		1	1		1		0	1	0	1	1				1		1	1			1			0	1	

Table 5.8. Actual number of daily samples taken at scoop-netting areas during 2007 – 08 survey within each morning and afternoon shift during each month, where AM = 6 a.m. to 12 noon. and PM = 12 noon to 8 p.m.

Month	Coodanup				Harvey				Peel/Harvey			
	Weekday		Weekend		Weekday		Weekend		Weekday		Weekend	
	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
11	0	1	0	2	1	1	1	1	0	2	1	1
12	1	1	1	1	1	1	1	1	1	1	1	1
2007	**1**	**2**	**1**	**3**	**2**	**2**	**2**	**2**	**1**	**3**	**2**	**2**
1	1	1	1	1	1	1	0	2	1	1	2	0
2	0	2	0	2	1	1	1	1	0	2	1	1
3	1	1	1	1	0	2	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1	1	1
5	1	0	0	1	0	1	1	0	0	1	1	0
6	0	1	1	0	1	0	0	1	1	0	0	1
7	1	0	0	1	0	1	1	0	0	1	1	0
8	0	1	1	0	1	0	0	1	1	0	0	1
9	1	0	0	1	0	1	1	0	1	0	1	0
10	1	0	1	0	1	0	0	1	1	0	0	1
2008	**7**	**7**	**6**	**8**	**6**	**8**	**6**	**8**	**7**	**7**	**8**	**6**

At each site, prior to conducting interviews, a one-off instantaneous count of fishers was undertaken and the value of this count was recorded on the survey form (see Malseed and Sumner 2001). People included in the instantaneous count were those who appeared to be engaged in fishing activity, i.e. those who were holding a net, line, rod, etc.

Following the recording of the count, interviewers attempted to interview a member of each fishing party present at the location, recording details of successful interviews on the survey form. No data were recorded if the parties approached declined to be interviewed, i.e. no interview record was produced. Although not stated by Malseed and Sumner (2001), the inference can be drawn from the survey form and results reported that interviewers measured and sexed the blue swimmer crabs that had been kept by those parties who were interviewed.

Survey of waterfront properties and houseboats

Waterfront properties in main canal developments

Numerous residents of the private houses with water frontage located in canal developments in the Mandurah Channel, Murray River and northern side of the Dawesville Channel fish from their properties for blue swimmer crabs. To ensure that the estimate of total blue swimmer crab catch for the 2007 – 08 survey period accounted for the entire recreational catch, residents of 2174 these houses were sent a letter in October 2007 asking if they would be willing to participate in a 12-month logbook program. Note that it was subsequently determined that, in addition to the households that received these letters, residents of a further 154 houses with water frontage had not been contacted. Houses with water frontage were defined as properties with either direct access or in close proximity to the estuary such that boats could be launched or moored within 50 m from the property. Properties with water frontage that were located outside of the canals were not included in the logbook survey.

Of the 2174 households contacted, a total of 920 responses were received, of which 613 expressed a willingness to participate, 101 declined to participate, and the remaining 206 were blank. The logbook program was designed to obtain data in two-monthly waves. Thus, diaries, i.e. logbooks, were sent to the 613 positive respondents to the original letter asking that they record details of their fishing activity for the November – December period then return the completed logbook. Similar requests were sent to the remaining participants to collect data for the January – February, March – Aril, May – June, July – August, and September – October periods (Table 5.9).

Table 5.9. Details of the numbers of logbooks that were distributed and returned in each two-month period by participants of the 2007 – 08 logbook program to obtain estimates of catches of blue swimmer crabs by residents of waterfront properties in the canal developments of the Mandurah Channel, Murray River and northern side of the Dawesville Channel.

Two-month period	Number of diaries sent	Number of diaries returned
November – December 2007	613	294
January – February 2008	613	237
March – April 2008	558	206
May – June 2008	534	221
July – August 2008	469	185
September – October 2008	469	170

Data to be recorded in logbooks comprised the date of fishing activity, fishing location, depth, start and finish times, breaks in fishing times, number of fishers, fishing method, species caught, and the length and fate of each fish, i.e. whether or not it was kept or released. For blue swimmer crabs, carapace width rather than length was recorded. The logbooks that were sent to the participants were accompanied by a map of the Peel-Harvey Estuary overlaid by a grid that divided the area into 2.78 square nautical mile blocks. Returned logbooks were subjected to a validation procedure, with participants being contacted to resolve issues relating to missing or incongruous data.

Hired houseboats

A small number of visitors to the Mandurah Estuary hire houseboats. To ascertain the catches of blue swimmer crabs by these fishers, customers of boat and house hire businesses, using boats on the estuary, were included in the logbook survey that was run for residents of waterfront canal properties. As with the latter survey, a logbook and map was provided to each participant for each two-month survey period. The businesses hiring the houseboats were requested to facilitate customer participation in the logbook survey. They were also asked to supply data on the number and duration of hires, the numbers of persons on board, and anecdotal information on proportions of people who fished or took fishing equipment on their trip.

5.2.2 Analysis of survey data

Strata used when analysing the data from the Peel-Harvey Estuary surveys

By dividing the daily surveyed time period into shifts, the survey design incorporated a form of systematic sampling which ensured that, within the days that were surveyed, surveys were distributed throughout the daily survey period. While stratification of the daily survey period into morning and afternoon shifts was recognised when analysing the boat-based data, shore-based survey data collected within different shifts were simply treated as random samples from the daily survey period.

The strata used when analysing the data for the surveys of the Peel-Harvey Estuary were area code (i.e. the bus route, bridge/jetty, or scoop-netting area), season and day type (weekday or weekend/ public holiday), and, in the case of the boat-based data, morning or afternoon shift. Recognising that the results could be sensitive to the nature of temporal stratification employed when analysing the data, a number of alternative temporal stratification schemes were investigated (Table 5.10). Bimonthly stratification was selected for use in this report as it assured adequate sample sizes in each time period and permitted investigation of intra-annual variation in catch and effort.

Table 5.10. The alternative temporal stratification schemes employed in the analysis.

Temporal stratification	Comments
1. Peak/non-peak	'JanFeb' = January & February; 'NonPeak' = March, April, November, & December; 'MJJA' = May, June, July, & August; and 'SepOct' = September & October
2. Bimonthly	'JanFeb' = January & February; 'MarApr' = March & April; 'MJJA' = May, June, July, & August; 'SepOct' = September & October; and 'NovDec'=November & December
3. Monthly	'Jan' = January; 'Feb' = February; 'Mar' = March; 'Apr' = April; 'MJJA' = May, June, July or August; 'SepOct' = September or October; 'Nov' = November; and 'Dec' = December

Boat ramp-based recreational surveys

The interval count method, based on counts of boat trailers, boat launch and retrieval time (Pollock *et al.*, 1994) was used in these surveys because it was reasonable to attribute parked trailers to fishing parties. The primary sampling unit (PSU) was the survey day. Data collected at the boat ramps visited within each survey day were then expanded to produce estimates of the total catch and fishing effort in the two districts, East and West, of the Peel-Harvey Estuary.

The estimate of the total boating activity time (h) e_{dm} during the daily survey period T over all boat ramps r ($1 \le r \le R$) on Day d ($1 \le d \le D_m$) in Stratum m ($1 \le m \le M$) (Jones and Robson 1991) was calculated as

$$e_{dm} = T \sum_{r=1}^{R} \frac{1}{w_{rdm}} \sum_{b=1}^{B_{rdm}} X_{rbdm},$$

and its variance as

$$Var(e_{dm}) = T^2 \sum_{r=1}^{R} \frac{B_{rdm}^2}{w_{rdm}^2} Var(\overline{X}_{rdm}), \text{ where}$$

$$Var(\overline{X}_{rdm}) = \frac{1}{B_{rdm}(B_{rdm} - 1)} \sum_{b=1}^{B_{rdm}} (X_{rbdm} - \overline{X}_{rdm})^2,$$

and where X_{rbdm} is the time that Boat b ($1 \le b \le B_{rdm}$) was on the water (or the trailer associated with Boat b was at the site) during the wait time w_{rdm} of the interviewer's visit to the boat ramp. B_{rdm} is the total number of boats that were on the water during that period. If there were too few trailers at a ramp at the time of the interviewer's visit to calculate the above variance, i.e. $B_{rdm} < 2$, the estimated variance of the mean of the pooled values of X_{rbdm} across all boat ramps for Day d and Stratum m was employed in the calculation rather than $Var(\bar{X}_{rdm})$.

The proportion p_{dm} of boats that were crabbing on Day d in Stratum m was estimated as

$$p_{dm} = \frac{n_{dm}^{Fishing}}{n_{dm}},$$

and, assuming a binomial distribution, its variance as

$$Var(p_{dm}) = \frac{p_{dm}(1 - p_{dm})}{n_{dm}},$$

where n_{dm} represents the number of boating parties interviewed on Day d in Stratum m and $n_{dm}^{Fishing}$ is the number of these parties that had been fishing for crabs. If no boating parties were successfully interviewed on Day d, the estimate of the proportion fishing during Day d, and its variance, were derived from the pooled interview data over all survey days for the stratum.

An estimate of the total fishing time e_{dm}^{f} during the survey period T on Day d for Stratum m was calculated as

$$e_{dm}^{f} = p_{dm} e_{dm},$$

where the variance of e_{dm}^{f} is calculated using the formula for the variance of a product presented by Goodman (1960), i.e.

$$Var(e_{dm}^{f}) = (p_{dm} e_{dm})^2 \times \left[\frac{Var(p_{dm})}{p_{dm}^2} + \frac{Var(e_{dm})}{e_{dm}^2} - \frac{Var(p_{dm}) Var(e_{dm})}{(p_{dm} e_{dm})^2} \right],$$

which has been employed in similar access-point studies of recreational fishing (e.g. Steffe *et al.* 2008).

The total fishing time $\hat{E}_m^*$ within the daily survey period for Stratum m, over all possible survey days, was calculated as

$$\hat{E}_m^* = \frac{D_m}{d_m} \sum_{d=1}^{d_m} e_{dm}^{f} = D_m \bar{e}_{dm}^{f},$$

and its variance as

$$Var(\hat{E}_m^*) = \frac{D_m^2}{d_m(d_m - 1)} \left[\sum_{d=1}^{d_m} \left(e_{dm}^{f} - \frac{1}{d_m} \sum_{d=1}^{d_m} e_{dm}^{f} \right)^2 \right] \times \left[\frac{D_m - d_m}{D_m} \right] + \frac{D_m}{d_m} \sum_{d=1}^{d_m} [Var(e_{dm}^{f})].$$

An adjustment factor f_m was required to extrapolate from the estimate for the survey period and, thereby, to obtain an estimate of effort that included fishing activity before the start of the daily survey period (Sumner and Williamson 1999). For each Trip t for which interview data were recorded within Stratum m, the durations (h) of the trip L_{tm}, i.e. the period between launch and retrieval, and the period between the interviewer's arrival at the boat ramp and retrieval of the boat at the ramp, L'_{tm} , were calculated. Next, the duration (h) of the overlapping period while the boat was at sea and the interviewer was at the ramp, L^*_{tm} , was calculated as the minimum of L_{tm} and L'_m. The means $\bar{L}_m$ and $\bar{L}^*_m$, variances $Var(\bar{L}_m)$ and $Var(\bar{L}^*_m)$, and correlation $Corr(\bar{L}_m, \bar{L}^*_m)$ over all interviews for Stratum m were then calculated. Subsequently, the adjustment factor and its variance were calculated as

$$f_m = \frac{\bar{L}_m}{\bar{L}^*_m}, \text{ and}$$

$$Var(f_m) \approx \left(\frac{\bar{L}_m}{\bar{L}^*_m}\right)^2 \left[\frac{Var(\bar{L}_m)}{\bar{L}^2_m} + \frac{Var(\bar{L}^*_m)}{(\bar{L}^*_m)^2} - \frac{2Corr(\bar{L}_m, \bar{L}^*_m)\sqrt{Var(\bar{L}_m)Var(\bar{L}^*_m)}}{\bar{L}_m\bar{L}^*_m}\right], \text{ respectively.}$$

The total fishing time $\hat{E}_m$ for Stratum m, over all possible survey days, was then calculated by multiplying the total fishing time within the daily survey period by the expansion factor. Thus,

$$\hat{E}_m = f_m\hat{E}^*_m$$

and its variance was

$$Var(\hat{E}_m) \approx (f_m\hat{E}^*_m)^2 \left[\frac{Var(f_m)}{f^2_m} + \frac{Var(\hat{E}^*_m)}{(\hat{E}^*_m)^2} - \frac{Var(f_m)Var(\hat{E}^*_m)}{(f_m\hat{E}^*_m)^2}\right].$$

The catch rate $\hat{R}_m$ for each stratum was estimated as the ratio of the means for catch and fishing effort (Crone and Malvestuto 1991), i.e.

$$\hat{R}_m = \frac{\sum_{b=1}^{n_m} c_{bm}}{\sum_{b=1}^{n_m} L_{bm}},$$

where n_m is the number of boating parties in the stratum that were interviewed, c_{bm} is the catch of crabs, and L_{bm} is the duration (h) of the fishing trip, i.e. the difference between launch and retrieval times, reported by the interviewed party in Boat b. The variance for $\hat{R}_m$ was estimated using the formula described in Kendall and Stuart (1969), as follows:

$$Var(\hat{R}_m) \approx \hat{R}^2_m \left(\frac{Var(\bar{c}_m)}{\bar{c}^2_m} + \frac{Var(\bar{L}_m)}{\bar{L}^2_m} - \frac{2Corr(\bar{c}_m, \bar{L}_m)\sqrt{Var(\bar{c}_m)Var(\bar{L}_m)}}{\bar{c}_m\bar{L}_m}\right),$$

where $Corr(\bar{c}_m, \bar{L}_m)$ represents the correlation between $\bar{c}_m$ and $\bar{L}_m$. The mean, correlation and variance (of the mean) for catch and trip duration were calculated using standard statistical equations.

The total catch $\hat{C}_m$ for Stratum m was calculated as

$$\hat{C}_m = \hat{E}_m \hat{R}_m,$$

and, by using the formula presented by Goodman (1960, eqn 5), its variance as

$$Var(\hat{C}_m) \approx \hat{C}_m^2 \left(\frac{Var(\hat{E}_m)}{\hat{E}_m^2} + \frac{Var(\hat{R}_m)}{\hat{R}_m^2} - \frac{Var(\hat{E}_m)Var(\hat{R}_m)}{(\hat{E}_m \hat{R}_m)^2} \right).$$

The total catch over all M strata was calculated as

$$\hat{C} = \sum_{m=1}^{M} \hat{C}_m,$$

and its variance as

$$Var(\hat{C}) = \sum_{m=1}^{M} Var(\hat{C}_m).$$

Shore-based recreational fishing surveys

Calculation of proportions crabbing

Each interview, which produced details of fishing data recorded for a fishing party (group) derived from information provided by one member of the group, was processed. Each interviewed group was identified as a crabbing group if (a) the net type being considered in the analysis was a crab net or scoop net and the group was recorded as using the corresponding net type, or (b) the data being considered in the analysis was the pooled data for both crab and scoop nets and the group was recorded as using one of these net types.

It was assumed that the groups interviewed were representative of the groups comprising all of those people on the shore, who had been counted in the instantaneous count taken at each location, where each group consisted of one or more individuals. The total number of crabbing and non-crabbing groups, which were interviewed, and the number of those groups that were crabbing (i.e. crabbing groups) were determined for each stratum, together with the total numbers of the people within all groups, people in crabbing groups, and people who were recorded as actively fishing in those crabbing groups. From these totals, estimates were calculated over all survey days for each stratum m of the proportion of groups, $P_{G,m}$, that were classified as crabbing, the proportion of the total number of people on the shore in both crabbing and non-crabbing groups who were members of crabbing groups, $P_{P,m}$, the proportion of the total number of people in the crabbing groups who were actually fishing, $P_{F,m}$, and the proportion, $P_{PF,m}$, of the total number of people on the shore, i.e. in crabbing and non-crabbing groups, who were actively engaged in crabbing, i.e. were in groups that were crabbing and were engaged in fishing.

The paucity of data for some strata made it necessary to pool the data over all survey days within each stratum. This calculation imposes an assumption that, within a stratum, the above proportions are drawn from the same binomial distributions over all survey days. If, after pooling over all survey days, there were still no interview data available for a stratum, it was assumed that the proportions (and their associated variances) were zero.

Let $N_{G,j,m}$ be the number of people in the *j*th group, i.e. party, within stratum m and let $N_{F,j,m}$ be the number of people fishing in that group. The group represents the subject of an interview at a specific location on a specific survey day and, in calculating the proportions, one of the groups interviewed over all survey days within stratum m. It is assumed that $n_{G,m}$ groups were interviewed at the location on the various survey days within the stratum. Set $X_{j,m} = 1$ if this *j*'th group had been classified as fishing for crabs, otherwise set $X_{j,m} = 0$.

The proportion of groups that were involved in fishing for crabs within the stratum, $P_{G,m}$, i.e. participating in the blue swimmer crab fishery, was calculated as

$$P_{G,m} = \begin{cases} 0 & \text{if } n_{G,m} = 0 \\ \dfrac{\sum_{j=1}^{n_{G,m}} X_{j,m}}{n_{G,m}} & \text{otherwise} \end{cases}$$

where

$$Var\left(P_{G,m}\right) = \begin{cases} 0 & \text{if } n_{G,m} < 1 \\ \dfrac{P_{G,m}\left(1 - P_{G,m}\right)}{n_{G,m}} & \text{otherwise} \end{cases}$$

.

The proportion of people within the groups interviewed, where the group was recorded as fishing for crabs (i.e. actively participating in the blue swimmer crab fishery), relative to the total number of people within all interviewed groups (parties), $P_{P,m}$, was calculated as

$$P_{P,m} = \begin{cases} 0 & \text{if } n_{G,m} < 1 \\ \dfrac{\sum_{j=1}^{n_{G,m}} N_{G,j,m} X_{j,m}}{\sum_{j=1}^{n_{G,m}} N_{G,j,m}} & \text{otherwise} \end{cases}$$

where the ratio above represents the ratio of means of the variables $N_{G,j,m} X_{j,m}$ and $N_{G,j,m}$ over all interviewed groups in stratum *m*, i.e.

$$\frac{\sum_{j=1}^{n_{G,m}} N_{G,j,m} X_{j,m}}{\sum_{j=1}^{n_{G,m}} N_{G,j,m}} = \frac{\frac{1}{n_{G,m}} \sum_{j=1}^{n_{G,m}} N_{G,j,m} X_{j,m}}{\frac{1}{n_{G,m}} \sum_{j=1}^{n_{G,m}} N_{G,j,m}}$$

Thus, assuming that the covariance term of the formula for the variance of the ratio is zero,

$$Var\left(P_{P,m}\right) = \begin{cases} 0 & \text{if } n_{G,m} < 2 \text{ or } \sum_{j=1}^{n_{G,m}} N_{G,j,m} = 0 \text{ or } \sum_{j=1}^{n_{G,m}} N_{G,j,m} X_{j,m} = 0 \\ P_{P,m}^2 \left\{ \dfrac{Var\left(N_{G,j,m} X_{j,m}\right)}{n_{G,m}\left[\frac{1}{n_{G,m}} \sum_{j=1}^{n_{G,m}} N_{G,j,m} X_{j,m}\right]^2} + \dfrac{Var\left(N_{G,j,m}\right)}{n_{G,m}\left[\frac{1}{n_{G,m}} \sum_{j=1}^{n_{G,m}} N_{G,j,m}\right]^2} \right\} & \text{otherwise} \end{cases}$$

This proportion is the appropriate value by which the instantaneous count of the people on the shore should be multiplied to estimate the number of people on the shore who were members of groups that were fishing for crabs, i.e. who were actively participating in the blue swimmer crab fishery.

The proportion of the total number of individuals in the groups in stratum m that were fishing for crabs, who were actively involved in fishing, $P_{F,m}$, was calculated as

$$P_{F,m} = \begin{cases} 0 & \text{if } n_{G,m} < 1 \text{ or } \sum_{j=1} N_{G,j,m} X_{j,m} = 0 \\ \dfrac{\sum_{j=1}^{n_{G,m}} N_{F,j,m} X_{j,m}}{\sum_{j=1}^{n_{G,m}} N_{G,j,m} X_{j,m}} & \text{otherwise} \end{cases}$$

where, once again, the ratio in the above expression may be considered to be the ratio of the means of the variables, i.e. of $N_{F,j,m} X_{j,m}$ and $N_{G,j,m} X_{j,m}$.

Finally, the proportion of the people within all interviewed groups for stratum m that were both in crabbing groups and were actively fishing, P_{PF} , was calculated as

$$P_{PF,m} = P_{P,m} P_{F,m} = \frac{\sum_{j=1}^{n_{G,m}} N_{G,j,m} X_{j,m}}{\sum_{j=1}^{n_{G,m}} N_{G,j,m}} \frac{\sum_{j=1}^{n_{G,m}} N_{F,j,m} X_{j,m}}{\sum_{j=1}^{n_{G,m}} N_{G,j,m} X_{j,m}} = \frac{\sum_{j=1}^{n_{G,m}} N_{F,j,m} X_{j,m}}{\sum_{j=1}^{n_{G,m}} N_{G,j,m}} = \frac{\frac{1}{n_{G,m}} \sum_{j=1}^{n_{G,m}} N_{F,j,m} X_{j,m}}{\frac{1}{n_{G,m}} \sum_{j=1}^{n_{G,m}} N_{G,j,m}}$$

when the denominator exceeded zero. That is,

$$P_{PF,m} = \begin{cases} 0 & \text{if } n_{G,m} < 1 \text{ or } \sum_{j=1}^{n_{G,m}} N_{G,j,m} = 0 \\ \dfrac{\sum_{j=1}^{n_{G,m}} N_{F,j,m} X_{j,m}}{\sum_{j=1}^{n_{G,m}} N_{G,j,m}} & \text{otherwise} \end{cases}$$

From this, it may be seen that $P_{PF,m}$ is the ratio of the mean of the number of fishers within all interviewed groups for stratum *m* and the mean of the number of people in all of those interviewed groups. We may write

$$\bar{N}_{F,m} = \begin{cases} 0 & \text{if } n_{G,m} = 0 \\ \dfrac{1}{n_{G,m}} \sum_{j=1}^{n_{G,m}} N_{F,j,m} X_{j,m} & \text{otherwise} \end{cases}$$

and

$$\bar{N}_{G,m} = \begin{cases} 0 & \text{if } n_{G,m} = 0 \\ \dfrac{1}{n_{G,m}} \sum_{j=1}^{n_{G,m}} N_{G,j,m} & \text{otherwise} \end{cases}$$

and the variances of these respective means as

$$Var\left(\bar{N}_{F,m}\right) = \begin{cases} 0 & \text{if } n_{G,m} < 2 \\ \dfrac{1}{n_{G,m}\left(n_{G,m} - 1\right)} \sum_{j=1}^{n_{G,m}} \left(N_{F,j,m} X_{j,m} - \bar{N}_{F,m}\right)^2 & \text{otherwise} \end{cases}$$

and

$$Var\left(\bar{N}_{G,m}\right)=\begin{cases}0 & \text{if } n_{G,m}<2\\ \dfrac{1}{n_{G,m}\left(n_{G,m}-1\right)}\displaystyle\sum_{j=1}^{n_{G,m}}\left(N_{G,j,m}-\bar{N}_{G,m}\right)^2 & \text{otherwise}\end{cases}$$

The variance of this ratio, i.e. $Var(P_{PF,m})$, was calculated as

$$Var\left(P_{PF,m}\right)=\begin{cases}0 & \text{if } n_{G,m}<2 \text{ or } \bar{N}_{F,m}=0 \text{ or } \bar{N}_{G,m}=0\\ P_{PF,m}^2\left\{\dfrac{Var\left(\bar{N}_{F,m}\right)}{\bar{N}_{F,m}^2}+\dfrac{Var\left(\bar{N}_{G,m}\right)}{\bar{N}_{G,m}^2}\right\} & \text{otherwise}\end{cases}$$

where it was assumed that, for the analysis of the recreational blue swimmer crab data, the covariance $Cov(\bar{N}_{F,m}, \bar{N}_{G,m})$ was zero.

Durations of the daily survey period

As a result of survey design, coverage of the hours of the day within which random instantaneous counts were made differed during different periods of the year. Daily coverage also differed between the bridges/jetties and the scoop-netting areas. Estimates of the daily survey periods for which the instantaneous counts were likely to be representative are presented in Table 5.11. The values recorded in this table include those that were employed as the daily duration of the survey period by Malseed and Sumner (2001). Other values recorded in this table were determined by examining scatterplots of the times at which instantaneous counts were taken against day of year (Figures 5.2 and 5.3) (Figs 3 – 6).

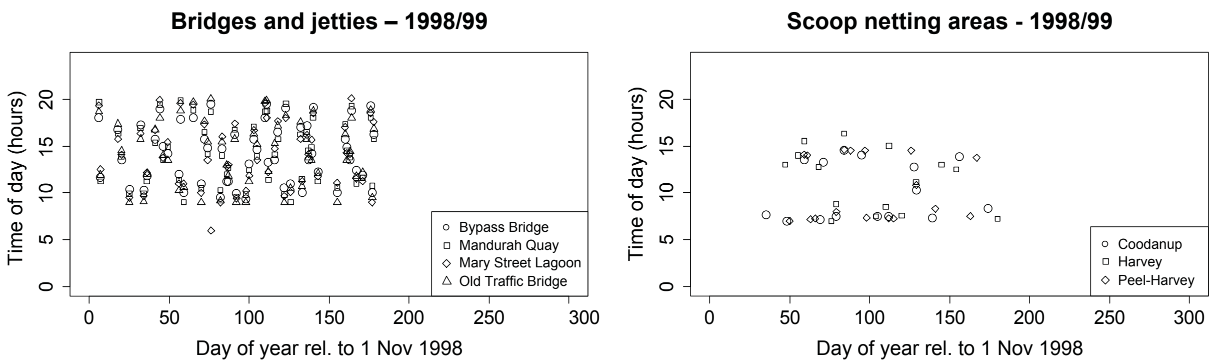

Figure 5.2. Time at which instantaneous counts was made for 1998 – 99 roving survey of bridges & jetties and scoop-netting areas in the Peel-Harvey Estuary.

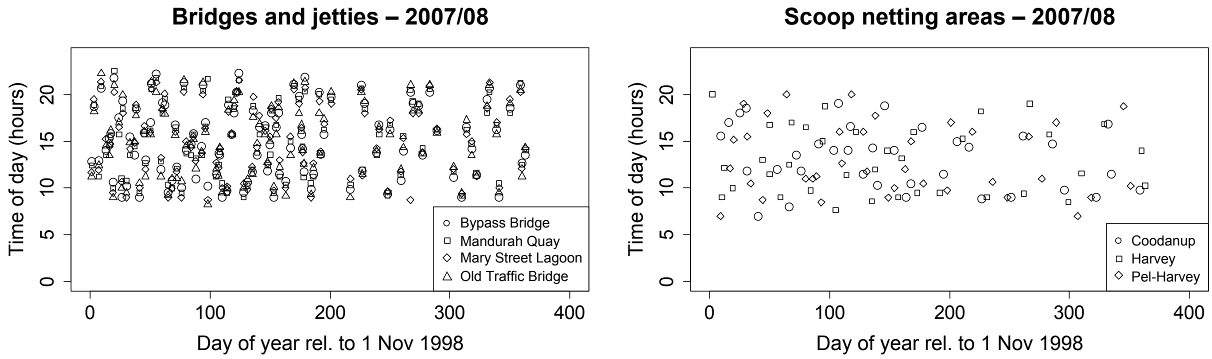

Figure 5.3. Time at which instantaneous counts was made for 2007 – 08 roving survey of bridges & jetties and scoop-netting areas in the Peel-Harvey Estuary.

While the daily survey periods used for bridges/jetties by Malseed and Sumner (2001) for 1998 – 99 were 11.25 hours and were relatively consistent with the values in the data, the durations that were used for scoop-netting areas, i.e. 12 hours for December to March and 11 hours for April, differed from the daily period that appeared to be covered by the counts. Accordingly, When initially exploring the sensitivity of the results to alternative methods of analysis, separate analyses were undertaken for the 1998 – 99 survey, firstly using the values of daily survey period employed by Malseed and Sumner (2001) while subsequently employing values derived from examination of the data. The latter approach was selected as more appropriate for the analysis of the scoop-netting data in this report.

Table 5.11. Duration (hours) of daily survey periods in different months for the bridges & jetties (one scenario) and for the scoop-netting areas in 1998 – 99 (two scenarios, i.e. (a) as designed when planning the survey, and (b) using values derived from data) and 2007 – 08 (one scenario).

Area	Survey	Scenario	Months when this survey period was applied	Duration of daily survey period (hours)
Bridges & jetties	1998 – 99	1	Nov – Apr	9:00 am – 8:05 pm (11.25)
			May – Oct	Not Surveyed
	2007 – 08	1	Nov – Apr	9:00 am – 10:30 pm (13.5)
			May – Oct	9:00 am – 9:15 pm (12.25)
Scoop-netting areas	1998 – 99	1	Dec – Mar	12 Malseed and Sumner (2001)
			Apr	11 Malseed and Sumner (2001)
			May – Nov	9 Malseed and Sumner (2001)
		2	Dec – Mar	7:00 am – 4:20 pm (9.5) Derived from the data (Figure 3).
			Apr	7:00 am – 1:50 pm (7) Derived from the data (Figure 3).
			May – Oct	Not Surveyed
	2007 – 08	1	Nov – Apr	7:00 am – 8:00 pm (13)
			May – Oct	7:00 am – 7:00 pm (12)

Total shore-based activity (person hours) by both blue swimmer crab fishers and others on the shore for the stratum

Let $N_{IC,m}$ be the number of shore-based fishers recorded in the instantaneous count of the number of people present at the location at the start of the survey. This value is assumed to represent the number of people (both crabbing and non-crabbing) in groups present at the location at the time of the count, which, if those groups remained present later in the survey visit, were potentially subject to interview. It was assumed that the instantaneous count at a location on a survey day was made at a random time within the daily survey duration, and thus represents a random sample of the number of people engaged in shore-based fishing (crabbing or angling) activity at the location for that day. With only a single instantaneous count recorded at each location for each survey day a number of strata possessed insufficient data to estimate a mean count, and/or variance, and either such strata were pooled or the estimated values were assumed to be zero.

A similar approach to that employed in the analysis of the 1998 – 99 survey data for the Peel-Harvey Estuary by Malseed and Sumner (2001), was employed in the present study when estimating the level of participation in the blue swimmer crab fishery for each stratum. Thus, prior to combining the data for the various strata, an estimate of the total activity (person hours) at the location on the survey day was obtained by multiplying the instantaneous count by the average daily survey duration, $\bar{T}_m$, for stratum *m*, where this duration was selected from the values in Table 10 for the specific analysis being undertaken. That is, for the *k*'th instantaneous count for the different survey days in stratum *m*, the total activity, i.e. by both crabbers and non-crabbers, $a_{k,m}$ may be calculated as:

$$a_{k,m} = N_{IC,k,m}\bar{T}_m$$

The uncertainty associated with the possibility that the time of the instantaneous count was randomly selected from daily survey durations that differ from those that appeared to reflect the survey design was estimated in separate analyses by considering the range of alternative daily survey durations set out in Table 5.11.

An estimate of the mean daily activity (person hours), $\bar{a}_m$, for stratum *m* over the n_m survey days on which the stratum was visited was then calculated from these products, i.e.

$$\bar{a}_m = \begin{cases} 0 & \text{if } n_m = 0 \\ \dfrac{1}{n_m}\sum_{k=1}^{n_m} a_{k,m} & \text{otherwise} \end{cases}$$

where

$$Var(\bar{a}_m) = \begin{cases} 0 & \text{if } n_m < 2 \\ \dfrac{1}{n_m(n_m-1)}\sum_{k=1}^{n_m}\left(a_{k,m}-\bar{a}_m\right)^2 & \text{otherwise} \end{cases}$$

The decision was taken not to include a finite population correction in this estimate of variance as the counts represent random samples of the daily activity and, despite the fact that the number of possible survey days for the stratum is constrained, there is therefore not just a single possible value of activity for each day. Thus, even if every possible survey day was to be surveyed, the estimate of mean daily activity would still be imprecise.

If N_m is the total number of days of the day type within stratum *m*, the total activity (person-hours) for the stratum, A_m , may be calculated by expansion of the mean daily activity, as follows

$$A_m = N_m\,\bar{a}_m$$

The variance of this total is

$$Var(A_m) = N_m^2 Var(\bar{a}_m).$$

An estimate of the total activity of people on the shore in stratum m who were in crabbing groups (person hours of people in crabbing groups) may be calculated by multiplying the total activity (person hours) for the stratum, A_m, by the proportion of groups involved in fishing for crabs within the stratum, $P_{G,m}$. This calculation assumes that the average number of people in crabbing groups is the same as that of non-crabbing groups. Thus,

$$A_{G,m} = A_m P_{G,m}$$

and using Goodman's (1960) formula,

$$Var\left(A_{G,m}\right) = \begin{cases} 0 & \text{if } A_m = 0 \text{ or } P_{G,m} = 0 \\ A_{G,m}^2 \left\{ \dfrac{Var\left(A_m\right)}{A_m^2} + \dfrac{Var\left(P_{G,m}\right)}{P_{G,m}^2} - \dfrac{Var\left(A_m\right)Var\left(P_{G,m}\right)}{A_m^2 P_{G,m}^2} \right\} & \text{otherwise} \end{cases}$$

The resulting values were aggregated over strata to produce estimates over all locations for each region and area. The variance of the aggregated participation/effort was calculated as the sum of the variances of the estimates of participation/effort for the strata contributing to the total for the location, region and area.

Catch rate

An estimate of the catch rate $\hat{R}_m$ for each stratum m was calculated as a weighted mean of the ratio of the catch reported by the group and the effort recorded for the group within the various interviews (including those interviews for which zero crabs were caught). The data were analysed separately for each sex, however it should be noted that, for many records, the sexes of the crabs that were caught or released were not recorded. This approach follows the method employed by Malseed and Sumner (2001). That is,

$$\hat{R}_{\mathrm{m}} = \frac{\sum_{j=1}^{n_m} \dfrac{w_{j,m} c_{j,m}}{L_{j,m}}}{\sum_{j=1}^{n_m} w_{j,m}} = \frac{\sum_{j=1}^{n_m} \dfrac{c_{j,m}}{\bar{L}_{j,m}}}{\sum_{j=1}^{n_m} w_{j,m}} = \frac{\sum_{j=1}^{n_m} U_{j,m}}{\sum_{j=1}^{n_m} w_{j,m}} = \frac{\bar{U}_m}{\bar{w}_m}$$

where $w_{j,m}$ is the weight, $c_{j,m}$ is the j catch recorded for the crabbing group (where the catch is either the retained catch of crabs or the number of crabs that was released by the crabbing group), and $U_{j,m}$ is the catch rate for the crabbing group (see below). When calculating catch rate, only trips for which the duration of the fishing trip exceeded 15 minutes were employed.

For interview j in stratum m, the value of the catch rate was calculated (separately for both kept and released crabs), based on the number of fishers ($w_{Fishers,j,m}$) in the interviewed group, and was denoted by $\hat{R}_{Fishers,j,m}$ (crabs per fisher hour). Let $\bar{L}_{j,m}$ represent the average fishing time recorded for (each individual within) the crabbing group represented by interview j at the time of the interview. The total hours of fishing by the fishers within the group up till the time at which the interview was conducted is therefore $L_{kj,Fishers} = w_{kj,Fishers} \bar{L}_{kj}$ fisher-hours.

Let $c_{j,m}$ represent the catch recorded for the crabbing group (where the catch is either the number of retained crabs or the number of crabs that was released by the crabbing group up till the time of interview j). Let $U_{Fishers,j,m}$ represent the catch per unit of effort (crabs per fisher-hour) for the fishers in the crabbing group. Then,

$$U_{\mathrm{Fishers},j,m} = \frac{c_{j,m}}{L_{\mathrm{Fishers},j,m}} = \frac{c_{j,m}}{w_{\mathrm{Fishers},j,m} \bar{L}_{j,m}}$$

The weight $w_{j,m}$ was set to $w_{Fishers,j,m}$, i.e. the number of fishers in the crabbing group j in stratum m, and the fishing effort $L_{j,m}$ (fisher hours) was calculated as

$$L_{j,m} = L_{Fishers,j,m} = w_{Fishers,j,m} \overline{L}_{j,m}$$

Writing the catch per hour for crabbing group j as $U_{j,m} = c_{j,m} / \overline{L}_{j,m}$, the estimate of the catch rate $\hat{R}_m$ is seen to be simply the ratio of the means of the catch per hour for the groups and the mean number of either the individuals or fishers in those groups. Thus,

$$\hat{R}_m = \begin{cases} 0 & \text{if } n_m < 1 \text{ or } \overline{w}_m = 0 \\ \dfrac{\overline{U}_m}{\overline{w}_m} & \text{otherwise} \end{cases}$$

Assuming that the covariance term is zero, the variance of the above estimate may be calculated as

$$Var\left(\hat{R}_m\right) = \begin{cases} 0 & \text{if } n_m < 2 \text{ or } \overline{U}_m = 0 \text{ or } \overline{w}_m = 0 \\ \hat{R}_m^2 \left\{ \dfrac{Var\left(U_m\right)}{n_m \overline{U}_m^2} + \dfrac{Var\left(w_m\right)}{n_m \overline{w}_m^2} \right\} & \text{otherwise} \end{cases}$$

Catch

Estimates of the total kept and released catches for the various strata were obtained by forming the product of the estimate of fishing effort and the catch rate. Thus, in simple terms,

$$C_m = E_m R_m$$

and

$$Var\left(C_m\right) = \begin{cases} 0 & \text{if } E_m = 0 \text{ or } R_m = 0 \\ C_m^2 \left\{ \dfrac{Var\left(E_m\right)}{E_m^2} + \dfrac{Var\left(R_m\right)}{R_m^2} - \dfrac{Var\left(E_m\right) Var\left(R_m\right)}{E_m^2 R_m^2} \right\} & \text{otherwise} \end{cases}$$

where the covariance term is assumed in the analysis of the recreational blue swimmer crab data for the Peel-Harvey Estuary to be zero.

Finally, as with the measures of fishing effort, the catch estimates for the different strata are aggregated to determine the total catch for the location or region, while the variance of the total is calculated as the sum of the variances. Thus,

$$C = \sum_m C_m \text{ and } Var(C) = \sum_m Var\,(C_m).$$

Survey of waterfront properties and houseboats

Logbooks for each two-month period returned by residents of waterfront properties were divided into two categories, i.e. those with no fishing activity and those that reported fishing. The means (and standard error) of kept and released catches for the two-month period were calculated for the latter returns. These means were then expanded by multiplying by the number of such returns to produce estimates of the total number of kept and released crabs for the returned logbooks for the two-month period. The resulting estimate was further expanded by multiplying by the ratio of logbooks that had been sent out at the beginning of the two-month to the total number (nil and non-nil logbooks) that were returned. Totals of these estimates were then calculated by summing the values over all of the two-month periods. The resulting totals of kept and retained catches were considered to represent the total catches by the participants in the logbook program.

If non-participants in the logbook program did not fish for crabs, the values would represent estimates of the total kept and released catches by the residents of private houses with water frontage in the three canal developments. Alternatively, if the participants in the logbook program represented a random sample of the canal residents, estimates of total kept and released catches would be calculated by expanding the number of logbook participants to the total number of waterfront residences in the canals, i.e. by multiplying the totals for the logbook participants by the ratio of the number of waterfront residences to the number of waterfront residences that participated in the logbook program. Neither scenario is entirely satisfactory, as the true values of total kept or released catches are likely to lie somewhere between the two estimates. Thus, estimates of the total kept and released catches for the canal component of the blue swimmer crab catch have been calculated as the average of the two estimates, i.e. that for which it is assumed that non-participants of the logbook program did not fish and that for which it is assumed that the participants of the logbook program were a random sample of the households with waterfront properties in the canal developments. To account for the uncertainty associated with these final estimates, their variances were calculated as the sum of the variances of the estimates for the two scenarios plus the variance of the point estimates for those scenarios.

A small number of visitors to the Mandurah Estuary hire houseboats. To ascertain the catches of crabs by these fishers, customers of boat and house hire businesses, using boats on the estuary, were included in the logbook survey that was run for residents of waterfront canal properties. As with the latter survey, a logbook and map was provided to each participant for each two-month survey period. The businesses hiring the houseboats were requested to facilitate customer participation in the logbook survey. They were also asked to supply data on the number and duration of hires, the numbers of persons on board, and anecdotal information on proportions of people who fished or took fishing equipment on their trip. Logbook data were provided by a very limited number of parties who hired houseboats during the survey period in 2007 – 08. The total catches reported within logbook were considered to represent results of a census rather than survey. Extrapolating from number of vessels providing logbooks to the total number (36) houseboats yields the estimates of kept and released catch and fishing effort for 2007 – 08. The corresponding estimates for 1997/98 reported by Malseed and Sumner (2001) were the results of a census conducted by boat hire companies.

Mean weight of blue swimmer crabs

The sex and carapace widths of random samples of the blue swimmer crabs kept by recreational fishers were recorded where possible in each survey. However because of the limited numbers of blue swimmer crabs available for some strata, it was considered inappropriate to use the weights associated with the stratification employed in the sampling design for the roving survey to produce an overall estimate of the average mass of the blue swimmer crabs that were retained. Accordingly, the average masses of the individual male, female and unsexed blue swimmer crabs in the retained catches were calculated for the pooled data for boat ramps, the bridges & jetties, the scoop netting areas, waterfront properties and houseboats. The average was calculated as

$$\overline{W} = \frac{1}{\sum_{j=1}^{n} f_j} \sum_{j=1}^{n} W_j f_j$$

where n is the number of crabs of the specified sex, a and b are the parameters of the weight (grams) to carapace width (mm) relationship for the associated sex (or for unsexed crabs), f_j is the frequency of the crabs in the jth group of crabs, and W_j is the estimate of the body weight of each individual in the jth group of crabs for the specified sex derived from the carapace width CW_j (mm) of those crabs. The average body weight $\overline{W}$ was calculated by pooling the data for all crabs that were measured during the survey for the bridges & jetties or scoop netting areas. This statistic is considered to be the best estimate available of the body weight of the crabs that were kept. The variance of $\overline{W}$ was calculated as

$$Var(\overline{W}) = \frac{1}{\sum_{j=1}^{n} f_j \left(\sum_{j=1}^{n} f_j - 1 \right)} \sum_{j=1}^{n} \left(f_j W_j^2 - \frac{\left(\sum_{j=1}^{n} f_j W_j \right)^2}{\sum_{j=1}^{n} f_j} \right)$$

The relationships between body weight (g), W, and carapace width (mm), CW, have been reported by Potter *et al.* (1983) as

$$W = 0.0000597\ CW^{3.056} \text{ for females and } W = 0.0000256\ CW^{3.26} \text{ for males}$$

The body weight of unsexed individuals was calculated as

$$W = 0.5\left(0.0000597\ CW^{3.056} + 0.0000256\ CW^{3.26}\right)$$

The resulting estimate of $\overline{W}$ was then multiplied by the number of crabs that were caught and retained within each stratum k to produce an estimate of the approximate mass of crabs M_k that were caught, where

$$M_m = C_m \overline{W} \text{ and } Var(M_m) = M_m^2 \left[\frac{Var(C_m)}{C_m^2} + \frac{Var(\overline{W})}{\overline{W}^2} - \frac{Var(C_m)Var(\overline{W})}{C_m^2 \overline{W}^2} \right]$$

Finally, the estimates of the masses of the catches for the different strata that were retained by recreational fishers are aggregated to determine the mass of the total catch for the location or region, while the variance of the total is calculated as the sum of the variances. Thus,

$$M = \sum_m M_m \text{ and } Var(M) = \sum_m Var(M_m).$$

5.3 Results

Number of interviews and geographic distribution of interviewees

In the 1998 – 99 survey, there were 1939 interviews used in the boat analyses. Of these, 1130 boats had been crabbing, 131 angling (39 were both crabbing and angling) and 6 fishing with other gears (e.g. potting) in the estuary (Table 5.12). There were 399 boat parties fishing or diving in the marine waters outside the Peel-Harvey Estuary and 312 boat parties not involved in any fishing activity. There were 593 interviews at bridges & jetties with 397 crabbing and 317 shore scoopers interviewed with 304 crabbing. The low numbers of non-crabbing interviews from shore scoopers reflect the focus in this survey on interviewing crabbers only. Logbooks were returned for four houseboats in the 1998 – 99 survey.

During the 2007 – 08 survey, there were 1555 interviews conducted at the boat ramps and used in the analysis. Of these, 783 boat parties were crabbing, 126 angling (49 were both crabbing and angling) and 7 fishing with other gears in the estuary. There were 383 boat parties fishing or diving in the marine waters outside the Peel-Harvey Estuary and 305 boats not involved in any fishing activity. There were 506 interviews at bridges & jetties with 233 crabbing and 281 shore scoopers interviewed with 238 crabbing. Logbooks were returned from eight houseboats in the 2007 – 08 survey. Only in the 2007 – 08 survey were 613 canal homes sent logbooks, of which 374 were returned.

Geographic distribution of the numbers of fishers in interviewed groups, which had been classified as being involved in blue swimmer crab fishing.

Fishers within the group were assigned the postcode reported by the person who was interviewed, and such postcodes were then assigned to the Perth Metropolitan and Peel local government regions, or other regions, which predominantly encompassed them (Figure 5.4). This information provides a snapshot of the residential locations from which fishers were drawn, under the assumption that all members of the fishing party come from the same locality. However, it should be noted that these data are based on raw interview data only and have not been adjusted to account for sampling intensity or expanded to provide estimates of total fishers.

For the 1998 – 99 survey, the majority of the boat crabbing fishers (56%) were residents from the Perth metropolitan region and (36%) were local Peel residents (Figure 5.5). Slightly higher proportion (64 – 68%) of shore scoopers and crabbers on bridges & jetties were residents from the Perth metropolitan region and only 25 – 32% were local Peel residents. For the 2007 – 08 survey, there was an increase in the crabbing fishers who were local Peel residents (44 – 47%) and a corresponding decline in the residents from the Perth metropolitan region (45 – 49%). No postcode information was collected from houseboats and 94% of crabbing fishers residing at canal homes were local Peel residents with 6% from the Perth metropolitan region.

Table 5.12. Numbers of interviews at each sampling location. NC=information not collected, NA=not applicable to this survey, ^ residents sent logbooks and number returned in parenthesis, * houseboat logbooks returned.

	1998 – 99						2007 – 08					
	Inside Estuary		Outside Estuary		Non-fishing	Total	Inside Estuary		Outside Estuary		Non-fishing	Total
	Non-crabbing	Crabbing	Non-crabbing	Crabbing			Non-crabbing	Crabbing	Non-crabbing	Crabbing		
Boats (East)	10	226	2	0	101	339	13	147	9	3	85	257
Allambi	0	10	0	0	4	14	0	15	1	0	6	22
Fernisdale	2	119	1	0	24	146	0	51	2	1	27	81
Murray Bend	2	1	0	0	1	4	3	1	0	0	3	7
Nairns	0	45	1	0	9	55	3	50	3	2	16	74
North Yunderup	2	14	0	0	26	42	4	15	1	0	15	35
River Road	0	12	0	0	12	24	1	6	0	0	0	7
Riverview	0	16	0	0	3	19	2	7	2	0	12	23
Wharf Cove	4	9	0	0	22	35	0	2	0	0	6	8
Boats (West)	88	904	395	2	211	1600	71	636	325	46	220	1298
Cobblers	2	1	0	0	1	4	Not surveyed in 2007 – 08					
Dolphin Pool	2	35	47	0	9	93	3	12	26	2	15	58
Dawesville South	17	328	56	0	58	459	27	219	79	14	66	405
Eastport Marina	52	166	175	1	47	441	18	106	134	7	32	297
The Lagoon	8	36	108	1	44	197	3	17	70	2	54	146
Novara	2	111	1	0	17	131	10	156	10	11	17	204
Park Ridge	0	133	0	0	2	135	2	86	1	4	5	98
Waterside Canal	5	94	8	0	33	140	8	40	5	6	31	90
Bridges & Jetties	196	397	NA	NA	NC	593	273	233	NA	NA	NC	506
Bypass Bridge	31	117	NA	NA	NC	148	71	69	NA	NA	NC	140
Mandurah Quay	16	139	NA	NA	NC	155	25	44	NA	NA	NC	69
Mary Street Lagoon	31	32	NA	NA	NC	63	17	9	NA	NA	NC	26
Old Traffic Bridge	118	109	NA	NA	NC	227	160	111	NA	NA	NC	271
Shore Scoopers	3	314	NA	NA	NC	317	43	238	NA	NA	NC	281
Coodanup	1	110	NA	NA	NC	111	12	67	NA	NA	NC	79
Harvey	1	78	NA	NA	NC	79	1	92	NA	NA	NC	93
Peel/Harvey	1	126	NA	NA	NC	127	30	79	NA	NA	NC	109
Canals						NC						613 (374)^
Houseboats						4*						8*

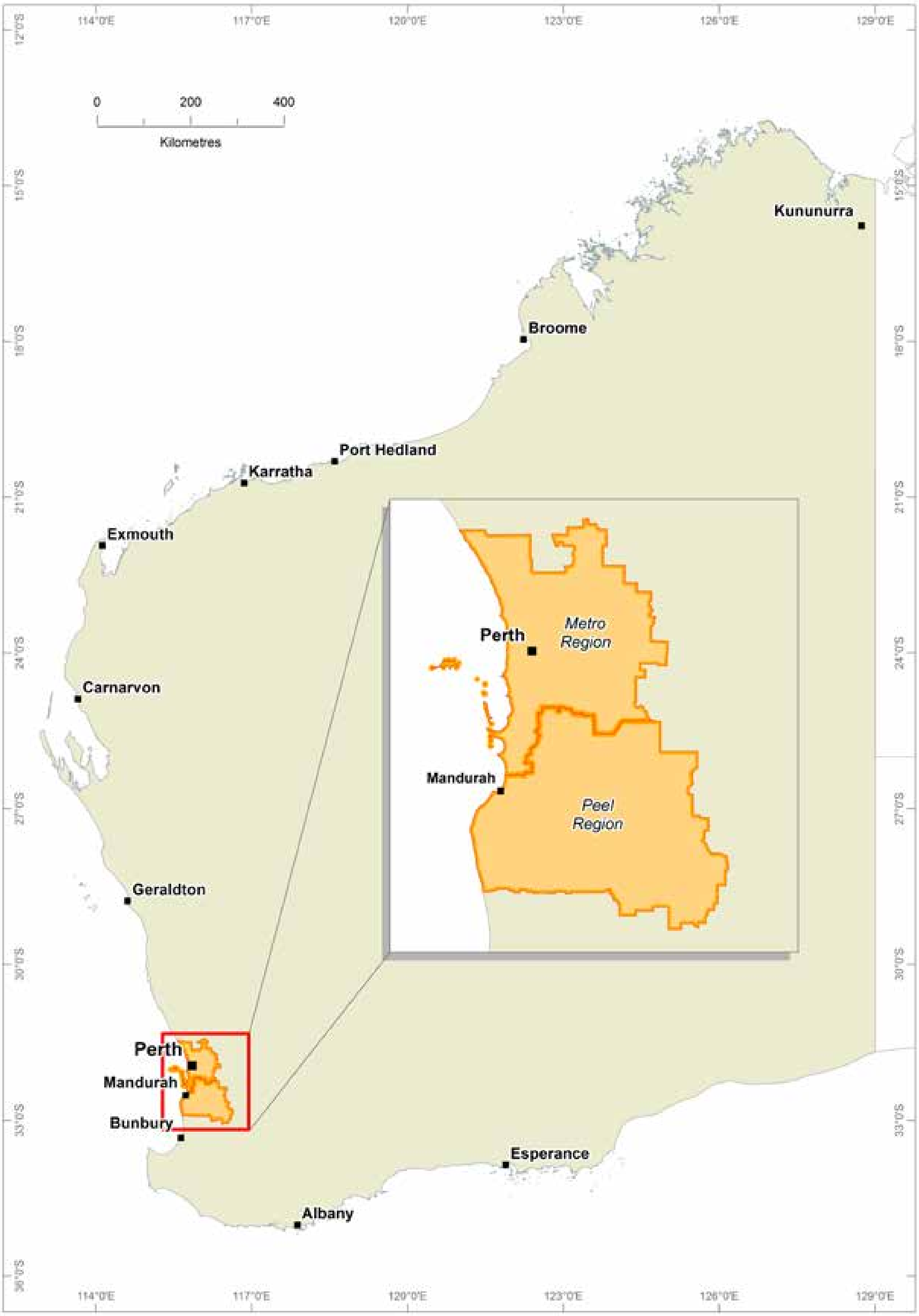

Figure 5.4. The Perth metropolitan and Peel regions.

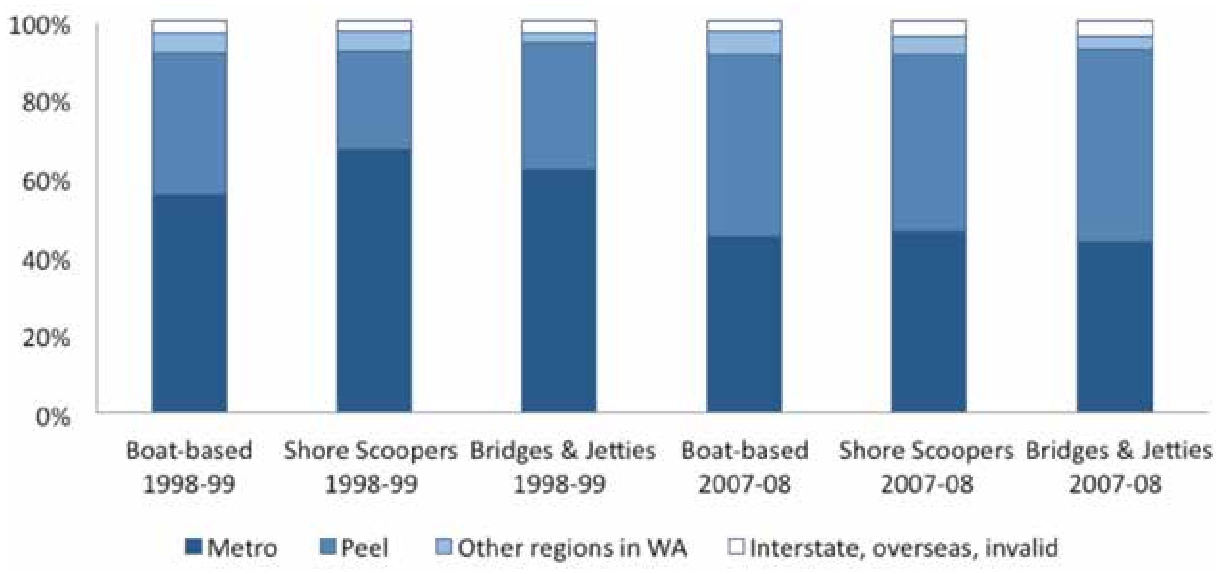

Figure 5.5. The percentage of recreational crabbing fishers, who were interviewed during the 1998 – 99 and 2007 – 08 surveys, in the Perth metropolitan, Peel, other regions in Western Australia and interstate, overseas or invalid information.

Re-estimation of 1998 – 99 survey

As outlined in the methods, the results of the analyses, which are presented in this report, were modified from those employed for the 1998 – 99 survey to accommodate the outcomes of the Steffe (2009) review of the survey methods previously used by the Department of Fisheries, Western Australia (Sumner *et al.*, 2008), and the advice resulting from a recreational survey workshop held at the Research Division at Hillarys from 22 – 26 February 2010 involving both national and international experts (Wise and Fletcher, 2013). Thus, greater attention was given to the calculation of estimates of uncertainty and statistical analyses were extended to explore the consequences of alternative, albeit equally viable, methods yielding slightly different estimates of catch and fishing effort.

The slightly higher estimates from the re-analysis (Table 5.13) of the 1998 – 99 survey of boat fishers differed as a result of undertaking the re-analysis at the stratum level rather than the ramp level as recommended by Steffe (2009). The lower estimates resulting from the re-analysis of the 1998 – 99 survey of the shore scoopers were based on daily durations derived from the data (Figure 3) rather than the estimates of daily duration used by Malseed and Sumner (2001) were consistently greater. Other differences between the estimates derived using different temporal stratification, or obtained by combining the separate estimates obtained by analysing the data for each gear type rather than analysing the pooled data for the different fishing methods, were not significantly different. Re-estimation of bridges & jetties effort and catches for the 1998 – 99 survey produced results that were not significantly different regardless of stratification or methods of calculation.

For consistency and to facilitate comparison, analysis of the 2007 – 08 survey used the same methods as employed in the re-analysis of the 1998 – 99 survey.

Estimates of crabbing effort

The effort estimates (crabbing hours) of the boat crab-fishing parties in 2007 – 08 were lower than in 1998 – 99 for boats, shore scooping and bridges & jetties (Figure 5.6). In 1998 – 99, the crabbing effort of boats and shore scoopers were similar, however in 2007 – 08, the greater decline in the shore scooping resulted in boat crab-fishing being the dominant crabbing activity in Peel-Harvey Estuary. Conversely, houseboat crabbing effort was slightly higher in 2007 – 08 compared to 1998 – 99 (Figure 5.6 and 5.7). While considerable uncertainty exists around the canal effort, estimates from the 2007 – 08 survey suggest that it is comparable to the other shore-based crabbing activity (Figure 5.6 and 5.7). Seasonal crabbing activity occurs generally between November to May with greatest activity in January and February (Figure 5.7). The declines in crabbing effort between survey years are reflected across the seasonal activity.

Estimates of kept and released blue swimmer crabs

Similar to crabbing effort, the number of boat crab-fishing parties in 2007 – 08 was lower than in 1998 – 99 for boats, shore scooping and bridges & jetties (Table 5.13, Figure 5.8). Boat crab fishing parties caught and kept the majority of blue swimmer crabs in both surveys followed by shore scoopers, bridges & jetties and houseboats. While the crabbing activity of canal owners was considerable, crab catches were comparatively lower. Boat crabbers released a greater proportion than they kept in both surveys. However, while in 1998 – 99 shore scoopers and bridges & jetties released less crabs than kept in the 2007 – 08 survey, they released a substantially higher proportion of their catch (Table 5.13). Similar to seasonal crabbing activity, catches are generally taken between November and May with the highest number of crabs kept and released recorded in January and February (Figure 5.9). The declines in crabbing effort between survey years are reflected across the seasonal activity.

Table 5.13. Estimates of the numbers (and standard errors) of blue swimmer crabs kept or released during the 1998 – 99 and 2007 – 08 surveys. Numbers are thousands of crabs.

		1998 – 99				2007 – 08			
		Kept	**SE**	**Released**	**SE**	**Kept**	**SE**	**Released**	**SE**
Boats		1071	118	1228	105	508	37	711	57
Shore Scoopers		330	38	225	30	157	49	262	60
Bridges & Jetties		77	9	93	11	16	2	47	7
Canals	A	Not surveyed in 1998 – 99				15	1	18	1
	B					55	4	71	4
Houseboats		8		10		2		1	

A assumes no fishing by non-logbook participants

B assumes that logbook participants are a random sample of total population of private homes

Sex ratio and size frequency of blue swimmer crabs

Male blue swimmer crabs dominated the seasonal kept boat catch (Figure 5.10), however the released catches indicate that a higher number of females were present in the Estuary. The trend was similar for the shore scoopers with a higher proportion of females present in the scooping areas in March to August. The bridges & jetties show a stronger seasonal change in sex ratio, which, in the period November to February, was dominated by males but which, in March to August, switched to a greater prevalence of females. Information of sex ratios was not available for catches taken by fishers from the houseboats or canals.

The size frequency data show that the majority of blue swimmer crabs kept were above the minimum legal size of 127 mm carapace width (Figure 5.11). Boat crabbers were less likely to have kept undersize crabs compared to shore-based crabbers. Over 90% of legal-sized crabs range between 127 and 145 mm carapace width. Due to the low numbers of female blue swimmer crabs kept by crabbers, only a small quantity were measured. The average weight of these crabs was 0.2 kg (Table 5.14).

Bag and boat catches

In 1998 – 99, the number of blue swimmer crabs that could be retained was 24 per person and, for those boats occupied by two or more persons, 48 crabs per boat. On 1 October 2003, the bag and boat limits were reduced to 20 and 40 crabs, respectively, and then, on 1 November 2007, further reduced to 10 and 20 crabs, respectively. The average kept catch per trip reported by boat-based fishers in the 2007 – 08 survey was 35% lower than that recorded in the 1998 – 99 survey, but a considerable proportion of that decline may be attributed to the reduced boat limit. Of the boat crabbers, 57% kept 20 crabs or less in the 1998 – 99 survey, increasing to 98% in 2007 – 08 survey as a result of the new boat limit. In both the 1998 – 99 and 2007 – 08 surveys, 92% of shore scoopers and 97% of crabbers on bridges & jetties kept 5 or less crabs (Figure 5.12). Note, however, that the numbers recorded for these shore-based fishers, i.e. shore scoopers and fishers from bridges & jetties, represent catches from incomplete trips as interviewers intercepted fishers during their fishing activity, not at the conclusion of that activity.

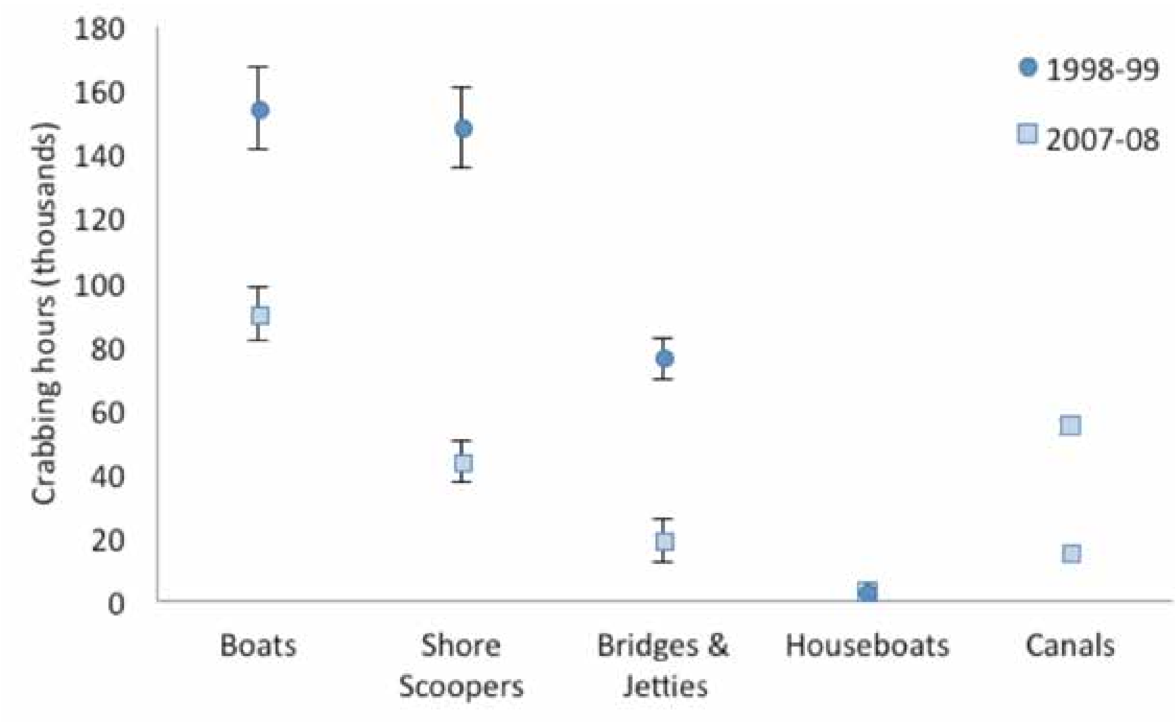

Figure 5.6. Total estimated recreational crabbing effort for the 1998 – 99 and 2007 – 08 surveys. The two 2007 – 08 estimates for canals are based on (lower) the assumption that no fishing was undertaken by non-logbook participants and (upper) the assumption that logbook participants are derived from a random sample of the total population of private waterfront homes.

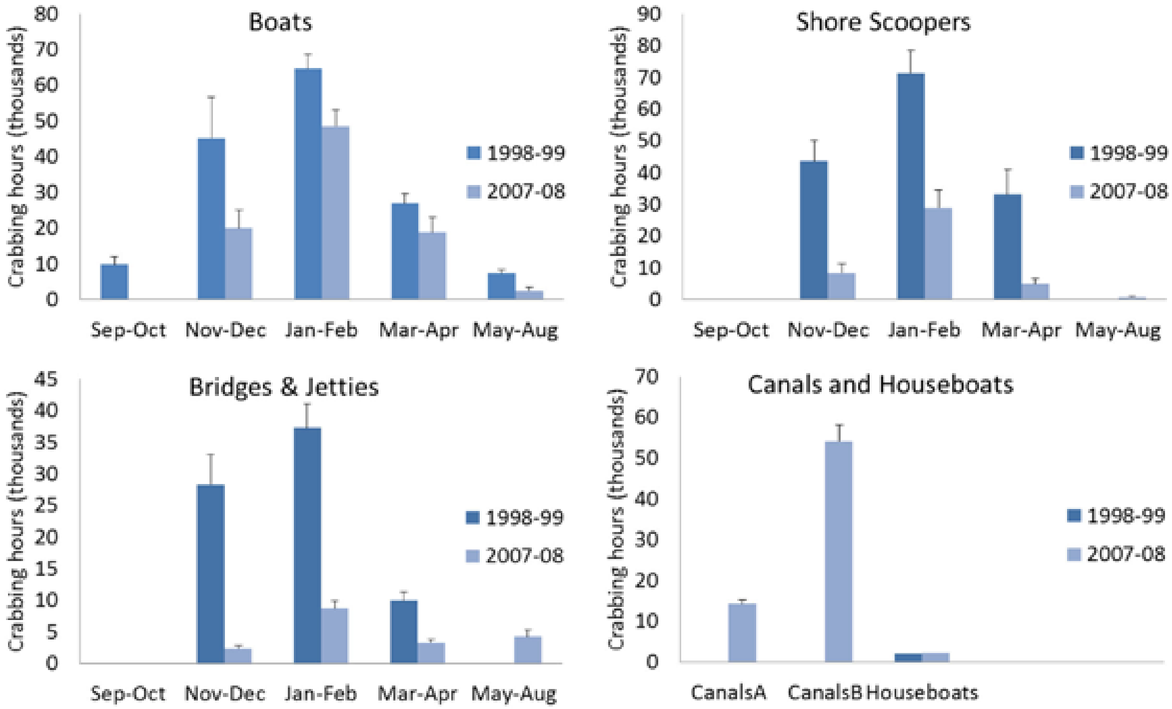

Figure 5.7. Estimated seasonal recreational crabbing effort (and standard errors) for the 1998 – 99 and 2007 – 08 surveys. The 1998 – 99 survey of shore scoopers occurred December – April and bridges & jetties occurred November – April. September and October were closed to crabbing in 2007 – 08. The two 2007 – 08 estimates for canals are based on (A) the assumption that no fishing by non-logbook participants and (B) the assumption that logbook participants are derived from a random sample of the total population of private waterfront homes.

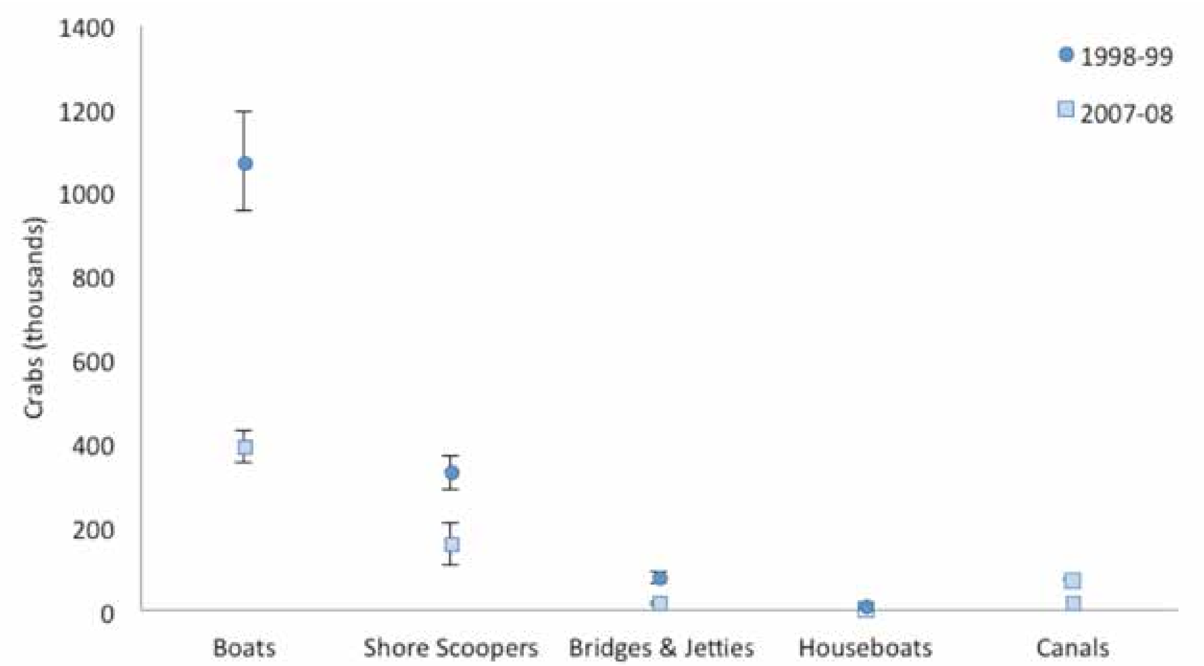

Figure 5.8. Estimates of the total number (and standard errors) of blue swimmer crabs kept for the 1998 – 99 and 2007 – 08 surveys. The two 2007 – 08 estimates for canals are based on (lower) the assumption that no fishing by non-logbook participants and (upper) the assumption that logbook participants are derived from a random sample of the total population of private waterfront homes.

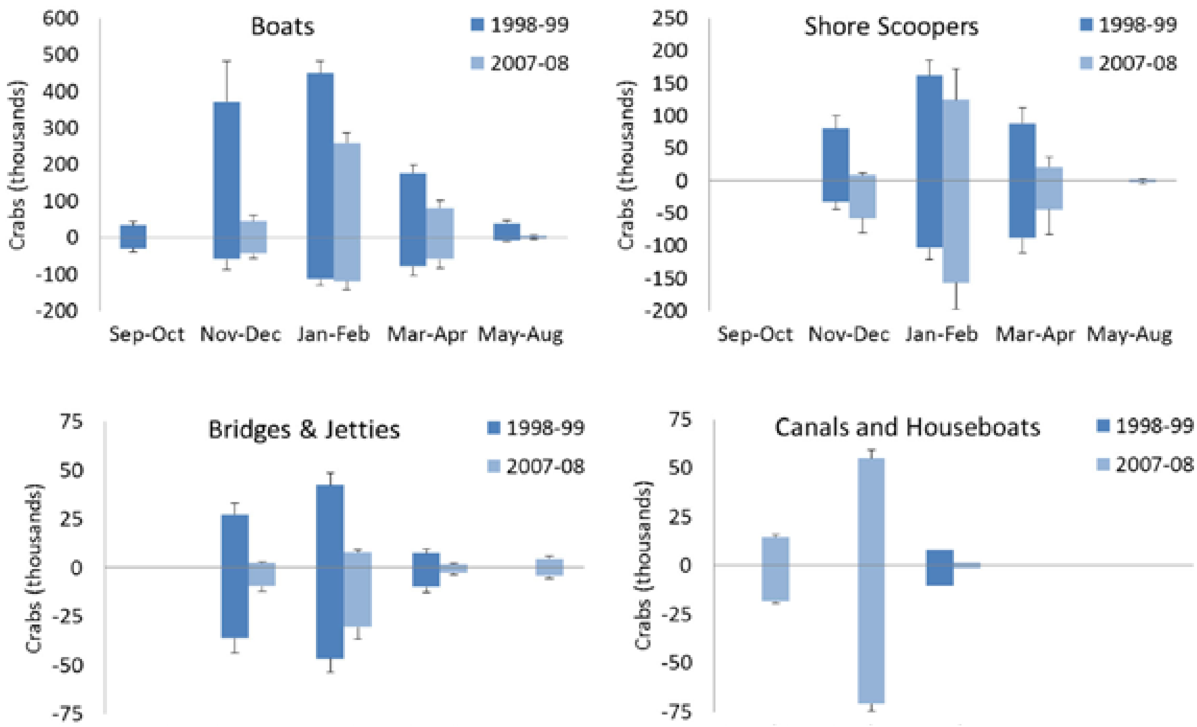

Figure 5.9. Estimates of the seasonal number (and standard errors) of blue swimmer crabs kept (above) or released (below) for the 1998 – 99 and 2007 – 08 surveys. The 1998 – 99 survey of shore scoopers occurred December – April 1998 – 99 and bridges & jetties occurred November – April. September and October were closed to crabbing in 2007 – 08. The two 2007 – 08 estimates for canals are based on (A) the assumption that no fishing by non-logbook participants and (B) the assumption that logbook participants are derived from a random sample of the total population of private waterfront homes.

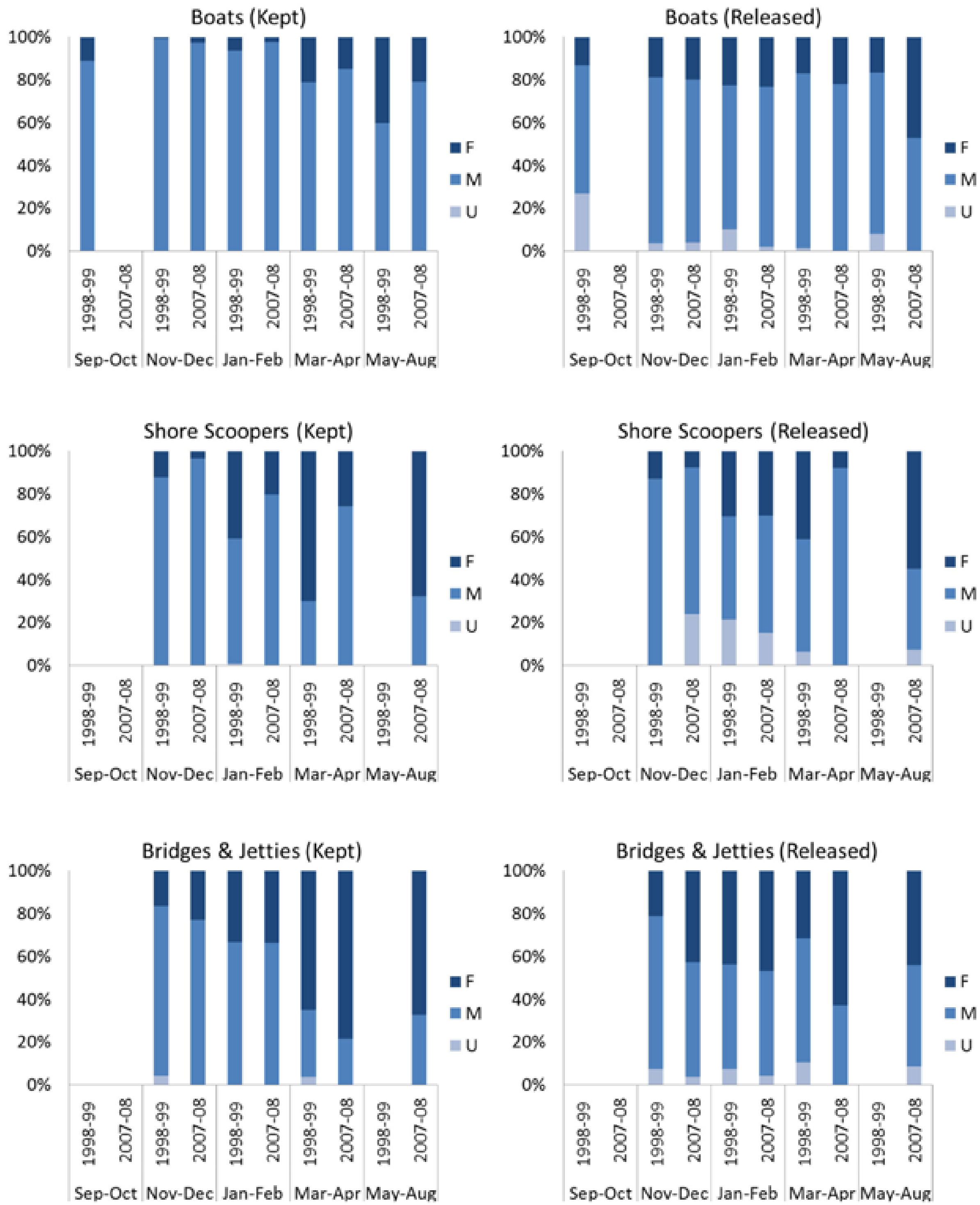

Figure 5.10. Estimates of the seasonal numbers (and standard errors) of blue swimmer crabs of each sex kept or released during the 1998 – 99 and 2007 – 08 surveys. The 1998 – 99 survey of shore scoopers occurred in December – April 1998 – 99 and bridges & jetties occurred in November – April. September and October were closed to crabbing in 2007 – 08. F=Female, M=Male, U=Unrecorded sex.

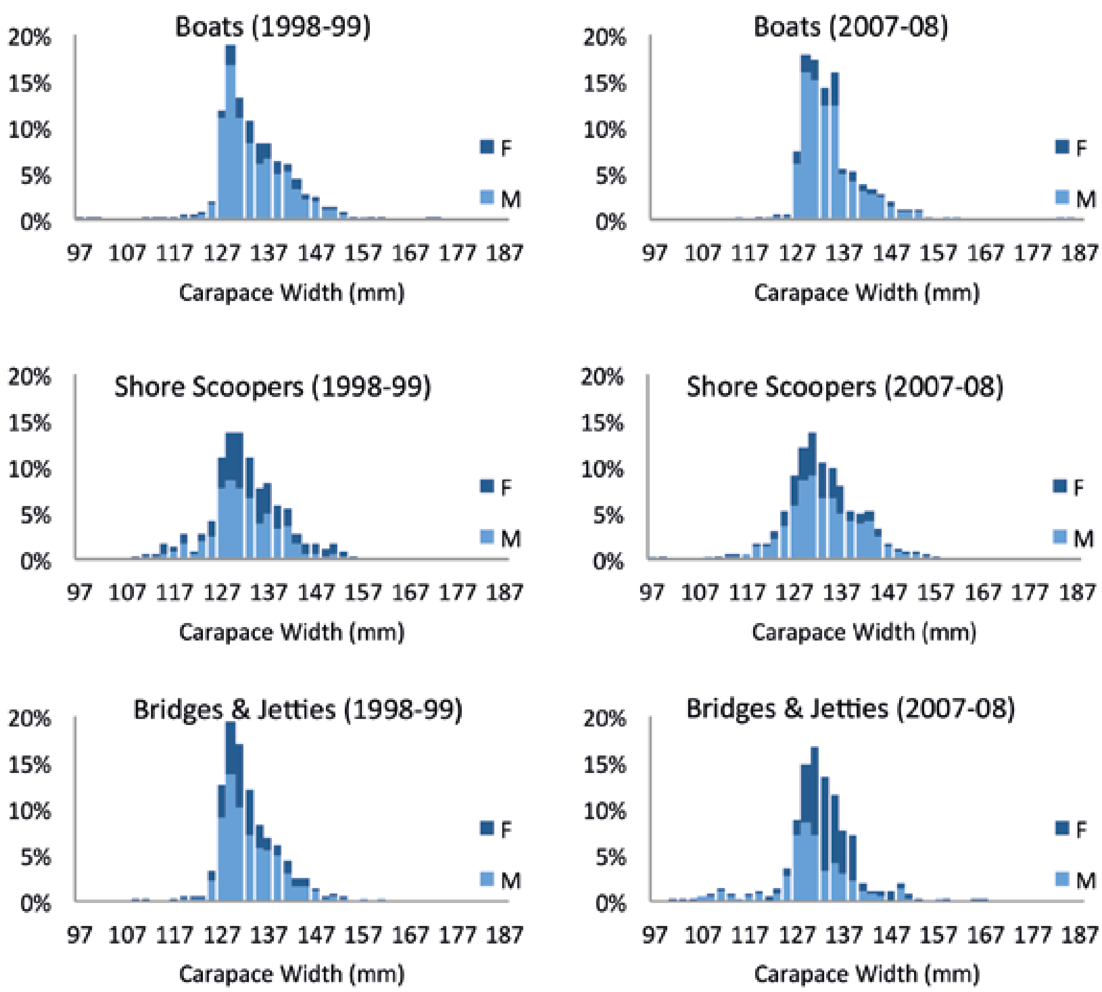

Figure 5.11. Size frequency of blue swimmer crabs kept and measured in the 1998 – 99 and 2007 – 08 surveys. The minimum legal size is 127 mm carapace width. F = Female, M = Male.

Table 5.14. Estimated average weight (and standard errors) of blue swimmer crabs caught by each of the fishing methods in Peel-Harvey Estuary in 1998 – 99 and 2007 – 08 surveys.

	1998 – 99			2007 – 08		
	Mean (kg)	**SE**	**n**	**Mean (kg)**	**SE**	**n**
Boats	0.22	0.001	6467	0.22	0.001	1175
Shore scoopers	0.20	0.001	1152	0.20	0.002	857
Bridges & Jetties	0.21	0.001	1088	0.19	0.001	440
Canals	Not surveyed in 1998 – 99			0.21	0.018	1056
Houseboats	Malseed and Sumner (2001)			Insufficient data – The estimate from private homes along the canals was used.		1

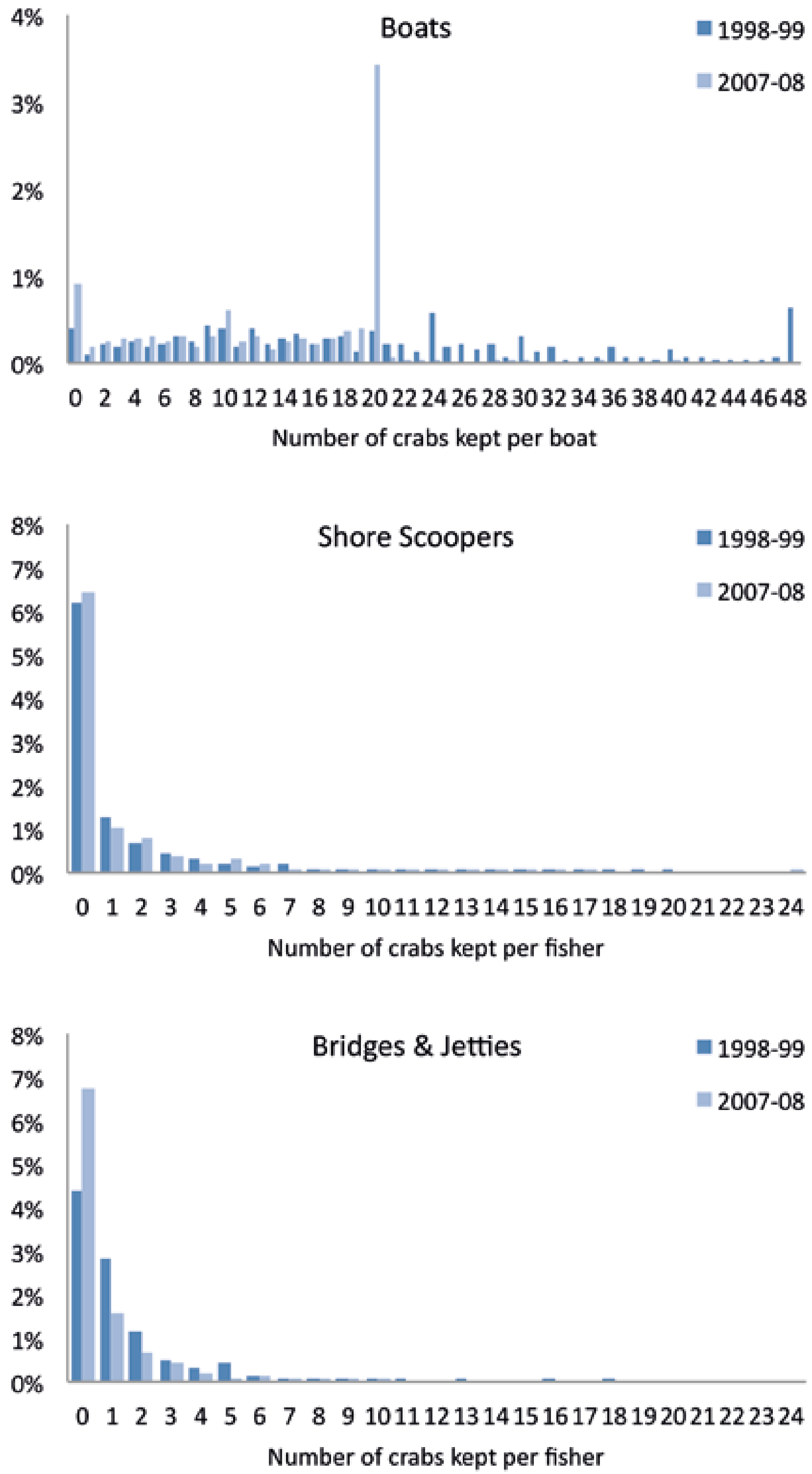

Figure 5.12. Percentage of crabs kept per boat (top) and, for incomplete trips, per fisher scoop netting (middle) or crabbing from bridges & jetties (bottom). The boat (for boats with two or more fishers) and bag limits during the 1998 – 99 survey were 48 blue swimmer crabs per boat and 24 crabs per person, respectively, but, during the 2007 – 08 survey, were 20 crabs per boat and 10 crabs per person, respectively.

5.4 Discussion

The recreational fishery for blue swimmer crabs in the Peel-Harvey Estuary comprises fishers deploying drop nets from boats, bridges, jetties and house boats, and scoop netting along the shore of the estuary. In addition to these “visiting” crab fishers, some fishers crab directly from private houses along canals within real estate developments.

Overall sample sizes of interviewed crabbers were adequate for determining estimates of crabbing effort and catch. However it is important to recognise that there is considerable statistical uncertainty in the point estimates of the various statistics. As such, consideration of the uncertainty (presented in the figures presented by the error bars drawn from the points) is important when drawing conclusions around trends associated with the estimates.

Interviewees in the 2007 – 08 surveys demonstrated a shift to a higher proportion of residents from the Peel local government region, i.e. the Mandurah region, than in the previous survey where the majority of crabbers were residents of the Perth Metropolitan Region. This could represent a trend that crabbers are more likely to fish in local areas, however, in the absence of data on inter-annual variation in crabbing activity in the Peel-Harvey Estuary and the factors involved in such variation, it is also possible that the activity reported in these two surveys represent high and low proportions but not necessarily a trend.

Comparison of recreational methods of catching of blue swimmer crabs in the Peel-Harvey Estuary in 1998 – 99 and 2007 – 08 indicated marked declines in boat-based crabbing effort and in shore-based crabbing effort around bridges & jetties and at scoop netting areas. However, hire houseboat crabbing effort remained similar in the two survey periods.

For all catching methods, the recreational catch of blue swimmer crabs in the Peel-Harvey Estuary in the 2007 – 08 survey exhibited a marked decline compared with that recorded in 1998 – 99. These declines occurred despite the fact that, while the daily period and period of the year covered by the boat-based survey were similar to those periods surveyed in 1998 – 99, the shore-based fishing survey in 2007 – 08 extended over a greater period within each survey day and covered the full year rather than the restricted period that was surveyed in 1998 – 99. The decreased bag limits in 2007 – 08 relative to those applicable in 1998 – 99, i.e. 10 versus 24, did not appear to have influenced markedly the numbers of crabs kept (to the time of interview) by shore-based fishers. Between the two surveys, the boat limit (for boats with two or more fishers) had reduced from 48 to 20 blue swimmer crabs and, while the number of boats recording a catch of 20 crabs increased in 2007 – 08 as a result of the constraint on the retention of a larger number of crabs, there was a substantial decrease in the overall number of crabs kept by boats. This may have been a factor that could assist in explaining the drop in boat-based crabbing effort and crab catches between the two survey years. The catch estimated for the hire houseboats and private homes along the canals only contributed a small proportion of the total catch from the Peel-Harvey Estuary. As with crabbing effort, it is not possible to suggest that the decline in the numbers of kept crabs between the two surveys represents a trend, as data are available for only two periods and there are no data on inter-annual variation in catches or in the abundance, catchability and vulnerability of crabs. Because data are not available on such variation, and because the demographic data demonstrate that the decline in effort was not random, it is not possible to determine from the survey data the extent to which the decline in estimated numbers of kept crabs could be attributed to a reduced abundance of crabs in 2007 – 08.

The most popular season for recreational crabbing was found to be summer, with autumn and spring being the next most popular seasons. Very little crabbing took place in winter. In the

1998 – 99 survey, low blue swimmer crab catches were taken in September and October and these months were closed to crabbing in 2007 – 08 to protect breeding stock (Chapters 2 and 3).

Male blue swimmer crabs typically dominated the kept and released catches, particularly between November and February, but with an increased proportion of females from March to August and, in the case of fishing from bridges & jetties, with females dominating the kept catches in this latter period. The sex ratio of catches from these fishing platforms in the Mandurah entrance channel is consistent with the data from independent research sampling in the same location (Chapter 3).

The majority of blue swimmer crabs kept were above the minimum legal size and between 127 and 145 mm carapace width and weighed on average 0.2 kg.

The introduction in Western Australia of a licence for recreational fishing from boats (RFBL) in 2010 has resulted in the development of a database containing details of such licence holders. Phone surveys involving random samples of fishers selected from this database are now providing valuable state-wide data on boat-based recreational catch and effort at regular intervals (Ryan *et al.* 2013). In future years, this broad-based survey will provide data on recreational catches of blue swimmer crabs in the Peel-Harvey Estuary. Increased sampling intensity of RFBL holders with residences in the Perth and Peel regions may be required, however, to obtain estimates of catch and effort from this survey of comparable precision to that obtained from earlier on-site bus route surveys. The data from the RFBL phone survey will need to be supplemented by shore-based surveys to provide details of crab catches and fishing effort by the non-boat-based fishing sectors.

As with the refinement of methods used to analyse the survey data following the recommendations of the Steffe (2009) review, re-analysis of the data from past surveys may be required as a consequence of need to calibrate estimates of boat-based catch and effort from the RFBL phone survey with data derived from the bus-route boat ramp-based survey. Such refinement is inevitable as the science of recreational fishing surveys evolves. Re-analysis of past data using improved methods is essential if management is to be based on the best scientific data available at the time.

Ideally, in common with the findings of Wise and Fletcher (2013), use of a common survey covering all fishing sectors, i.e. boat-based, shore-based, waterfront resident-based, or hire boat-based fishers, would be preferable to the use of separate surveys with different statistical designs when producing estimates of the catches and fishing effort of the boat-based and non-boat-based fishers. The implementation of such a common survey would require, however, the development and maintenance of a sampling frame containing the contact details of all individuals intending to fish for blue swimmer crabs each year throughout Western Australia.

6.0 General Discussion

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The main aims of this study were to 1) establish fishery-independent and commercial monitoring programs to determine the spatial and temporal stock structure and stock dynamics in and around the Peel-Harvey Estuary and assess whether the stock status has changed considerably in the past decade, 2) provide current estimates of recreational catches from PHE and assess its impact on the overall crab stock. In addressing these aims, the current study 1) describes the stock characteristics including life-cycle, current levels of recruitment and spawning stock; 2) assesses possible impacts of commercial and recreational fishing pressure on the stock; 3) presents rationalised monitoring programs for the future; 4) proposes a potential harvest strategy for the PHE and 5) discusses future management recommendations based on the comprehensive data presented in this project.

6.1 Biology of *P. armatus* in the Peel-Harvey Estuary

6.1.1 Moulting, mating and spawning

The soft-shell condition in crustaceans indicates ecdysis (recent moult event) and its frequency is usually once a year for sexually mature animals and generally more frequent for juveniles (<80 mm CW). In the PHE there are two key moulting periods; during the summer months November to January and April. The summer moult is largely growth related and is consistent with high catch rates of legal and sub-legal males during this period, whereas the April moult is required for mating (soft-shell condition to allow for easy copulation) of females and is consistent with increase in catch rates of sub-legal and legal females after April when their catchability improves. Annual variation in catch rates could be due to environmental (e.g. temperature) changes between years and timing of the sampling and locations of the traps for a given month. The prevalence of berried females between October and January is consistent with this timing as eggs require approximately 18 days to mature (Kangas, 2000), and the lower catch rates of berried females inside the PHE than at the Estuary Channel and oceanic sites supports the hypothesis that females move into deeper offshore oceanic waters for spawning. There is an early spawning period between September and November (early cohort) and a late spawning period between November and January (late cohort). Females produce between 180,000 and 2 million eggs (Kangas, 2000) and eggs hatch into its larval phase known as a zoea. The zoea metamorphozes and undoes four stages of development and finally develops into a megalopa. The megalopa moults and becomes a crablet, at which point they begin settlement among sheltered nursery grounds (usually seagrass beds) from December to June (a combination of both the early and late cohorts) (Figure 6.1).

6.1.2 Spawning females

The soft-shell data indicated that a large proportion of immature females will enter into the mature sub-legal female category, while mature sub-legal females will enter the legal sizes during the April moulting period. Since mating usually occurs after moulting in decapods, a large proportion of post-mated legal crabs are being fished during the winter months, however mated sub-legal females will have the opportunity to spawn. The spawning potential of females in the stock thus depends on several factors such as recruitment strength which determines the strength of the cohort, fishing pressure which determines what proportion is removed thus prevented from spawning, and environmental conditions which determines the timing of the crab flushing from the Estuary. For example, catch rates of mated females may be higher within the Estuary in years of low rainfall, due to higher salinities and less flushing out of the Estuary. Spawned sub-legal females will return to the Estuary to moult and mate, but many of these females now of legal-size are mostly fished before they exit to spawn again. It's unclear if post-spawned legal females return to the Estuary, but given that the catch compositions from the oceanic sites were dominated by legal-sized females, it is probable many of these females become resident outside the Estuary. This is consistent with increased proportions of females in the commercial catches from the Mandurah to Bunbury Developing Crab Fishery (see section 6.6).

6.1.3 Recruitment

Recruitment signals (crabs < 50 mm) were difficult to detect from fishery-independent data as length frequencies consisted of unimodal progressions and monthly catch rates were either very low or completely absent. This was most likely due to traps with a low retention of small sized crabs and the location of the traps in sandy, deeper waters of the Estuary where small crabs are less prevalent (Coulson *et al.* 2010). It was for these reasons, de Lestang (2002) supplemented trapping with otter trawling and seine netting in shallower depths where up to three cohorts were detectable from the length frequency data. The interference between trawl gear and seagrass prevented any establishment of a trawl monitoring program in the PHE in the recent years. Nonetheless the limited trawl data together with the recent seine data (Coulson *et al.* 2010) does show recruitment from February onwards. This recruitment pulse is consistent with early spawners between September and November and late spawners between November and January. We speculate crablet *P. armatus* reaches 30 mm between 2 – 3 months during the summer months between December and March. These crablets utilise the inshore, shallow sea grass habitat for food and protection. From the seine netting data, juvenile *P. armatus* between 30 – 60 mm were captured from March onwards. Immature and sub-legal crabs between 40 – 90 mm that were captured using trawl and trap were detectable from March onwards, but only in small numbers. Therefore from trapping alone, recruitment strength can only be accurately inferred from the strength of sexually mature sub-legal size classes of crabs within each fishing year.

6.1.4 Life-cycle of Peel-Harvey Estuary crab stock

Entry of 0+ class (0 – 11 months, 0 – 115 mm (immature and sexually mature sub-legal crabs): The juvenile stage of *P. armatus* is a period of rapid growth. Juveniles (immature crabs) from the early cohort will undergo their pre-pubertal moult and become sexually mature sub-legal crabs, while juveniles from the late recruiting cohort will remain immature (Figure 6.1 Life cycle of the blue swimmer crab in Peel-Harvey Estuary and adjacent oceanic waters and its relationship with the Estuary.). Therefore there are two categories of 0+ class crabs, immature and sub-legal mature. Sexually mature males and females will mate (April to June) and at the onset of winter rains most 0+ class crabs will exit PHE between June and September. Ovigerous 0+ females will now spawn for the first time in oceanic waters outside of PHE.

Entry of 1+ class (12 – 23 months, 116 – 140 mm, sexually mature sub-legal and legal-sized crabs): At the end of spring and throughout summer 0+ class crabs re-enter PHE where males re-enter earlier (between November and January) than females (between January and March). Inside PHE, immature 0+ (late recruiting cohort) crabs will undergo their pre-pubertal moult to become sexually mature sub-legal 1+ class crabs (followed by mating), while sexually mature 0+ class crabs (early recruiting cohort) will moult and become the legal-sized 1+ class crabs (followed by mating) that are subject to fishing. At the onset of winter rains, most mated sub-legal 1+ class crabs and unfished mated legal 1+ class crabs exit the Estuary. Mated, sub-legal 1+ class females will spawn for the first time and mated legal 1+ class females will spawn for the second time.

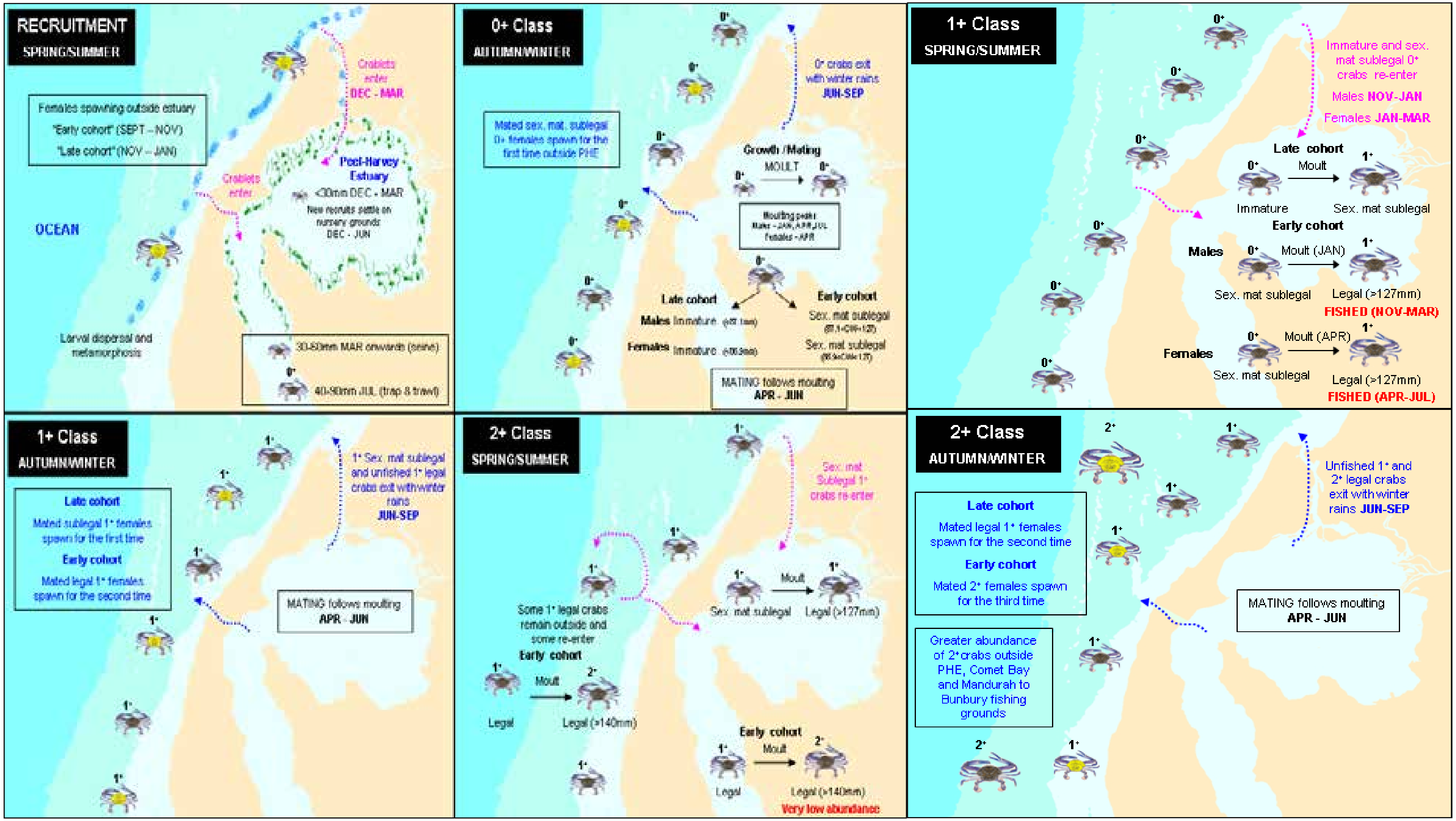

Figure 6.1 Life cycle of the blue swimmer crab in Peel-Harvey Estuary and adjacent oceanic waters and its relationship with the Estuary.

Entry of 2+ class (24 – 35 months, > 140 mm, all legal-sized crabs): At the end of the spring and during the summer months, some legal 1+ class crabs will re-enter PHE and some remain outside. The latter is the more likely outcome given 2+ class crabs are not seen inside PHE, although this may reflect the intensity of fishing. Most likely legal 1+ class crabs moult and become 2+ class crabs outside the Estuary and either remain outside PHE or move into adjacent embayments and estuaries. Sub-legal 1+ class crabs (late recruiting cohort) appear to re-enter PHE where they will moult and become legal-sized 1+ class crabs. Following mating, a proportion will be fished and the rest will exit the Estuary with the winter rains.

6.2 Commercial catch and effort trends

Increased fishing efficiency after the conversion to traps has resulted in increased catch landings in the Peel-Harvey Estuary where catches have generally fluctuated between 40 and 100 t since 2000 and fishing effort has varied between 1000 and 1600 days. In this study we report on the last four fishing years where catches have ranged from 46 t in 2008/09 to 104 t in 2007/08 but catches have not yet reached a level that has been deemed unsustainable. Variable catch trends are common to crustacean fisheries for several reasons such as environmental conditions, management changes, disease/mortality events and changes in fishing pressures (Sumpton *et al.*, 2003; Svane and Cheshire, 2005; Johnston *et al.*, 2011a,b; Harris *et al.*, 2012). Nonetheless, declining catch rates of legal and sub-legal males from historical (1998 – 01) to current fishing years (2007 – 11) are of concern and need to be monitored closely as they may indicate negative impact of fishing pressure. The proposed harvest strategy for the PHE includes the catch rate of legal and sub-legal crabs as a key indicator of stock performance derived from commercial monitoring (see section 6.10)

The extended fishing into winter months after the introduction of traps has also resulted in increased fishing pressure on females which are more catchable during the autumn/winter period. A similar trend was observed in Cockburn Sound (Johnston et al, 2011a, b) where heavy winter fishing pressure on mated pre-spawning females (after conversion to traps) was one of the key factors contributing to the collapse of this fishery in 2006. However the PHE differs to Cockburn Sound fishery in that the majority of mated pre-spawn females are flushed out of the Estuary in winter to spawn in the ocean. This provides some natural immunity to overfishing the female breeding stock for this fishery. However, the high numbers of females caught outside in Area 1 and Area 2 of Mandurah to Bunbury Developing Crab Fishery and Zone D SWTMF needs to be monitored closely and taken into account for future management changes such as breeding stock/spawning closure (see section 6.9).

Higher catch rates of mature males during summer months (November to February) and peak catch rates for females later during April is largely a catchability issue driven by the aggressive behaviour of males that inhibit females from entering the traps during the warmer summer months. This is similar to the catch trends observed in Cockburn Sound whereby males dominate catches in summer and females during autumn/winter (Johnston *et al.* 2011a,b).

6.3 Change in stock status in the past decade

Statistically only one fishing year from de Lestang's (2002) survey data was comparable with the current time series, and given the large inter-annual variation in the catch rate trends within 2007 – 11, any notable differences with 1996/97 cannot be interpreted as significant changes to stock status. Overall, catch trends from 1996/97 were most similar to the 2007/08 fishing year and generally the lowest catch rates compared to the recent time series. There was however two exceptions, firstly the catch rate of legal males in the Cut-Harvey was the lowest for the 1996/97 fishing year (Figure 3.15c), and the secondly, the catch rate of legal females in winter being the highest during the 1996/97 fishing year (Figure 3.15b). Several factors may have contributed to these variations such as differences in the recruitment class strengths, differences in the timing of crab movement influenced by environmental factors, differences in management arrangements, and differences in recreational fishing patterns and strengths between the current years and from a decade ago. In terms of management changes, bag limits of recreational fishers were halved from 40 per boat/20 per person to 20 per boat/10 per person in 2007 (Fletcher and Santoro, 2008), the fishing closure during September and October also introduced in 2007 and voluntary escape gaps on commercial traps since 2005/06. Salinity and rainfall trends show current salinities during winter months much more saline due to declining rainfall patterns (Figure 3.3, Figure 3.4), so now crabs are likely to stay within the Estuary longer than a decade ago. Reduced flushing of crabs from the Estuary means greater fishing pressure during the winter months and this trend is likely to intensify under the current climate change predictions for this region (Indian Ocean Climate Initiative 2012).

Furthermore, greater intrusion of seawater into the Estuary at the end of the winter rain period had led to female crabs becoming ovigerous earlier between October and February as opposed to January to April during the 1980 – 81 period (de Lestang 2002). This trend has not changed as current commercial monitoring and fishery-independent data sets both show increased catch rates of berried females over a greater number of months (October – January) compared to historical years. This is also consistent with the timing of berried females in other south-west crab fisheries such as Cockburn Sound (Johnston *et al.* 2011a) and Comet Bay (refer to Figure 4.5). The relatively high catch rate of ovigerous females from the Estuary Channel location further suggests conditions may potentially be suitable for females to spawn within areas of the Channel without it being necessary to completely exit the Estuary. The importance of the Estuary Channel for all size classes of males and females was not highlighted by de Lestang (2002) as all the analyses were combined across sites and fishing methods.

6.4 Environmental influence on stock dynamics

Changes to the Estuary hydrodynamics after the construction of the Dawesville Channel resulted in changes to the faunal community, including altering some of the stock characteristics of *P. armatus*. Changes to stock structure in the 10 years since the Channel opening does not appear to be significant. Variability in population dynamics was present among the fishing years analysed and this was largely due to environmental conditions. For instance, the significant drop in catches in 2008/09 was due to a combination of events driven by the timing of the flushing from rainfall patterns. The 0+ cohort (immature crabs) from the 2007/08 fishing year was a particularly large recruitment class (refer to Figure 3.13a, b). Male crabs from this cohort returned to the estuary during November/December of 2007 and after their moulting in January, the majority of the males became sexually mature sub-legal crabs and the rest became legal-sized crabs (>127 mm). This is consistent with the high catch rate of sub-legal males between December and April of 2008 (see Figure 2.10c, Figure 3.9c). Females enter the Estuary later than males during March/April to moult and then mate. However, the winter rains, which usually peak during June/July, began much earlier and produced heavy rainfall from April through to July of 2008 (Figure 3.3). This meant, most sub-legal crabs that would have become legal after the April moulting period were flushed much earlier from the Estuary, thus the resulting drop in commercial catches observed for the 2008/09 financial year. This event suggests that even small environmental variations can highly influence the stock dynamics of *P. armatus* in the Peel-Harvey Estuary.

The south-west region of Western Australia is currently a climate change hotspot with predictions forecasting increasing water temperatures, decreasing rainfall and rise in overall sea levels (Pearce and Feng 2007, Indian Ocean Climate Initiative 2012.). Rogers *et al.* (2010) hypothesised a likely scenario for the PHE that includes deepening across the whole Estuary, widening of the Estuary and Dawesville Channels, and the overall Estuary becoming more marine from reduced freshwater inflow. While these changes will impact both the marine and terrestrial community infrastructure within the Estuary, for the opportunistic blue swimmer crab, a change to a more tropical marine embayment would be highly favourable as it is a tropical species. Therefore a more marine PHE is likely to encourage resident crabs to stay in the Estuary and a more permanent stock may be established assuming suitable habitat and food sources are available. Blue swimmer crabs is a case study species that is part of a FRDC funded project investigating the management implications of the effects of climate change on key commercial species in Western Australia (N. Caputi pers. comm.).

6.5 Differences in trap selectivity

In reviewing the catch data of *P. armatus* between the commercial monitoring and the fishery-independent research survey, catch trends of all size classes were generally more visible from the fisheries research surveys, particularly for immature and sub-legal sized crabs. This is probably due to the trap selectivity differences where the trap configurations of the commercial traps are designed for optimal retention of legal-sized crabs whereas research traps (with no escape gaps) are designed for maximum retention of all sized crabs.

Trap selectivity was evident when comparing the catch trends of small sized crabs, where catch rates of immature crabs were generally higher, and trends more defined from the fisheries research survey data set than from the commercial monitoring surveys. Likewise for the sexually mature sub-legal crabs, catch rates of both males and females were several magnitudes higher and monthly trends more clear from the fisheries research surveys than from commercial surveys. For example, fisheries research survey data showed the highest catch rate of sub-legal males were caught from the Harvey locations between November and March but this trend was absent from the commercial survey data. For legal-sized crabs however, the commercial survey dataset produced similar monthly trends although commercial catch rates were higher than data from fisheries research surveys. The escape gaps on commercial traps aids smaller crabs to escape therefore a greater abundance of large sized crabs can be retained. Despite these escape gaps being variable in size and shape among PHE fishers (no mandatory specifications), overall the selectivity threshold is approximately the same as the minimum legal size limit of 127 mm.

6.6 Mandurah to Bunbury Developing Crab Fishery

The current commercial catch monitoring program for Areas 1 and 2 of the Mandurah to Bunbury Developing Crab Fishery provides valuable insight to the stock structure in these regions, particularly in highlighting the female dominance among the stock. The increased proportion of females in this fishery is consistent with the observed female dominated catch compositions from the outside PHE oceanic surveys sites. The presence of berried females between October and January is also consistent with catch trends from the Estuary Channel and outside oceanic sites, thus confirming late spring / early summer as the spawning period. Currently there is no spawning closure for any of these fisheries although there is no take of berried female crabs. The risk is mostly for mated pre-spawned females between April and

October. The no fishing ban for September and October in the PHE is not in place for Areas 1 and 2. If the crab assemblages from PHE and Areas 1 and 2 (and Zone D) are to be considered as part of one stock, then management needs to reflect this by introducing the same regulations to all these fishing grounds including consistency with legal minimum size limits.

The commercial monitoring program in Area 1 and 2 and Zone D trawl fishery only provided data for some months of the year. For example, the operator in Area 2 fishes crabs to supplement his income from other main licences, thus there is no fishing for crabs for half the year and sometimes none at all e.g. 2011. Therefore it is difficult to assess stock status from this region from inconsistent commercial monitoring data. Furthermore, if this fishery were to transition to an interim managed fishery, the current high levels of latent effort would pose a potential risk to the sustainability of the stocks due to the likelihood that new operators would fish more consistently.

6.7 Impact of recreational and commercial fishing pressure on the crab stock

For the blue swimmer crab stocks in the Peel-Harvey Estuary, the dominance of the recreational sector presents challenges to assessing the impact of each fishing sector on the resource, particularly given the fact that there are only two estimates (1998/99 and 2007/08) of recreational catch and effort for the PHE (see Chapter 5). Furthermore, the boundary of the PHE crab stock is unknown given the highly mobile nature of the species as crabs move into and out of the Estuary driven by environmental changes in temperature and salinity (rainfall). Therefore levels of recruitment within the Estuary are influenced by the spawning stock status of nearby south-west crab populations (Warnbro Sound to Geographe Bay, Figure 1.1)

There are only two point estimates of recreational catches of crabs and, in the absence of information on inter-annual variation of such catches, these provide insufficient data from which to draw inferences regarding changes in the proportional catch relationship between recreational and commercial sectors. However as commercial catches have fluctuated significantly over time due to various factors it is likely that recreational catches have also fluctuated. Comparisons between current and historical commercial and fishery-independent data sets have shown no significant adverse changes in stock status over time, therefore current levels of commercial and recreational fishing are likely to be sustainable. Until more estimates of annual recreational catches are obtained, commercial catch rates will be used to assess stock status (See section harvest strategy).

The total recreational catch of blue swimmer crabs in the Peel-Harvey Estuary decreased from 251 – 337 tonnes in 1998 – 99 to 107 – 193 tonnes in 2007 – 08. Marked declines of catch occurred for all catching methods; however the proportion of catch remained 30% shore-based to 70% boat-based catch in both survey periods. The seasonal survey data for blue swimmer crabs demonstrated that the reduction in catches in the two survey periods occurred over all months, with low winter catches. The primary factor involved in the decline in catch was the decline in fishing effort by boat and shore-based fishers. Management changes between survey periods to reduce the bag limit from 24 to 10 crabs per fisher and the boat limit (for boats with two or more fishers) from 48 to 20 crabs may also have had a direct impact on retained catches. The change in boat and bag limits, however, may also have been an indirect factor that influenced decisions of fishers as to whether or not to fish for blue swimmer crabs. Another possible contributing factor is the shift to a higher proportion of residents in the 2007 – 08 survey from the Peel local government region, i.e. the Mandurah region, than in the previous survey where the majority of crabbers were residents of the Perth Metropolitan Region. Overall, it is not possible to suggest that the decline in the numbers of kept crabs between the two surveys represents a trend, as data are available for only two periods and there are no data on inter-annual variation in catches or in the abundance, catchability and vulnerability of crabs.

Comparison of the recreational kept catch to the commercial catch (Table 6.1) demonstrates a marked decrease in the recreational proportion of the total catch from 79 – 85% in 1998 – 99 to 54 – 68% in 2007 – 08 with the commercial proportion increasing from 15 – 21% in 1998 – 99 to 32 – 46% in 2007 – 08. The 2010 – 11 statewide recreational boat-based survey (Ryan *et al.*, 2013) suggests a further decrease in the recreational proportion of catch and conversely increased commercial proportion of the catch (unpublished data). The commercial catch has been increasing during the period between the surveys, with the highest commercial catches occurring in 2006 – 07 and 2007 – 08, where the latter year corresponds to the year of the second recreational survey, thus influencing the increase in the commercial proportion of the catch for that survey year.

The commercial catch data shows greater catches of females over time, however it is not possible to discern if the pattern is similar in the recreational catch data, although the proportion of females increases in March to August in both fisheries. In addition, the increased proportion of females in the catches in the Mandurah entrance channel is consistent with the data from independent research sampling in the same location, which indicate that this is a key area for female blue swimmer crabs.

Table 6.1. Commercial and recreational kept catch of blue swimmer crabs in the Peel-Harvey Estuary in 1998 – 99 and 2007 – 08. Recreational catch comprises fishers crabbing from boats, bridges & jetties, scoop netting areas along the shore of the estuary and hire houseboats in 1998 – 99 and also includes private houses along canals in 2007 – 08. Recreational catch is the 95%CI.

	Commercial catch (tonnes)	Total recreational catch (tonnes)
1998 – 99#	66 (15 – 21%)	251 – 377 (79 – 85%)
2007 – 08*	90 (32 – 46%)	107 – 193 (54 – 68%)

 # catch calculated for the survey period August 1998 – July 1999

** catch calculated for the survey period November 2007 – October 2008 which includes the two month crabbing closure*

6.8 Rationalisation of crab data collection in the Peel-Harvey Estuary

The four year fishery-independent survey and commercial monitoring data series has provided key information relating to the stock structure, biology and behaviour of blue swimmer crabs in and around the PHE. For future monitoring however the current intensive sampling regime in the PHE can be refined to key locations and months for ongoing assessment of stock status.

6.8.1 The Estuary Channel

The generally higher magnitude in catch rate of crabs of all sizes from the Estuary Channel over the Peel and Harvey regions, suggests that this is a key region for future monitoring. In particular the breeding stock (i.e. reached sexual maturity (males > 87.1 mm; females > 86.9mm)) comprised of sexually mature sub-legal and legal-sized males and females were caught in high abundance in the Estuary Channel across most months. The first peak in catch rate of mature females during January/February corresponds with females returning to the Estuary (after spawning) as water temperatures increase, and the decline in catch rate after the second peak during May/June corresponds with females exiting the Estuary as salinities decrease from winter rainfall (see Figure 3.9b, Figure 3.10b). Similarly the catch rate of mature males peak during December/January as they enter the Estuary, and a second peak occurs during July as males exit the Estuary (see Figure 3.9a, Figure 3.10a). The catch rate of legal males is however the lowest during the July peak (~1 crab/traplift) as most males are fished before they reach the Estuary Channel. The catch rate of mature sub-legal crabs in the Estuary Channel is > 4 crabs/traplift for males and > 2 crabs/traplift for females across all months, which lends support to the high mobility of the stock as most are likely transient individuals but there may also be a resident population within the Estuary Channel. The oceanic nature of the Estuary after the Dawesville Channel construction (Figure 3.4c, d) supports the trends observed and presumably there are suitable habitat and food sources to support high densities of crabs in the Estuary Channel. The Dawesville Channel which provides an alternate passageway for crabs to enter and exit the Estuary also plays a key role in the spatial dynamics of the stock as evident from the aggregation of commercial fishing at the entrance to this Channel during the winter period (see Figure 2.8). The strong tidal flow within the Channel presents several logistical sampling difficulties and given the lack of suitable habitat within the Channel (mostly sandy bottom) it's unlikely that a resident population resides within the Dawesville Channel. Furthermore the Estuary Channel sites are not impacted by fishing and as survey sites are positioned at the entrance to the Channel opening, it is the ideal sampling location to capture the status of the stock as they enter and exit the Estuary.

Key months of sampling for the fishery-independent surveys can been reduced from all year round to June to November (or September/October if there are budgetary/time constraints). This period provides an estimate of crab abundance as they exit the Estuary during the autumn/winter months and for the legal-sized crabs this provides the residual legal biomass after the peak fishing months. This provides an indication of (a) the spawning stock for the next spring/summer; (b) the effects of winter rainfall on the movement of stocks out of the Estuary; and (c) the effects of fishing on legal-sized crabs.

6.8.2 Outside oceanic sites

Additional survey sites placed outside the Estuary were intended to supplement the stock trends observed from within the Estuary, particularly during the months between winter (when crabs exit the Estuary) and summer (when crabs re-enter the Estuary). Catch rate of immature crabs was barely detectable outside the Estuary (<0.1 crabs/traplift), while the catch rate of sub-legal and legal males were the lowest from the outside sites and provides no support of male crab movement in and out of the Estuary. Catch rates of sub-legal females from the outside sites were comparable to the catch rates from the Harvey sites, but no clear temporal trends to suggest movement of crabs. The catch rate of legal females were however the only size class where the catch rate from the oceanic sites were higher than Peel and Harvey between July and February, but not higher than the catches from the Estuary Channel.

Although habitat and environmental conditions are likely to be similar between the Estuary Channel and outside the Estuary, there is likely to be a concentration effect on the crab abundance within the Channel compared to the much greater area outside where the density of crabs is diluted. Thus it's possible a combination of poor positioning of traps and low number of survey sites may have contributed to the lack of catch rate trends observed from the oceanic sites. Therefore, the overall catch rate trends from outside the Estuary suggests abundance is probably highly diluted in terms of spatial distribution, so continuing monitoring outside Estuary sites in the future would not be cost effective. Nevertheless, the relatively high abundance of berried and/or mature females in the outside sites compared to inside the PHE (Figure 3.5 – Figure 3.7 & Figure 3.11) confirms the importance of the outside spawning area in the recruitment of crabs in the PHE. More effective sampling of this breeding stock population will occur through the commercial monitoring program (see below).

6.8.3 Commercial monitoring program

Future commercial monitoring will be reduced to peak fishing periods for males and females between November and May, sampling all sites within the Peel-Estuary and Harvey Inlet. These months will complement data collected during the fishery-independent surveys between June and November. Monitoring during this period will also provide estimates of the proportion of undersized to legal-sized crabs entering the Estuary which will inform future management arrangements regarding season openings. Commercial monitoring will occur in Comet Bay and Mandurah to Bunbury Developing Crab Fisheries in all months of fishing to provide abundance estimates of the breeding stock, as well as providing information on the size structure of stocks in these areas.

6.8.4 Future survey and monitoring program

Therefore in reviewing the fishery-independent survey and commercial monitoring program the following refinements are recommended:

- The Estuary Channel provided the strongest evidence of stock class structure with the most defined temporal patterns and highest catch rates across all the sites. Thus this location will remain for future monitoring. Months of fishery-independent monitoring however will be reduced to only 6 months; June to November.
- Sampling of all sites inside the PHE will also continue during the reduced sampling period of June to November, which will provide additional data on overall stock dynamics within the Estuary.
- In contrast to the Estuary Channel, the outside oceanic sites were not effective in providing supplementary information to the PHE stock but did show the higher proportion of females outside the Estuary. Given the commercial monitoring program in Comet Bay and Mandurah to Bunbury fisheries will continue and represents the same stock, the outside oceanic sites from the PHE fishery-independent surveys will be discontinued. This is supported by fishery review comments relating to the effectiveness of the oceanic sites.
- Commercial monitoring within the Peel-Harvey Estuary will be reduced to the peak fishing months of November – May, with the Peel Estuary and Harvey Inlet each being sampled per month. Future sampling could be extended to every second month for the remainder of the season.
- Commercial monitoring in Comet Bay and Mandurah to Bunbury Developing Crab Fisheries will continue in all months of fishing to provide information on stock structure and breeding stock abundance.

6.9 Future management recommendations

- *Protection of mated pre-spawning females inside PHE* – the movement of females out of the Estuary during winter ensures a relatively low risk to the sustainability of the breeding stock within the Estuary and therefore adequate protection to mated pre-spawning females would seem to be sufficient at present. However, catchability of mature females increases after April (after they have moulted and mated) as reflected by commercial peak catches for females which are between April and August. This may pose a potential risk to sustainability from increased fishing pressure on mated pre-spawned females during this period. Following the conversion to traps, commercial fishing has extended into winter and commercial spatial patterns shows fishers concentrating their fishing effort at the entrance to the Dawesville Cut as mated females move towards more saline waters for spawning. Furthermore, there is some protection currently in place from the 127 mm CW size limit that is well above the size of maturity (86.9 mm CW) which allows all female crabs the opportunity to spawn at least once before they are potentially harvested. More recently, the voluntary minimum size limit of females of 130 mm CW by some fishers and seasonal closure between September and October (and voluntary no take of females between November and March) provides further protection to the breeding stock. Finally, highest catch rates of mature sub-legal and legal females occur in Estuary Channel where they are permanently protected from fishing all year round.
- *Protection of mated pre-spawning females outside PHE* – mature females exiting the PHE are targeted by fishers from the Mandurah to Bunbury Developing Crab Fishery and Zone D SWTMF. Therefore for effective protection of the breeding stock (that is essentially part of a single crab stock moving in and out of the PHE), protection of mated pre-spawned females should also be in place to commercial fisheries outside PHE. Currently there is no protection to the breeding stock in oceanic waters outside PHE where the commercial catches are predominantly mature females, Therefore it is important to consider a similar closure to protect both males and females during the key spawning period September to January and/or ensure there is no significant increase in fishing effort outside the Estuary.
- *Size limits* – there needs to be consistency in the minimum legal size limits set across the south-west crab fisheries as highlighted by 127 mm CW size limit in PHE and Zone D trawl fishery, versus 128 mm CW size limit in Area 1 and Area 2 of Mandurah to Bunbury Developing Crab Fishery. Given there is substantial evidence to support that a single stock of similar biological life-history traits is harvested in these fisheries, there needs to be consistent management arrangements to maintain sustainability.
- *Monitor the undersize to legal size ratio at the start of season in November* – to assess whether there are significant numbers of undersize crabs being fished in November. This issue was reviewed recently (~2010) by the Department due to concerns by recreational fishers and the community that undersize crabs were being handled excessively in the Estuary by commercial fishers. Due to the importance of establishing commercial markets at the beginning of the season and that escape gaps have been adopted by the commercial sector it was deemed this issue was not adversely affecting sustainability at that time. Nevertheless, the high proportion of undersize crabs in commercial catches during November is an issue that should be closely monitored in the future.
- *Ban on fishing by recreational sector in Estuary Channel* – highest female catches were recorded in the Estuary Channel by the recreational sector which was consistent with fishery independent data where high numbers of all size classes of females were recorded. This

suggests that the Estuary Channel is an important area for female crabs and consequently this area should be closed to recreational fishing to protect the breeding stock. A ban on commercial fishing in the Estuary Channel already exists.

6.10 Proposed Harvest Strategy for the Peel-Harvey Estuary Commercial Crab Fishery

A harvest strategy (decision rule framework) provides a set of transparent and verifiable measures against which one can assess and report on the performance of the fishery and demonstrate its sustainability. A potential harvest strategy has been proposed for the Peel-Harvey Estuary (PHE) commercial crab fishery which will be reviewed by fishery managers and researchers, and following consultation with industry stakeholders, implementation and annual reporting will commence. The harvest strategy should be regularly reviewed to ensure it is meaningful, defensible, precautionary, and responsive, taking into account the most appropriate information available.

In broad terms, a performance measure is used to measure the stock status against management objectives, and is a measure of where an indicator such as stock size sits in relation to its reference points. The indicator may be some direct observation such as CPUE (catch rate), or a model estimate such as biomass. Reference points define particular levels of an indicator where the;

- *limit reference point* indicates a state of a fishery or resource that is considered to be undesirable and below which point immediate remedial management action should be taken;
- *threshold reference point* is the minimum level above which the performance indicators need to be;
- *target reference point* indicates a state of fishery or resource that is considered to be desirable and at which management, whether during development or stock rebuilding should aim.

6.10.1 Primary performance indicators

For the Peel-Harvey Estuary commercial crab fishery we propose two key performance indicators sourced from annual commercial catch and effort data as these currently provide the longest time series available to judge the performance of the fishery:

- Commercial catch (tonnes)
- Commercial CPUE (kg/traplift)

According to the Commonwealth guidelines LRP (limit reference point) (BLIM- biomass level at which risk to the stock is unacceptably high and recruitment overfishing likely to occur) must to greater than 0.5 BMSY (biomass that gives the maximum sustainable yield). However in the absence of robust estimates of BLIM and BMSY, reference points can be set by analyzing the variability in CPUE from a time period over which the fishery has been considered sustainable. Sometimes BLIM may be aligned with an economic BLIM, i.e. the level below which it becomes economically unviable to fish.

For PHE, since the introduction of crab traps in 1995/96, catches have increased and have remained between 40 and 100 t, with catch rates between 0.8 and 1.6 crabs kg/traplift. The primary performance indicators were estimated as a 3-year moving average of the annual catch and CPUE (non-standardised). A moving average enables a better estimate of the trend of the time series and reduces the variation associated with annual variation that may be driven by environmental conditions and differences in fisher efficiencies. Standardised CPUE will be developed as a primary performance indicator in the future (using year, month, fisher, location).

The first step was to select a threshold value, and the rationale was based on the lowest catches indicated by the moving average in the period 1996/97 to 2010/11. Within this period, the 3-year moving average centered on 1997/98 and 1998/99 recorded 53.2 and 53.3 t respectively and subsequently 53 t becomes the threshold value for this fishery. A limit reference point of about 20% below the threshold value was set at 42.4 t (Figure 6.2). This criteria was also applied to CPUE data from 1996/97 to 2010/11. Similarly the lowest catch rates were recorded for 1997/98 and 1998/99 at 1.04 and 1.05 kg/traplift respectively, therefore 1 kg/traplift was set as the threshold value and the limit of 20% below this value at 0.8 kg/traplift (Figure 6.3). For the time being, we have opted not to set a target reference point given the uncertainty in the catches taken by the recreational sector. Ongoing annual review of this fishery will determine if there is a risk to the stock through incremental increases to commercial catches due to increases in fishing effort and/or efficiency coupled with significant changes to recreational fishing activities. A target catch and catch rate range will be developed in the future based on the 3 year moving average, with a preliminary target range set as 53 t – 90 t and 1 kg/traplift – 1.4 kg/traplift, respectively.

A harvest control framework with management decision rules for scenarios where the primary performance indicator drops below the threshold and limit are proposed in Table 6.1. Management responses and reference points in relation to the performance indicators will be reviewed on a regular basis.

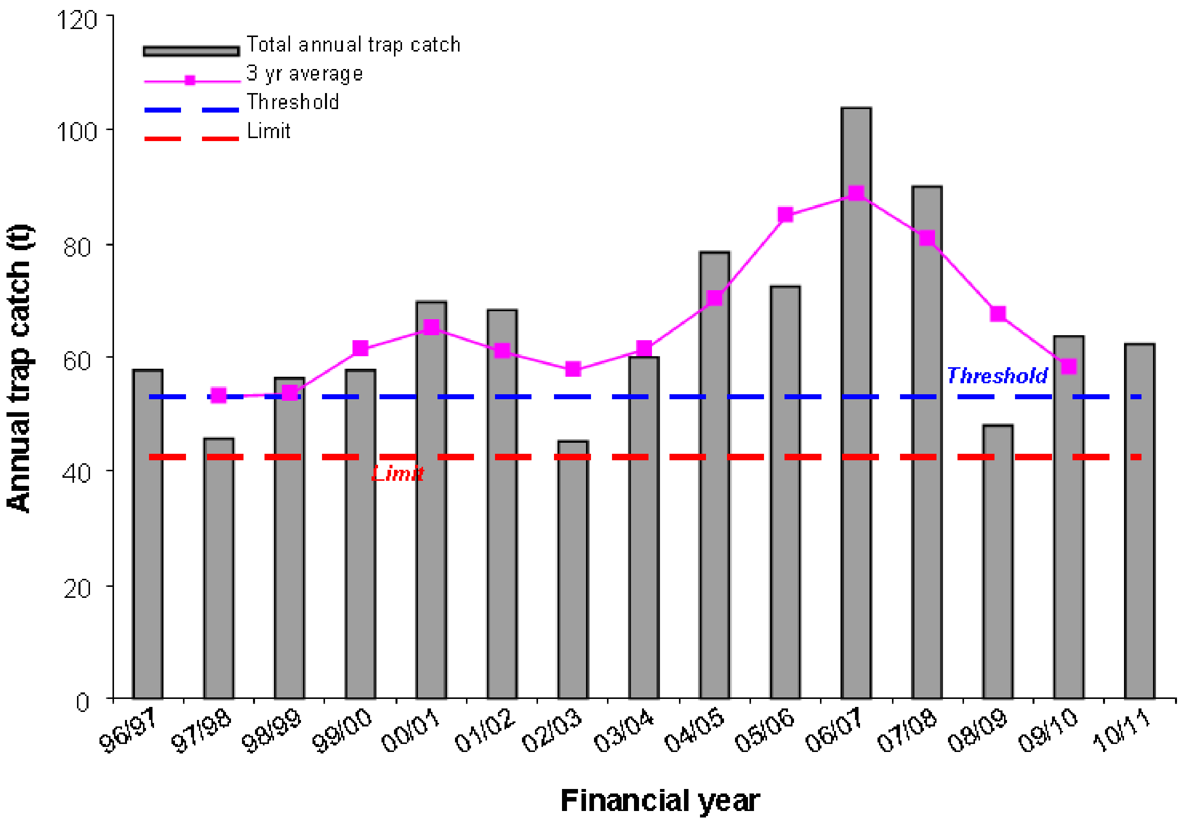

Figure 6.2 Proposed performance indicator of 3-year moving average of catch (t) (—) and reference points; Threshold (—) and Limit (—), for the Peel-Harvey Estuary commercial crab fishery.

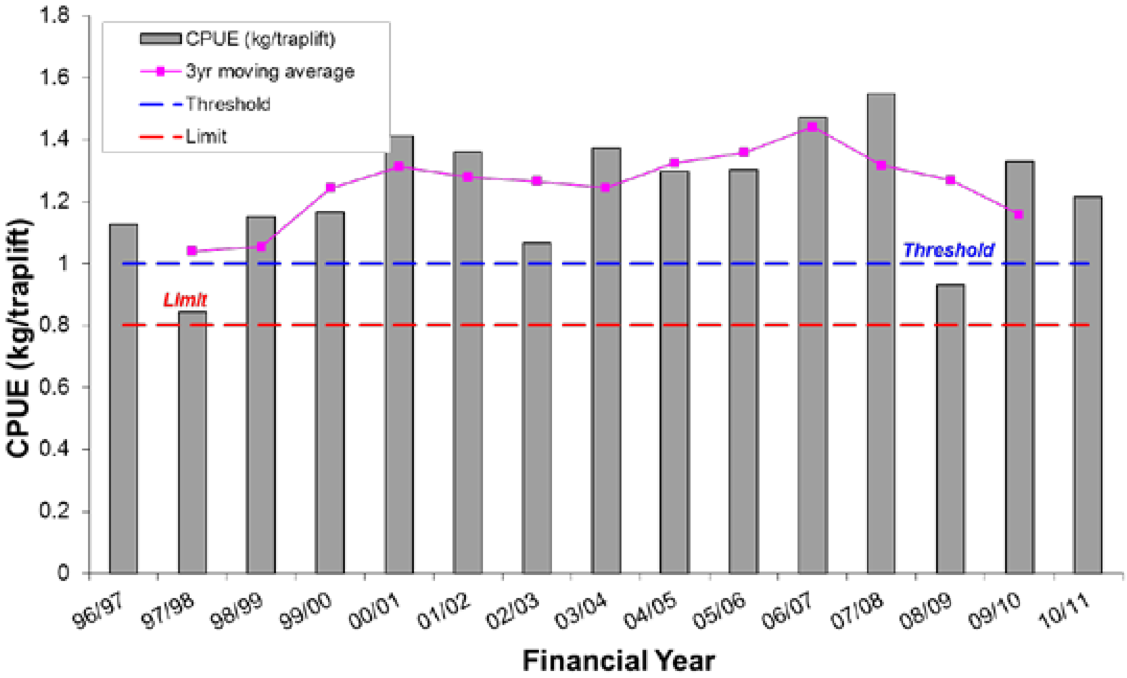

Figure 6.3 Proposed performance indicator of 3 year moving average catch rate (CPUE, kg/traplift) (—) and reference points; Threshold (—) and Limit (—), for the Peel-Harvey Estuary commercial crab fishery.

6.10.2 Secondary performance indicators

We also propose secondary performance indicators for the Peel-Harvey Estuary commercial crab fishery which will provide additional measures to assess the performance of the fishery (Figure 6.4, Table 6.2). These indicators have been derived from the monthly, spatial and annual catch rate trends of fishery-independent surveys between 2007 and 2011. Rationalisation of this survey have identified the key monitoring months and locations (section 6.8) from which abundance indices of juveniles (immature crabs), primary breeding stock (sexually mature sub-legal crabs) and sexually mature legal crabs were based on. Given the short time series of both these monitoring programs (only 4 years to date), there is insufficient robust data to set reference points (eg Target, Threshold and Limit). Instead, we propose to set reference levels (lower and upper) based on the variability in CPUE over the time period 2007/08 to 2010/11. The upper and lower reference level will be reviewed annually and adjusted until such time as enough time-series data are available to determine a robust threshold and limit reference levels.

Proposed secondary performance indicators are:

- Relative abundance of immature crabs from FIRP (proxy for juvenile index) (crabs/traplift)

Juvenile index: In the absence of a dedicated juvenile crab trawl monitoring survey and given the current research trap sampling method is not selective for juvenile crabs < 50 mm, juvenile crab abundance is based on the standardised catch rates of crabs that are sexually immature (males < 87.1 mm CW; females < 86.9 mm CW). These crabs would potentially grow to be legal size the following season. Fishery-independent surveys revealed the Estuary Channel sites were the key region where highest immature crab abundance was found, with the peak catch rates occurring in the period June to August.

- Relative abundance of sexually mature sub-legal and sexually mature legal crabs from FIRP (crabs/traplift)

Breeding stock Index: We define the breeding stock as crabs that are sexually mature and sub-legal (87.1 < males < 127 mm; 86.9 < females < 127 mm) as these crabs dominate egg production. These crabs have the potential to mate and spawn at least once before they are harvestable from within the Estuary. For both males and females, we identified the period between July and November in the Estuary Channel as the key location and months for an index of sub-legal crabs captured as they exit the Estuary with the winter rains. Although legal-sized crabs also constitute as being part of the breeding stock, it is unknown what proportion of the legal stock will be harvested before they mate, what proportion of the post mated crabs are harvested and what proportion of the mated crabs will leave the Estuary to spawn.

- Relative abundance of residual sexually mature legal-sized crabs from FIRP surveys (crabs/traplift)

Harvestable (legal) biomass: From the fishery-independent surveys, the catch rates of legal crabs from the Estuary Channel during the period July to November was identified as an appropriate period to provide an estimate of the residual legal abundance exiting the Estuary which may or may not return to the Estuary the following year.

Future analyses may combine sexually mature sub-legal and sexually mature legal female catch rates to develop a single index for breeding stock abundance. Females would be weighted by the number of eggs produced (size-fecundity relationship) (sum of egg production = sum of eggs at a given size * Female size).

Table 6.1 Proposed primary performance indicators and management decision rules for the Peel-Harvey Estuary commercial crab fishery.

Primary Performance Indicator	Performance Measure	Management Response
Commercial catch (t) and Commercial catch rate (kg/traplift)	If Threshold < indicator	No response required if secondary performance indicators are within reference levels
	If Threshold > indicator > Limit	Review secondary performance indicators Appropriate management response required (commercial and recreational sectors)
	If indicator < Limit	Review secondary performance indicators Review management for possible causes to set conservative management measures

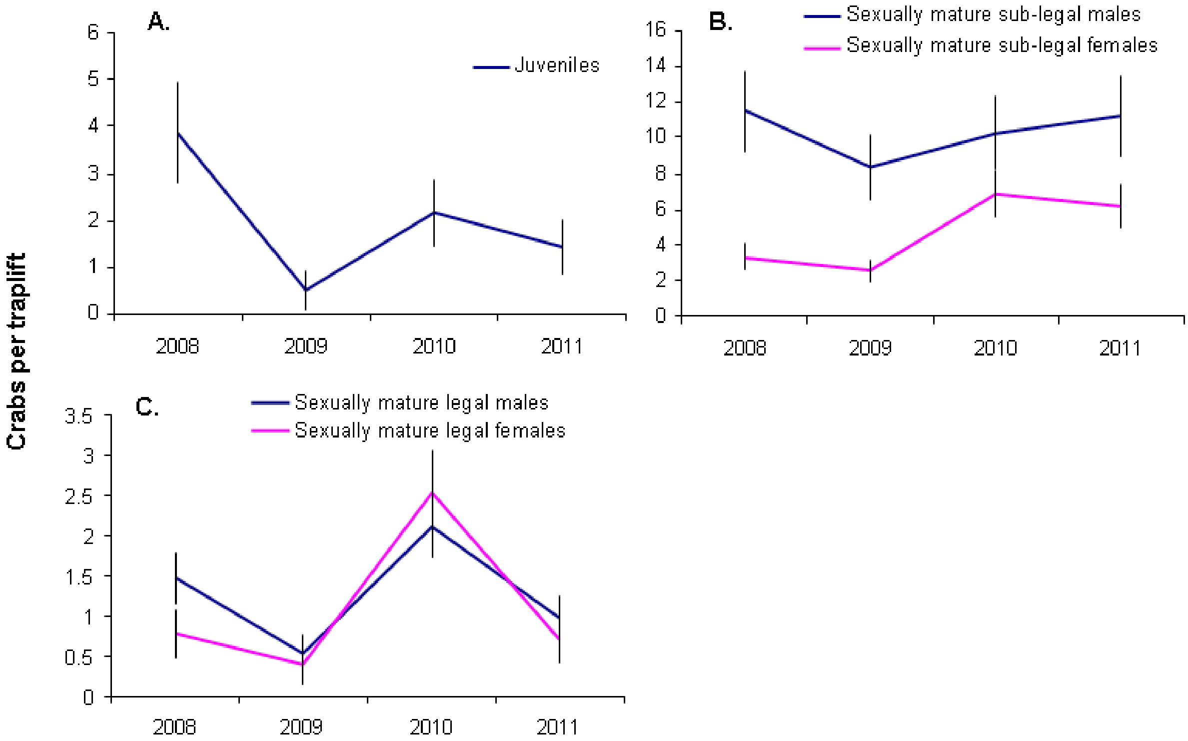

Figure 6.4 Mean (SE) abundance (crabs/traplift) of A. juveniles during June-August in the Estuary Channel, B. sexually mature sub-legal and C. sexually mature legal crabs during July-November in the Estuary Channel from fishery independent surveys.

Table 6.2 Proposed secondary performance indicators (PI) and measures and associated reference levels for the Peel-Harvey Estuary commercial crab fishery.

Secondary PIs	PI measure	Sex	Data Source	Location	Months	Lower Ref. range	Upper Ref. range
Juvenile Index	Immature abundance	Males and Females	Fish. Indep. surveys	Estuary Channel	Jun – Aug	1	4
Breeding stock Index	Sexually mature sub-legal abundance	Males	Fish. Indep. surveys	Estuary Channel	Jul – Nov	7	11
		Females	Fish. Indep. surveys	Estuary Channel	Jul – Nov	3	8
	Sexually mature legal abundance	Males	Fish. Indep. surveys	Estuary Channel	Jul – Nov	1	3
		Females	Fish. Indep. surveys	Estuary Channel	Jul – Nov	1	3

6.11 Stock Status

This study has confirmed the close relationship between crab stocks inside and outside the Peel-Harvey Estuary and the need to manage crab fisheries in the south-west as one stock. Since conversion from gill nets to traps, crab catches have increased from proportionately less fisher days, indicating increased fishing efficiency over time. Trap catch between 2002/03 and 2010/11 has fluctuated between 45 and 104 t and catch rates have fluctuated between 0.8 and 1.5 kg/traplift, but have generally remained above 1.2 kg/traplift since 2003/04. Conversion to traps has been increased fishing in autumn/winter, but most (62%) of the catch and highest catch rates are still taken between December – March. Comparisons between current and historical commercial (CAES and commercial monitoring) and fishery-independent data sets have shown that crab stock abundance appears to have been relatively constant over the past decade, with natural protection of the spawning stock occurring due to their exiting the Estuary over winter to spawn in oceanic waters. Consequently, based on a weight of evidence approach it is believed that current levels of fishing in the Peel-Harvey Estuary are sustainable. Nevertheless, there are a few indicators which suggest that the crab fishery in Peel-Harvey is complex and further analyses may be needed to determine appropriate indices that are suitably robust to assess sustainability. In particular, commercial monitoring has shown declining catch rates of sexually mature sub-legal and legal males between 1998/99 and 2010/11 and within the recent survey period between 2007/08 and 2010/11, and that the commercial catch rate of sexually mature sub-legal females appears to be increasing. This trend in increasing catch of females was also observed in the recreational surveys with higher numbers of females being caught in the Estuary channel. These trends, and the focus of commercial fishing opposite the Dawesville Channel in winter indirectly targeting mated pre-spawning females, need to be closely monitored as well as the trends in the offshore fisheries (Comet Bay and Mandurah to Bunbury) where the majority of catch is females. It must also be noted that environmental patterns and long term climate changes such as declining rainfall may significantly influence the abundance and movement of crabs in the Peel-Harvey Estuary. The dominance of the recreational sector in this fishery presents challenges to assessing the impact of each fishing sector on the resource, particularly given there are only two estimates (1998/99 and 2007/08) of recreational catch and effort in the Peel-Harvey Estuary and a state-wide boat based survey carried out in 2011/12.

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9.0 Appendices

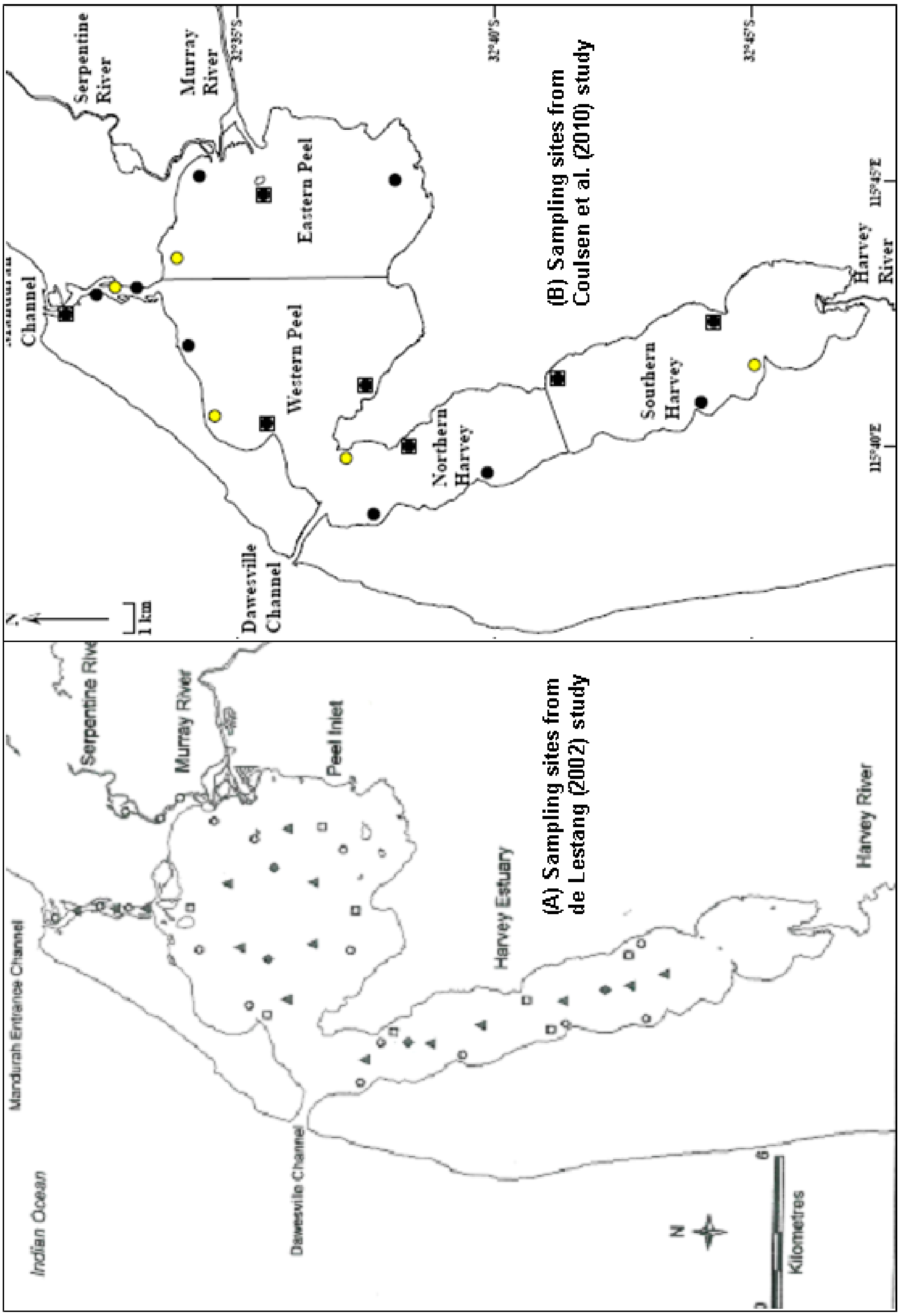
9.1 Appendix A – Size at the onset of female maturity estimates

Potter *et al.*, (2001) suggested that, in southwest Australian fisheries, plotting the logistic curve of the proportion of adult female *P. armatus* crabs in estuaries produces greater mean sizes at sexual maturity than adult females in marine embayments. This inequity arises because female crabs migrate out of the estuaries to spawn, reducing the proportion of mature females remaining within the Estuary and shifting the logistic curve to the right. As spawning occurs outside the Peel-Harvey Estuary, it was not considered appropriate to use an estimate derived from sampling female crabs inside the Estuary. Consequently, the mean female size at sexual maturity for Koombana Bay (ref) was used as it was the closest to an open marine embayment similar to the oceanic waters outside Peel-Harvey Estuary.

In the current study, the extension of survey sites outside the Estuary in oceanic waters provided the opportunity to re-examine male and female maturity data. Thus female maturity based on the shape of the abdomen (de Lestang, 2002) and male maturity based on the propodus length were recorded from 500 males and 2000 females measured (samples collected between April 2010-April 2011). The analysis of this data failed since approximately 95% of the crabs measured were sexually mature and no immature crabs were caught from the outside oceanic sites. Factors that are likely to have contributed to these results were the capture method of trapping which was not selective for small crabs, the position of these traps in the central regions of the Estuary where small crabs are less prevalent, and the lack of a wide coverage of oceanic sites. The latter may not be a significant factor if reefs outside is not suitable habitat for juvenile crabs.

Due to the above reasons, the SOM estimates from Koombana Bay were used for all analyses from the PHE.

9.2 Appendix B



Maps of Peel-Harvey Estuary showing the sampling locations from (A) de Lestang (2002) study where crab samples were collected through 10.5 and 21.5 m seine nets (circles), 102.5 m seine net (squares), crab traps (diamonds) and otter trawls (triangles), (B) Coulson *et al.*'s study where crabs were sampled using 21.5 and 102.5 m seine nets. The black circles in boxes represent sites sampled in the 1980s (Potter *et al.* 1996), which were also sampled in the 1990s (de Lestang 2002) and Coulson *et al.*, black circles represent sites sampled in the 1990s (de Lestang 2002) and Coulson *et al.*, and yellow circles represent additional sites sampled only during Coulson *et al.*'s study'.

9.3 Appendix C

Table 1. Number of pot lines for each combination of fishing year and month for the analysis of current commercial catch monitoring surveys

	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
2006/07					7	9	5	7	10	6	11	12
2007/08	6	7	5	4	7	5	9	6	8	5	9	10
2008/09	7	4	2	6	8	4	7	6	3	7	7	10
2009/10	7	10	7	7	9	6	5	9	6	7	12	9
2010/11	7	8	7	6	8	7	5	8	5	8	9	8

Table 2. Number of pot lines for each combination of fishing year and season for the analysis of historical and current commercial catch monitoring surveys in the PHE.

	Summer (Nov-Jan)	Autumn (Feb-Apr)	Winter (May-Jul)	Spring (Aug-Oct)
1998/99	6	5	7	4#
1999/00	7	3	6	1#
2007/08	22	21	19	19
2008/09	19	19	16	17
2009/10	31	20	22	21
2010/11	28	20	21	17

 # Data from Harvey Estuary only (i.e. no Peel Inlet).

Table 3. Number of sampling sites for each combination of fishing year and month for the analysis of fishery-independent research surveys undertaken (A) inside the Peel-Harvey Estuary including the Estuary Channel sites and (B) outside oceanic sites

(A) Inside	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
2006/07								5	5	5	5	5
2007/08	5	15	15	15	15	15	15	15	15	15	15	15
2008/09	15	15	15	15	15	15	15	15	15	15	15	14
2009/10	15	15	15	15	15	15	15	15	15	15	15	15
2010/11	15	15	15	15	15	15	15	15	15	15	15	15

(B) Outside	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
2007/08										9	9	9
2008/09	9	9	9	9	11	11	11	11	11	11	11	11
2009/10	11	11	11	11	11	11	11	11	11	11	11	11
2010/11	11	11	11	11	11	11	11	11	11	11	11	11

Table 4. Number of observations traps for each combination of fishing year and season for the analysis of trap sampling undertaken by de Lestang (2002).

		Summer (Nov-Jan)	Autumn (Feb-Apr)	Winter (May-July)	Spring (Aug-Oct)
Peel	1995/96	32	96	80	32
	1996/97	64	96	64	32
	1997/98	64	0	0	0
Cut-Harvey	1995/96	16	32	48	48
	1996/97	32	48	32	16
	1997/98	32	0	0	0
Deep-Harvey	1995/96	16	32	48	16
	1996/97	32	48	32	0
	1997/98	32	0	0	0

9.4 Appendix D – ANOVA Tables from commercial catch monitoring analyses from current fishing years.

Table 1. Immature females: Full model (R^2 = 0.215)

Source	df	Type III SS	MS	*F*	*p*
Fishing year	3	1.32	0.44	0.57	0.63
Month	11	10.43	0.95	1.23	0.27
Site	1	1.71	1.71	2.22	0.14
Fishing year X Month	33	32.66	0.99	1.29	0.14
Fishing year X Site	3	1.81	0.6	0.79	0.5
Month X Site	11	8.78	0.8	1.04	0.41
Residuals	269	207.11	0.77		

Table 2. Immature males: Full model (R^2 = 0.293)

Source	df	Type III SS	MS	*F*	*p*
Fishing year	3	1.66	0.55	1.24	0.3
Month	11	7.28	0.66	1.49	0.14
Site	1	0.08	0.08	0.18	0.67
Fishing year X Month	33	21.44	0.65	1.46	0.06
Fishing year X Site	3	5.44	1.81	4.07	<0.01
Month X Site	11	13.69	1.24	2.79	<0.01
Residuals	269	119.91	0.45		

Table 3. Sexually mature sub-legal females: Full model (R^2 = 0.585)

Source	df	Type III SS	MS	*F*	*p*
Fishing year	3	19.29	6.43	4.88	<0.01
Month	11	279.93	25.45	19.31	<0.01
Site	1	0.01	0.01	0.01	0.93
Fishing year X Month	33	143.53	4.35	3.3	<0.01
Fishing year X Site	3	0.74	0.25	0.19	0.91
Month X Site	11	56.63	5.15	3.91	<0.01
Residuals	269	354.44	1.32		

Table 4. Sexually mature sub-legal males: Full model (R^2 = 0.658)

Source	df	Type III SS	MS	*F*	*p*
Fishing year	3	138.6	46.2	38.14	<0.01
Month	11	191.3	17.39	14.36	<0.01
Site	1	7.96	7.96	6.57	0.01
Fishing year X Month	33	133.1	4.03	3.33	<0.01
Fishing year X Site	3	107.04	35.68	29.45	<0.01
Month X Site	11	50.23	4.57	3.77	<0.01
Residuals	269	325.84	1.21		

Table 5. Legal females: Full model (R^2 = 0.853)

Source	df	Type III SS	MS	*F*	*p*
Fishing year	3	102.26	34.09	39.62	<0.01
Month	11	1043.65	94.88	110.28	<0.01
Site	1	1.58	1.58	1.83	0.18
Fishing year X Month	33	127.69	3.87	4.5	<0.01
Fishing year X Site	3	12.89	4.3	4.99	<0.01
Month X Site	11	58.12	5.28	6.14	<0.01
Residuals	269	231.44	0.86		

Table 6. Legal males: Full model (R^2 = 0. 849)

Source	df	Type III SS	MS	*F*	*p*
Fishing year	3	79.83	26.61	26.73	<0.01
Month	11	1259.14	114.47	114.98	<0.01
Site	1	0.17	0.17	0.17	0.68
Fishing year X Month	33	121.03	3.67	3.68	<0.01
Fishing year X Site	3	19.14	6.38	6.41	<0.01
Month X Site	11	20.7	1.88	1.89	0.04
Residuals	269	267.8	1		

Table 7. Berried females: Full model (R^2 = 0.592)

Source	df	Type III SS	MS	*F*	*p*
Fishing year	3	1.21	0.4	1.01	0.39
Month	11	72.56	6.6	16.53	<0.01
Site	1	1.89	1.89	4.74	0.03
Fishing year X Month	33	38.84	1.18	2.95	<0.01
Fishing year X Site	3	4.05	1.35	3.39	0.02
Month X Site	11	37.49	3.41	8.54	<0.01
Residuals	269	107.35	0.4		

Table 8. Soft-shelled females: Full model (R^2 = 0.740)

Source	df	Type III SS	MS	*F*	*p*
Fishing year	3	13.08	4.36	8.14	<0.01
Month	11	176.74	16.07	29.99	<0.01
Site	1	0.19	0.19	0.35	0.55
Fishing year X Month	33	203.32	6.16	11.5	<0.01
Fishing year X Site	3	5.74	1.91	3.57	0.01
Month X Site	11	11.13	1.01	1.89	0.04
Residuals	269	144.12	0.54		

Table 9. Soft-shelled males: Full model (R^2 = 0.736)

Source	df	Type III SS	MS	*F*	*p*
Fishing year	3	77.14	25.71	29.56	<0.01
Month	11	179.14	16.29	18.72	<0.01
Site	1	18.74	18.74	21.55	<0.01
Fishing year X Month	33	286.32	8.68	9.98	<0.01
Fishing year X Site	3	26.87	8.96	10.3	<0.01
Month X Site	11	63.29	5.75	6.61	<0.01
Residuals	269	233.97	0.87		

9.5 Appendix E – ANOVA Tables from commercial catch monitoring analyses from historical and current fishing years.

Table 1. Immature females: Full model (R^2 = 0.072)

Source	df	Type III SS	MS	*F*	*p*
Fishing year	5	4.19	0.84	1.16	0.33
Season	3	1.07	0.36	0.5	0.69
Site	1	0.71	0.71	0.99	0.32
Fishing year X Season	15	10.48	0.7	0.97	0.49
Fishing year X Site	5	1.86	0.37	0.52	0.76
Season X Site	3	0.57	0.19	0.27	0.85
Residuals	338	243.41	0.72		

Table 2. Immature males: Full model (R^2 = 0.248)

Source	df	Type III SS	MS	*F*	*p*
Fishing year	5	3.71	0.74	1.75	0.12
Season	3	7.93	2.64	6.23	<0.01
Site	1	2.84	2.84	6.71	0.01
Fishing year X Season	15	13.86	0.92	2.18	<0.01
Fishing year X Site	5	6.98	1.4	3.29	<0.01
Season X Site	3	11.92	3.97	9.37	<0.01
Residuals	338	143.34	0.42		

Table 3. Sexually mature sub-legal females: Full model (R^2 = 0.32)

Source	df	Type III SS	MS	*F*	*p*
Fishing year	5	27.75	5.55	2.59	0.03
Season	3	170.59	56.86	26.5	<0.01
Site	1	0.1	0.1	0.04	0.83
Fishing year X Season	15	113.89	7.59	3.54	<0.01
Fishing year X Site	5	5.36	1.07	0.5	0.78
Season X Site	3	23.5	7.83	3.65	0.01
Residuals	338	725.35	2.15		

Table 4. Sexually mature sub-legal males: Full model (R^2 = 0.472)

Source	df	Type III SS	MS	*F*	*p*
Fishing year	5	180	36	18.04	<0.01
Season	3	55.45	18.48	9.26	<0.01
Site	1	71	71	35.57	<0.01
Fishing year X Season	15	91.7	6.11	3.06	<0.01
Fishing year X Site	5	190.18	38.04	19.06	<0.01
Season X Site	3	14.52	4.84	2.43	0.07
Residuals	338	674.61	2		

Table 5. Legal females: Full model (R^2 = 0.563)

Source	**df**	**Type III SS**	**MS**	***F***	***p***
Fishing year	5	96.02	19.2	8.54	<0.01
Season	3	778.46	259.49	115.35	<0.01
Site	1	0.03	0.03	0.01	0.91
Fishing year X Season	15	71.06	4.74	2.11	<0.01
Fishing year X Site	5	16.28	3.26	1.45	0.21
Season X Site	3	19.39	6.46	2.87	0.04
Residuals	338	760.37	2.25		

Table 6. Legal males: Full model (R^2 = 0. 47)

Source	**df**	**Type III SS**	**MS**	***F***	***p***
Fishing year	5	118.36	23.67	8.78	<0.01
Season	3	570.56	190.19	70.57	<0.01
Site	1	0.11	0.11	0.04	0.84
Fishing year X Season	15	100.19	6.68	2.48	<0.01
Fishing year X Site	5	14.91	2.98	1.11	0.36
Season X Site	3	4.17	1.39	0.52	0.67
Residuals	338	910.97	2.7		

Table 7. Berried females: Full model (R^2 = 0.185)

Source	**df**	**Type III SS**	**MS**	***F***	***p***
Fishing year	5	1.01	0.2	0.31	0.91
Season	3	16.99	5.66	8.66	<0.01
Site	1	0.09	0.09	0.14	0.71
Fishing year X Season	15	16.16	1.08	1.65	0.06
Fishing year X Site	5	7.61	1.52	2.32	0.04
Season X Site	3	8.31	2.77	4.23	<0.01
Residuals	338	221.13	0.65		

Table 8. Soft-shelled females: Full model (R^2 = 0.294)

Source	**df**	**Type III SS**	**MS**	***F***	***p***
Fishing year	5	14.63	2.93	2.49	0.03
Season	3	33.23	11.08	9.42	<0.01
Site	1	2.05	2.05	1.74	0.19
Fishing year X Season	15	76.89	5.13	4.36	<0.01
Fishing year X Site	5	32.06	6.41	5.45	<0.01
Season X Site	3	6.88	2.29	1.95	0.12
Residuals	338	397.39	1.18		

Table 9. Soft-shelled males: Full model (R^2 = 0.309)

Source	df	Type III SS	MS	*F*	*p*
Fishing year	5	63.14	12.63	7.03	<0.01
Season	3	49.23	16.41	9.13	<0.01
Site	1	9.99	9.99	5.56	0.02
Fishing year X Season	15	86.3	5.75	3.2	<0.01
Fishing year X Site	5	53.81	10.76	5.99	<0.01
Season X Site	3	9.03	3.01	1.68	0.17
Residuals	338	607.38	1.8		

9.6 Appendix F – ANOVA Tables from fishery-independent research survey analyses

Table 1. Immature males: Full model (R^2 = 0.45)

Source	df	Type III SS	MS	*F*	*p*
Fishing year	2	0.08	0.04	0.39	0.67
Month	11	22.12	2.01	20.40	<0.01
Site	4	18.21	4.55	46.20	<0.01
Fishing year X Month	22	7.71	0.35	3.56	<0.01
Fishing year X Site	8	3.16	0.40	4.01	<0.01
Month X Site	44	23.53	0.53	5.43	<0.01
Residuals	835	82.29	0.1		

Table 2. Immature females: Full model (R^2 = 0.37)

Source	df	Type III SS	MS	*F*	*p*
Fishing year	2	0.24	0.12	2.98	0.05
Month	11	6.37	0.58	14.14	<0.01
Site	4	4.14	1.03	25.27	<0.01
Fishing year X Month	22	1.84	0.08	2.04	<0.01
Fishing year X Site	8	1.16	0.14	3.53	<0.01
Month X Site	44	8.18	0.19	4.54	<0.01
Residuals	835	34.18	0.04		

Table 3. Sexually mature sub-legal males: Full model (R^2 = 0.65)

Source	df	Type III SS	MS	*F*	*p*
Fishing year	2	1.45	0.73	0.64	0.53
Month	11	124.33	11.30	9.91	<0.01
Site	4	1357.86	339.47	297.51	<0.01
Fishing year X Month	22	65.59	2.98	2.61	<0.01
Fishing year X Site	8	37.30	4.66	4.09	<0.01
Month X Site	44	172.76	3.93	3.44	<0.01
Residuals	835	952.76	1.14		

Table 4. Sexually mature sub-legal females: Full model ($R^2 = 0.39$)

Source	df	Type III SS	MS	*F*	*p*
Fishing year	2	6.89	3.44	3.54	0.03
Month	11	53.52	4.87	4.99	<0.01
Site	4	308.34	77.08	79.13	<0.01
Fishing year X Month	22	42.26	1.92	1.97	<0.01
Fishing year X Site	8	18.73	2.34	2.40	<0.01
Month X Site	44	81.97	1.86	1.91	<0.01
Residuals	835	813.37	0.97		

Table 5. Legal males: Full model ($R^2 = 0.63$)

Source	df	Type III SS	MS	*F*	*p*
Fishing year	2	38.58	19.29	43.41	<0.01
Month	11	246.00	22.36	50.33	<0.01
Site	4	237.53	59.38	133.63	<0.01
Fishing year X Month	22	17.68	0.80	1.81	0.01
Fishing year X Site	8	13.78	1.72	3.88	<0.01
Month X Site	44	133.09	3.02	6.81	<0.01
Residuals	835	371.04	0.44		

Table 6. Legal females: Full model ($R^2 = 0.36$)

Source	df	Type III SS	MS	*F*	*p*
Fishing year	2	20.71	10.35	14.98	<0.01
Month	11	118.72	10.79	15.62	<0.01
Site	4	54.10	13.52	19.57	<0.01
Fishing year X Month	22	43.51	1.98	2.86	<0.01
Fishing year X Site	8	3.54	0.44	0.64	0.74
Month X Site	44	75.74	1.72	2.49	<0.01
Residuals	835	577.04	0.69		

Table 7. Berried females: Full model ($R^2 = 0.34$)

Source	df	Type III SS	MS	*F*	*p*
Fishing year	2	2.52	1.26	8.79	<0.01
Month	11	16.52	1.50	10.46	<0.01
Site	4	8.48	2.12	14.76	<0.01
Fishing year X Month	22	6.02	0.27	1.91	0.01
Fishing year X Site	8	3.76	0.47	3.27	<0.01
Month X Site	44	16.05	0.36	2.54	<0.01
Residuals	835	119.92	0.14		

9.7 Appendix G – ANOVA Tables from fishery-independent research survey analyses from historical and current fishing years

Table 1. Immature males: Full model (R^2 = 0.40)

Source	df	Type III SS	MS	*F*	*p*
Fishing year	4	15.42	3.85	14.26	<0.01
Season	3	15.71	5.24	19.37	<0.01
Site	2	2.27	1.13	4.19	0.02
Fishing year X Season	12	20.53	1.71	6.33	<0.01
Fishing year X Site	8	3.98	0.50	1.84	0.07
Season X Site	6	1.23	0.20	0.76	0.60
Fish. year X Season X Site	24	8.23	0.34	1.27	0.18
Residuals	540	145.96	0.27		

Table 2. Immature females: Full model (R^2 = 0.35)

Source	df	Type III SS	MS	*F*	*p*
Fishing year	4	6.61	1.65	12.71	<0.01
Season	3	4.99	1.66	12.79	<0.01
Site	2	0.65	0.33	2.51	0.08
Fishing year X Season	12	8.82	0.74	5.65	<0.01
Fishing year X Site	8	1.96	0.25	1.89	0.06
Season X Site	6	0.82	0.14	1.05	0.39
Fish. year X Season X Site	24	3.49	0.15	1.12	0.32
Residuals	540	70.23	0.13		

Table 3. Sexually mature sub-legal males: Full model (R^2 = 0.56)

Source	df	Type III SS	MS	*F*	*p*
Fishing year	4	113.51	28.38	43.51	<0.01
Season	3	46.42	15.47	23.72	<0.01
Site	2	5.71	2.86	4.38	<0.01
Fishing year X Season	12	133.27	11.11	17.03	<0.01
Fishing year X Site	8	28.62	3.58	5.48	<0.01
Season X Site	6	23.41	3.90	5.98	<0.01
Fish. year X Season X Site	24	39.18	1.63	2.50	<0.01
Residuals	540	352.19	0.65		

Table 4. Sexually mature sub-legal females: Full model (R^2 = 0.35)

Source	df	Type III SS	MS	*F*	*p*
Fishing year	4	23.52	5.88	11.94	<0.01
Season	3	19.38	6.46	13.11	<0.01
Site	2	21.28	10.64	21.59	<0.01
Fishing year X Season	12	12.40	1.03	2.10	0.02
Fishing year X Site	8	4.56	0.57	1.16	0.32
Season X Site	6	5.84	0.97	1.97	0.07
Fish. year X Season X Site	24	15.26	0.64	1.29	0.16
Residuals	540	266.07	0.49		

Table 5. Legal males: Full model (R^2 = 0.51)

Source	df	Type III SS	MS	*F*	*p*
Fishing year	4	34.69	8.67	15.31	<0.01
Season	3	138.80	46.27	81.70	<0.01
Site	2	1.43	0.71	1.26	0.28
Fishing year X Season	12	14.17	1.18	2.09	0.02
Fishing year X Site	8	5.49	0.69	1.21	0.29
Season X Site	6	4.80	0.80	1.41	0.21
Fish. year X Season X Site	24	21.53	0.90	1.58	0.04
Residuals	540	305.81	0.57		

Table 6. Legal females: Full model (R^2 = 0.38)

Source	df	Type III SS	MS	*F*	*p*
Fishing year	4	8.83	2.21	5.58	<0.01
Season	3	43.01	14.34	36.21	<0.01
Site	2	6.28	3.14	7.93	<0.01
Fishing year X Season	12	16.63	1.39	3.50	<0.01
Fishing year X Site	8	4.48	0.56	1.41	0.19
Season X Site	6	5.52	0.92	2.33	0.03
Fish. year X Season X Site	24	9.77	0.41	1.03	0.43
Residuals	540	213.78	0.40		

9.8 Appendix H – Reprint of the comments provided by Dr Wayne Sumpton on the review of Blue Swimmer Crab research in Southern West Australia

The scope of this review was to provide feedback on material presented in a number of draft fisheries reports and a one-day workshop convened to review blue swimmer crab (*Portunus pelagicus*) (BSC) research in Cockburn Sound, Peel-Harvey Estuary and elsewhere (e.g. Swan River, Warnbro Sound). This review, and its level of detail, is not intended to provide a comprehensive assessment of all aspects of these reports and the discussions from the workshop. My comments are limited to those issues that were immediately obvious from reviewing the reports without any reanalysis or detailed examination of all aspects presented.

I have reviewed each of the three components of the research separately (e.g. Cockburn Sound Fishery, Peel-Harvey Fishery, Peel-Harvey recreational survey) and have concentrated most effort on the Cockburn Sound Fishery as this was the one that had most information and was the focus of most discussion at the workshop. It was also the fishery that, prior to the workshop, I was advised was the focus of the review.

The terms of reference originally asked for comments regarding the Cockburn Sound Fishery under a prescribed set of headings. I have chosen to address comments under those headings but point out that many of the comments I have made under the "weaknesses" headings are more issues for consideration rather than inherent weaknesses in either the design, data or analyses. The assessment of the recreational surveys in particular was limited to my views of material presented at the workshop and the limited analyses and data presented in the draft Peel-Harvey report. This report was obviously a very early draft and I acknowledge that a more detailed assessment of the design and more detailed analyses of the data and results that were not available in the early draft report may indeed identify issues that were not immediately obvious from the material I have reviewed.

Peel-Harvey Crab Research

In contrast to the Cockburn Sound Fishery report there was not as much detail provided in the preliminary Peel-Harvey report and so I have limited my comments to a series of dot points that the researchers might want to consider in their ongoing review of the research in this system.

- The fact that this fishery has not suffered recruitment failure under current management measures does not ensure that it will not suffer failure (such as occurred in CS) in the future, however there are significant differences between the two systems which indicate lower risk (e.g. movement of females outside the estuary to spawn).
- Data sources in this fishery are limited to those obtained from pots, both in a fisheries-dependent and fishery-independent context. I would advise a reassessment of the placing of the research pots and, in particular, the positioning of the pots outside the Dawesville Channel as these pots have not caught well and have provided little useful data.
- I was unable to understand fully the value of the beach seine data presented during the workshop and am thus unable to comment fully on its use in the context of understanding this fishery. I make the point that the fact that this sampling method is essentially limited to shallow shoreline areas limits its value in understanding the dynamics of a species that is distributed widely throughout the system. Seining will only be useful if it is adequately sampling the juvenile habitat.
- It may be possible to explore sampling outside the estuary using trawls or other non-potting methods.
- The collation of bottom type and hydrodynamic data would assist in determining whether habitat is suitable both for crabs and for other sampling methods such as trawling.
- Too few data have so far been collected to assess fully the recruitment index based on the catch of juveniles in modified pots. While catch rates in pots may not be a representative sample of the population in some circumstances, the fact that fishers in many similar fisheries have been able to successfully predict the success of future catches based on the bycatch of smaller undersized crabs that they see in their pots suggests that this method may be useful. I thus recommend that this method of predicting future relative abundance be continued until there are enough data to review whether it is a reasonable predictor.

- It would be beneficial to understand the temporal pattern of fishing in this estuary given the strong seasonal nature of the catch compositions with respect to sex ratio. Figure 10 of the report does show fishing effort concentrated towards the two openings to the system.

Peel-Harvey Recreational Surveys

As noted in the preamble to this review, comments on the recreational surveys do not reflect an extensive analysis of the reports or in depth probe of methods. They merely reflect first impressions after discussions provided in the workshop and review of very early drafts of reports.

The vast majority of the catch in the Peel-Harvey system is taken by the recreational sector (in contrast to Cockburn Sound) so there is a more pressing need for accurate estimates of recreational catch and effort in this system. If recreational surveys are to be conducted infrequently, it may be important to have an alternative independent means of monitoring and assessing the status of this fishery. Obviously this is an important budgetary question as the costs and benefits of different monitoring methods need to be compared.

The fact that the Peel-Harvey surveys attempt to obtain estimates of recreational catch from, what appears to be, most of the fishing platforms is to be applauded as this is rarely done in these types of surveys due to logistic constraints. The studies do confirm that some of these platforms are only a minor component of the overall recreational catch with the majority of the catch and effort being from boat and scoop net fishers. Given the low contribution of some of these platforms to the total catch, it may be possible to restrict the sample frame by removing some of these platforms from the sampling. Houseboats in particular seems to contribute little to the overall catch and effort and cost saving could possibly be made by restricting the sample frame. These comments are of course predicated on an understanding that fishing from this platform is likely to continue to contribute little to the total catch and effort in the future.

I have read the methods sections for each of the three surveys undertaken and while I have not checked equations or calculations, I note that techniques appear to have followed protocols used throughout Australia and elsewhere. These techniques are accepted practises worldwide and, if applied with care and diligence in a well designed sampling program, should provide acceptable levels of accuracy and precision in estimated catch and effort parameters.

I note that the researchers have extensively reviewed these methods internally and have also sought the advice of external experts in developing their analytical techniques. I am aware that the methods used in an earlier survey were recently reviewed by an external consultant and the researchers have attempted to incorporate reviewer comments in the design and analysis of the most recent survey.

It was clear that some of the analytical techniques and stratification methods had little impact on the precision of the estimated parameters but there were specific analyses where the magnitude of the estimated parameters differed quite significantly among the various parameter calculation methods. I understand that one of the reasons these analyses were undertaken was to determine the influence that each method had on the point estimate and its variance, and thus bracket uncertainty. I am not in a position to provide specific advice to resolve which of the analytical methods (or combination of methods) would be preferable as this would involve access to data and information than were not at my disposal. The fact that there were differences in the survey design (particularly related to temporal scope from some fishing platforms) between the two surveys means that, wherever possible, comparative analyses should be constrained to the same periods. It is clear that methods have been improved in the latter survey as a result of careful review of the earlier survey and, as such, later estimates are likely to be more accurate and precise (which is generally noticeable in the figures).

Overall, the levels of precision of estimated parameters are within acceptable limits expected in these types of surveys. The exception to this is the scoop netting release data (Figure 10) where uncertainty is quite high and the different analytical techniques provide very different parameter estimate trends across the two surveys. This is also the data set where the different analytical methods have the greatest impact on the magnitude of the estimates. I am not in a position to offer reasons for these discrepancies, but note that data and analyses used to generate this figure, in particular, need closer examination.

While I did not closely review the Voluntary Fisheries Liaison Officer (VLFO) report I am very aware of the structure and nature of these types of data and would advise caution in using them to infer catch rate trends. It is often tempting to use these data to back up trends that are apparent from other experimentally-controlled data sources such as stratified random surveys but I would advise caution in doing this as the lack of understanding about how and why these data are often collected can lead to biases and other problems. I do support the conclusions of this report, which note that data such as these may be useful in cases where there is some control over when and where the data are collected.

The catch from private homes along canals is an area that appears to be important as it is one which, as the report highlights, may be expanding. The two different analytical techniques underpinning the catch estimates from this fishing platform result in a four fold difference in estimated parameters. This is clearly an area that requires careful consideration as the assumptions of the first scenario, where non-diary participants were assumed not to have fished, is probably flawed. It is important to know whether diary participants are a random representative sample of fishers from this platform.

There are currently only two point estimates of recreational catch for this fishery, and the fact that the later survey estimate was lower than the first does not necessarily imply an overall declining trend in recreational catch or effort between the two periods. The result that recreational effort was lower in this system after nine years is an interesting and somewhat surprising result given comments about expanding recreational fishing pressure that were made during the workshop. Tighter bag limit restrictions imposed during the period between the two surveys was hypothesised as a reason for this decline but I have trouble accepting this given my observations of recreational fisher effort (in terms of time fishing) in other fisheries, which is often fairly independent of catch. Nevertheless, I acknowledge that scientists in WA are in a better position to assess this as there are often regional differences in fisher behaviour. I just make the point that, from my experience, it appears unusual.

Dr Wayne Sumpton
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5 October 2010