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GOVERNMENT OF WESTERN AUSTRALIA

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Blue Swimmer Crab (*Portunus armatus*) Resource in the West Coast Bioregion, Western Australia

Part 1: Peel-Harvey Estuary, Cockburn Sound and Swan-Canning Estuary

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List of Abbreviations

CAES	Catch and Effort Statistic
CS	Cockburn Sound
CSCMF	Cockburn Sound Crab Managed Fishery
CW	Carapace Width
DoF	Department of Fisheries (Western Australia)
DPIRD	Department of Primary Industries and Regional Development (Western Australia)
EBFM	Ecosystem-Based Fisheries Management
ESD	Ecologically Sustainable Development
FRMA	Fish Resources Management Act
MSC	Marine Stewardship Council
PHE	Peel-Harvey Estuary
RAP	Research Angler Program
RFBL	Recreational Fishing from Boat Licence
RFIF	Recreational Fishing Initiatives Fund
SAFS	Status of Australian Fish Stocks
SCE	Swan-Canning Estuary
WA	Western Australia
WCB	West Coast Bioregion
WCEMF	West Coast Estuarine Managed Fishery

Executive Summary

Blue swimmer crabs (*Portunus armatus*) are found along the entire coastline of Western Australia in a range of estuarine, inshore and continental shelf areas (<50 m). In the West Coast Bioregion (WCB), crab fisheries are centred in estuaries and coastal embayments from Geographe Bay to the Swan River. Commercial fisheries include the Cockburn Sound Crab Managed Fishery (CSCMF), the Warnbro Sound Crab Managed Fishery, the Swan-Canning Estuary (SCE) Crab Fishery (Area 1 of the West Coast Estuarine Managed Fishery (WCEMF)), Peel-Harvey Crab Fishery (Area 2 of the WCEMF), Hardy Inlet (Area 3 of the WCEMF) and the Mandurah to Bunbury Developing Crab Fishery (Area 1, Comet Bay and Area 2, Mandurah-Bunbury).

In line with the current harvest strategy for the south west crab resource, this Resource Assessment Report focuses on the key WCB fisheries for which comprehensive stock assessments are undertaken annually — Peel-Harvey Estuary (PHE), Swan-Canning Estuary and Cockburn Sound (CS). The Peel-Harvey Estuary fishery, which has been certified as sustainable against the highly regarded Marine Stewardship Council (MSC) Standard for Sustainable Fishing since 2016, currently contributes more than 90% of the total WCB blue swimmer crab commercial catch.

Crabbing is a very popular recreational fishing activity, with blue swimmer crabs being one of the most important recreationally fished invertebrate species in the State. The recreational sector primarily targets blue swimmer crabs in the Swan-Canning Estuary, Peel-Harvey Estuary, Leschenault Estuary and Geographe Bay, although recreational fishing occurs throughout most estuarine and nearshore areas of the WCB.

The commercial sector targets blue swimmer crabs using baited hourglass traps, with the exception of the Swan-Canning Estuary Crab Fishery where crabs are targeted by set (gill) nets. The recreational sector targets blue swimmer crabs using scoop nets, drop nets or by hand (snorkelling/diving). Management arrangements for the commercial and recreational fisheries include a minimum size limit, protection of breeding females, and seasonal closures with effort controls for the commercial fishery. Total annual commercial catch of blue swimmer crabs for the WCB was ~92 t in 2019. Total boat-based recreational catch of blue swimmer crabs in the WCB for 2017/18 was estimated to be 54 t (Ryan *et al*., 2019).

A recent review of the south-west blue swimmer crab resource (WCB; Swan-Canning Estuary to Geographe Bay) aimed to improve the level of protection to the breeding stock (mated pre-spawn females), resilience of the resource and the efficiency and consistency of management arrangements across the resource. Management options were outlined in *Fisheries Management Paper 288 - Protecting breeding stock levels of the blue swimmer crab resource in the south west* (DPIRD, 2018) and involved stakeholder and public consultation. Revised management measures were implemented in late 2019 and are detailed in this report.

Harvest Strategy, Monitoring and Assessment

Harvest strategy, monitoring and assessment activities for the WCB crab resource focus on assessing stock sustainability based on commercial catch rates, juvenile recruitment, breeding stock status, and how the environment may influence these stocks. Harvest strategies with explicit control rules have been developed for all crab fisheries with the Peel-Harvey Crab Fishery (commercial and recreational sectors) achieving full MSC certification in 2016. As part of the harvest strategies for these fisheries, there are several ongoing programs to monitor commercial catch (and effort), the size and sex composition of harvested crabs, recruitment strength and breeding stock levels.

Assessment of all commercial crab fisheries in the WCB use fishery-dependent commercial monitoring surveys to determine catch composition including of discarded catch and bycatch, as well as fishery-independent trawl surveys of recruitment and breeding stock to calculate long-term annual juvenile and egg production indices. These indices are the key components of some harvest strategies. This information has been applied in a breeding stock-recruit-environment (temperature, chlorophyll-*a*) relationship, as well as seasonal growth analyses, to provide a greater understanding of stock dynamics in CS. Length-weight relationships and reproductive biology (size at maturity and fecundity estimates) in all fisheries are being re-examined to explore the extent to which these biological aspects have changed over time. These analyses have been used to provide greater understanding of the factors contributing to two recent declines and subsequent closures in CS. Effects of environmental variables on commercial catch rates are also being examined as blue swimmer crab fisheries are highly influenced by changes in the environment.

A fishery-independent recruitment index for the Peel-Harvey Estuary Crab Fishery is being developed using trawl survey data collected since 2016. This index will form a potential future biological indicator in the harvest strategy of this fishery, which is currently based on fishery-dependent estimates of standardised commercial catch rate. Fishery independent trap survey data is used to generate a November pre-recruit and legal crab abundance index (year t) - catch prediction (t+1) model to provide greater certainty of stock status for fishers and managers. The stock in the Peel-Harvey Estuary is considered to be linked to those in Comet Bay, Mandurah-Bunbury and Warnbro Sound, due to the movement of crabs into and out of the estuary. Environmental effects of rainfall and temperature on catch rates are also being examined, acknowledging the role that the environment plays in this shallow water fishery.

Fishery-independent recruitment and breeding stock surveys for the Swan-Canning Estuary Crab Fishery commenced in 2013. A recreational fisher logbook program was also implemented to provide temporal and spatial estimates of recreational catch rate and catch composition.

Status of Stocks

Cockburn Sound

The harvest strategy for the CS crab fishery uses a juvenile abundance index and an egg production index as the primary performance indicators for the stock. These are compared to reference levels, which for the juvenile index corresponded with historical periods of decline where recruitment was considered unacceptable, and for the egg production index were based on the stock-recruitment relationship. A weight of evidence approach is used for the stock assessment where these indices are taken into account with commercial catch rates, spatial distribution, size structure and the proportion of mature and berried females.

Juvenile index: In 2019, the juvenile index improved slightly to 0.04 juveniles/100 m^2, but remains well below the harvest strategy limit of 0.4 juveniles/100 m^2 trawled. This indicates the abundance of crab recruits remains at unacceptable levels in CS

Egg Production index: The egg production index has shown a steady decline in 2017, 2018 and 2019, with levels well below the limit reference level of 12 $\times 10^6$ eggs/traplift, based on the stock recruitment relationship outlined in the harvest strategy. This indicates that crab spawning stock remains at unacceptable levels in CS.

Commercial Monitoring (leased vessel in closure period): The decline in mean monthly legal trap catch rates in 2018 and 2019 is evidence of continuing low abundance of legal-sized crabs and supports fishery-independent juvenile and breeding stock indices.

Recruitment and breeding stock therefore remains at unacceptable levels in the CSCMF in 2019, and a recommendation has been made to extend the closure of the fishery to commercial and recreational fishing for the 2020/21 season.

Reasons for the stock decline being investigated include combined effects of reduced levels of primary productivity within CS, changes in water temperature, increased predation and the negative effects of density-dependent growth which appears to have had an effect on the proportion of berried females. The decline in abundance is believed to be substantially attributable to environmental changes, rather than fishing, and the stock is currently classified as **Environmentally Limited**.

Peel-Harvey Estuary

The commercial catch and effort from the Peel-Harvey Estuary for the 2018/19 season was 66.5 t from 59,472 traplifts, a decrease of 30 t from 2017/18. Recreational catch estimates for the Peel-Harvey Estuary account for the majority of the total boat-based recreational catch in the WCB of 54 t in 2017–18 (Ryan *et al*., 2019).

The harvest strategy for the Peel-Harvey Crab Fishery (DPIRD 2020) uses the standardised annual commercial catch rate (kg/traplift) as the primary performance indicator for the stock, which is compared to reference levels calculated from the catch rates observed during a reference period of relative stability when the fishery was considered to have been operating sustainably (2000/01 and 2016/17 inclusive). Since the complete gear conversion from nets to traps in 2000/01, annual commercial catch rates have fluctuated (0.7–1.4 kg/traplift), but have generally remained above 1 kg/traplift. The standardised commercial catch rate of 0.9 kg/traplift for the 2018/19 fishing season was above the harvest strategy threshold of 0.7 kg/traplift. A weight-of-evidence approach was used for the stock assessment, with information from fishery-independent surveys, commercial monitoring and environmental data also taken into account. On the basis of this evidence, the crab stock in the Peel Harvey Estuary is classified as **Sustainable.**

Swan-Canning Estuary Crab Fishery

The harvest strategy for the Swan-Canning Estuary Crab Fishery (Area 1 of the West Coast Estuarine Fishery) uses standardised commercial annual (December to November) catch rate (kg 100 m net^{-1}) as the primary performance indicator for the stock, which is compared to reference levels calculated from the catch rates observed during a reference period of relative stability when the fishery was considered to have been operating sustainably (2007/08 and 2016/17 inclusive). The Swan-Canning Estuary is an important recreational fishery and represents an important component of the total boat-based recreational catch in the WCB of 54 t in 2017–18, (Ryan *et al*., 2019).

Annual catches in the Swan-Canning Estuary Crab Fishery between 2010 and 2017 ranged from 1 to 10 t, largely reflecting the amount of fishing effort. The catch rate has been maintained above the harvest strategy threshold of 6.2 kg 100 m net^{-1}, indicating the stock is currently being fished at sustainable levels. A weight-of-evidence approach was used for the stock assessment, with information from fishery-independent surveys, commercial monitoring and environmental data also taken into account. On the basis of this evidence, the crab stock in the Swan-Canning Estuary is classified as **Sustainable.**

1. Scope

This document provides a description and assessment of the South-West Blue Swimmer Crab Resource and all the fishing activities (*i.e.* fisheries / fishing sectors) affecting this resource in the West Coast Bioregion (WCB) of Western Australia (WA). The report is focused on the single species that comprises this resource, the Blue Swimmer Crab (*Portunus armatus*), which inhabits the inshore and estuarine waters throughout the bioregion. This species is primarily captured by trapping and gill netting by the commercial sector, as well as scooping and drop netting by the recreational sector. In line with the current harvest strategy for the resource (DPIRD 2020), this report is focused on the key fisheries for which comprehensive stock assessments are undertaken annually — Peel-Harvey Estuary (PHE), Swan-Canning Estuary (SCE) and Cockburn Sound. Information on other fisheries in the WCB are outlined in a separate Resource Assessment Report.

This report contains information relevant to the assessment of the resource against the Marine Stewardship Council (MSC) Principles and Criteria for Sustainable Fishing and for other reporting requirements, *e.g.* Status of Australian Fish Stocks (SAFS).

2. How the Department Operates

Fisheries management in WA has evolved over the last 40-50 years from a focus on managing catch of target species by commercial fishers to a fully integrated Ecosystem-Based Fisheries Management (EBFM) approach, which ensures that fishing impacts on the overall ecosystems are appropriately assessed and managed (Fletcher *et al.*, 2010). In line with the principles of Ecologically Sustainable Development (ESD; Fletcher 2002), the EBFM approach also recognises that the economic and social benefits of fishing to all users must be considered.

Implementation of EBFM involves a risk-based approach to monitoring and assessing the cumulative impacts on WA's aquatic resources from all fishing activities (commercial, recreational, customary), operating at a bioregional or ecosystem level. The level of risk to each resource is used as a key input to the Department of Primary Industries and Regional development (DPIRD) Risk Register, which is an integral component of the annual planning cycle for assigning activity priorities (research, management, compliance, education etc.) across each bioregion. A summary of the Department's risk-based planning annual cycle that is delivering EBFM in the long-term is provided in Figure 2.1.

To ensure that management is effective in achieving the relevant ecological, economic and social objectives, formal harvest strategies are being developed for each resource. These harvest strategies outline the performance indicators used to measure how well objectives are being met and set out control rules that specify the management actions to be taken in situations when objectives are not being met. The WA harvest strategy policy (DoF, 2015) has been designed to ensure that the harvest strategies cover the broader scope EBFM and thus considers not only fishing impacts of target species but also other retained species, bycatch, endangered, threatened and protected (ETP) species, habitats and other ecological components (Fletcher *et al.*, 2016).

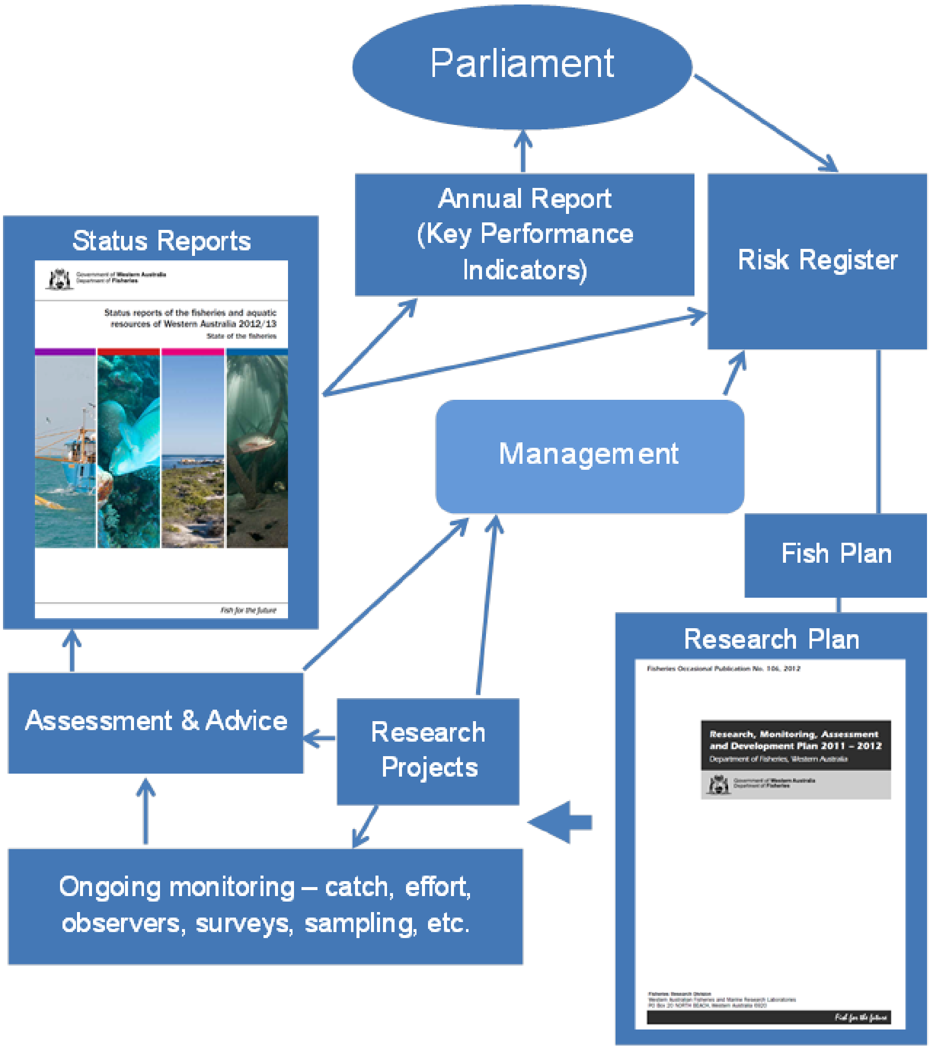


Figure 2.1. An outline of the risk-based planning cycle used for determining Departmental priorities and activities.

3. Aquatic Environment

The West Coast Bioregion (WCB), which extends from north of Kalbarri to just east of Augusta (Figure 3.1), is predominately a temperate marine zone, but receives substantial warm tropical water from the southward flowing Leeuwin Current. The bioregion encompasses Geraldton, Perth, Bunbury, Busselton and Dunsborough. Marine waters typically range from 15 to 24 °C. The region is micro-tidal (*c.* 0.6 m tidal range) and a temperate climate with warm summers and cool winters. Rainfall is protracted and occurs mostly during winter. Average annual rainfall in coastal areas ranges from less than 400 mm in the north (Kalbarri) to approximately 1000 mm in the south (Augusta).

The Leeuwin Current system, which runs along the entire west coast and can be up to several hundred km wide, varies considerably in strength from year in relation to El Nino or Southern Oscillation Events. The clear, warm, low nutrient waters of the Leeuwin Current are key to the growth and distribution of seagrasses and influence the spawning success of many fish and invertebrate species with pelagic egg and larval development stages.

Predominant habitats of the WCB include exposed sandy beaches and limestone reef systems. A long limestone reef system approximately 5 km offshore runs along much of the coast which dissipates wave energy to nearshore coastal areas. The region also contains two significant coastal embayments (Cockburn Sound and Geographae Bay) and several large estuarine systems (the Swan-Canning, Peel-Harvey, Leschenault and Blackwood-Hardy estuaries). Additionally, the bioregion encompasses a unique southern coral reef system at 29° latitude, the Abrolhos Islands.

Aquatic biota are predominately temperate, although substantial populations of certain tropical species occur at the Abrolhos Islands and various offshore islands and reef systems southwards. Following a marine heatwave in 2011, tropical species have also been recorded in nearshore and estuarine waters, although generally sporadically and in low numbers.

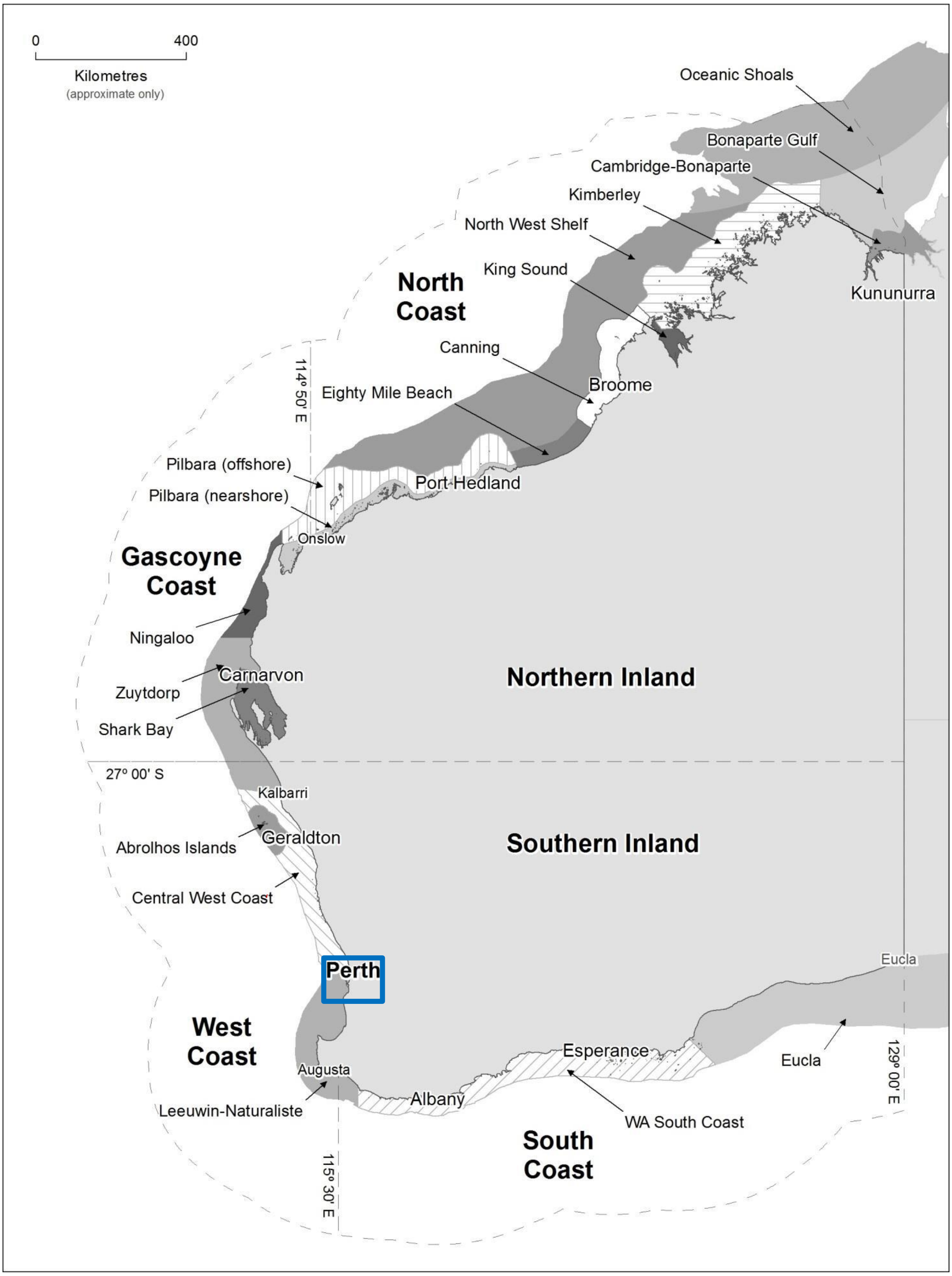


Figure 3.1. Bioregions of Western Australia and the locality of key blue swimmer crab stocks (Cockburn Sound, Swan-Canning Estuary, Peel-Harvey Estuary) within the WCB. Individual fishery locations are denoted in Figure 4.1.

4. Resource Description

The south-west blue swimmer crab (*P. armatus*) resource extends across the West Coast Bioregion (WCB) and occurs primarily in estuaries and coastal embayments from Geographe Bay in the south, to Swan River (Swan-Canning Estuary (SCE)) and Cockburn Sound (CS) in the north (Figure 4.1). The blue swimmer crab generally occurs in sand or seagrass habitats <50 m in depth.

Currently, commercial fisheries that target this resource include the Cockburn Sound Crab Managed Fishery, the Warnbro Sound Crab Managed Fishery, the Swan-Canning Estuary Crab Fishery (Area 1 of the West Coast Estuarine Managed Fishery (WCEMF)), Peel-Harvey Crab Fishery (Area 2 of the WCEMF), Hardy Inlet (Area 3 of the WCEMF) and the Mandurah to Bunbury Developing Crab Fishery (Area 1 - Comet Bay and Area 2 - Mandurah-Bunbury; Figure 4.1). Recreational fishing for crabs occurs throughout WCB, with effort particularly focused in estuaries. In line with the harvest strategy for the West Coast Crab Resource, this Resource Assessment Report focuses on the key fisheries for which comprehensive stock assessments are undertaken annually — Peel-Harvey Estuary (PHE), Swan-Canning Estuary and Cockburn Sound.

The blue swimmer crab is a short-lived, fast-growing species with a high fecundity and potential for wide dispersal and distribution of recruits. Taking into account these biological traits and the highly specific hourglass traps, a Productivity Susceptibility Analysis (PSA) indicates the risk and inherent vulnerability to commercial fishing is low. Nevertheless, collapses of *P. armatus* stocks have occurred in Cockburn Sound and Shark Bay in WA, and in other Australian stocks, where adverse environmental conditions combined with heavy fishing pressure have led to declines in recruitment and breeding stock. Therefore, the vulnerability of the stocks, particularly at the southern extreme of their distribution in south-west WA, is likely to be higher than once thought.

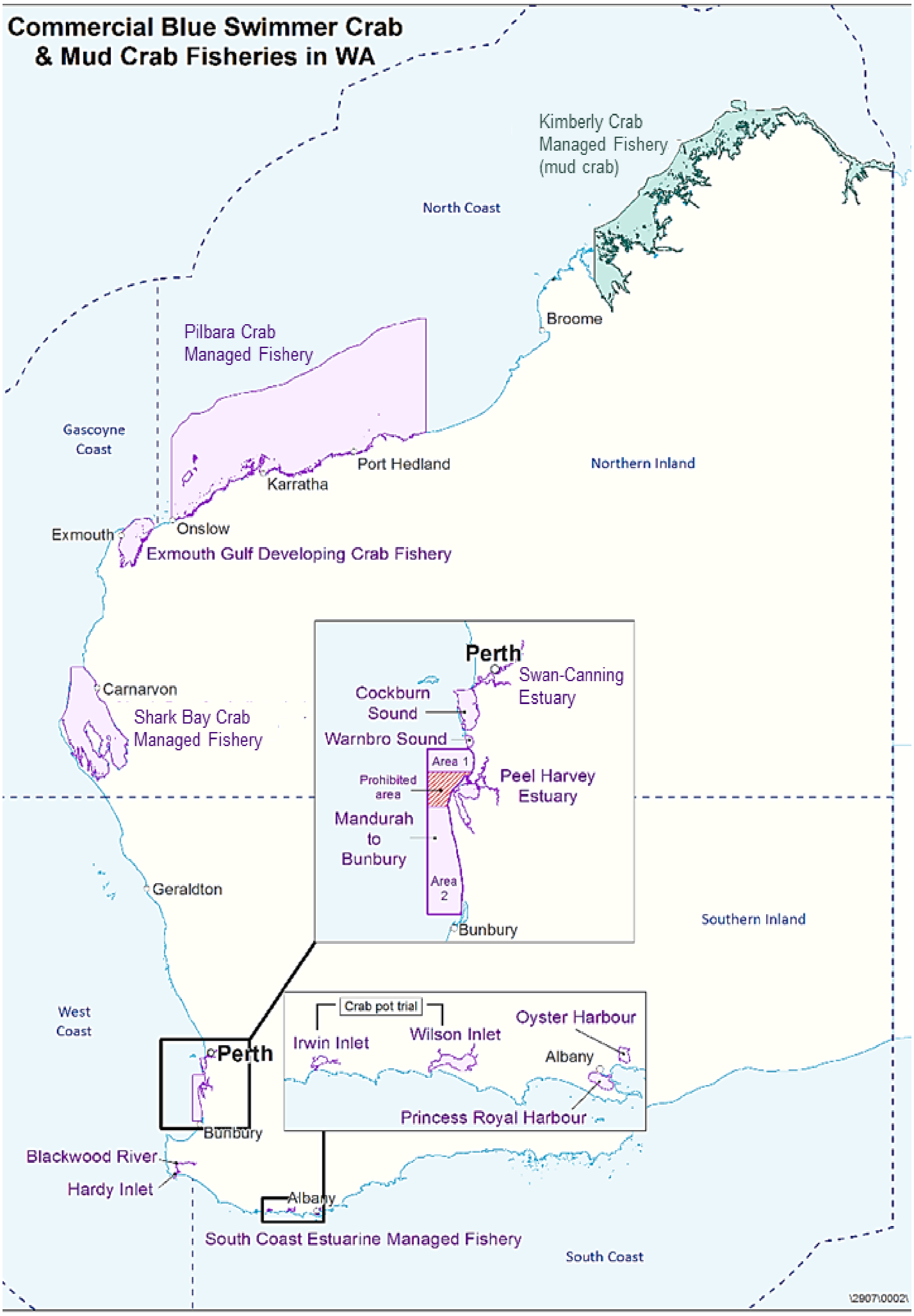


Figure 4.1. Location of commercially important blue swimmer crab and mud crab fisheries in Western Australia.

5. Species Description

Blue Swimmer Crab *(Portunus armatus)*

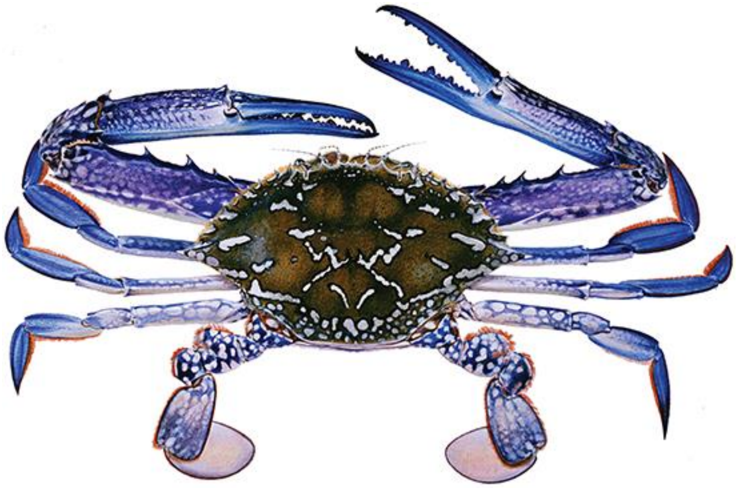


Figure 5.1. The blue swimmer crab, *Portunus armatus*. Illustration © R. Swainston (www.anima.net.au)

5.1 Taxonomy and Distribution

The blue swimmer crab, *Portunus armatus* (formerly *Portunus pelagicus* Linnaeus 1758; Lai *et al*., 2010), is a member of the family Portunidae (Figure 5.1). They are widely distributed throughout the Indo-West Pacific, ranging from east Africa to Japan, Tahiti and northern New Zealand (Kailola *et al*., 1993). In Australia, the species inhabits coastal waters from Esperance in WA, around the northern and eastern coastline to the south coast of New South Wales (Figure 5.2). The warmer waters of the South Australian gulfs also sustain blue swimmer crabs (Figure 5.2). Throughout this range, they inhabit inshore and continental shelf ecosystems, from the intertidal zone to at least 50 m in depth (Kangas, 2000), but are most common in sheltered coastal systems.

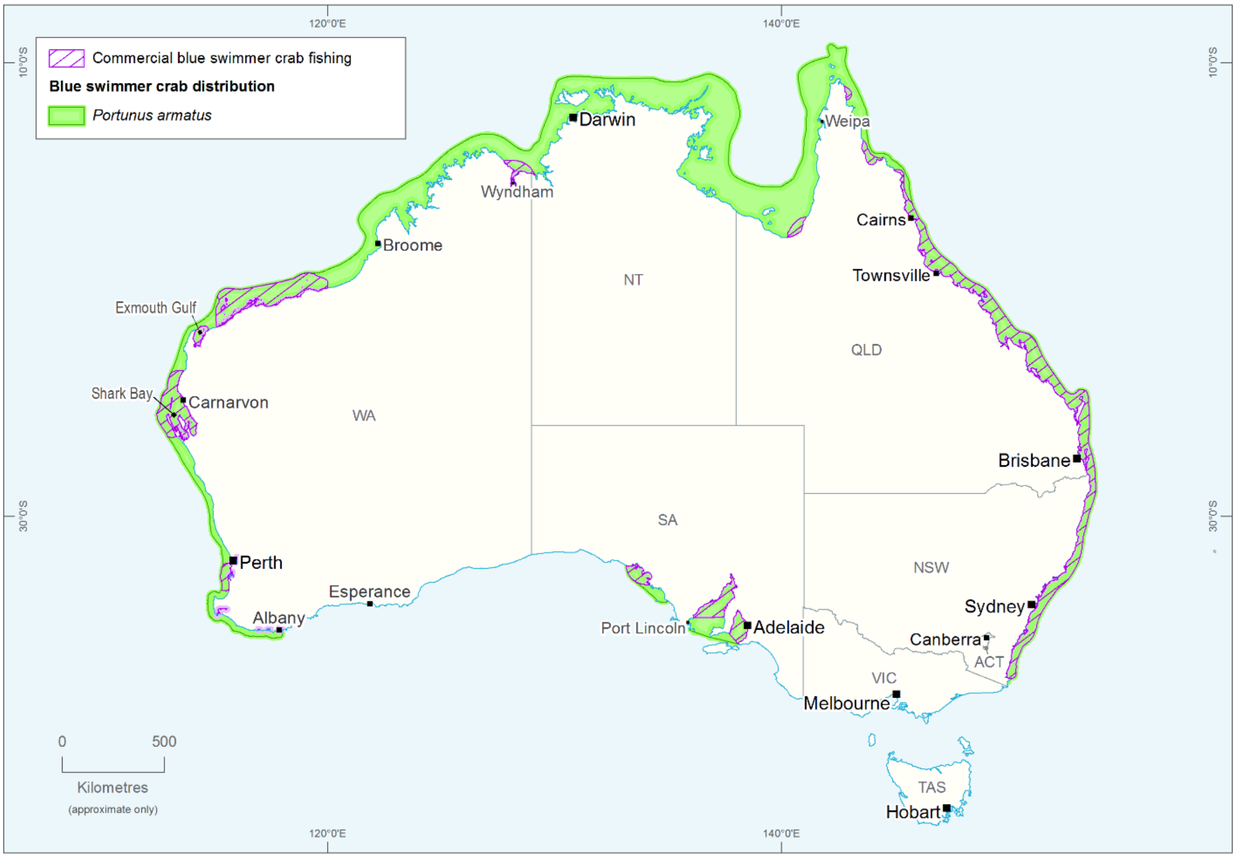


Figure 5.2. Geographic distribution (green) and commercial fishing areas (purple stripes) of the blue swimmer crab, *Portunus armatus* in Australian waters. Note: geographic distribution information is based on what areas are assumed permanent, self-recruiting populations and the presence of these populations depends on suitable habitat with this range. Commercial fishing data indicated on the maps is based on commercial fishing zones and/or commercial fishing data provided by FRDC (see Johnston *et al*., 2018).

5.2 Stock Structure

In WA, the blue swimmer crab is fished across all four marine bioregions, from the north coast to the south coast. Extensive genetic work for blue swimmer crabs in Australia was conducted in the 2000s, using six microsatellite loci (Chaplin *et al*., 2001; Sezmiş, 2004). Within WA, this research covered a vast portion of the coast, and included crabs from Exmouth Gulf, Shark Bay, Port Dennison, Cockburn Sound, Peel-Harvey Estuary (PHE) and Geographe Bay. Within the West Coast Bioregion (WCB), assemblages from Cockburn Sound, Peel-Harvey Estuary and Geographe Bay contained low levels of diversity compared to sites further north of Port Denison, Shark Bay and Exmouth Gulf (Sezmis, 2004). There is evidence of the assemblages in the south-west having undergone a genetic bottleneck followed by an expansion in population size with *P. armatus* assumed to have colonised the south-west from a site/s north of Dongara (Sezmis, 2004). This limited penetrance of genetic variation into the temperate waters of WA is presumably due to one or more barriers of gene flow, such as hydrological barriers to dispersal and discontinuities of sheltered coastal environments (Sezmis, 2004). Stocks in Peel-Harvey Estuary and Geographe Bay were found to be genetically homogenous, whereas crabs from Cockburn Sound were relatively distinct, despite the fact that Cockburn Sound is located only ~50 km and ~150 km north of the Peel-Harvey Estuary and Geographe Bay, respectively (Sezmis, 2004). Crabs from Port Denison were intermediate between stocks in the south and north, with statistically significant heterogeneity between crabs from Shark Bay and Exmouth Gulf, which are separated by ~ 400 km.

A later study by Chaplin and Sezmiş (2008) focused on the south-west of WA found that the genetic compositions of assemblages of *P. armatus* in Cockburn Sound, the Swan-Canning Estuary (SCE) and Warnbro Sound were homogeneous at the time of sampling (2007/2008) and that *P. armatus* is represented by either a single biological stock, or a series of overlapping stocks, in these water bodies. It was not possible to use the genetic data of this study to distinguish between these alternatives (single versus overlapping stocks) because only small amounts of gene flow are required to homogenise the genetic compositions of different sub-units of a species. Chaplin and Sezmiş (2008) concluded that the amount of gene exchange between the assemblages of *P. armatus* in Cockburn Sound and those in the Swan-Canning Estuary and Warnbro Sound is variable through time and generally insufficient to have a major impact on the abundance of this species in any of these areas. Blue swimmer crabs in these water bodies most likely represent a series of overlapping and essentially self-recruiting stocks, rather than a single stock, and are considered as such for management purposes. While it is assumed that gene flow occurs between Peel-Harvey Estuary and the inshore waters adjacent to the estuary (*i.e.* Comet Bay, Warnbro Sound and the waters from Mandurah to Bunbury), the level of this exchange has yet to be determined.

Due to the uncertainty in the level of connectivity in the south-west of WA, monitoring and assessments are currently undertaken at the management unit level and focused on the key fisheries, i.e. Cockburn Sound, Swan-Canning Estuary and Peel-Harvey Estuary.

5.3 Life History

A substantial amount of biological information has been collected for blue swimmer crab in sub-tropical waters along the west coast of Australia. While several studies have been undertaken in Shark Bay (Bellchambers and Smith, 2005; Harris *et al*., 2012; Harris *et al*., 2014; Chandrapavan *et al*., 2017; 2019), most of the research on blue swimmer crabs in WA has been carried out in the temperate waters of the Leschenault and Peel-Harvey Estuaries (Meagher, 1971; Potter *et al*., 1983, 1998; Potter and de Lestang, 2000; de Lestang, 2002; de Lestang *et al*., 2003a,b; Johnston *et al*., 2014, Harris *et al*., 2017), and marine embayments of Cockburn Sound (Penn, 1977; de Lestang *et al*., 2003a, 2010; Bellchambers *et al*., 2005a; Johnston *et al*., 2011a; 2011b), Koombana Bay (de Lestang *et al*., 2003a) and Geographe Bay (Sumner and Malseed, 2004; Bellchambers *et al*., 2006b; Harris *et al*., 2017).

On the basis of these studies, the sub-sections below provide an overview of the life history characteristics of *P. armatus* in south-western Australia, with a summary of the relevant biological parameters used in stock assessments provided in Table 5.1

Table 5.1. Summary of biological parameters for *Portunus armatus* from key commercial fisheries in the south-west of WA. Note that length (L) is carapace width (CW) quoted elsewhere in the report.

Parameter	Value(s)	Comments	Source(s)
Growth parameters: L_∞ (mm) K (year^{-1}) t_0 (years)	Cockburn Sound: 170 (166 – 174) 0.78 (0.74 – 0.83) 0 (fixed at 0)	$CW_t = CW_\infty \left\{1 - e^{-[K(t-t_0)+S(t)-S(t_0)]}\right\}$ where $S(t) = (CK/2\pi)\,sin(2\pi(t - t_c))$, and $S(t_0) = (CK/2\pi)\,sin(2\pi(t_0 - t_c))$ - Somers 1988 $C = 1$ (fixed value) $t_c = 0.13$	Marks *et al*., 2020
Maximum age (years)	2-3		de Lestang *et al*., 2003a,b,c; Marks *et al*., 2020
Maximum size (mm CW)	~220		
Natural mortality, M (year^{-1})	~ 1.4	Based on a longevity of 3 years	See below (5.3.4)
Length-weight parameters: a b	Females -10.0709, Males -10.4871 Females 3.1272, Males 3.2390	Ln(W)= a + b ln(CW) Females Ln(W) = -10.0709 + 3.1272 ln(CW) Males Ln(W) = -10.4871 + 3.2390 ln(CW)	Johnston and Yeoh, 2020
Reproduction	Gonochoristic, external fertilisation and highly fecund		
CW_{50} *2013-2019*	<u>Cockburn Sound</u> Females 79.1 (77.9-80.2) <u>Peel-Harvey Estuary</u> Females 92.2 (91.4-93.1) <u>Swan-Canning Estuary</u> Females 92.4 (90.5-94.3) <u>Leschenault Estuary</u> Females 98.6 (95.6-101.7) <u>Koombana Bay</u> Females 91.7 (89.7-93.7)	Size at maturity mm CW (95% confidence limits). Logistic regression of maturity at length data. Female estimates only. External morphology used to identify female maturity.	Johnston *et al*., *in prep.*

<table>
<tr><td>1995-2000</td><td colspan="2"><u>Geographe Bay</u>
Females 95.0 (92.8-97.2)
<u>Shark Bay</u>
Females 98.8 (97.3-100.2)
Females 110*
Males 105*
<u>Cockburn Sound</u>
Females 86.4
Males 86.2 - 88.4
<u>Peel-Harvey</u>
Females 97.5
Males 86.2-86.5
<u>Leschenault Estuary</u>
Females 98.0
Males 87.2 - 88.3
<u>Koombana Bay</u>
Females 86.9
Males 87.1 - 88.0
<u>Shark Bay</u>
Females 92.0
Males 96.0 – 97.0</td><td>Size at maturity mm CW (95% confidence limits). Logistic regression of maturity at length data. External morphology used to identify maturity of females. Gonad examination used for males. Each location was sampled for 2-3 years during this period (not all years).
Estimates have been recalculated in Johnston et al. (in prep.) for this earlier time period, but not presented here. Original published data only.</td><td>*Chandrapavan et al., 2017

de Lestang et al., 2003a</td></tr>
<tr><td>Fecundity</td><td colspan="2">200 000 – 2 million eggs per batch (at size 85-168 mm CW)
1-3 batches per season
Cockburn Sound: $Ln(BF)=2.84LN(CW) – 6.91$ $r^2=0.88$
Peel-Harvey Estuary:
$Ln(BF)=3.22Ln(CW) – 8.71$ $r^2=0.899$
Shark Bay:
$Ln (BF) = 3.11Ln(CW) – 8.37$ $r^2=0.91$</td><td>$$BF_{r,j} = \left[\left(\frac{N_{r,j}}{SW_{r,j}}\right) W_j\right] / 1000$$</td><td>Johnston et al., (in prep.)</td></tr>
<tr><td>Size-fecundity parameters

a

b</td><td>Cockburn Sound:

2.837 ± 0.227

6.909 ± 1.11</td><td>Peel-Harvey Estuary:

3.22 ± 0.241

8.71 ± 1.16</td><td>$$\ln(BF) = a(\ln CW) + b$$</td><td>Johnston et al., (in prep.)</td></tr>
<tr><td>Spawning frequency</td><td colspan="2">Spawn 1-3 times per season from a single mating event</td><td></td><td>de Lestang et al., 2003a</td></tr>
</table>

5.3.1 Life Cycle

The reproductive cycle of blue swimmer crab populations along the WA coast is strongly influenced by water temperature (de Lestang *et al*., 2010). The waters of the lower west coast are at the southern extreme of this species temperature tolerance and reproduction is restricted to the warmer months, with mating occurring in late-summer when females are soft-shelled (Figure 5.3, Kangas 2000; de Lestang *et al*., 2010). In comparison, the warmer, tropical waters of Shark Bay induce spawning all year round with most of the contribution from spawning coming from the winter period (July – September) (de Lestang *et al*., 2003a; Harris *et al*., 2012; Chandrapavan *et al*., 2017). See Section 5.3.5 for details on fertilisation and spawning.

Adults generally spawn in oceanic waters, either in the entrance channels of estuaries or in adjacent coastal waters. This migration is thought to be necessary for the survival of the larvae due to lowered oxygen levels and lack of suitable food in estuaries (Meagher, 1971). After spawning, eggs are planktonic for ~15 days (at 24°C), before hatching. The larval phase consists of four zoeal stages and one megalopal (Meagher, 1971) and is estimated to be between three and six weeks in duration although this is highly dependent on water temperature (Bryars, 1997; Kangas, 2000). Zoeae are distributed throughout the upper 20 m of the water column, dispersed by the prevailing tide- and wind-generated currents. It is estimated that larvae of *P. armatus* disperse over distances of less than 300 km (Chaplin *et al*., 2001; Sezmis, 2004). The shorter, megalopal phase maintains a surface distribution and is dispersed inshore by wind-generated surface currents before metamorphosing and settling as juvenile crabs in the inshore nursery habitats (Bryars, 1997). Blue swimmer crabs moult frequently during the juvenile phase and growth is rapid. Individuals attain commercial size at around 12 – 15 months of age. Blue swimmers are estimated to live to a maximum of around three years in natural conditions.

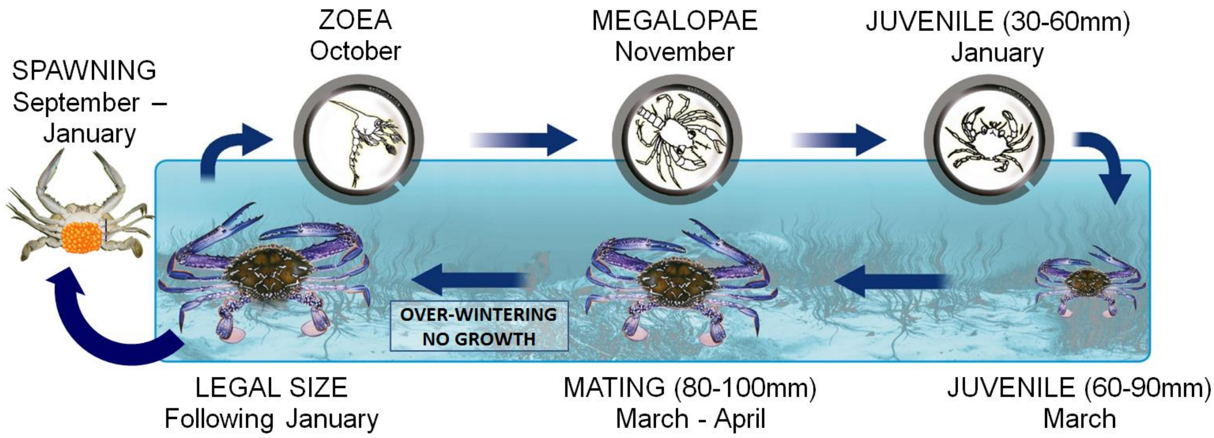


Figure 5.3. Life cycle of blue swimmer crab *Portunus armatus* in south-western Australia.

5.3.2 Habitats and Movements

Blue swimmer crabs live in a wide range of inshore and continental shelf habitats, including sandy, muddy, algal and seagrass habitats, from the intertidal zone to waters of at least 50 m in depth (Williams, 1982; Edgar, 1990). The majority of the commercially and recreationally-fished stocks along the WA coast are concentrated in the coastal embayments and estuaries between Nickol Bay (~ 21° S) in the north and Geographe Bay (~ 34° S) in the south-west. In an estuarine system such as the Peel-Harvey Estuary, *P. armatus* can be found in shallow waters < 0.5 m. Extensive stands of macroalgae and seagrass (including *Zostera*, *Ruppia* and *Halophila* spp.) exist in this estuary, supporting large populations of small invertebrates. In the nearshore embayment of Cockburn Sound, juvenile crabs are mostly found in seagrass habitats in the shallow waters of Mangles Bay, Jervois Bay and James Point. A study carried out in the nearshore coastal environment of Cliff Head, WA, identified five major habitats for *P. armatus* that formed successive bands running parallel to the shore to a distance of 50 m from the water's edge (Edgar 1990). These shallow water (<3) m habitats were classified as; debris (detached macrophtyes and sand), *Amphibolis*, *Halophila*, *Posidonia* and unvegetated habitat. Smaller crabs inhabited the shallowest band of debris, while larger individuals inhabited the deeper *Amphibolis* and un-vegetated habitats (Edgar, 1990). *P. armatus* characteristically move from intertidal and shallow subtidal sand flats into deeper water as they develop. Additionally, diurnal movement of crabs from debris and un-vegetated habitats in the day, to *Amphibolis* or *Posidonia* habitats at night were observed to be strongly associated with prey densities (Edgar 1990).

Blue swimmer crab movements are influenced by changes in temperature and salinity, with crabs more active (with higher susceptibility of capture) at higher temperatures during summer months (Potter and de Lestang, 2000). Movement of crabs from shallower to deeper waters occurs in late autumn to winter, coinciding with falling temperatures over this period (Kangas, 2000; Potter and de Lestang, 2000; Aguilar *et al*., 2005). In estuaries such as the PHE, movements of crabs are also influenced by the terrestrial inflow of fresh water following the onset of winter rains (Potter *et al*., 1998). Most crabs will migrate towards the mouth of estuaries between June and September, with some exiting into oceanic coastal waters (Johnston *et al*., 2014a). In particular, the movement of female crabs into oceanic waters to spawn may play an important role in the survival of first stage zoea due to increased levels of dissolved oxygen, higher salinity, improved planktonic food sources and increased opportunity for larval distribution (Smith, 1982; Meagher, 1971). Most sub-legal crabs (< 127 mm carapace width (CW)) will re-enter estuaries and rivers at the end of spring and throughout summer, with males re-entering between November and January and females between January and March (Johnston *et al.,* 2014a). Some legal (1+ class) crabs will remain outside of the estuary, or move to adjacent estuaries or embayments.

In contrast to the movements utilised by blue swimmer crabs in estuaries and rivers, the population in Cockburn Sound is self-recruiting with little immigration into, or emigration out of, the fishery from neighbouring bodies of water. Juveniles congregate in southern inshore waters around Mangles Bay, Jervois Bay and James Point, before moving into central deeper waters (Potter *et al*., 2001).

5.3.3 Age and Growth

While most blue swimmer crabs in the West Coast will have died through natural or fishing mortality by the time they are 18-20 months (Potter *et al*., 2001; de Lestang *et al*., 2003b), those that are not subjected to fishing pressure could be expected to live for 2-3 years (Marks *et al*., 2020) and reach a maximum size of 220 mm in some habitats.

Growth of blue swimmer crabs in the temperate south-west is comparable both between sexes, and between estuaries and embayments. A study by de Lestang *et al*. (2003b) found that the pattern and rate of growth in Cockburn Sound and Peel-Harvey Estuary markedly similar, with the CW of crabs at the end of their first year of life being virtually identical in each region. However, growth could vary markedly if there were large differences in the availability or quality of food. Growth is highly seasonal and influenced by temperature and salinity (Fisher, 1999; de Lestang *et al*., 2003b). de Lestang *et al*. (2003b) found that size of crabs in Cockburn Sound and the Peel-Harvey Estuary did not change significantly between late autumn (May) and mid-spring (October), suggesting growth is limited in winter months due to declines in water temperature.

Juvenile crabs are recruited into the estuaries and embayments over summer (November to March), with the patterns of growth during this first year relatively consistent. At approximately 10 months they reach a size of ~95 mm CW (late spring) and as growth continues over summer, they reach a legal size of ~130 mm CW by early autumn (~March at 15 months of age) (de Lestang *et al*., 2003b). The pubertal moult (and hence maturity) occurs at a size of 80 - 100 mm CW and coincides with copulation. The majority of 0+ females attain maturity and copulate in late autumn (de Lestang *et al*. 2003b), within their first 6-7 months of life. However, their pubertal moult may occur at 10–15 months of age if crabs recruit into the system from a late spawning event. Females retain sperm over the winter months until they spawn in the following spring. The retention of sperm is facilitated by the absence of moulting, and hence the restriction of growth, over winter (de Lestang *et al*., 2003b). After the pubertal moult, moulting changes from being temperature-dependent to being annual, thus it is assumed that adults moult just once a year.

For Cockburn Sound, a substantial time series of trawl data has been used to fit a seasonal growth curve based on the model from Somers (1988) (Marks *et al*., 2020). From these data, growth parameters L_∞, k, and t_0, and seasonal parameters C, and t_c have been estimated (Table 5.1).

Length-weight data has been collected and analysed from various fisheries in the south-west of WA (Johnston and Yeoh, 2020). Length-weight parameters can be found in Table 5.1. Male *P. armatus* were found to be significantly heavier than females for a given size, which supports a generic trend among portunid crabs (Olmi and Bishop, 1983; Thomas, 1984; Prasad *et al*., 1989; Josileen, 2011). This length-weight information is used for stock assessment (*e.g.* calculation of harvest weights from CW size data) and compliance statistics.

5.3.4 Natural Mortality

While no direct estimates of natural mortality (*M*) have been determined for *P. armatus*, *M* has been estimated indirectly for *P. pelagicus* using various empirical formulas in locations such as the Arabian Sea, the Persian Gulf, and in the waters surrounding Indonesia and Thailand, (Afzaal *et al*., 2016). While *M* values ranged considerably, the vast majority lay in the range of 1.2 - 1.6 y^{-1}. Where M was calculated separately for males and females, females consistently showed a lower natural mortality rate.

Natural mortality for both sexes of *P. armatus* in south-west WA has been estimated at ~1.4 y^{-1} (Table 5.2), determined using an assumed maximum age (t_{max}) for *P. armatus* in equations relating mortality of unfished/lightly fished stocks to maximum age (Hoenig, 1983; Quinn and Deriso, 1999; Hewitt and Hoenig, 2005). As length frequency data from relatively lightly fished crab populations in Cockburn Sound in the 1970s provide evidence that at least a few individuals survive into their third year of life (2+ cohort; de Lestang, 2002; de Lestang *et al*. 2003b), the assumed maximum age of *P. armatus* in south-west WA is 3 years.

Note that indirect estimates of natural mortality from empirical equations are highly uncertain. The methods chosen here, as used for many WA fish/invertebrate species (*e.g.* Smith *et al*., 2013, Norriss and Crisafulli, 2010), tend to yield conservative estimates of M (*i.e.* suggesting lower productivity). If used in assessments, these estimates are likely to lead to precautionary assessment advice.

Table 5.2. Comparison of several methods to estimate natural mortality, M, based on the assumed maximum age of three years for Portunus armatus.

Method	Equation	Estimated *M*	Description
1 Quinn and Deriso 1999	$M = -\ln(P)/t_{\max}$	1.40	Rule-of-thumb approach, where *P* is the proportion of animals in the stock that survive to age t_{max} (*P* set to 0.015 in this case).
2 Hoenig 1983	$M = e^{1.44-0.982\ln(t_{\max})}$	1.44	Linear regression model for fish, molluscs and cetaceans
3 Hewitt and Hoenig 2005	$M = \frac{4.22}{t_{\max}}$	1.41	Simplified and approximated version of method 2

5.3.5 Reproduction

Blue swimmer crabs are gonochoristic, meaning sexes are separate (no sex change). *P. armatus* exhibits sexual dimorphism, where adult males are deep royal blue in colour (particularly on the carapace claws and legs). Females are olive green or sandy brown in colour with stockier chelae.

The size at which blue swimmer crabs reach maturity tends to be inversely-related to water temperature (Fisher, 1999) and thus varies considerably between water bodies of the south-west coast and Shark Bay in the north (de Lestang *et al*., 2003a). In the south-west, females reach maturity and undergo a pubertal moult in late summer/autumn of their first year (6-10 months). During this pubertal moult, the abdominal flap changes from a triangular to oval shape and from being tightly to loosely-fixed to the cephalothorax (Figure 5.4; Fisher 1999; de Lestang *et al*., 2003a). Morphological changes during the pubertal moult are not as definitive in males (*e.g*. increased relative size of first cheliped) and cannot be used to determining maturity as accurately as those of females.

Figure 5.4. The ventral view of female P. armatus that are immature (left), immature pre-pubertal (centre) and mature (right), showing triangular abdominal flap and fusion of this flap to the sternal plates. Arrows show abdominal width measurement.

Male courtship is triggered by a sex pheromone released by the female (Meagher, 1971). Mature males moult up to 6 weeks before the females, and mating takes place while the female is in the soft-shell condition. If the female is pre-pubertal, she will moult to maturity and undergo her first mating during this process. Each male carries a female clasped beneath him for 4 to 10 days until she moults and mating occurs. The copulation process can take 6-8 hours after which the male will remain coupled with the female for 3-4 days until her shell begins to harden (Smith, 1982). Males can mate with multiple females during the season. In temperate waters, female crabs store the sperm in the spermatheca for several months during winter until ovarian maturation is complete and eggs are fertilised and spawned (Penn, 1977; Smith, 1982). In warmer waters, females retain the sperm for a shorter period and mating and spawning can occur all year round. Females receive enough sperm from a single mating to produce up to three batches of eggs over the spawning period. Fertilisation takes place externally when the female simultaneously extrudes unfertilised eggs from her ovaries and releases the sperm from her spermatheca (Smith, 1982; Kangas, 2000). Females with eggs attached under their abdominal flaps are known as ovigerous or “berried”. Eggs are bright yellow or orange when first extruded and change progressively to dark grey as they develop and use up the yolk. Incubation takes 8 to 18 days, depending upon water temperature (20 - 25 °C), and after spawning, the eggs hatch after ~15 days (at 24 °C, Kangas, 2000). Females produce between ~180,000 and 2 million eggs (Kumar *et al*., 2003, Johnson *et al*., 2010, Ikhwanuddin *et al*., 2012; Johnston *et al*., *in prep.*), with smaller crabs generally carrying fewer eggs. For details on larval behaviour/dispersal, see Section 5.3.1.

Reproductive studies of *P. armatus* in south-west WA by de Lestang *et al*., (2003a) reported size at maturity estimates for males and females for five water bodies (Table 5.1), and a size-fecundity relationship for Cockburn Sound. Male maturity was determined based on examinations of gonads, whether spermataphores and seminal fluid were present in the medial region of the vas deferentia, and on the relative size of the largest cheliped. More recent size at maturity estimates for females and fecundity-size relationships have been determined for several south-west WA fisheries including key recreational fisheries (Johnston *et al*., *in prep.*). Size at maturity estimates for Cockburn Sound are currently used to calculate an index of egg production (EPI) (refer to Section 9.3 Analyses and Assessments).

Males dominate the catch during summer in most south-west fisheries, (Johnston *et al*., 2011b, Johnston *et al*., 2014), as occurs in other commercial trap fisheries throughout Australia (Sumpton and Smith 1990; Xiao and Kumar 2004). This is likely to be attributed to aggressive behaviour of large males towards females over summer, a period which also coincides with female moulting and spawning cycles that deter them from entering the traps. The relative abundance of females in WA commercial trap catches typically starts increasing in late summer/early autumn (*i.e.* February and March). Females dominate commercial trap catches during late autumn and winter in the nearshore fisheries of Cockburn Sound, Warnbro Sound, Mandurah-Bunbury and Comet Bay. However, more females than males are caught in late autumn/early winter in the Peel-Harvey and Swan-Canning estuaries. The sex ratios in these estuaries then come close to parity in late winter and spring, presumably reflecting many female crabs leaving these estuaries to spawn in adjacent marine waters.

5.3.6 Factors Affecting Year Class Strength and Other Biological Parameters

Water temperature has been implicated as an important factor in the majority of the recruitment-environment relationships for marine fish and crustacean species and is often robust enough to persist over substantial time frames (Caputi *et al*., 1995; Uphoff, 1998). Water temperature may affect recruitment in a variety of ways. For example, elevated water temperatures typically have a positive effect on decapod recruitment by accelerating larval development and reducing the duration of the larval phase and larval mortality (Bryars and Havenhand 2006; Fisher, 2007). Elevated water temperatures prior to spawning may also directly affect the timing of larval release by controlling gonad development, mating and the timing of spawning (Rosenkranz *et al*., 2001). It may also influence the larval survival through changes to the abundances of larval foods and predators.

Spawning in subtropical Shark Bay mainly takes place in the winter period, when temperatures are at their lowest, whilst the reverse is true for temperate WA crab fisheries where spawning is restricted to spring and summer (de Lestang *et al*., 2003a). Presumably, there is an optimal temperature range for spawning in each fishery (see Johnston *et al., in prep.* for analysis of timing and duration of spawning in Cockburn Sound).

A stock-recruitment relationship was determined for the Cockburn Sound crab managed fishery (CSCMF), using annual commercial catch rate (as a proxy for egg production) and juvenile recruitment, where temperature was shown to be an important influence on spawning and recruitment success (de Lestang *et al.,* 2010; Johnston *et al.*, 2011a).

A more recent analysis of the stock-recruitment-environment relationship has been determined using egg production (based on commercial trap monitoring) and juvenile recruitment over a longer times series (since 2001). Briefly, a correlation exists between water temperature and recruitment success, with low temperatures being associated with below average recruitment.

There is also a weak positive correlation between chlorophyll a concentration (as a proxy for primary productivity) and recruitment success. The stock-recruitment-environment relationship explained ~52% of the variation in the data (n=16 years) with the effects of temperature and chlorophyll contributing 10% to the percent of variation explained. However, poor recruitment was observed irrespective of water temperature in years where egg production was below 12 x 10^6 eggs/traplift, indicating that there is a critical level of breeding stock required for recruitment success to occur. A revision of this relationship will occur in the near future, extending the time series and incorporating trawl data into the egg production index calculation. Further details of the stock-recruitment relationship are provided in Section 9.3.8.1.

The effects of climate change are likely to differ between blue swimmer crab fisheries in WA, based on the large latitudinal and longitudinal range of this species. Range extensions into south coast waters and retractions in northern waters are likely with warming temperatures, the extent of which will depend on the strength of the Leeuwin Current each year. Long-term climate change predictions indicate that rainfall will decrease over time, potentially increasing salinity and hyper-salinity in shallow estuarine environments. Such a rise in salinity may lead to increased mortality, or shift in the distribution of juvenile and adult crabs which have differing salinity tolerances. Temperature and salinity fluctuations and long-term trends therefore need to be considered in future stock assessments and fishery management.

5.3.7 Diet and Predators

The blue swimmer crab employs an opportunistic feeding behaviour, utilising different modes which helps account for the success of this species in different environments (Edgar, 1990). Studies by de Lestang *et al*. (2000) and Campbell (2017) in Cockburn Sound, Swan-Canning, Peel–Harvey and Leschenault estuaries in south-western Australia found the diet of blue swimmer crabs to be highly variable dependent on location, size and shell state, with crabs that have recently moulted ingesting a higher proportion of calcareous material, such as that from the small bivalve *Arthritica semen*. The diet of intermoult crabs tends to be more diverse with the three main diet categories being small bivalve molluscs, crustaceans such as gammarid amphipods and polychaetes. The blue swimmer crab does not, however, feed immediately prior to, or just after, moulting. As the shell hardens, feeding on organic material is greatest during the intermoult period (Williams, 1982).

On average, shelled molluscs, teleosts and crustaceans combined make up over 60% of volume of the diet of Portunids, with bivalves typically contributing significantly more than gastropods to the overall diet. Teleosts, while being the third most voluminous category, are eaten predominantly by larger crabs (Hsueh *et al*., 1992; de Lestang *et al*., 2000; Kunsook *et al*., 2014). Among the crustacean prey, brachyuran crabs, including conspecifics, represent the majority of the volume, with notable contributions made by penaeids, shrimp, hermit crabs and amphipods (Stoner and Buchanan, 1990; de Lestang *et al*., 2000).

As blue swimmer crabs feed on many of the small macro-invertebrates such as polychaete worms, small bivalves and crustaceans they are considered to occupy the trophic position of a second-order predator (PSA Level 2).

Studies on predation of blue swimmer crabs have yet to be undertaken in WA waters. However, it is presumed that the larval stage can be eaten by small fish when floating with the plankton, while in the post-larvae and juvenile stages they are preyed on by larger fish species such as the pink snapper, *Chrysophrys auratus*, and other crustaceans. Smith (unpublished) identified smooth stingray, *Dasyatis brevicaudata*, southern fiddler ray, *Trygonorhina fasciata guanerius*, and gummy shark, *Mustelus antarticus*, as known predators of adult blue swimmer crabs in South Australia.

5.3.8 Parasites and Diseases

Crabs are known to be infected by several parasites including *Sacculina granifera*, a parasitic barnacle that brings about a number of major changes in the host crab, including degeneration of the sex organs in both sexes and modification of the male crab to a more female form. Infestation is common in northern Australian waters, and is found regularly in commercial trap catches along the Pilbara coast (Bellchambers *et al*., 2005).

The parasite consists of two sections: an internal root system and an external sac, connected by a stalk attached to the underside of the crab's abdomen. The sac is a reproductive organ and occupies the space that is normally filled with developing eggs in a berried female. Infection usually results in castration for both sexes, however, infected hosts are still capable of mating and some females are still able to produce a clutch of eggs.

Chitinoclastic shell disease is an external bacterial infection found in crabs and other crustaceans that have been subjected to stress. Chitinoclastic bacteria (including *Vibrio* species, *Beneckea*, *Aeromonas* and *Pseudomonas*) produce an enzyme chitinase, which breaks down the chitinous exoskeleton (Kennedy and Cronin 2007). Although these bacteria are part of the normal flora of bacteria found on crustaceans, infection can occur through injury, moulting, environmental pollutants and other stressors. In October/November 2016, up to 60% of crabs sampled in the Leschenault Estuary and Koombana Bay were observed with chitinoclastic shell disease. Samples were assessed by Fish Health and no further outbreaks have been observed since this period.

5.4 Inherent Vulnerability

The blue swimmer crab is a highly fecund species with a short life span (Kangas, 2000) and is therefore generally considered to have a low inherent vulnerability to fishing. A 2014 risk assessment, which considered the productivity of blue swimmer crabs and its susceptibility to each of the fisheries targeting the overall stock of this species in south-west WA, determined the risk to the stock as low (see Section 9.3.6). However, as recruitment of this species can be significantly influenced by changes in environmental conditions (de Lestang *et al.*, 2010), blue swimmer crab catches can fluctuate significantly between years as a consequence of impacts on the stock that may not necessarily be related solely to fishing pressure.

Stock collapses have been experienced in the WA blue swimmer crab fisheries of Cockburn Sound and Shark Bay during the last decade. These collapses are considered to have been triggered by a number of factors including fishing pressure, exacerbated by adverse environmental conditions impacting on the spawning potential and subsequent recruitment of crab stocks subject to high levels of fishing pressure at the time (Caputi *et al*., 2015).

Like many other blue swimmer crab fisheries, management of the CSCMF relied primarily on controls on fishing effort and a minimum legal size set well above the size at sexual maturity to allow crabs to spawn at least once before entering the fishery as this was presumed to provide adequate protection to the breeding stock. However, a combination of biological, environmental and fishery-dependent factors contributed to a collapse in 2006 included: (1) vulnerability to environmental fluctuations as Cockburn Sound is at the southern extreme of this tropical species' temperature tolerance, (2) a life cycle contained within the confines of a relatively small marine embayment, (3) increased fishing pressure on mated pre-spawning females in winter following conversion from gill nets to traps, (4) four consecutive years of cooler water temperatures contributing to poor recruitment, and (5) continued high fishing pressure during years of low recruitment resulting in low breeding stock (Johnston *et al.*, 2011a). Consequently, the fishery was closed to both commercial and recreational fishing in December 2006 for three years to allow crab stocks to recover.

Following a slow recovery, the fishery was re-opened on 15 December 2009 with a reduced commercial and recreational fishing season (from 10 to 3.5 months), an increase in the minimum commercial size from 130 mm to 140 mm CW, and a 20% reduction in effort (800 to 640 traps). As fishery-independent and fishery-dependent surveys indicated that the stock continued to build, season length was increased to 6 months and minimum size dropped back to 130 mm CW, although the 20% trap reduction remained (Johnston *et al*., 2011a).

A review of the fishery in December 2013 again highlighted concerns with the Cockburn Sound crab stock, including a low level of recruitment and a decrease in the breeding stock and overall abundance of crabs. Consequently, the commercial and recreational fishery was again closed in 2014 (Johnston *et al*., 2015c). Reasons for the second stock decline being investigated include combined effects of reduced levels of primary productivity (using chlorophyll *a* as a proxy) impacting recruitment, variations in water temperature, increased predation of crabs by snapper, and density-dependent growth and changes in the proportion of berried females. As the fishery has been closed since 2014, the declines in abundance (and subsequent poor recovery of stocks) are believed to be substantially attributable to environmental changes rather than fishing.

6. Fishery Information

6.1 Fisheries/Sectors Capturing Resource

The south-west blue swimmer crab resource is targeted by commercial fishers using gill nets in the Swan-Canning Estuary (SCE) Crab Fishery and hourglass traps in Cockburn Sound and the Peel-Harvey Estuary (PHE). They have also been retained as by-product by the South-West Trawl Fishery since the early 1980s, although annual catches have generally been low (<3 tonnes) and the fishery closed in the mid 2000's. It is one of the most important recreationally fished species (Ryan *et al*., 2019) with recreational fishers primarily targeting crabs using drop nets, scoop nets, or by hand when snorkelling or diving.

A review of the south-west blue swimmer crab resource was initiated in late 2018 and included the release of *Fisheries Management Paper 288 - Protecting breeding stock levels of the blue swimmer crab resource in the south west* (DPIRD, 2018). The aim of the review was to improve the level of protection to the breeding stock, in particular mated pre-spawn females, and improve resilience of the resource and the efficiency and consistency of management arrangements across the resource. FMP 288 outlined a range of options to achieve this. Having considered public submissions and consulted with peak sector bodies, in August 2019 the Minister for Fisheries announced his decision to implement:

- an annual 3-month (1 September through 31 November) fishing closure (commercial and recreational) in all waters from the Swan-Canning estuary to just north of Geographe Bay,
- a reduced recreational bag limit of 5 crabs in the Swan and Canning Rivers;
- a maximum of 5 female crabs (as part of the 10 bag limit) for recreational fishers in Geographe Bay; and
- a process to buy back commercial fishing licences in the Cockburn Sound, Warnbro Sound and Mandurah to Bunbury Crab Fisheries prior to their permanent closure.

The Department is now implementing the Minister's decisions and also working with Recfishwest, WAFIC and the Southern Seafood Producer's Association to consider other potential changes to the management of the south-west blue swimmer crab resource.

The section(s) below provide more detailed information about the main fisheries /sectors that target the south-west crab resource.

6.1.1 Cockburn Sound Crab Managed Fishery

6.1.1.1 History of Development

Commercial crab fishing in Cockburn Sound started in the 1970s using gillnets, with catches steadily increasing from around 50 t (~120 days fished) to around 150 t by the late 1980's - early 1990's (~ 300 days fished) (Johnston *et al*., 2011a) (Figure 6.1). Few restrictions were placed on commercial fishing other than a prohibition on taking berried females and a minimum size limit (130 mm carapace width (CW); measured spine to spine across the carapace). Total annual net length, as a measure of effort, also increased significantly during this time from <60 km in the early 1980s to over 3,000 km in the early 1990s (**Figure 6.1**). The *Cockburn Sound (Crab) Fishery Management Plan* was introduced in 1995 and in 1994/95 the fishery was converted from gillnets to purpose-designed hourglass traps to reduce the impact on non-target species.

The fishery was managed through input controls that regulated fishing methods and gear specifications, seasonal and daily time restrictions, retainable species, minimum size limits and the number of licences. Due to their increased efficiency, the total number of traps has been reduced several times, from 1600 in 1998 to 800 in 2003/04 through catch share arrangements to increase the recreational sector's share of total catch (Melville-Smith *et al*., 1999). The nets were suited to fishing in summer, while traps could be effectively fished all year round.

At this time, the principal management tool to ensure adequate breeding stock levels involved minimum size limits set well above size at sexual maturity (de Lestang *et al*., 2003a). This allowed crabs to spawn at least once prior to entering the fishery, and was thought to provide adequate protection to breeding females under average recruitment. Commercial fishers operated from 1 December to 30 September, with a closed spawning season between 1 October and 30 November (introduced in 1999) to protect berried females. Prior to the closure of the fishery in December 2006, there were 12 license holders sharing a total allocation of 800 crab traps.

Historically, commercial catches in Cockburn Sound have fluctuated dramatically as a result of changes in commercial fishing practices and normal variations in recruitment strength (Bellchambers *et al*., 2006a). Commercial catches increased slowly from the late 1970's to around 160 t in 1992/93 with effort in net length increasing significantly during this time to ~ 3 million meters per year. Following conversion from gill nets to traps, catch increased markedly peaking at ~ 350 t by the late 1990's, with effort also increasing to ~ 300 000 traplifts (Figure 6.1). This significant increase in catch was primarily due to the increased efficiency of traps and the ability of fishers to fish during winter, which did not occur with gillnets. Catch and effort declined from 2000 due to very low crab abundance, resulting in the closure of the fishery in December 2006, with the last season prior to closure (2005/2006) reporting 49 t from 81 309 traplifts (Johnston *et al*., 2011a) (Figure 6.1). The fishery remained closed for three years, with slow recovery of recruitment and breeding stock levels.

When the Cockburn Sound crab managed fishery (CSCMF) was re-opened on 15 December 2009, the Department implemented a number of management changes, including a reduced season length from 10 months to 3.5 months (December 15 to March 31), 20% reduction in the number of traps (800 to 640 traps) and an increase in commercial size limit from 130 to 140 mm CW. A progressive easing of these management restrictions were implemented between 2009 and 2013 and details of these management changes have been outlined in Johnston *et al*., 2015c.

Following re-opening of the fishery, commercial catch, effort, catch per unit effort (CPUE), recruitment and breeding stock levels, were monitored closely. Catch increased to 62 t in 2012/13 but CPUE decreased to ~ 0.6 kg traplift which was well below the 1.0 kg/traplift consistently reported prior to the decline. These catch rates were similar to those immediately preceding closure, indicating that legal biomass was very low. The egg production index declined in 2012 and 2013 and the juvenile recruitment index also declined to below the limit in 2013 and 2014. Consequently, the fishery was closed to commercial fishing on 16 April 2014, followed by a recreational sector closure on 14 May 2014.

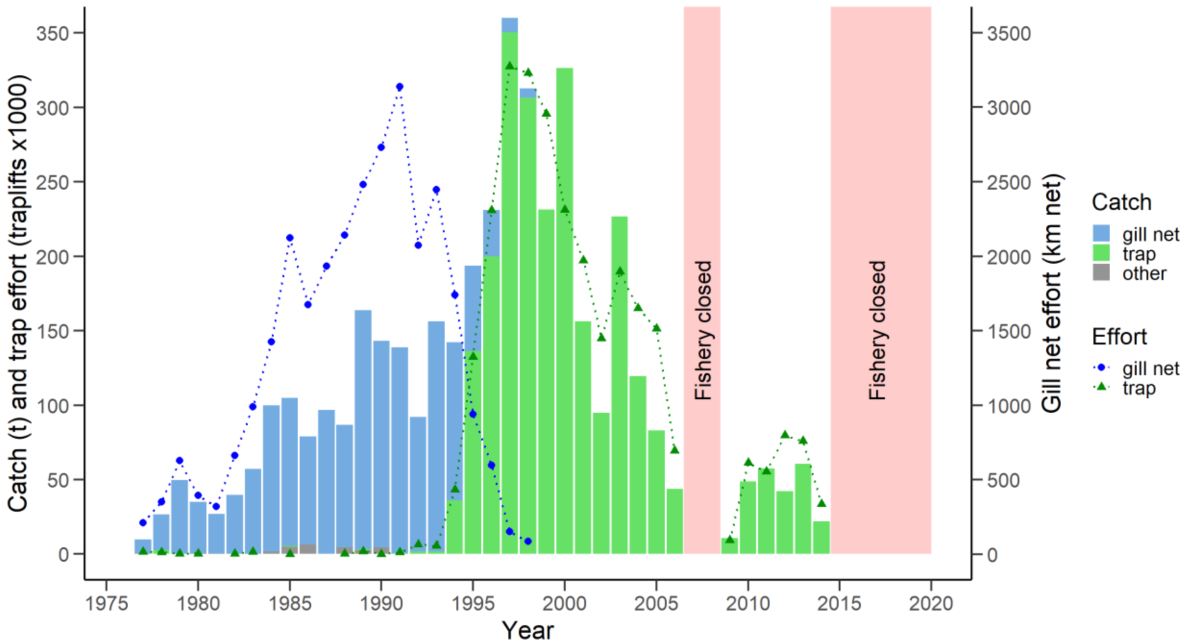


Figure 6.1. Annual commercial catch (tonnes) and effort for each fishing method in Cockburn Sound from 1976 to 2019. Gill net effort is measured by length of net set (km) and trap effort is measured in numbers of trap lifts. For clarity, effort from other methods (which had negligible catch) is not shown. A spawning closure from October 1 to November 1 was introduced in 1999. The fishery was first closed to fishing between 2006 and 2009 reopening under modified management and a second closure has been in place since April 2014.

6.1.1.2 Current Fishing Activities

Key attributes of the CSCMF are summarised in Table 6.1.

The CSCMF encompasses the waters of Cockburn Sound, from South Mole at Fremantle out to Stragglers Rocks, through Mewstone to Carnac Island and Garden Island, along the eastern shore of Garden Island, and back to John Point on the mainland (Figure 6.2). Three areas were permanently closed to fishing; the south-eastern side of Garden Island, Coogee Beach and South Beach.

The CSCMF is currently closed to all commercial fishing. Prior to the 2006 closure, the whole area of the fishery was fished between 1 December and 30 September and the majority of catch was sold locally. Recreational crabbing, however, is permitted north of a line between Woodman Point and Carnac Island (see Section 6.2 for details on the recreational sector).

Table 6.1. Summary of key attributes of the commercial Cockburn Sound Crab Managed Fishery. This fishery has been closed since 2014.

Attribute	
Fishing methods	Hourglass crab traps
Fishing capacity	800 traps reduced by 20% in 2009 to 640 traps
Number of licences	12 (across 5 operators; 3 of which were active in season prior to closure in 2014)
Number of vessels	3 active in season prior to closure
Size of vessels	8.5 – 12 m
Number of people employed	0 due to current closure
Value of fishery	$0 due to current closure

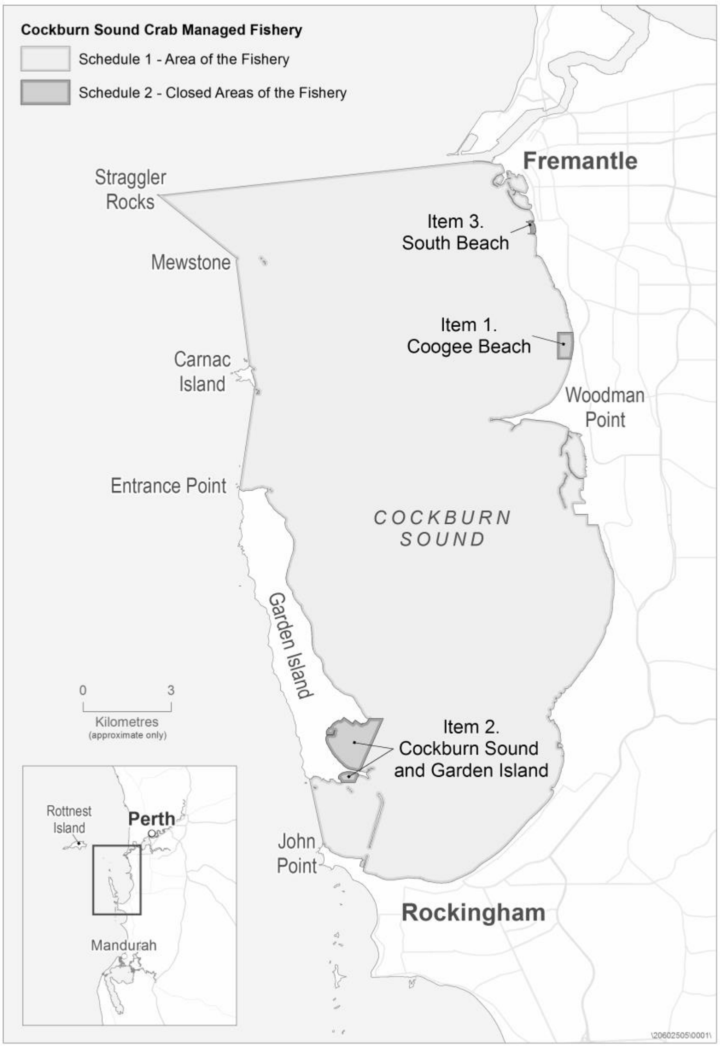


Figure 6.2. Boundaries of the Cockburn Sound Crab Managed Fishery and its closed areas.

6.1.1.3 Fishing Methods and Gear

Blue swimmer crabs in most south-west crab fisheries, including CSCMF, are captured by purpose-designed ‘hourglass’ crab traps. The traps used in CSCMF are collapsible, with a solid galvanised steel base ring for support and structure, and a buoyant pneumatic upper ring to set the trap (Figure 6.3). Traps must have a height of ≤ 45 cm and the diameter must be ≤ 116 cm. Traps typically have one, two or three pairs of opposing side entry funnels. Escape gaps and mesh size is not legislated, and all fishers use slightly different configurations. The largest mesh used is 89 mm (3.5 inches) and the smallest is 51 mm (two inches). Fishers typically did not use escape gaps. Traps were also commonly made of two different mesh sizes, with the smaller mesh usually on the bottom half of the trap and the larger mesh on top half. Traps are baited with filleted fish frames (such as pink snapper *Chrysophrys auratus* and emperors *Lethrinus spp.*) and set across long lines of up to 20 traps per line for a 24-hour period.

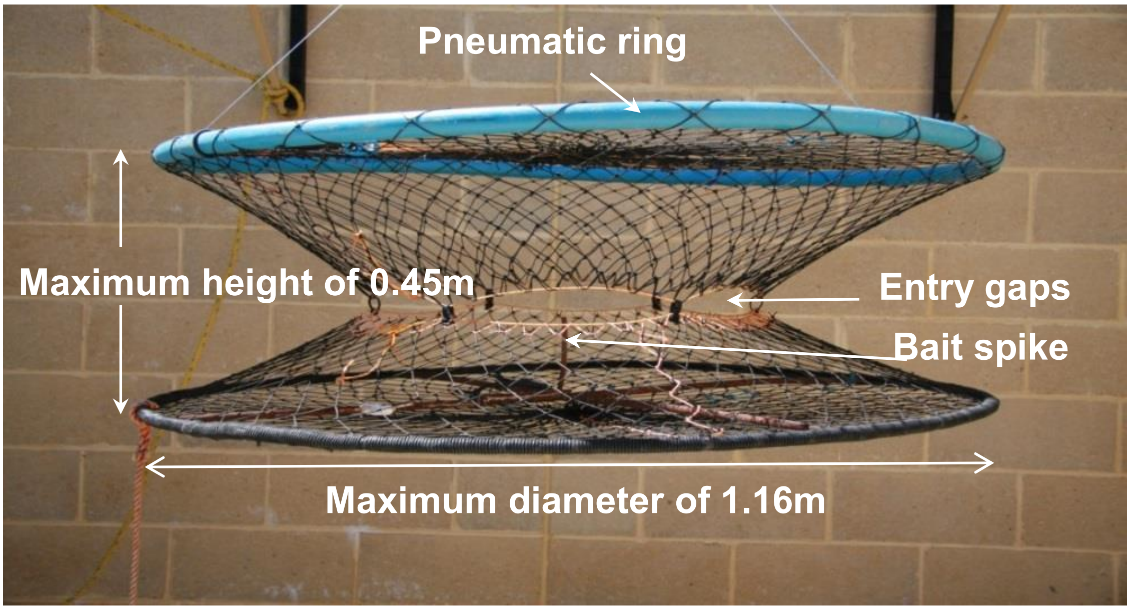


Figure 6.3. Commercial hourglass crab trap used in the Cockburn Sound Crab managed Fishery showing central bait spike, entry gaps, upper pneumatic ring and the maximum size restrictions.

6.1.1.4 Susceptibility

For the purposes of the Productivity Analysis (PSA, see Section 9.3.6), assemblages of blue swimmer crabs in Cockburn Sound and the Swan-Canning Estuary are considered one stock as they are genetically homogenous due to some migration of crabs and movement of larvae between these water bodies (Chaplin and Sezmis, 2008). They are likely to be overlapping stocks with genetic exchange variable between years.

The CSCMF covers an area of approximately 100 km^2.While most of this area is suitable habitat for the blue swimmer crab, commercial effort has historically concentrated in the area south of Woodman Point. Due to the broad spatial distribution of stock in relation to fishing effort, areal overlap (availability) is high, *i.e.* > 30%.

The purpose-designed baited hourglass traps used in the CSCMF are highly efficient at capturing blue swimmer crabs due to their placement in benthic habitats where crabs are located, and increased likelihood of crabs to encounter and enter the traps due to attraction to the bait. Traps are selective for both adult and juvenile crabs, however, the mesh size used allows the majority of undersize crabs and bycatch to escape. Vertical overlap (encounterability) is therefore considered moderate.

Blue swimmer crabs can survive out of water for up to several hours provided their gills remain moist. As regulations stipulate that commercial fishers must return berried and undersize crabs to the water within 5 minutes of being landed, post-release mortality rates of non-retained catch with and without exposure to ice-slurries are low (Bellchambers *et al*., 2005; Broadhurst and Millar, 2018; Leland, 2014; Uhlmann *et al*., 2009).

6.1.2 Peel-Harvey Crab Estuary Fishery

6.1.2.1 History of Development

The commercial finfish net fishery in the Peel-Harvey Estuary (Area 2 of the West Coast Estuarine Managed Fishery (WCEMF)) was first established in the mid-1800s (Bradby, 1997). This fishery is one of the oldest in Australia, with up to 150 fishers historically operating in family-based fishing units to supply fresh fish to the local Perth and Fremantle markets (Mandurah Licenced Fishermen’s Association [MLFA] 2008).

Although abundant within the estuary, blue swimmer crabs were typically ignored by the commercial fishers during the early 1900s as there was no market for them (Bradby, 1997). Sea mullet *Mugil cephalus* and yelloweye mull*et aldrichetta forsteri*, targeted to supply the bait market, dominated finfish catches. The commercial crab fishery did not begin until the late-1950s, with fishers originally targeting blue swimmer crabs using the same gillnets that were used to capture finfish species. During the late-1970s and early-1980s, several changes to the management of the commercial PHE fishery were announced. The number of licence holders authorised to operate in the fishery was determined, and restrictions on the length and mesh size of the fishing nets used by fishers were introduced. Fishery data from the PHE during the late-1970s and early 1980s showed an overall decline in fishing effort following changes to management. Since 1996, a Voluntary Fishery Adjustment Scheme (VFAS) resulted in the number of commercial crab licensees in the fishery being reduced to 10.

In the mid-1990s, the Department allowed fishers in the estuary to trial crab traps (instead of gillnets) to target blue swimmer crabs. Trapping proved to be less time-consuming, produced less bycatch, reduced the environmental impact from fishing gear and improved catch quality (Bellchambers *et al*., 2005). Fishers were also able to extend their winter fishing season as traps were more effective in winter than gillnets. By 2000, the majority of the blue swimmer crab catch was landed using crab traps. Each operator currently uses 42 traps with commercial fishing prohibited on weekends from 0900 h (1 Nov-31 Mar) or 1000 h (1 Apr-31 Aug) on Saturday to 1330 h on Monday. Localised spatial closures encompass the Mandurah Entrance Channel, Dawesville Cut and rivers entering the Estuary. Additional management measures were implemented in August 2007 including a seasonal closure to both commercial and recreational fishers for September and October to protect spawning females.

The earliest records of commercial crab catches in the PHE are from the 1950s, with catches less than 1 t reported up to 1960. Catches were variable but rose steadily throughout the 1960s and 1970s (see Johnston *et al*., 2014 for detail). Substantive commercial fishing for blue swimmer crabs in the Peel-Harvey Estuary began in the 1980s, with fishers using gillnets primarily over the summer months. Annual catch and effort was highly variable, fluctuating from less than 2 t in 1982 to 65–67 t in 1987–88 (Figure 6.4). The gradual conversion from gillnets 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 and winter fishing. Since gear conversion, annual commercial catches have fluctuated between 47 t in 2003 and 107 t in 2013 (Figure 6.4). Recreational fishing is also extremely popular in the Peel-Harvey Estuary (see Section 6.2 for a description of the recreational sector).

A review of the south-west blue swimmer crab resource was initiated in late 2018 (FMP 288; described earlier in Section 6.1. A key management change affecting the Peel-Harvey Crab Fishery from this review is an annual 3-month closure (1 September through 31 November) which is an increase from 2 months previously (1 September – 31 September).

Separate to the Crab Review, a Voluntary Fisheries Adjustment Scheme (VFAS) is currently underway to reduce the number of commercial licenses in the Peel-Harvey Estuary[1] and re-allocate a component of the resource to recreational fishers and the ecosystem.

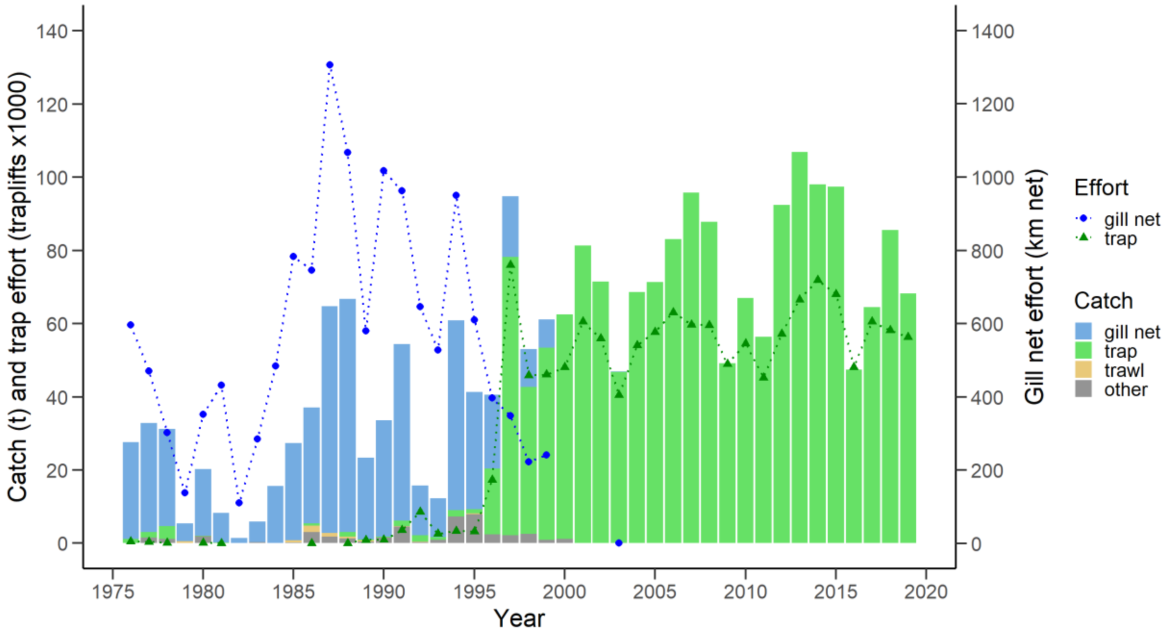


Figure 6.4. Annual commercial catch (tonnes) and effort for each fishing method in the Peel-Harvey Estuary from 1976 to 2019. Gill net effort is measured by length of net set (km) and trap effort is measured in numbers of trap lifts. For clarity, effort from trawling and other methods (which had negligible catch) is not shown.

[1] As of 1 January 2020, the number of commercial crab licences in the Peel-Harvey Estuary had been reduced from 10 to eight, each permitted to use 42 purpose-built hour-glass traps to target blue swimmer crabs.

6.1.2.2 Current Fishing Activities

A summary of key attributes of the PHE commercial fishery is provided in Table 6.2.

The PHE comprises Area 2 of the WCEMF and encompasses the waters of the Peel Inlet and Harvey Estuary, together with the Murray, Serpentine, Harvey and Dandalup Rivers and all their tributaries and effluents (Figure 6.5). The fishing season currently runs from December 1 to August 30, with a three-month spawning closure. There is a minimum commercial size limit of 127 mm CW. Commercial catch is sold on domestic markets.

Over half the annual commercial catch in the PHE is taken during the summer months (December – March). Catch rates are also highest over the summer months, peaking in January, February and March. Catch and catch rates then decline in winter, with June to August contributing up to 36% of the total catch.

Fishing during summer is focused on the central regions of the Peel Inlet and Harvey Estuary. During autumn, fishing shifts towards the north-west region of the Peel Inlet and top end of the Harvey Estuary, and by winter, fishing is largely concentrated around the entrance to the Dawesville Channel due to its higher salinity at this time compared to the rest of the estuary (Figure 6.5). Very little fishing activity for blue swimmer crabs occurs in the lower region of the Harvey Estuary and the south-east region of the Peel Inlet, where water is very shallow.

Table 6.2. Summary of key attributes of the commercial Peel-Harvey Estuary Crab Fishery

Attribute	
Fishing methods	Hourglass crab traps
Fishing capacity	336 traps (336 fishing units)
Number of licences	8 (100% active)
Number of vessels	8
Size of vessels	3 – 4 m
Number of people employed	~12 (fishers)
Value of fishery	< \$500, 000 (2018/19 season GVP at \$6.16/kg); Level 1 (weighted average price calculated for the financial year 2017/18)

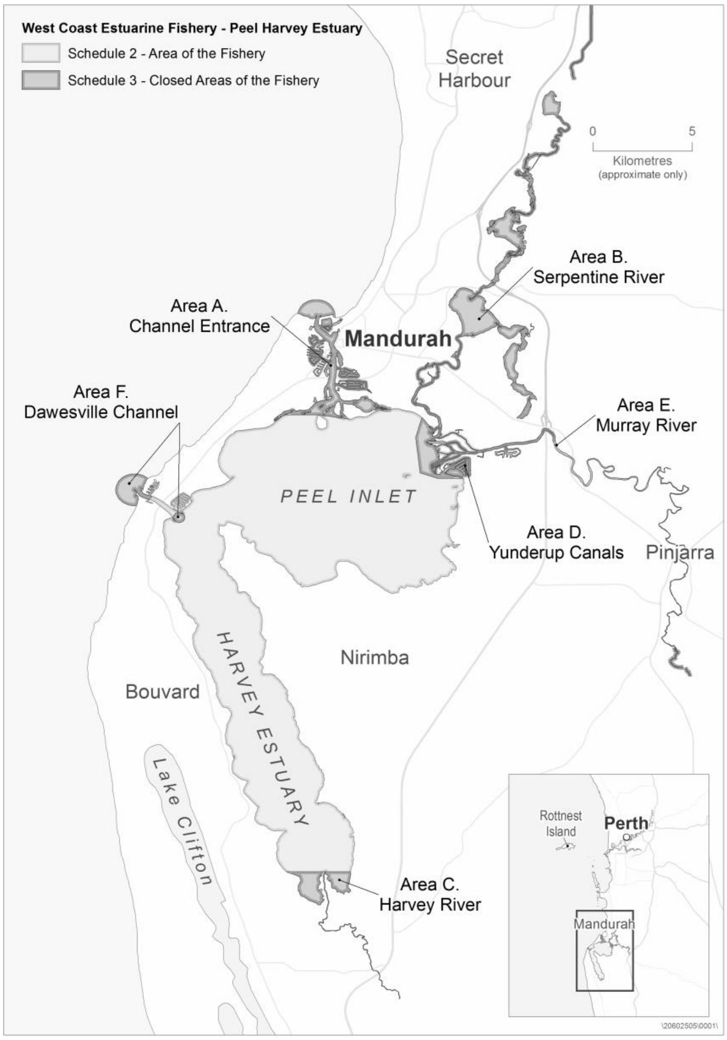


Figure 6.5. Boundaries of the commercial Peel-Harvey Estuary Crab Fishery and closed areas.

6.1.2.3 Fishing Methods and Gear

The blue swimmer crab catch in the PHE is taken by purpose-designed 'hourglass' crab traps. There are eight licenced operators in the commercial fishery permitted to use crab traps, with each licensee entitled to 42 traps.

Hourglass traps are similar to those in Cockburn Sound although both circular rings are made of solid stainless steel. Traps must have an internal volume $\leq 0.31\ m^3$ or, if the trap is cylindrical, the diameter must be ≤ 1 m. Mesh size is not legislated, and all fishers use slightly different configurations of mesh sizes, colours and net grade. The largest mesh used is 89 mm (3.5 inches) and the smallest is 51 mm (two inches). Traps may also be made of two different mesh sizes, with the smaller mesh usually on the bottom half of the trap and the larger mesh on top half. Fishers generally use multiple gear configurations at any one time, and are constantly trying to improve trap efficiency.

Since 2000, fishers have included voluntary escape gaps in all crab traps (Figure 6.6), with the intention of reducing the catch of undersize and juvenile crabs. This fishery is the only commercial crab fishery in WA using escape gaps.

The crab traps are typically set individually, attached to a surface float clearly branded or stamped with the licensed fishing boat number. Traps can only be pulled once in every 24-hour period and are typically baited with sea mullet and yellow eye mullet from the local net fishery (see Johnston *et al*., 2011a for more information on bait usage).

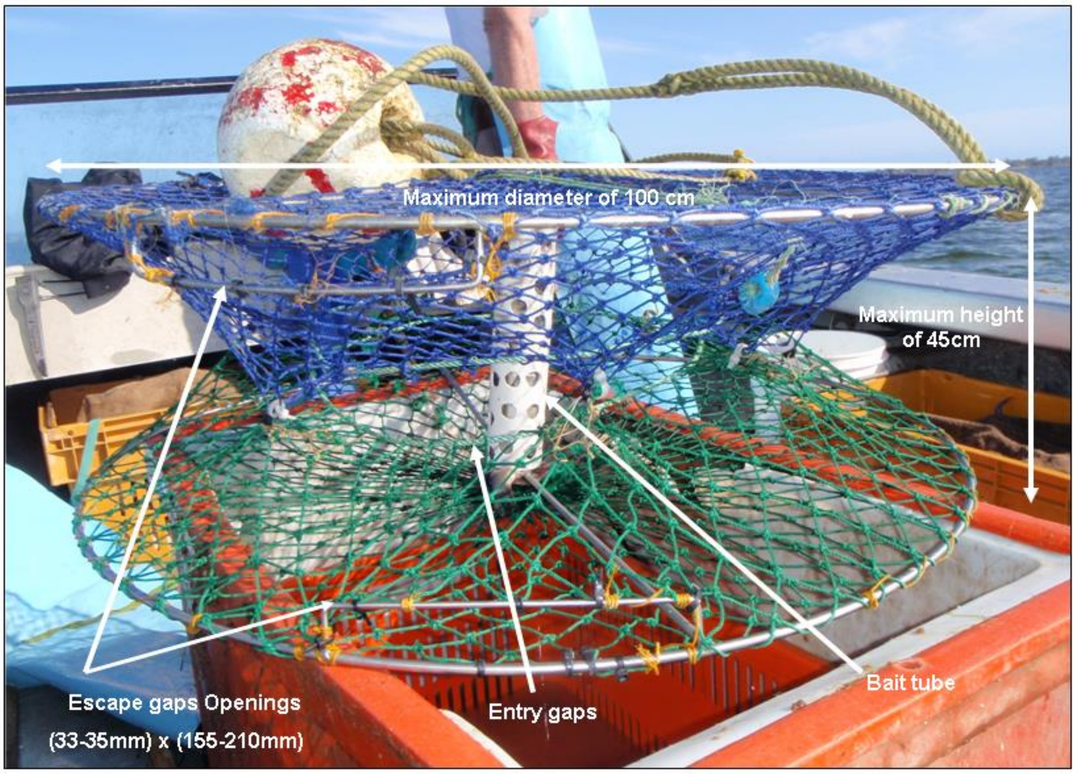


Figure 6.6. Commercial hourglass crab trap used in the Peel-Harvey Estuary Crab Fishery showing escape gaps.

6.1.2.4 Susceptibility

Blue swimmer crab assemblages in the Peel-Harvey Estuary and coastal waters of Warnbro Sound, Comet Bay and between Mandurah to Bunbury are highly likely to be the same genetic stock due to the migration of crabs between these water bodies. Thus for the purposes of Productivity and Susceptibility Analysis (PSA, see Section 9.3.6), these will be deemed as the same stock.

The PHEF covers an area of approx. 135 km^2 with the majority being suitable habitat for crabs. Commercial effort in this fishery is concentrated in the Peel Inlet and Harvey Estuary, with the Estuary Channel (1.45 km^2) closed to commercial fishing. Due to the spatial distribution of this stock throughout the estuary and the expansive area fished by both commercial and recreational sectors, the approximate areal overlap is likely to be high (>30%).

The purpose-designed baited hourglass traps used in the PHEF are highly efficient at capturing crabs as they are deployed on the estuary floor, usually in patches of sand, to specifically target blue swimmer crabs as they are primarily a benthic dwelling species and attracted to bait.

However, the mesh size used and the presence of escape gaps in this fishery enable the majority of juvenile and undersize crabs to escape. Vertical overlap is therefore considered moderate.

Blue swimmer crabs can survive out of water for up to several hours. As regulations stipulate that commercial fishers must return berried and undersize crabs to the water within 5 minutes of being landed, post-release mortality rates of non-retained catch with and without exposure to ice-slurries are low (Bellchambers *et al*., 2005; Broadhurst and Millar, 2018; Leland, 2014; Uhlmann *et al*., 2009).

6.1.3 Swan-Canning Estuary Crab Fishery

6.1.3.1 History of Development

Commercial fishing in the Swan-Canning Estuary commenced shortly after European settlement in 1829 (Smith, 2006), and it has almost exclusively been a set (gill) net fishery. Annual catch and effort for the fishery since 1907 are shown in Figure 6.7. Peak fishing effort (based on numbers of vessels) occurred in 1938, with 68 vessels operating. This rapidly declined to only seven in 1944, coinciding with the period of World War II. From the 1950s to early 1970s catches ranged 0.7 to 23.2 t, with 12–30 vessels operating. A period of very low catches from 1963 to 1966 (< 2 t) coincided with substantial flooding of the estuary during both 1963 and 1964 (Waters and Rivers Commission, 2000). Commercial catches peaked in 1977, with almost 35 t landed by 24 vessels fishing a total of 572 km of net (Figure 6.7).

A succession of Voluntary Fishery Adjustment Schemes (VFAS) saw the number of registered vessels targeting crabs decrease, from approximately 30 vessels in the 1970s to just one fisher by 2008. Annual commercial crab catches have fluctuated markedly since 1980, with catches ranging from 4 t in 1988 to 28 t in 1998 to less than 5 tonnes in 2016 and 2017 (Figure 6.7). The steady decline in catch since 1998 has been in line with the removal of fishing effort through VFAS, from 280 km of net per year in the late 1990s, to less than 100 km in recent years (Figure 6.7).

Recreational fishing is also extremely popular in the Swan-Canning Estuary (see Section 6.2 for a description of the recreational sector).

A review of the south-west blue swimmer crab resource was initiated in late 2018 (FMP 288; described earlier in Section 6.1) and key changes affecting the Swan-Canning Estuary Crab Fishery include:

- implementation of an annual 3-month closure (1 September through 31 November) (previously no closed season)
- a reduced recreational bag limit of 5 crabs in the Swan-Canning Estuary (previously 10 crabs).

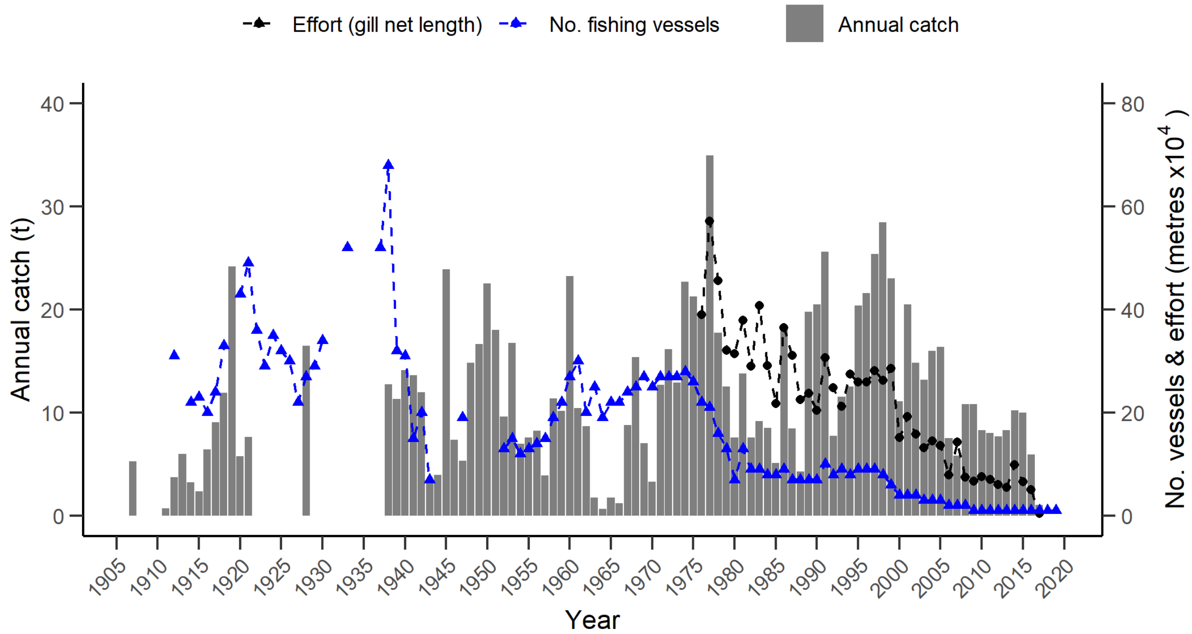


Figure 6.7. Annual commercial blue swimmer crab catch (tonnes), fishing effort (gill net length, metres of net $\times 10^4$) and the number of fishing vessels operating in the Swan–Canning Estuary from 1907 to 2019. Note that catch data are missing for several periods prior to 1938, and net length data are only available since catch and effort statistics (CAES) records began in 1976. A seasonal closure from September to November inclusive was introduced in 2019, with no closures prior. Note, due to confidentiality, catch and effort information for 2018–2019 is not shown.

6.1.3.2 Current Fishing Activities

A summary of key attributes of the Swan-Canning Estuary Crab Fishery is provided in Table 6.3.

The Swan-Canning Estuary Crab Fishery encompasses Area 1 of the WCEMF and covers the waters upstream from a line drawn from the westernmost point of the southern mole at Fremantle to the westernmost point of the north mole at Fremantle and all their tributaries and effluents (Figure 6.8). The areas open to commercial fishing include the waters of the Swan and Canning Rivers, upstream from Point Walter to Heirisson Island on the Swan River and Salter Point on the Canning River (see Figure 6.8). There is a minimum commercial size limit of 127 mm CW. Fishing effort tends to be concentrated in the summer months to target male blue swimmer crabs with 88% of the catch landed between December and April. All catch is sold on the local market.

Table 6.3. Summary of key attributes of the commercial Swan-Canning Estuary Crab Fishery

Attribute	
Fishing methods	Set (Gill) Net
Fishing capacity	1000 m net length
Number of licences	1 (100% active)
Number of vessels	1
Size of vessels	4 m
Number of people employed	3
Value of fishery	<$500,000 (2018/19 season GVP at $6.16/kg); Level 1 (weighted average price calculated for the financial year 2017/18)

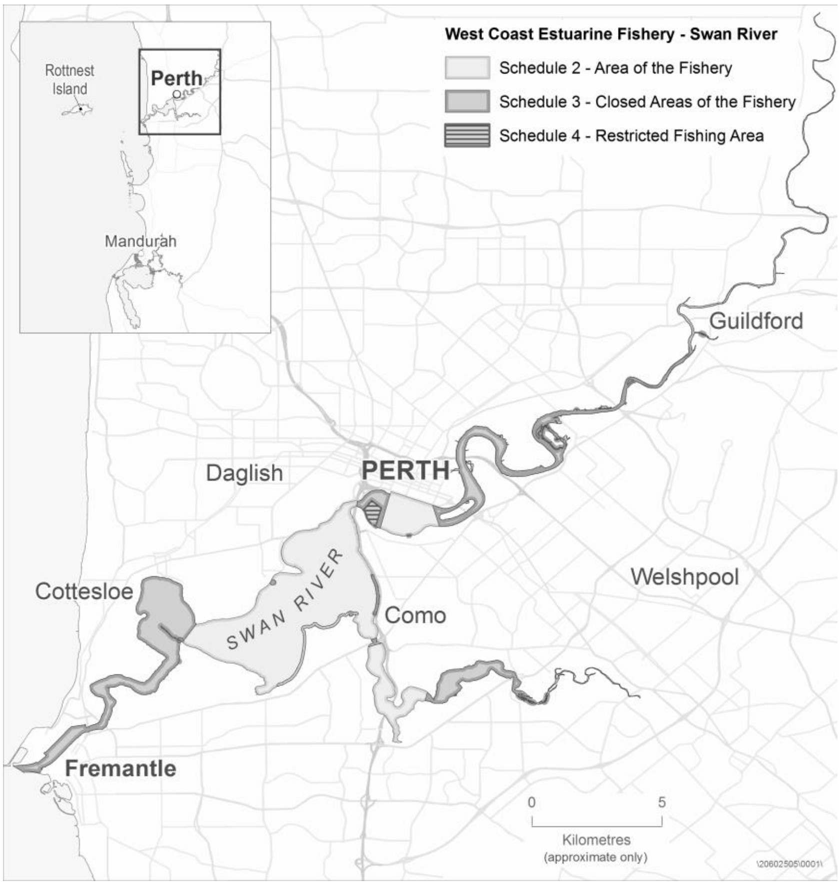


Figure 6.8. Boundaries of the commercial Swan-Canning Estuary Crab Fishery and its managed areas.

6.1.3.3 Fishing Methods and Gear

There is currently one licensed commercial crab fishing vessel within the Swan-Canning Estuary Crab Fishery employing no more than 1000 m of set-net in the water at one time. The current fisher usually operates up to 480 m (in lengths of 120 m) on a daily basis. Composed of mesh sizes ≥ 127 mm (stretched internal diameter), nets are approximately 1 m in height and constructed with a weighted bottom lead line and a floating top line so that they sit vertically in the water column above the substrate (Figure 6.9).

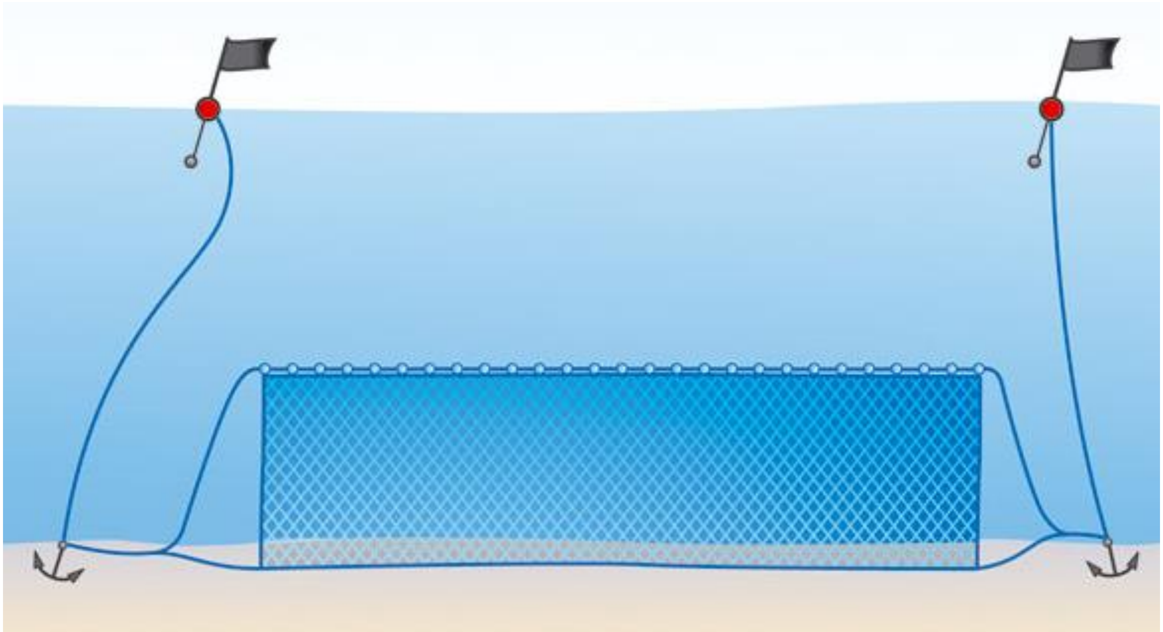


Figure 6.9. Conceptual illustration of a benthic set (gill) net as used by commercial crab fishers in the Swan-Canning Estuary. Note, surface floats are typically not used.

6.1.3.4 Susceptibility

The Swan-Canning Estuary covers an area of approx. 53 km^2, most of which is suitable habitat for the blue swimmer crab during summer and autumn. The commercial fishery operates in an area of 39 km^2 while the recreational sector operates in virtually all waters from Fremantle through to the upper reaches of the estuary. Due to the smaller area fished by the commercial sector in relation to spatial distribution of the stock, the approximate commercial areal overlap is likely to moderate (10-30%), whereas the recreational sector is considered high (>30%).

Gillnets used by commercial fishers in the Swan-Canning Estuary are set on the benthos, and sit approximately 1 m above the substrate targeting blue swimmer crabs as they are primarily a benthic dwelling species. However, the mesh size used enables the majority of juvenile and undersize crabs to escape with ~3% post-release mortality of crabs caught (Uhlmann *et al*., 2009). Therefore, encounterability and post release mortality by gill nets is considered moderate.

6.2 Recreational Crab Fishery

6.2.1 History of Development

Blue swimmer crabs represent one of the most important recreationally-fished inshore species in WA, with most recreational fishing occurring in the West Coast Bioregion (WCB; Ryan *et al*., 2019). A national survey of recreational and indigenous fishing was conducted in Australia during 2000-01 by Henry and Lyle (2003). Blue swimmer crabs represented the most numerous of the crabs taken by recreational fishers, with a national harvest of approximately 3.9 million crabs (Henry and Lyle, 2003). Harvest levels were greatest in Western Australia (57% of total). More recent recreational catch statistics for Western Australian crab fisheries have been gathered through 'iSurveys' (recreational fishing from boat surveys) conducted biannually since 2011/12 (see Section 6.2.2 below).

Recreational crab fisheries in the WCB are centred largely on the estuaries and coastal embayments from Geographe Bay to the Swan-Canning Estuary with the Peel-Harvey Estuary being the largest recreational fishery in the WCB. Recreational fishers use either baited drop nets, scoop nets or diving. Management arrangements for the commercial and recreational fisheries include minimum size, protection of breeding females and seasonal closures with effort controls in place for the commercial fishery (Johnston *et al.*, 2015a).

The State minimum legal recreational size limit is set at 127 mm CW, which is substantially above the size at 50% maturity (see Section 5.3). Further protection is provided to the breeding stock through a ban on keeping berried females and a recently implemented seasonal closure during the peak spawning period from September to November (introduced in 2019, see Section 6.1 for further details).

Recreational fishers are subject to a daily bag limit of 10 crabs per fisher per day in the WCB, which was decreased from a limit of 20 prior to November 2007. In the Swan-Canning Estuary, the daily bag limit was reduced to 5 crabs in December 2019 to preserve the fishery as 'trophy fishery' (see Section 6.1).

There is no specific recreational crabbing licence in WA, however, crabbers fishing from a powered vessel have required a Recreational Fishing from Boat Licence (RFBL) since March 2010. There is currently a daily boat limit of 20 crabs, provided there are two or more people on-board holding RFBLs, except for within the Swan-Canning Estuary, where four or more licence holders are required to catch the boat limit of 20. Additionally, fishers within Geographe Bay are only permitted to retain a maximum of 5 female crabs as part of the 10 crab bag limit. The southern waters of Cockburn Sound (south of a line from Woodman Point to Carnac Island) are currently closed to all crab fishing year-round (recreational and commercial) due to unacceptable stock levels in recent years (see Section 6.1.1.1).

Several dedicated recreational surveys were undertaken in Cockburn Sound and the Swan Canning and the Peel-Harvey estuaries during the 1990s and 2000s (outlined below). Although these surveys provided information on both boat- and shore-based fishing effort and catch of blue swimmer crabs, they typically only captured daylight fishing and may thus have underestimated the total recreational catch.

Cockburn Sound

Within Cockburn Sound, recreational crabbing surveys in 1996/97 and 2001/02, and in the 2002, 2003 and 2004 calendar years, produced relatively consistent recreational catch estimates of 24 t (Sumner and Williamson, 1999), 25 t (Sumner and Malseed, 2004), 18 t, 23 t and 18 t, (Bellchambers *et al*., 2005). However, the recreational catch for the 2005/06 financial year was estimated to be just 4 t due to a significant decline in stock abundance at that time (Sumner and Lai, 2012). All catch data are likely to be underestimates as surveys commenced between 7-9 am and finished between 4-8 pm, therefore missing any crabbing activity before or after these times.

Evidence from previous recreational crabbing surveys in Cockburn Sound, along with anecdotal accounts from Fisheries Compliance Officers, suggested there may be a significant amount of recreational crabbing taking place in Cockburn Sound in the early morning hours, especially in the Rockingham area. Information on recreational blue swimmer crab catch and effort in Cockburn Sound during the 2010 fishing season (Dec 15th 2009 – Mar 31st 2010) was obtained by extending the hours of an existing West Coast Creel Survey (Johnston *et al*., 2011a Appendix 1). Using the methodology employed in the West Coast Creel Survey, the five Cockburn Sound boat ramps were visited between the hours of 5:30am – 9:00am, over 12 randomised days each month and further stratified by weekday or weekend. Recreational catch for the 3½ month 2009/10 crabbing season was estimated to be 15.4 t (S.E.±3.3 t), for an area covering Cockburn Sound (south of latitude 32º05'S), Shoalwater Bay and the northern half of Warnbro Sound (north of latitude 32º20'S) between 9am and 5pm, with an additional 18.8 t (S.E.±5.5 t) caught between 530am and 9am (Johnston *et al*., 2011a). This resulted in a total recreational catch estimate of 34 t, demonstrating that previous recreational catch estimates for Cockburn Sound (above) were underestimated.

Swan-Canning Estuary

A 12-month survey of recreational fishing in the Swan-Canning Estuary conducted during daylight hours (07:00 am to 07:00 pm) between August 1998 and July 1999 estimated total recreational blue swimmer crab catch at 7.3 t, which compares with a commercial catch during the 1998/99 financial year of 24 t (Malseed and Sumner, 2001a). No further recreational surveys have been undertaken specifically in the Swan-Canning Estuary.

Peel-Harvey Estuary

Two dedicated recreational fishing surveys that covered fishing from boats, shore, canals and houseboats in the Peel-Harvey Estuary estimated total recreational catch to be 251-377 t in 1998/99 (Malseed and Sumner 2001b) and 107-193 t in 2007/08 (Lai *et al*., 2014). These creel survey estimates calculated recreational fishing in daylight hours only. Fishers crabbing from boats were interviewed at the conclusion of fishing on return to boat ramps, fishers at bridges/jetties and those scoop netting were interviewed in situ, while logbooks were issued to fishers crabbing from their private houses along canals or from houseboats (Lai *et al*., 2014). Each survey spanned a 12-month period and was stratified by season, time of day, weekdays or weekends and area (with each area further stratified by boat ramp). The design used for the

2007/08 recreational survey was a refinement of that employed for the earlier 1998/99 survey (Lai *et al*., 2014).

6.2.2 Current Fishing Activities

Recreational fishing for the blue swimmer crab resource is undertaken in waters of the Swan-Canning Estuary, Cockburn Sound, Warnbro Sound, the Peel-Harvey Estuary and the Geographe Bay region, where they dominate the inshore recreational catch. Highest recreational catches are taken from the Peel-Harvey Estuary followed by Swan-Canning Estuary and Geographe Bay.

In 2017-18, total boat-based recreational catch of blue swimmer crabs for Western Australia was estimated to be 61.1 t, of which 88.5% or 54.1 t (95% CI 45–63 t) taken from the WCB (1.57 t from the North Coast, 5.36 t from the Gascoyne and 0.078 t from the South Coast bioregions) (Ryan *et al*., 2019). This 2017/18 estimate for the WCB was similar to that of 2015/16 (44 t, 95% CI 36–50 t) and 2013/14 (59 t; 95% CI 50–68 t), but notably lower than during 2011/12 (87 t. 95% CI 75–97 t; Ryan *et al*., 2019).

Since 2013, a recreational voluntary logbook program, the Research Angler Program (RAP), where fishers record details of their catch and effort, has been targeted towards crab fishers in the Swan-Canning Estuary, as well as the Leschenault Estuary and wider Bunbury area and Geographe Bay. (Harris *et al*., 2017). This has allowed assessment of the recreational fishery through monitoring of catch rates and size composition over time (see Section 9.3).

6.2.3 Fishing Methods and Gear

Regulations govern the methods recreational fishers can use to fish for blue swimmer crabs in WA. Crabs may only be caught by hand (*e.g.* while diving and snorkelling), using hand-held wire or plastic scoop nets, drop nets or hand-held blunt wire hooks (not capable of piercing the crab). Scoop nets must be bowl-shaped and made of rigid mesh not capable of entangling a crab (Figure 6.10). Scoop nets must be no deeper than 210 mm and the internal diameter must be no greater than 375 mm. Drop nets must be no more than 1.5 m in diameter (Figure 6.10). There is a maximum limit of 10 drop nets per person when fishing from the shore, or 10 drop nets per boat, regardless of how many people are on board.

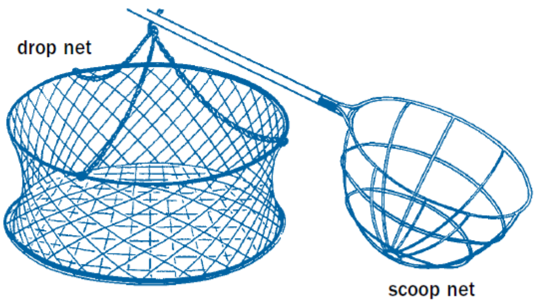


Figure 6.10. Drop and scoop nets employed by recreational fishers to target blue swimmer crabs.

6.2.4 Susceptibility

Areal overlap of stocks in Cockburn Sound and Swan-Canning Estuary is high (3) due to the close proximity to the Perth metropolitan region. Areal overlap using scoop netting in the second west coast stock is relatively low (approx. <10%), due to the small area available to shore-based scoop netters, however, due to the boat-based nature of drop nets the areal overlap is higher and approximately 10-30%. Recreational fishing in the south coast has been deemed to have a medium areal overlap of 10-30% availability of the overall South Coast Estuarine stock.

Encounterability of recreational fishing methods in all stocks is high as methods used, including using scoop and drop nets specifically target Blue Swimmer Crabs. Selectivity attributed to recreational fishers is considered moderate. Although undersize or ovigerous female crabs are often caught by recreational drop net fishers, divers and scoop netters actively avoid them. Post-capture mortality is generally low as recreational fishers are required to return undersize and ovigerous females to the water within 5 minutes of being landed.

6.3 Customary Fishing

There is currently no customary fishing of the blue swimmer crab resource in the south-west of WA.

6.4 Illegal, Unreported or Unregulated Fishing

Management arrangements for the south-west crab fisheries are enforced regularly by the Department's Fisheries and Marine Officers. Compliance is monitored via both sea and land-based inspections, with the majority of checks being carried out on land at the point of landing (boat ramps).

Compliance by the commercial sector is generally high, however illegal fishing activities by the recreational sector are a risk to some fisheries. The Peel-Harvey recreational crab fishery has a high level of enforcement risk with one of the highest levels of non-compliance in the State, particularly for retention of undersize crabs during night-time periods (Johnston *et al*., 2015a). Compliance effort in the PHE, in terms of overall presence of Fisheries Officers and the number of contacts made with fishers, has remained similar since 2014/15 (Johnston *et al*., 2015b - Addendum 2019). Although retention of undersized crabs remains the main offence type in the recreational crab fishery, the number of prosecution briefs, infringement notices and warnings recorded in 2017/18 were all lower than the previous year. Although this, coupled with the stable compliance effort, suggests that the level of non-compliance in this fishery has declined, these data are likely to be heavily influenced by changes in the abundance and availability of crabs between years (Johnston *et al*., 2015b - Addendum 2019). The introduction of a season closure extension to include November in 2020, will hopefully reduce the capture of undersize crabs which are prevalent in the fishery at this time.

7. Fishery Management

7.1 Management System

The harvest strategy for the blue swimmer crab resource of WA is, essentially, a constant exploitation approach, where the annual catch varies in proportion to variations in stock abundance. To implement this strategy, commercial and recreational fisheries capturing crabs are managed using a range of input controls. Commercial fishing effort is constrained by a cap on the number of licences/vessels operating in each fishery (limited entry) and restrictions on fishing gear, including the number and size of crab traps, and the length of nets. Recreational fishing effort is managed by gear controls (*e.g.* limits on the number of drop nets used) and daily bag and boat limits. Recreational fishers operating from a boat are required to hold a current Recreational Fishing from Boat Licence (RFBL). Other restrictions include retainable species, minimum size limits (commercial 127–130 mm carapace width (CW), recreational 127 mm CW) and spatio-temporal fishing closures (*e.g.* during spawning seasons).

7.2 Harvest Strategy

A harvest strategy for the blue swimmer crab resource in south-west WA outlines the long and short-term objectives for management (DPIRD, 2020). It also provides a description of the performance indicators used to measure performance against these objectives, reference levels for each performance indicator, and associated control rules that articulate pre-defined, specific management actions designed to maintain the resource at target levels.

The status of the blue swimmer crab resource in south-west WA is assessed annually using a weight-of-evidence approach of all available data for the key areas in which the resource is commercially targeted; the Swan-Canning and Peel-Harvey estuaries. As genetic studies have indicated that blue swimmer crabs in these estuaries are genetically distinct, these fisheries are currently monitored and assessed separately. Due to a lack of information about the total recreational effort and catch of blue swimmer crabs in individual fisheries of south-western Australia, the harvest strategy for these stocks is primarily based on standardised commercial catch rates relative to reference levels for each of the two key areas.

For each area, reference levels have been calculated from the standardised catch rates observed annually during a reference period of relative stability when the fishery was considered to have been operating sustainably (Swan-Canning Estuary (SCE): 2008/09–2016/17, Peel-Harvey Estuary: 2000/01–2016/17) (DPIRD, 2020) (Table 7.1). The target range extends between the maximum and minimum values recorded during that reference period, where the latter denotes the threshold level assumed to represent a proxy for the stock level at which Maximum Sustainable Yield (MSY) can be achieved. Any stock size above this level is therefore consistent with meeting the objectives for biological sustainability and also satisfy stock status requirements under the Marine Stewardship Council (MSC) standard for sustainable fishing. A conservative approach has been taken to set the limit reference level at 70% of the threshold value (*i.e.* $0.7B_{\mathrm{MSY}}$) and is considered to represent the level below which recruitment may be impaired (DPIRD, 2020).

Abundance information for blue swimmer crabs in the Swan-Canning and Peel-Harvey estuaries is also derived from commercial monitoring and fishery-independent surveys, which currently informs the broader weight-of-evidence assessments of these stocks (see Section 9.3). It is anticipated that the fishery-independent indices may be used as performance indicators in future harvest strategies for these resources, once sufficient time series of data are available.

Despite being closed since 2014, the harvest strategy for the Cockburn Sound crab managed fishery (CSCMF) has been included in this section as robust biological performance indicators have been developed that are important for assessing the future status of these stocks. The primary performance indicators are a juvenile abundance index (number of juveniles/100m^2), and an egg production index (10^6 eggs/traplift; Table 7.2).

The juvenile index is based on recruitment data from research trawls conducted in April, May and June each year (see Section 8.2). A threshold of 0.6 juveniles/100m^2 trawled and a limit of 0.4 juveniles/100m^2 trawled have been proposed based on levels that corresponded with historical declines (collapses) in this fishery. Juvenile recruitment during the periods of fishery closure have been deemed unacceptable and below the limit. A reference period has not been selected as there has not been an extended period over the last 15 years where the fishery was deemed sustainable.

The egg production index is based on commercial trap monitoring catch rates (in numbers / traplift), size data (see Section 8.2), and a size-fecundity and size at maturity relationship, assuming all sexually mature females contribute to egg production. A revised limit of 12.0 (10^6 eggs/traplift) has been proposed, based on the stock-recruitment relationship (SRR). An egg production index below 12 resulted in unacceptably low recruitment the following year, irrespective of environmental conditions (temperature), but above 12 recruitment in the following year was acceptable and improved in warmer years. See Section 9.3.8 for explanation of the stock recruitment relationship.

A weight of evidence approach is used for assessing stock status in this fishery, incorporating the juvenile index, egg production index, commercial catch rates and the proportion of females in the commercial catch (Table 7.2).

Table 7.1. Harvest strategy performance indicators, reference levels and control rules for the blue swimmer crab resource of south-west WA (see DPIRD, 2020 for associated ecological assets that may be impacted by fishing activities within the Peel-Harvey Estuary).

Component	Management objectives	Resource / Asset	Performance Indicators	Reference Levels	Control Rules
Target species	To maintain spawning stock biomass of blue swimmer crabs at a level where the main factor affecting recruitment is the environment	Blue swimmer crabs in south-west WA	Annual standardised commercial catch rate in the 1. Swan-Canning Estuary, and 2. Peel-Harvey Estuary	**Target:** Swan-Canning Estuary: 6.2-9.8 kg/100 m net length Peel-Harvey Estuary: 0.7-1.4 kg/traplift	Continue management aimed at achieving ecological, economic and social objectives.
				Threshold: Swan-Canning Estuary: 6.2 kg/100 m net length Peel-Harvey Estuary: 0.7 kg/ traplift	If the threshold level is breached, a review will be completed within three months to develop an appropriate management response. Management action (applicable to all relevant fisheries/sectors) will be taken to reduce catches by up to 50%[1] of the current harvest level to return stock to the target level.
				Limit: Swan-Canning Estuary: 4.3 kg/100 m net length Peel-Harvey Estuary: 0.5 kg/traplift	If the limit level is breached, management action (applicable to all relevant fisheries/sectors) will be immediately taken to reduce catches by at least 50% of the current harvest level. A review will be completed within three months to determine what additional management actions (up to 100% catch reduction[5]) are required to rebuild the stock to the target level within two generation times (*i.e.* informing the recovery strategy for the stock).

[1] The level of catch reduction to the relevant fisheries/sectors will be dependent on the extent by which the reference level has been breached, and the required rebuilding rate.

Table 7.2. Harvest strategy performance indicators, reference levels and control rules for the blue swimmer crab resource in the CSCMF. JI – Juvenile index, EPI Egg Production Index.

Management Objective	Performance Indicator(s)	Reference Levels	Control Rules
To maintain spawning stock biomass of blue swimmer crabs at a level where the main factor affecting recruitment is the environment	1. Juvenile Index, JI (juveniles/100m^2 trawled) 2. Egg Production Index, EPI (10^6 eggs/traplift)	**Target:** JI: 0.6–1.0 juveniles/100m^2 trawled	Continue management aimed at achieving ecological, economic and social objectives.
		Threshold: JI: 0.6 juveniles/100m^2 trawled	If the threshold level is breached, a review will be completed within three months to develop an appropriate management response. Management action (applicable to all relevant fisheries/sectors) will be taken to reduce catches by up to 50%[2] of the current harvest level to return stock to the target level.
		Limit: JI: 0.4 juveniles/100m^2 trawled EPI: 12 x 10^6 eggs/traplift	If the limit level is breached, management action (applicable to all relevant fisheries/sectors) will be immediately taken to reduce catches by at least 50% of the current harvest level. A review will be completed within three months to determine what additional management actions (up to 100% catch reduction[5]) are required to rebuild the stock to the target level within two generation times (*i.e.* informing the recovery strategy for the stock).

[2] The level of catch reduction to the relevant fisheries/sectors will be dependent on the extent by which the reference level has been breached, and the required rebuilding rate.

Annual catch tolerance levels have been developed for the two key commercial fisheries that target the blue swimmer crab resource in south-west WA (Table 7.3) (see DPIRD, 2020). Cockburn Sound is currently closed to fishing so catch tolerance levels are not presented here. Tolerance ranges for the Swan-Canning Estuary have been based on historical catch information relative to estimates of MSY derived from a preliminary production model to indicate the reference period in which the fishery has been operating sustainably (2008/09–2016/17). The 2017/18 catch was excluded due to high summer rainfall leading to reduced fishing in that season. In the absence of MSY estimates for the Peel-Harvey Estuary (PHE), the tolerance ranges for the commercial fishery have been based on catch levels observed during the specified reference period (2000/01–2016/17) and adjusted downwards to account for the effect of the current VFAS (see Table 7.3).

Tolerance ranges have also been developed for the boat-based recreational sector in the Swan-Canning and Peel-Harvey estuaries (Table 7.3), broadly based on preliminary catch estimates for each estuary from the four boat-based fishing surveys completed to date. Tolerance ranges for the Swan-Canning Estuary have been adjusted downwards (by 30%) to account for recent changes to management, including a seasonal closure and reduction of bag limits. Tolerance ranges for the Peel-Harvey have been adjusted upwards (by 20%) to account for recent changes to management, include the ongoing VFAS and extended seasonal closure to increase protection of breeding stocks. These tolerance levels are expected to be refined over time, and additional tolerance levels (likely based on effort as a proxy for catch) for the shore-based scooping sector in the Peel-Harvey Estuary may be added to a future version of this harvest strategy. If the breach of a specified catch tolerance level by either fishery/sector cannot be adequately explained (*e.g.* clear environmental impacts or marketing reasons), the performance is termed 'Unacceptable'. This would trigger a review to determine if management arrangements are still appropriate, and if a re-assessment of resource status is necessary to inform adjustments to the harvest strategy control rules and/or tolerance levels.

Table 7.3. Annual catch tolerance levels (tonnes, t) for the key fisheries/sectors that target the blue swimmer crab resource in south-west WA. Note that annual boat-based recreational catch is only estimated every 2-3 years.

Area	Commercial	Recreational (boat-based)
Swan-Canning Estuary	6–11 t	4–12 t
Peel-Harvey Estuary	6×N (lower) - 12×N (upper)* t	31–55 t

*Once VFAS has been finalised, the upper tolerance level will be determined as 12 t times the number, N, of remaining licence holders with crab trap entitlement in the Peel-Harvey Estuary. The lower tolerance level will be reduced proportionally to the original tolerance range per fisher (approximately 6 t).

7.3 External Influences

External influences include other activities and factors that occur within the aquatic environment that may or may not impact on the productivity and sustainability of fisheries resources and their ecosystems. The main external influences included here are environmental factors and market influences.

7.3.1 Environmental Factors

As a short-lived, invertebrate species, environmental factors are presumed to have a strong influence on the blue swimmer crab resource. Recent analyses have demonstrated that a number of environmental variables, including water temperature, rainfall, salinity and lunar phase can influence commercial catch rates (Johnston *et al*., 2020), and changes in temperature and primary production may also be linked to declines in recruitment, growth and overall abundance (see Section 9.3.8; Marks *et al*., 2020). Given that the crab resource is, at any given time, essentially comprised of only two cohorts (Marks *et al*., 2020), environmental perturbations could be expected to result in major fluctuations in population size.

7.3.1.1 Climate Change

A risk assessment of WA's key commercial and recreational finfish and invertebrate species has demonstrated that climate change is having a major impact on some exploited stocks (Caputi *et al*., 2015). This is primarily occurring through changes in the frequency and intensity of ENSO events, decadal variability in the Leeuwin Current, increase in water temperature and salinity, and change in frequency and intensity of storms and tropical cyclones affecting the state (Caputi *et al*., 2015). In 2010/11, a very strong Leeuwin Current resulted in unusually warm ocean temperatures in coastal waters of south-western WA (Pearce *et al*., 2011). This "marine heatwave" altered the distribution and behaviour (*e.g.* spawning activity and migration) of some species and caused widespread mortalities of others such as blue swimmer crabs in Shark Bay resulting in the closure of this fishery for 18 months (Chandrapavan *et al*., 2017, 2019).

A risk screening of WA's key commercial and recreational finfish and invertebrate species revealed *P. armatus* to have a high overall sensitivity to climate change (Caputi *et al*., 2015). Many of the biological processes of crabs are highly influenced by environmental variables, suggestive of a high sensitivity to climate change. The effects of climate change are likely to differ between blue swimmer crab fisheries in WA, based on the large latitudinal range between crab fisheries.

A strong correlation between water temperature and recruitment success was reported in Cockburn Sound, with poor recruitment resulting from four years of lower than average water temperatures in the pre-spawning months of August and September contributing to a decline in these stocks (de Lestang *et al*., 2010; Johnston *et al*., 2011a).

7.3.2 Introduced Pest Species

The introduction and spread of marine pests in WA waters poses a serious threat to native biodiversity and can have widespread effects on both the economy and public health. The Asian paddle crab (*Charybdis japonica*) has the potential to outcompete native species such as the blue swimmer crab if it becomes established in Australia. There is a biosecurity program run by DPIRD to record sightings of the Asian Paddle Crab with only very small numbers reported sporadically in south-western Australia.

7.3.3 Market Influences

Markets for blue swimmer crabs have been established for decades due to its popularity, with fishing dating back to the 1800s in the Swan-Canning Estuary (see section 6.1.3.1). Blue swimmer crab fisheries in the south-west of WA sell the majority of their product on the domestic market within Western Australia, although a small number of fishers are exploring markets on the East Coast. The value of each fishery is therefore strongly influenced by local demand. In these small fisheries, fishers often fish to meet orders which influences catch and effort. Demand for product is generally consistent between years, with peak demand over summer-autumn.

8. Information and Monitoring

8.1 Range of Information

There is a range of information available to support the assessment and harvest strategies for the blue swimmer crab resource in the West Coast Bioregion (WCB), which are outlined in **Table 8.1** below.

8.2 Monitoring

8.2.1 Commercial Catch and Effort

All fishers operating in the CSMCF, SCE and PHE are required to fill out and submit monthly statutory catch and effort statistics (CAES). These data have been used to provide the basis for ongoing stock assessment and are critical to the development of stock performance indices and harvest strategy evaluation.

Under the *Fish Resources Management Act 1994* (FRMA), licensees involved in fishing operations and/or the master of every licensed fishing boat must submit an accurate and complete monthly catch and effort return on forms approved by the Department. The returns record monthly catch totals (in kg) for each retained species, estimates of daily effort (*e.g.* number of traps pulled per day), spatial information by block (60 × 60nm) and bycatch/endangered and threatened species. These catch and effort returns are submitted monthly, with a deadline of 15 days after the end of the month. All CAES returns are validated by Departmental staff and any inconsistencies are further verified directly with fishers. The information provided in CAES returns is confirmed by processor unloads, which are also provided to the Department on a monthly basis.

These data are also validated by commercial monitoring information collected by Departmental research staff on-board commercial vessels throughout the fishing season.

Table 8.1 Summary of information available for assessing key blue swimmer crab resources in south-western Australia. CS; Cockburn Sound, PHE; Peel-Harvey Estuary, SCE; Swan-Canning Estuary (Swan River).

Data type	Fishery dependent / independent	Purpose / Use	Area of collection	Frequency of collection	History of collection
Commercial catch and effort statistics (CAES returns)	Dependent	Commercial catch and effort, catch rates and location of area fished (CAES blocks)	CS, PHE, SCE	Monthly	Since 1975
Commercial monitoring	Dependent	Length frequencies (size structure, catch composition), catch rates, spatial distribution fishing, Egg Production Index (CS)	CS, PHE, SCE	Monthly Twice a month in PHE	CS: 1999-2007 open season only; 2007-2017 all months; since 2017 key months PHE & SCE: 1998-2000, Since 2007
Recreational iSurvey	Dependent	Recreational catch and effort trends	State-wide	Biennial	Since 2011/12
Recreational voluntary logbook program	Dependent	Catch rates, catch composition, spatial patterns, angler behaviour	SCE	Continuous (reported by fishing trip)	Since 2013
Thermal cameras & on-site monitoring	Dependent	Shore-based fishing effort (day and night)	PHE	Continuous	Since 2014
Recruitment	Independent (trawling)	Juvenile Index of recruitment strength (catch rates)	CS PHE SCE	Monthly April-June Monthly - all Monthly February-June Monthly March-April	Since 2001 2016-2019 Since 2020 Since 2016
Spawning stock	Independent – trawling (large vessel; CS, trapping SCE)	Egg Production Index, berried & sexually mature catch rates	CS SCE	Annually October-November	Since 2001 Since 2013
Biological information	Dependent and Independent	Growth, reproduction (*e.g.* maturity, fecundity), length-weight, gear selectivity, movements	All fisheries with a focus on CS, SCE & PHE	Opportunistic	Since ~1990s

8.2.2 Recreational/Charter Catch and Effort

Recreational surveys have been undertaken periodically for a number of specific fisheries over specific time frames (Table 8.1; and see sections 6.2.1 and 9.3.2). Since 2011, a biennial state-wide recreational survey has been undertaken to collect information on recreational boat-based catch and effort in WA (Ryan *et al*., 2013; 2015; 2017; 2019). This survey uses three complementary components, off-site phone diary surveys, on-site boat ramp surveys and remote camera monitoring, to collect information on catch, effort, location and other demographic information, every two to three years. The latest 2017/18 survey also collected some information on shore-based recreational fishing by surveyed fishers.

These surveys provide a state-wide and bioregional estimate of the boat-based recreational catch; both kept and released. In each survey, state-wide on-site Biological Surveys were completed at key boat ramps to obtain length and weight information that would allow estimates of catch by numbers from the Phone-Diary Surveys to be converted to catch by weight. This enables direct comparison of recreational harvest estimates to commercial fishery information, which is routinely recorded as weights.

In the Peel-Harvey Estuary (PHE) a considerable amount of recreational effort occurs from shore-based scoop net fishers, both during the day and at night. To quantify this fishing activity, fixed-location cameras have been used to monitor scoop netting activity at three locations on the Peel Inlet and Harvey Estuary foreshore since 2014/15 (Taylor *et al*., 2018). The cameras run continuously at three locations around the estuary, to identify patterns of recreational fishing activity for blue swimmer crabs over 24-hours each day, throughout the year. This information, together with data from a recently completed 15-month survey of recreational scoop netting, will be used to provide an estimate of scoop netting effort across the broader estuary (Desfosses *et al*., 2019).

8.2.3 Fishery-Dependent Monitoring

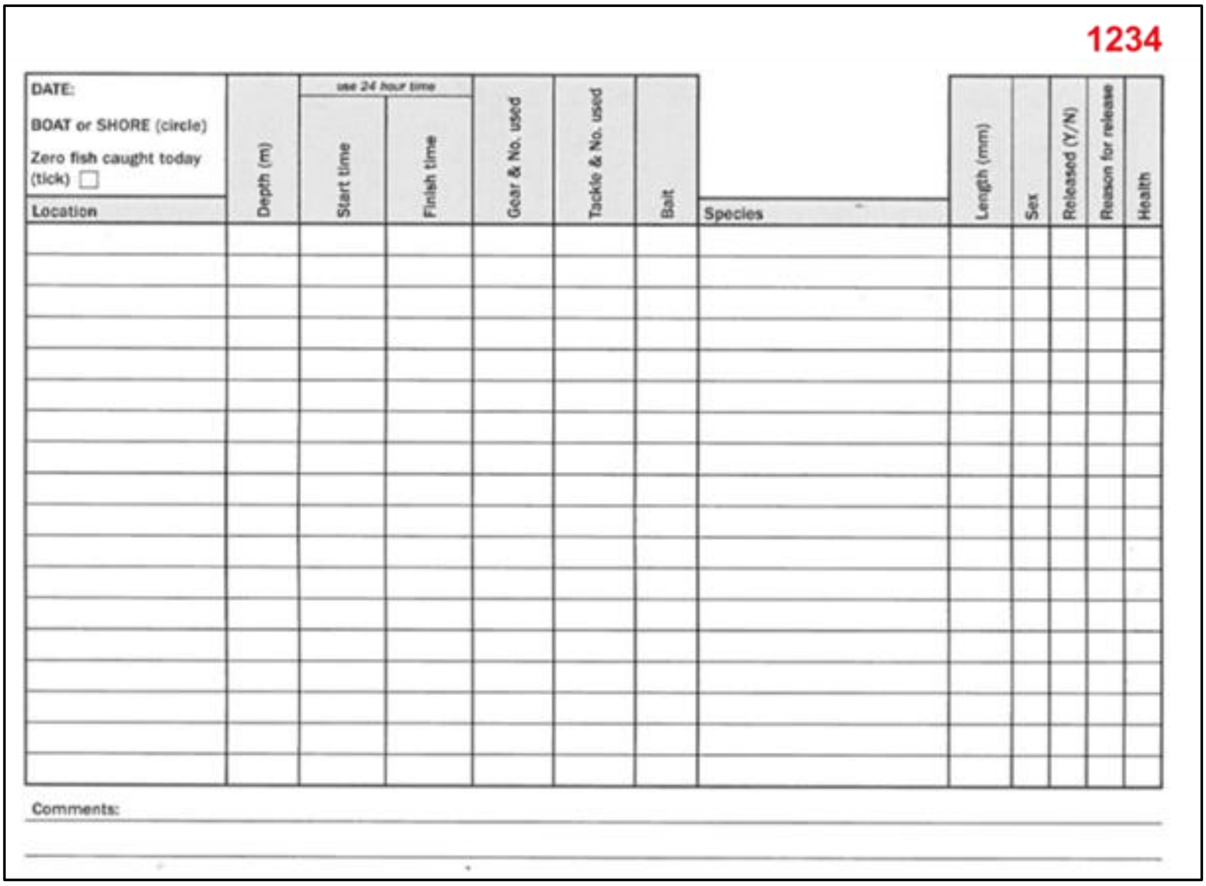
Commercial monitoring

In addition to catch and effort data, Departmental research staff undertake fishery–dependent monitoring on commercial vessels (commercial monitoring surveys) in the Cockburn Sound crab managed fishery (CSCMF), SCE and PHE (frequency has varied over time but majority has been monthly – see Table 8.1). These surveys provide data on catch composition (size structure, sex ratios, berried state), abundance data used to calculate standardised legal catch rates, female size at maturity and spatial distribution of commercial fishing. During each survey, all crabs captured are measured to the nearest mm (carapace width (CW); spine to spine) using Vernier calipers. Biological information, including sex, moult stage, sexual maturity status and berried state, are collected for each crab based upon visual examination (see Section 5.3.5). Any bycatch, obvious predation (*e.g.* by octopus) or dead crabs are also recorded. Data is recorded per line of traps or length of net, and includes the number of traps or metres of net in the line, soak time (number of hours traps or nets have been in the water since last serviced), a start latitude and longitude and a mean depth.

Data on the abundance of sexually mature and berried females collected during commercial monitoring surveys in the CSCMF are used to calculate the egg production index for this fishery (Section 9.3). During the periods of fishery closure (December 2006- December 2009; and since April 2014), a CSCMF commercial fisher has been contracted to conduct commercial monitoring surveys.

Recreational logbook

A recreational fisher logbook program was initiated as part of an external project funded by the Recreational Fishing Initiatives Fund (RFIF) project and has continued for the Swan-Canning Estuary (SCE) (and also Geographe Bay and Leschenault Inlet) to provide estimates of recreational crabbing catch rates and size composition (Harris *et al.*, 2017; Harris and Johnston, submitted; Figure 8.1).


1234

DATE:

BOAT or SHORE (circle)

Zero fish caught today (tick) ☐

Location	Depth (m)	Start time (use 24 hour time)	Finish time	Gear & No. used	Tackle & No. used	Bait	Species	Length (mm)	Sex	Released (Y/N)	Reason for release	Health

Comments:

Figure 8.1. Voluntary research log sheet completed by recreational crab fishers in the Swan-Canning Estuary as part of the Recreational Angler Program (RAP).

8.2.4 Fishery-Independent Monitoring

Fishery-independent recruitment surveys are carried out in Cockburn Sound, the Peel-Harvey Estuary and Swan-Canning Estuary, while breeding stock surveys are conducted in Cockburn Sound and the Swan-Canning Estuary only.

Cockburn Sound

The commercial-sized (~23m) trawler *RV Naturaliste* has been used to undertake annual recruitment surveys over one to two nights during April or May, and a breeding stock survey over one to two nights during November or December in the CSCMF since 2007 (Johnston *et al*., 2011a) (Table 8.1). Trawls are undertaken using a twin-rig demersal otter trawl configuration (Figure 8.1). Each net has a 10.97 m head rope and is constructed of 50 mm mesh in the wings and 45 mm mesh in the cod-ends. The nets are demersal with a 10 mm ground chain positioned two links in front of the ground rope. A net efficiency factor (0.67 × net head rope length in metres) is incorporated to adjust for the effective spread of the net on the seabed (de Lestang *et al*., 2003b), giving the effective opening of each net of 7.3 m wide by 1 m high. Trawling occurs at night (commencing at least 30 minutes after sunset) with three 5-minute trawls conducted at seven sites (Figure 8.2). CW (mm), sex, female sexual maturity, berried status and moult stage are recorded for every crab.

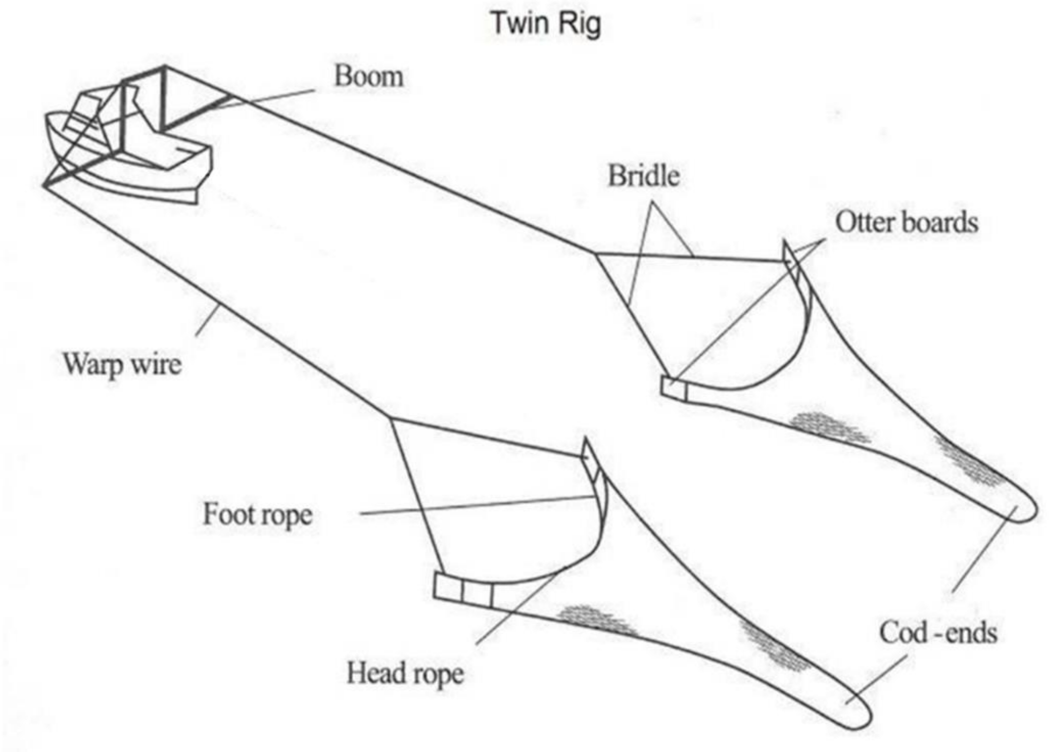


Figure 8.1. Standard twin-rig otter trawl as used by the *RV Naturaliste* during fishery-independent trawl surveys. (Source: adapted from Stirling 1998).

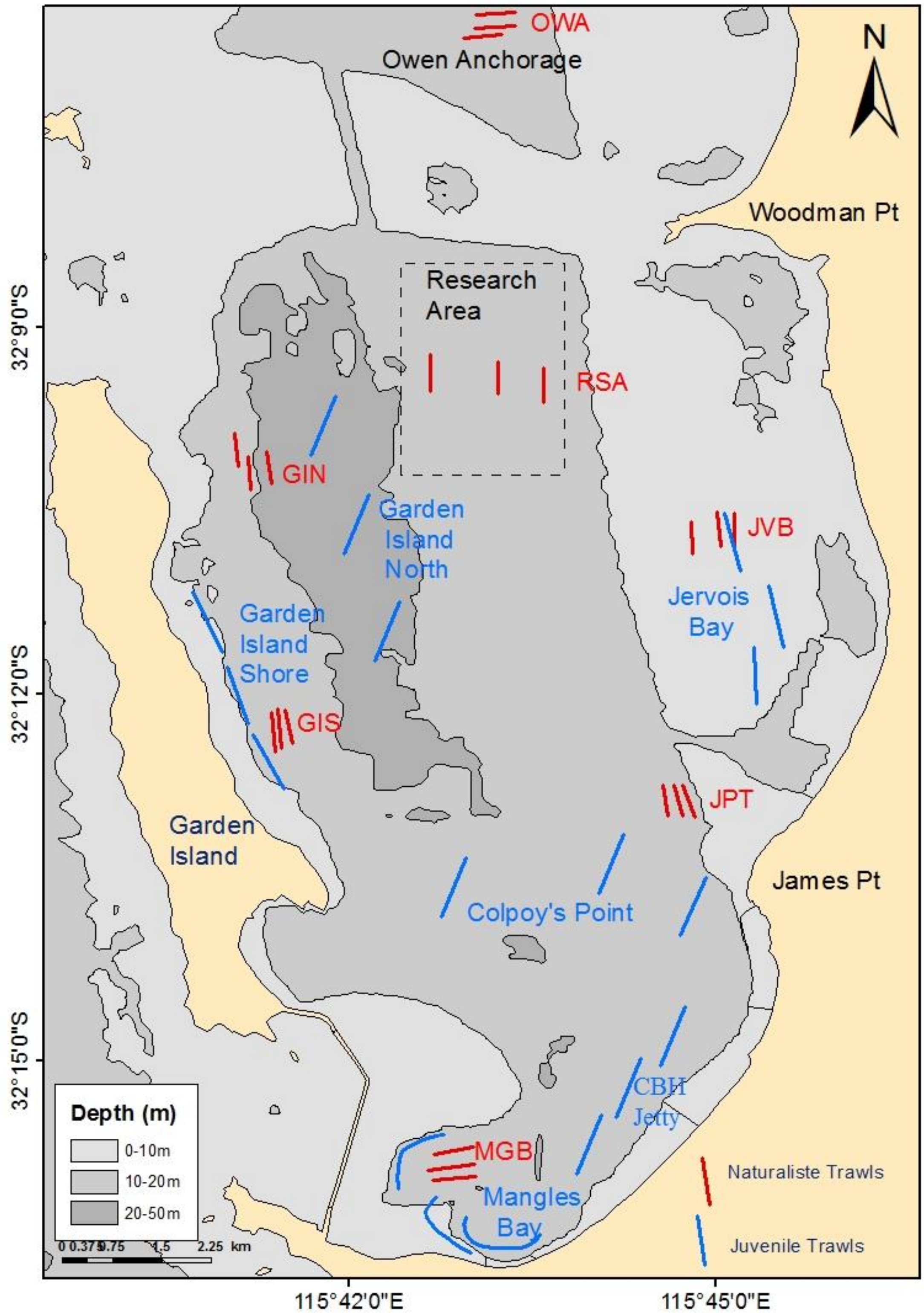


Figure 8.2. Locations of fishery-independent recruitment and breeding stock trawl surveys in Cockburn Sound on board *RV Naturaliste* (red lines) and recruitment trawl surveys on board a smaller research vessel (blue lines). GIN, Garden Island North; GIS, Garden Island Shore; JPT, James Point; JVB, Jervois Bay; MGB, Mangles Bay; OWA, Owen Anchorage; RSA, Research Area.

Juvenile recruitment surveys have also been conducted annually using a smaller ~7.5 m research vessel and a small otter trawl since 2002 (Table 8.1). Three replicate trawls are undertaken during April, May and June at six sites: Garden Island North, Garden Island Shore, Colpoys Point, CBH Jetty, Jervois Bay and Mangles Bay (Figure 8.2). The net, which has a 4.5 m headrope (effective opening width of 3 m based on a net efficiency factor of 0.67), and a height of 0.5 m, is constructed from 51 mm mesh in the wings and 9 mm mesh in the cod end (stretched internal diameter; Figure 8.3). The twin otter boards each measure 600 mm long and 310 mm wide, and weigh 17 kg, and the net has a 10 mm ground chain attached to the foot rope to maintain close contact with the benthos. Each trawl is conducted at a speed of 2.7 kts for nine minutes, equating to an approximate distance of 750 m (*c.* 2,250 m^2 swept area). Trawling occurs at night (at least 30 minutes after sunset) and the CW, sex, female maturity and berried status of every crab is recorded.

Juvenile Index

Crabs collected from juvenile trawl surveys using the smaller research vessel were allocated to juveniles (0+) and residuals (1+) according to size (using a monthly CW that separated the two year classes obtained from a seasonal von Bertalanffy growth curve) (Bellchambers *et al*., 2006; Johnston *et al*., 2011a). An index of juvenile (0+) crab abundance was calculated using monthly cut-offs based on size as detailed in Section 9.3.5.1.

Egg Production Index

The monthly fishery-dependent commercial trap monitoring data are used to calculate an index of egg production based on mature female abundance in September to December, *i.e.* during the main period of spawning. The index is calculated based on the catch rate of sexually mature females and a relationship between batch fecundity and crab size. See Section 9.3.5.1 for details of the egg production analyses. Egg production indices are currently being refined to incorporate trawl data to address potential bias in trap derived data.

Figure 8.3. Small otter trawl net and otter boards used during fishery-independent recruitment surveys in Cockburn Sound and the Swan-Canning and Peel-Harvey Estuaries.

Swan-Canning Estuary

Recruitment surveys have been conducted in the Swan-Canning Estuary over peak recruitment months April and May since 2014. Following poor catch rates using a 21.5 m beach seine, this method was discontinued after 2015 and replaced with otter trawling. Trawling has been shown to be an effective method for sampling juvenile crabs in estuarine environments (see Appendix 4). Trawling is conducted at 12 sites throughout the estuary (Figure 8.4) using a ~7.5 m research vessel. The net, which has a 4.5 m headrope (effective opening width of 3 m based on a net efficiency factor of 0.67), and a height of 0.5 m, is constructed from 51 mm mesh in the wings and 9 mm mesh in the cod end (stretched internal diameter; Figure 8.3). The twin otter boards each measure 600 mm long and 310 mm wide, and weigh 17 kg, and the net has a 10 mm ground chain attached to the foot rope to maintain close contact with the benthos. Each trawl is conducted at a speed of 2.7 kts for six minutes, equating to an approximate distance of 500 m (*c*. 1500 m^2 swept area). Trawling occurs at night, commencing at least 30 minutes after sunset.

Breeding stock surveys have been conducted over the peak spawning months of October and November since 2013 to sample sexually mature (SCE: ≥ 93 mm CW; Johnston *et al*., *in prep.*) and berried female *P. armatus* in the Swan-Canning Estuary (Harris *et al*., 2017; Harris and Johnston, submitted). These samples are conducted using research hourglass traps as this methodology is more efficient that a small otter trawl for sampling larger crabs (see Appendix 4). Three baited hourglass traps (1.16 m diameter, 0.5 m high, constructed with 51 mm mesh and baited with approximately 220 g of yelloweye mullet) are deployed 100 m apart for a 24-hour period at 10 sites (Figure 8.4).

For both the trawl and trap surveys, CW (to the nearest mm), sex, moult stage, female maturity and egg development are recorded for every crab caught.

A juvenile abundance index has been developed based on the trawl survey data and breeding stock and egg production indices have been developed based on the trap survey data. Calculations and analyses are outlined in Section 9.3.5.

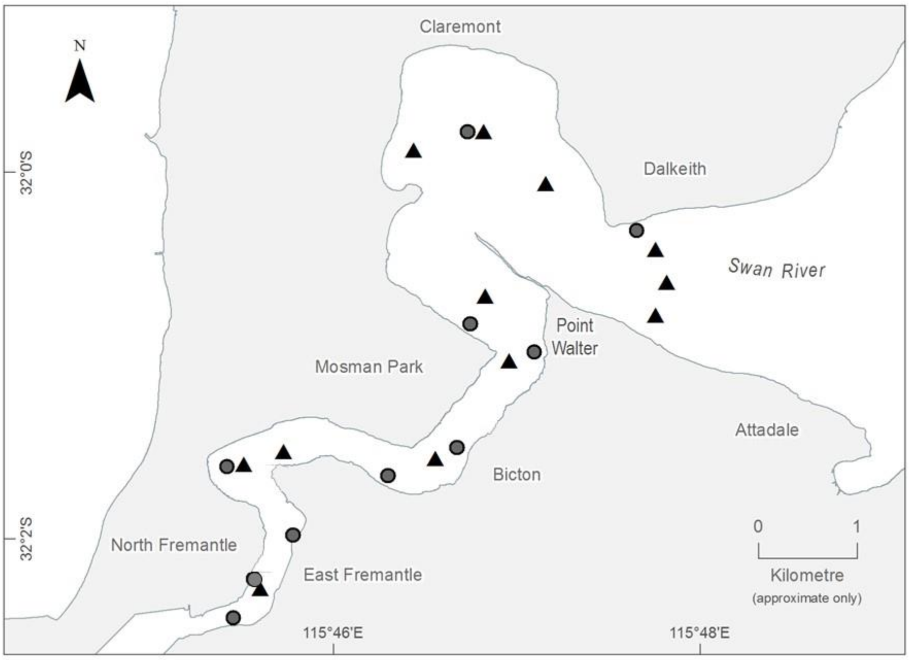


Figure 8.4 Fishery-independent recruitment trawl survey (triangles) and breeding stock trap survey (circles) sites in the Swan-Canning Estuary.

Peel-Harvey Estuary

Fishery-independent trap surveys have been undertaken in the PHE since June 2007 to investigate the status of stocks and develop a legal November index-catch prediction model for this fishery (Johnston *et al*., 2014). During the months of June to November, three baited research hourglass traps are deployed 50 m apart for 24-hours at 15 sites; 6 in the Peel Inlet, 6 in the Harvey Estuary and 3 in the Estuary Channel (**Figure 8.5**). The traps, which are approximately 1.16 m diameter, 0.5 m high and constructed with 51 mm mesh, are baited with approximately 220 g of yelloweye mullet. Unlike commercial traps used in the estuary, these research traps have no escape gaps to allow greater capture of juvenile, sub-legal and legal-sized blue swimmer crabs (Figure 8.6).

Since 2016, a trawl survey has been conducted in the PHE to develop a recruitment index as a potential biological indicator for this fishery (harvest strategy currently uses fishery-dependent estimates of standardised commercial catch rate). Trawls are conducted monthly on board a small research vessel (~6.5–7.5 m) during daylight hours at four sites in the Peel Inlet, three in the Harvey Estuary and three in the Estuary Entrance channel (Figure 8.5). The net, which has a 4.5 m headrope (effective opening width of 3 m based on a net efficiency factor of 0.67), and a height of 0.5 m, is constructed from 51 mm mesh in the wings and 9 mm mesh in the cod end (stretched internal diameter; Figure 8.3). The twin otter boards each measure 600 mm long and 310 mm wide, and weigh 17 kg, and the net has a 10 mm ground chain attached to the foot rope to maintain close contact with the benthos. Each trawl is conducted at a speed of 2.7 kts for three minutes, equating to an approximate distance of 250 m (*c*. 750 m^2 swept area.

For both the trawl and trap surveys, CW (to the nearest mm), sex, moult stage, female maturity and egg development are recorded for every crab caught.

A juvenile abundance index has been developed based on the trawl survey data and a legal November index – catch prediction model has been developed based on the trap survey data. Details of the calculations and analyses are outlined in Section 9.3.5.

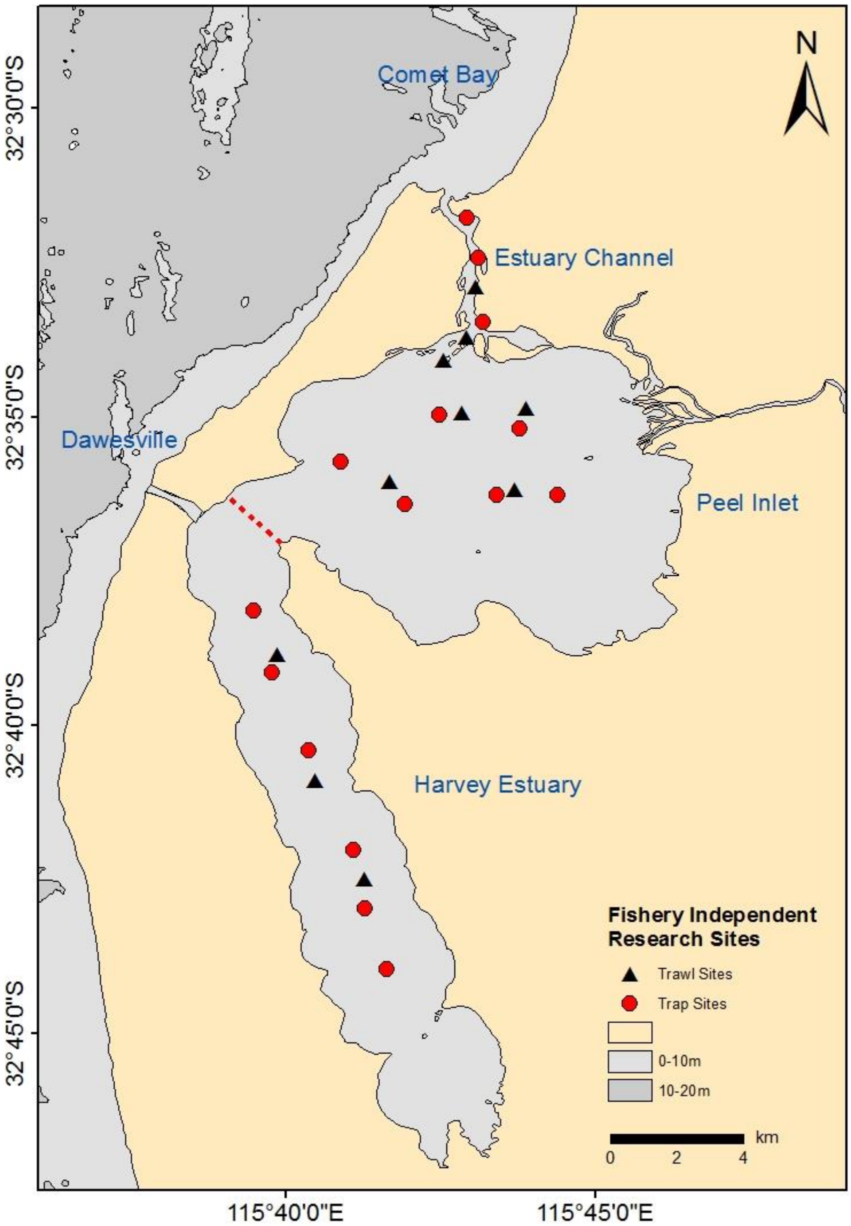


Figure 8.5. Fishery-independent trap survey (red dot) and trawl survey (black triangle) sites in the Peel-Harvey Estuary.

Figure 8.6. Hourglass research trap used in the fishery-independent surveys in the Peel-Harvey Estuary. Note, in comparison to commercial traps there is smaller mesh and no escape gaps.

8.2.5 Environmental Monitoring

Environmental databases are continuously updated and extended as new data becomes available from Departmental fishery dependent and fishery independent surveys (*e.g. in situ* temperature loggers and hand-held multiparameter water quality meters) and other agency sources such as the Bureau of Meteorology, Department of Water and Environmental Regulation, Department of Biodiversity and Conservation and Cockburn Sound Management Council (*e.g.* rainfall, salinity, chlorophyll-*a*). The environmental variables from these databases have been used in reporting long-term environmental and fishery trends (*e.g.* 2010/11 marine heatwave), analyses of correlations with biological parameters of species, influences on commercial catch rates and stock-recruit environment relationships (see Pearce *et al*., 2011; Caputi *et al*., 2015; CSMC, 2018; Johnston *et al*., 2020). The stock recruitment relationship for Cockburn Sound is described in Section 9.3.8.1.

Cockburn Sound

To continuously monitor water temperature in Cockburn Sound at one-hour intervals, *in situ* HOBO TidbiT temperature loggers have been deployed since 2007. Loggers were originally deployed mid-water at five sites in Cockburn Sound since June 2007 including Mangles Bay (MBS), Garden Island navy ammunition jetty (NAJ), Kwinana Grain Terminal (KGT), Southern Flats (SFM), and south Jervois Bay (JBM). In 2011, the logger sites were refined for logistical reasons to only MBS and JBM. Data from loggers is regularly downloaded using Onset HOBOware software (typically every three months). Handheld multiparameter water quality meters (*e.g.* Yellow Springs International™ ProDSS) have been used to measure temperature, salinity, dissolved oxygen and pH at the majority of sites sampled for fishery independent surveys since 2007.

Prior to 2007, in the absence of continuous water temperature data for Cockburn Sound, monthly water temperatures collected in nearby Warnbro Sound at rock lobster puerulus monitoring sites have been used as a proxy for Cockburn Sound water temperature.

Peel-Harvey Estuary

HOBO TidbiT temperature loggers have been deployed at two sites on the science platforms in central waters of both the Peel Inlet and Harvey Estuary since 2007. These are deployed at the middle of the water column and are programmed to record temperature at one-hour intervals. As for Cockburn Sound, data are downloaded typically every three-months. Handheld multiparameter water quality meters have been used to measure temperature, salinity, dissolved oxygen and pH at the majority of sites sampled for fishery independent surveys since 2007.

Swan-Canning Estuary

Handheld multiparameter water quality meters have been used to measure temperature, salinity, dissolved oxygen and pH at the majority of sites sampled for fishery independent surveys since 2007. Water quality monitoring data collected on a weekly basis throughout the estuary are also obtained from the Department of Water and Environmental Regulation through their online database (http://wir.water.wa.gov.au/Pages/Water-Information-Reporting.aspx).

8.2.6 Other Information

Length-Weight Relationships

Length (CW) and weight data were collected for a wide size range of crabs between 2014 and 2019 at six south-west fishery locations during fishery-dependent and fishery-independent surveys (Johnston and Yeoh, 2020). Locations included Comet Bay, Geographe Bay, Cockburn Sound, Warnbro Sound, Peel-Harvey Estuary and the Swan-Canning Estuary. Analyses results are summarised in Table 5.1 within Section 5.3.

Reproduction – Size at Maturity and Fecundity

The reproductive biology of female *P. armatus* has been analysed, specifically size at maturity and batch fecundity across a range of estuarine and coastal systems in WA (Johnston *et al*., *in prep.*). Maturity data were collected between 2011 and 2019 from Shark Bay, Cockburn Sound, Swan-Canning Estuary, Peel-Harvey Estuary, Geographe Bay, Koombana Bay and Leschenault Estuary, while fecundity data were collected in Shark Bay, Cockburn Sound and Peel-Harvey Estuary during the summer of 2013/14. Analyses results are summarised in Table 5.1 within Section 5.3. Timing and duration of spawning in relation to water temperature has also been analysed in Cockburn Sound (Johnston *et al*., *in prep.*).

9. Stock Assessment

9.1 Assessment Principles

The different methods used by the Department to assess the status of aquatic resources in WA have been categorised into five broad levels, ranging from relatively simple analysis of catch levels and standardised catch rates, through to the application of more sophisticated analyses and models that involve estimation of fishing mortality and biomass (Fletcher and Santoro 2015). The level of assessment varies among resources and is determined based on the level of ecological risk, the biology and population dynamics of the relevant species, the characteristics of the fisheries exploiting the species, data availability and historical level of monitoring.

Irrespective of the types of assessment methodologies used, all stock assessments undertaken by the Department take a risk-based, weight of evidence approach (Fletcher 2015). This requires specifically the consideration of each available line of evidence, both individually and collectively, to generate the most appropriate overall assessment conclusion. The lines of evidence include the outputs that are generated from each available quantitative method, plus any qualitative lines of evidence such as biological and fishery information that describe the inherent vulnerability of the species to fishing. For each species, all of the lines of evidence are then combined within the Department's ISO 31000 based risk assessment framework (see Fletcher 2015; Appendix 2) to determine the most appropriate combinations of consequence and likelihood to determine the overall current risk status.

9.2 Assessment Overview

In the absence of a population model, the annual assessment of *P. armatus*, is based primarily on an analysis of commercial catch rates, which are assumed to be an index of abundance and used as a proxy for spawning biomass (Level 2 assessment). Commercial catch data are standardised to account for the effects of year, month and vessel on catch rates (see Section 9.3.3). The annual standardised catch rates are compared to reference points specified in the harvest strategy (DoF, 2015; Johnston *et al*., 2015a; DPIRD, 2020). In the Cockburn Sound crab managed fishery (CSCMF), annual estimates of annual recruitment and egg production indices are also undertaken based on fishery-independent surveys (Level 4 assessment) and are being developed for the Swan-Canning Estuary (SCE) and Peel-Harvey Estuary (PHE) crab fisheries.

A weight-of-evidence approach is applied to all fisheries where fishery-dependent and fishery-independent data are considered with the results of a Productivity Susceptibility Analysis (PSA) to evaluate the inherent vulnerability of each species to fishing.

9.2.1 Peer Review of Assessment

Stock assessments of key target species are internally reviewed as part of the Department's process for providing scientific advice to management and the Minister on the status of fish stocks. Stock assessments for CSCMF and PHE have been peer reviewed both internally (Johnston *et al*. 2011a; Johnston *et al*. 2014) and externally (de Lestang *et al*.2010; Johnston *et* *al*. 2011b; Johnston *et al*. 2015a). External peer-reviews for the CSCMF and PHE fishery have also been undertaken by W. Sumpton, Department of Agriculture and Fisheries Queensland (Sumpton, 2012).

All blue swimmer crab fisheries underwent pre-assessment against the Marine Stewardship Council (MSC) standard for sustainable fishing in 2013-14 using a bioregional assessment approach (Bellchambers *et al*. 2016). The Peel-Harvey Estuary crab fishery was assessed against the MSC standard (v. 1.3), being the first commercial and recreational fishery in the world to achieve full certification in June 2016 (Johnston *et al*. 2015a).

9.3 Analyses and Assessments

9.3.1 Data Used in Assessment

CAES / Logbook
Economic data
Environmental data
Fishery-dependent data (commercial and recreational)
Fishery-independent survey data (trap and trawl surveys)

9.3.2 Catch and Effort Trends

9.3.2.1 West Coast Bioregion Overview

Total commercial blue swimmer crab catch in the West Coast Bioregion (WCB), which includes major fisheries in Cockburn Sound, Swan-Canning Estuary and the Peel-Harvey Estuary, as well as minor fisheries in Warnbro Sound, Mandurah to Bunbury (Area 1 and Area 2), Leschenault Estuary, Geographe Bay and Hardy Inlet, increased from 54-100 t during the late 1970s and early 1980s to over 250 t in the late 1990s and early 2000s (Figure 9.1). The highest catches on record of 524, 443 and 425 t occurred in 1997, 2000 and 1998, respectively. These catches were mostly taken by trap fishing (Figure 9.2). The number of fishing vessels retaining blue swimmer crabs in the WCB was highest in the late 1980s, peaking at 81 vessels in 1986 (Figure 9.1). This decreased substantially in the late 1990s and early 2000s, and since 2005 less than 25 vessels annually have landed blue swimmer crabs. Prior to 1995 the majority of catch from the WCB was taken by gill net, however, gill net effort has substantially declined since then and trap fishing now accounts for the vast majority of catch (Figure 9.2).

The very high annual catches during the late 1990s/early 2000s predominantly came from Cockburn Sound, where annual catches from 1995 to 2000 ranged from 194 to 360 t following conversion of the fishery from a gill net fishery to a trap fishery as described above and earlier in Section 6.1.1.1. Since the initial decline of the CSCMF in 2006, the Peel-Harvey Estuary has become the principal fishery contributing to total commercial catch in the WCB, with a peak in 2013/14 of 107 t (Figure 9.1). The total commercial catch from the WCB in 2019 was 92 t landed by 14 vessels, which contributed 14% to the total state-wide commercial Blue Swimmer Crab catch of 661 t. Of the 2019 WCB total, 70.1 t was landed from the Peel-Harvey Estuary and 21.8 t was landed from other areas including the Swan-Canning Estuary, Warnbro

Sound and Comet Bay (Table 9.1; Figure 9.1). No catch was taken from Cockburn Sound, which has remained closed to fishing since 2014.

Substantial recreational blue swimmer catch also occurs in the WCB. Recreational catches estimated by four state-wide surveys of recreational fishing from boats during 2011/12, 2013/14, 2015/16 and 2017/18 (Ryan *et al*., 2019) are shown in Figure 9.3. Shore-based recreational catch is also substantial in estuarine fisheries such as the Peel-Harvey and Swan-Canning (Malseed and Sumner, 2001b; Smith, 2006) and recent data for this component of the catch is currently being collected for assessment.

The highest boat-based recreational catches from 2011/12 to 2017/18 were taken in the Peel-Harvey Estuary, with annual totals ranging from 26 to 46 t (Figure 9.3). Recreational boat-based catches across this period were lower in the Swan-Canning Estuary (6–17 t) and Cockburn Sound (6–13 t). Since the closure of Cockburn Sound in 2014 recreational fishing has only occurred north of Woodman Point.

Detailed recent commercial catch and effort information for Cockburn Sound, the Swan-Canning Estuary and the Peel-Harvey Estuary crab fisheries are provided in subsection 9.3.2.2. Assessment of the minor fisheries in Warnbro Sound, Mandurah to Bunbury (Area 1 and Area 2), Leschenault Estuary, Geographe Bay and Hardy Inlet is contained in a separate Resource Assessment Report.

Table 9.1. Annual catches (t) of blue swimmer crabs retained by the commercial crab fisheries in the West Coast Bioregion during 2019 (calendar year) compared to the five-year average from 2014–2018. The total catch for each fishery during 2014–2018 is also given.

Fishery	**2019**	**2014-2018**	
		Mean (± SD)	Total
Cockburn Sound Crab Managed Fishery^	0	4.4 (± 9.8)	21.86
Peel-Harvey Crab Fishery (Area 2 WCEMF)	70.1	78.6 (± 22.1)	392.8
Other areas*	21.8	17.9 (± 8.12)	89.6
West Coast Bioregion Total*	91.9	100.8 (± 32.1)	504.2

^Closed to fishing since April 2014. *Total from all crab fisheries, including the Swan-Canning Estuary (Area 1, WCEMF), Warnbro Sound, Mandurah to Bunbury (Area 1 & 2) and Hardy Inlet (Area 3, WCEMF).

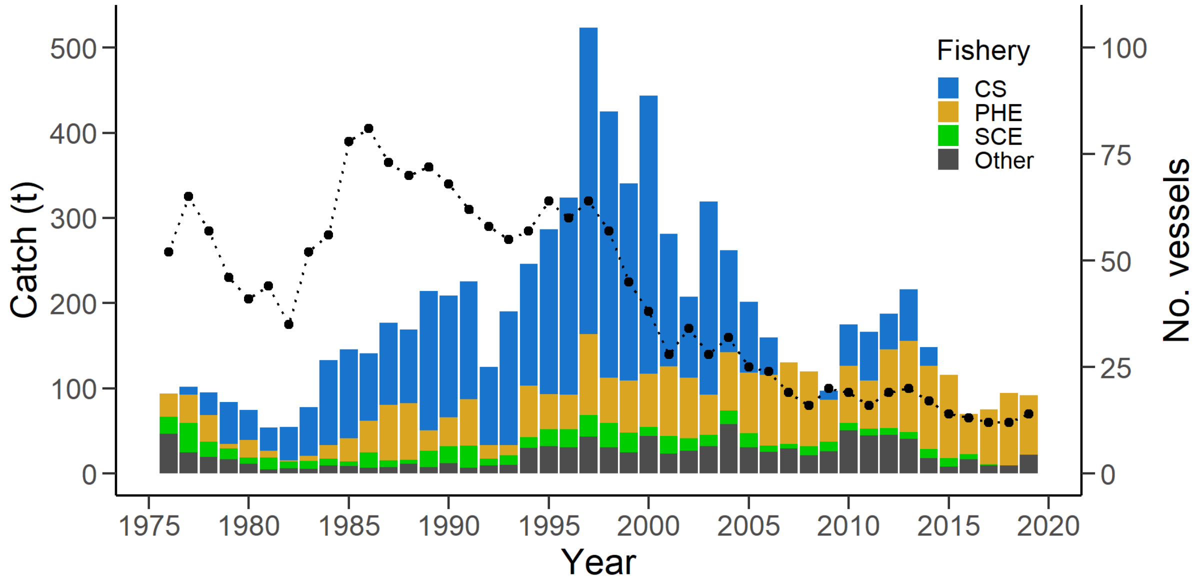


Figure 9.1. Annual commercial catch (by calendar year) for the blue swimmer crab fisheries in the West Coast Bioregion of Western Australia since 1976. The number of licensed fishing vessels retaining blue swimmer crabs each year is also shown (●). Fisheries: CS—Cockburn Sound, PHE—Peel-Harvey Estuary, SCE—Swan-Canning Estuary. Other refers to any other commercial blue swimmer crab catch from the West Coast Bioregion, and includes Warnbro Sound, Mandurah to Bunbury (Area 1 and Area 2), Leschenault Estuary, Geographe Bay and Hardy Inlet. Note, due to confidentiality, SCE catch data from 2018 and 2019 is presented with data for 'Other' fisheries.

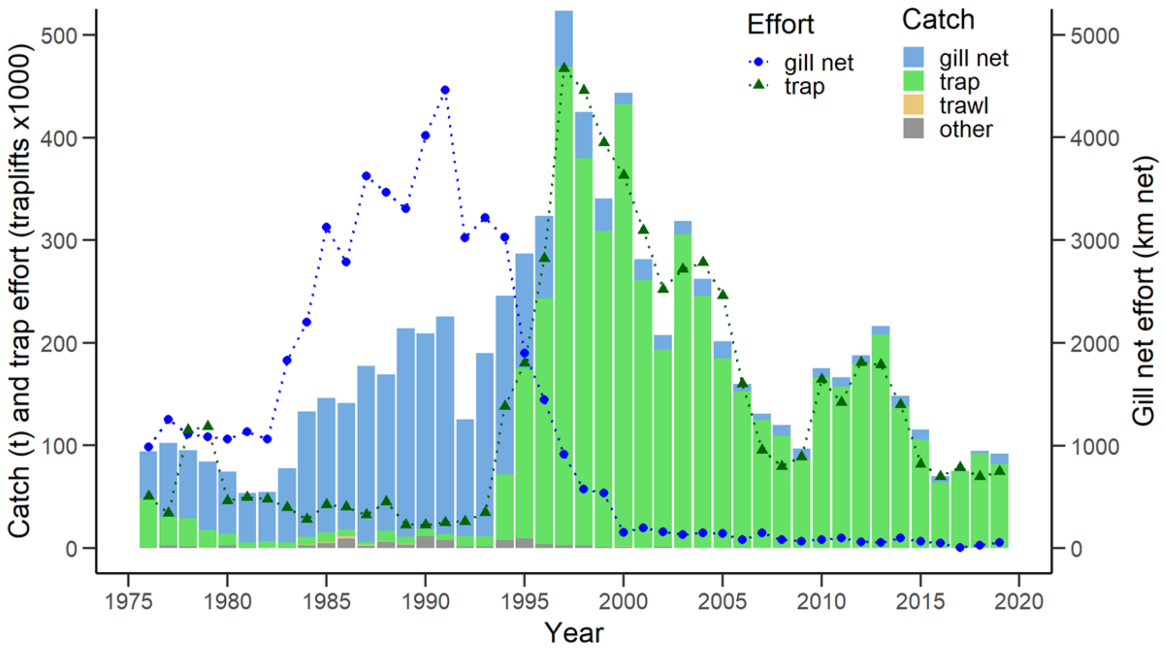


Figure 9.2. Total annual blue swimmer crab catch for the West Coast Bioregion caught by gill nets (set nets), traps, trawling and all other methods combined (*e.g.* haul net, beach seine) from 1976 to 2019. For clarity, effort is only shown for gill net and traps, which accounted for 99% of the total catch.

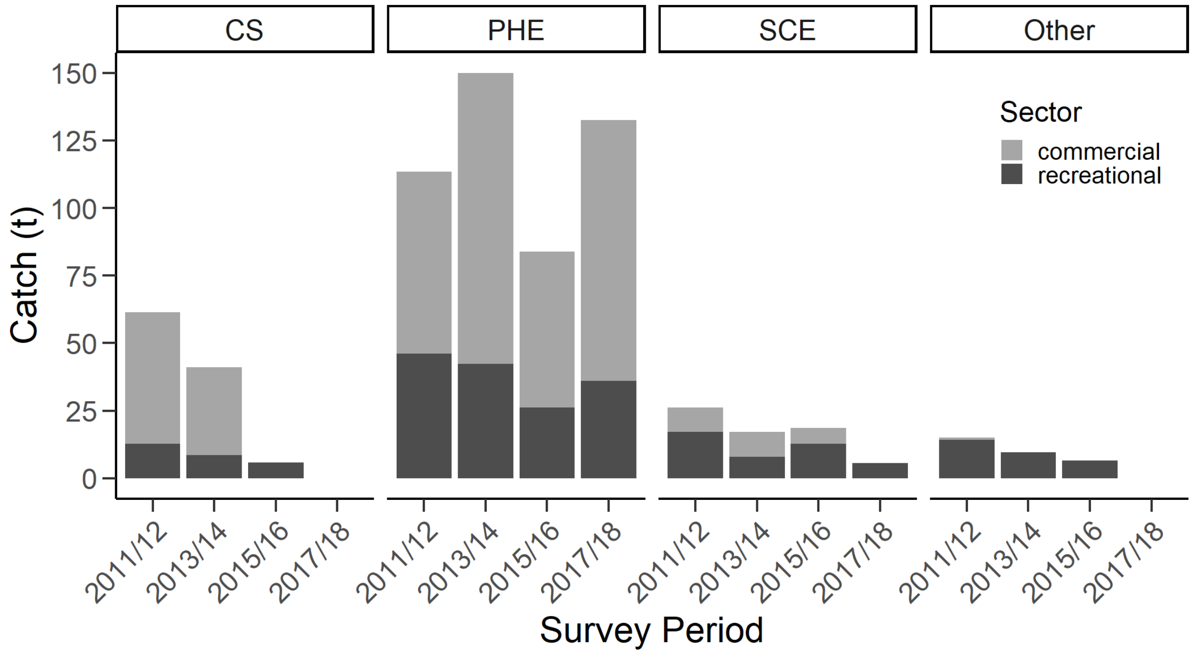


Figure 9.3. Annual blue swimmer crab catch by boat-based recreational and commercial fishers in Cockburn Sound (CS), Peel-Harvey Estuary (PHE), Swan-Canning Estuary (SCE) and other key fishing areas (Geographe Bay and Hardy Inlet, combined) during three state-wide survey periods (*i.e.* March 2011 to February 2012; 2011–12, May 2013 to April 2014; 2013-14, September 2015 to August 2016; 2015-16, September 2017 to August 2018; 2017–18). Recreational catch was estimated using the survey methodology outlined in Ryan *et al*. (2019). Note, 2017/18 data for CS and 'other' were not available at the time of publication, and 2017/18 commercial data for SCE are not shown due to confidentially. CS was closed to all commercial fishing from April 2014, and the allowable area for recreational fishing was reduced (see Section 6.2 for further details).

9.3.2.2 Commercial Catch and Effort

9.3.2.2.1 Cockburn Sound

Following conversion from gill nets to traps in the mid-1990s, commercial crab catches from the trap fishery increased rapidly to peaks of 350 t and 326 t in 1997 and 2000, respectively (Figure 9.4). Catches then declined progressively to only 49 t in 2006/07, at which point the fishery was closed for 3 years due to low stock abundance. With evidence of increases in stock abundance, the fishery was reopened for the 2009/10 to 2013/14 seasons, with precautionary management changes in place as outlined earlier in Section 6.2. Catch and effort remained low over these five seasons with only a few fishers operating during this time (Figure 9.4). Total annual catch from 1995 to 2014 was closely related to effort ($R^2 = 0.85$; $P < 0.001$; Figure 9.5a), although there was no relationship between total effort and CPUE ($P > 0.05$; Figure 9.5b).

Post-closure, the majority of catch over these seasons was landed in the summer months, predominantly January, with catches reducing considerably from March (Figure 9.6). In the 2012/13 fishing season, catches peaked in January at 15 t from 15,870 traplifts and remained above 12 t until April, after which catches reduced to 5 t in May, despite effort remaining fairly high at 10,535 traplifts (Figure 9.7). The fishing season ended on 15 June with catches <2 t from 4,735 traplifts. Catches remained low at the start of the 2013/14 fishing season and peaked at 8.7 t in January from 11,537 traplifts. With continuing reduced catches throughout the following months the fishery was closed to commercial fishing in April 2014 and to the recreational sector in May 2014.

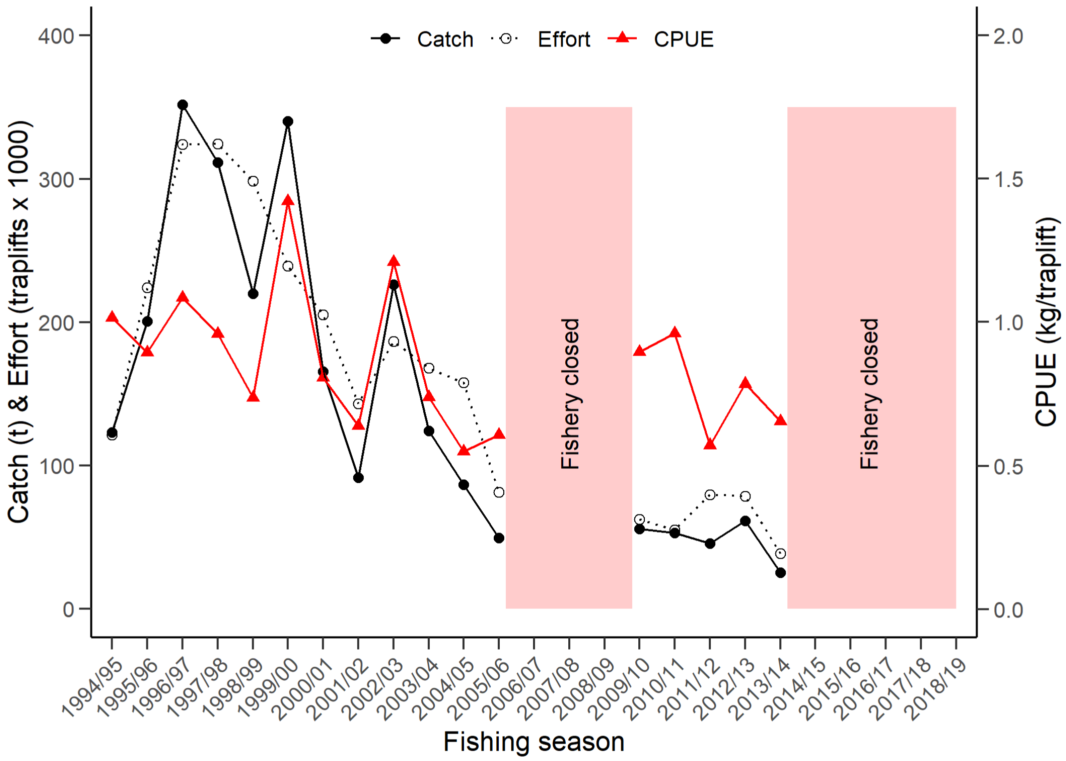


Figure 9.4 Annual commercial trap catch (tonnes) and effort (traplifts x 1000) in the Cockburn Sound Crab Managed Fishery since 1994/95. Data is presented over the fishing season (note fishing season changed between years). A spawning closure during October–November was introduced in 1999. The fishery was first closed to fishing between December 2006 and December 2009, reopening under modified management, before a second closure in April 2014.

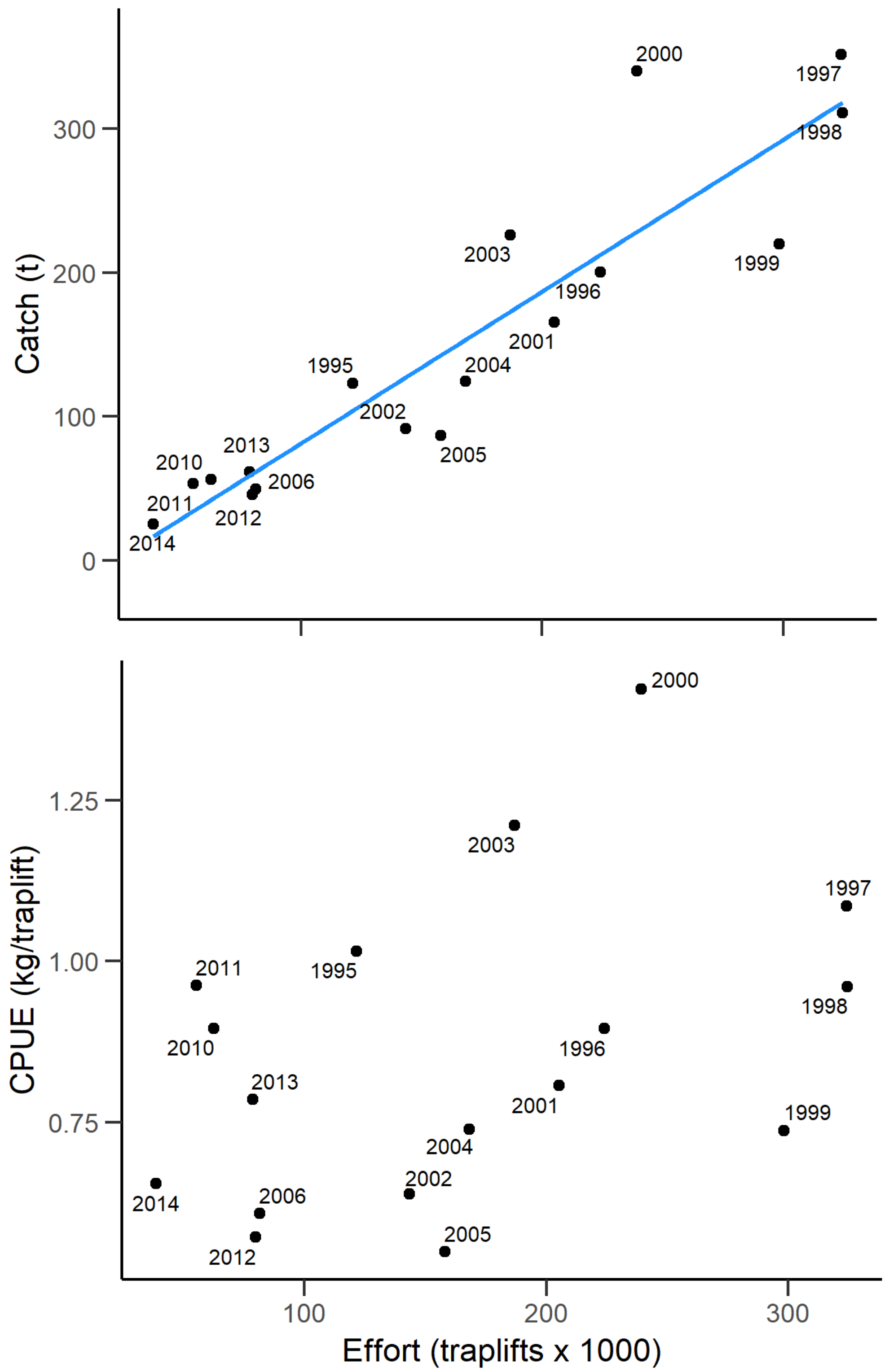


Figure 9.5 Correlation between fishing effort (no. traplifts x1000) and (a) total annual catch [R2 = 0.85; P < 0.001], and (b) CPUE (kg / traplift) [R2 = 0.11; P > 0.05] for the Cockburn Sound Crab Fishery each fishing season from 1996 to 2019.

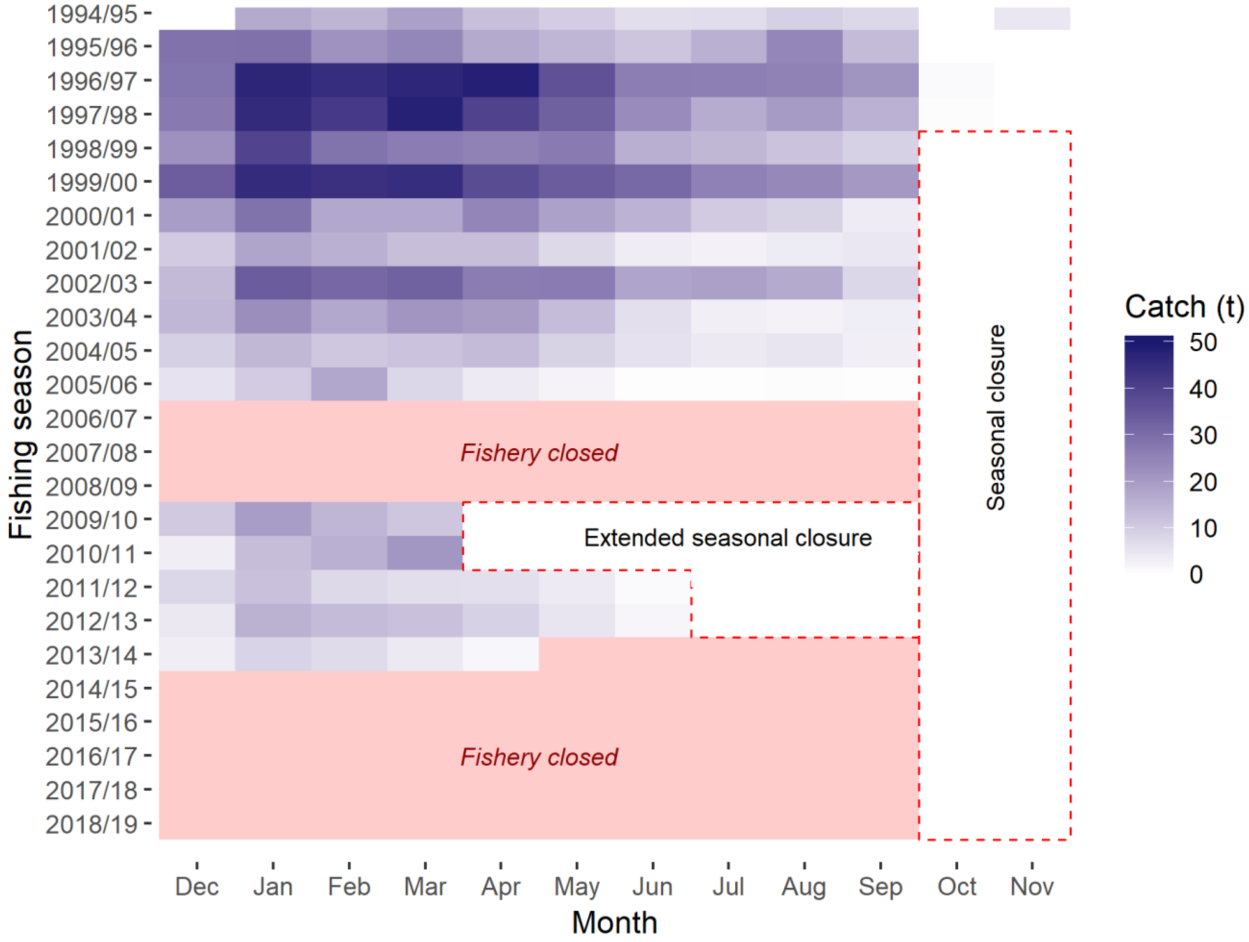


Figure 9.6 Total monthly commercial blue swimmer crab catch (t) in Cockburn Sound between the 1994/95 and 2018/19 fishing seasons (trap catch only). A seasonal closure during October–November was introduced in 1999. The fishery was first closed to fishing in December 2006, reopening in December 2009 under modified management with an extended seasonal closure. The fishery was again closed in April 2014.

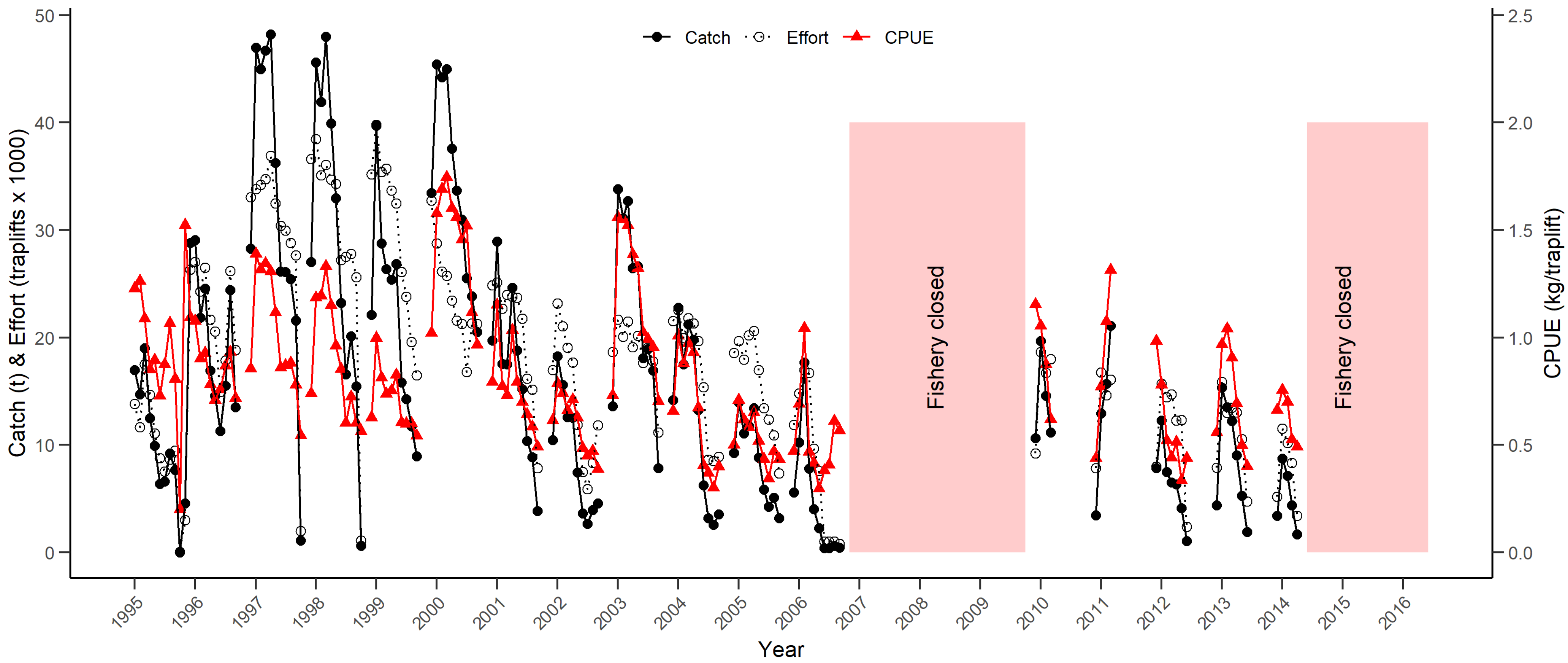


Figure 9.7 Commercial monthly trap catch (t), effort (traplifts x 1000) and CPUE (kg/traplift) in the Cockburn Sound Crab Managed Fishery from 1995 to 2019. The fishery was closed to fishing in two periods as described in Figure 9.6 earlier.

9.3.2.2.2 Peel-Harvey Estuary

Since the introduction of crab traps in the Peel-Harvey Estuary commercial fishery during the 1995/96 season, annual catches from 1995/96 to 2018/19 have ranged from 45 to 107 t, peaking in 2012/13 (Figure 9.8). There has been a general pattern where catches increase for four to five seasons, before substantially declining. Overall, annual catch is significantly correlated with effort ($R^2 = 0.61$; $P < 0.001$; Figure 9.9), although spikes in total catches during 2001/02, 2006/07, 2012/3 and 2017/18 appear to be due to increased catch rates in those seasons (Figure 9.8; Figure 9.9). The 2018/19 season catch was 66.5 t from 59,472 traplifts, a decrease of 30 t from 2017/18.

Commercial catches tend to be low in November when the season reopens, with catches increasing in December and a peak in January (Figure 9.10; Figure 9.11). Over the remaining fishing season catches tend to decline steadily. The decline is likely due to both (a) emigration of crabs from the estuary to marine waters in autumn and winter as water temperatures decline and freshwater flows increase due to rainfall (see Appendix 8), and (b), a reduction in abundance due to fishing throughout the season. In fishing seasons where lower than average total annual catches have occurred (*e.g.* 2008/09-2010/11, 2015/16, 2016/17) it is generally a result of lower than average January to March catches (Figure 9.11; Figure 9.12). In contrast, when catches remain high for longer throughout the year into late autumn and early winter (for example during 2017/18), total annual catch is generally higher than average.

Catches during the 2018/19 season were very low during the start of the season, with November and December catch rates the lowest on record since 1995/96 (Figure 9.12; Figure 9.13). Catch rates during January, March, July and August were also notably lower than the long-term average for these months. These decreased catch rates are likely attributable to cooler than average water temperatures throughout much of the 2018/19 season (see Appendix 8), which likely decreased catchability and may have caused emigration of crabs to warmer marine waters earlier in the season than is typical.

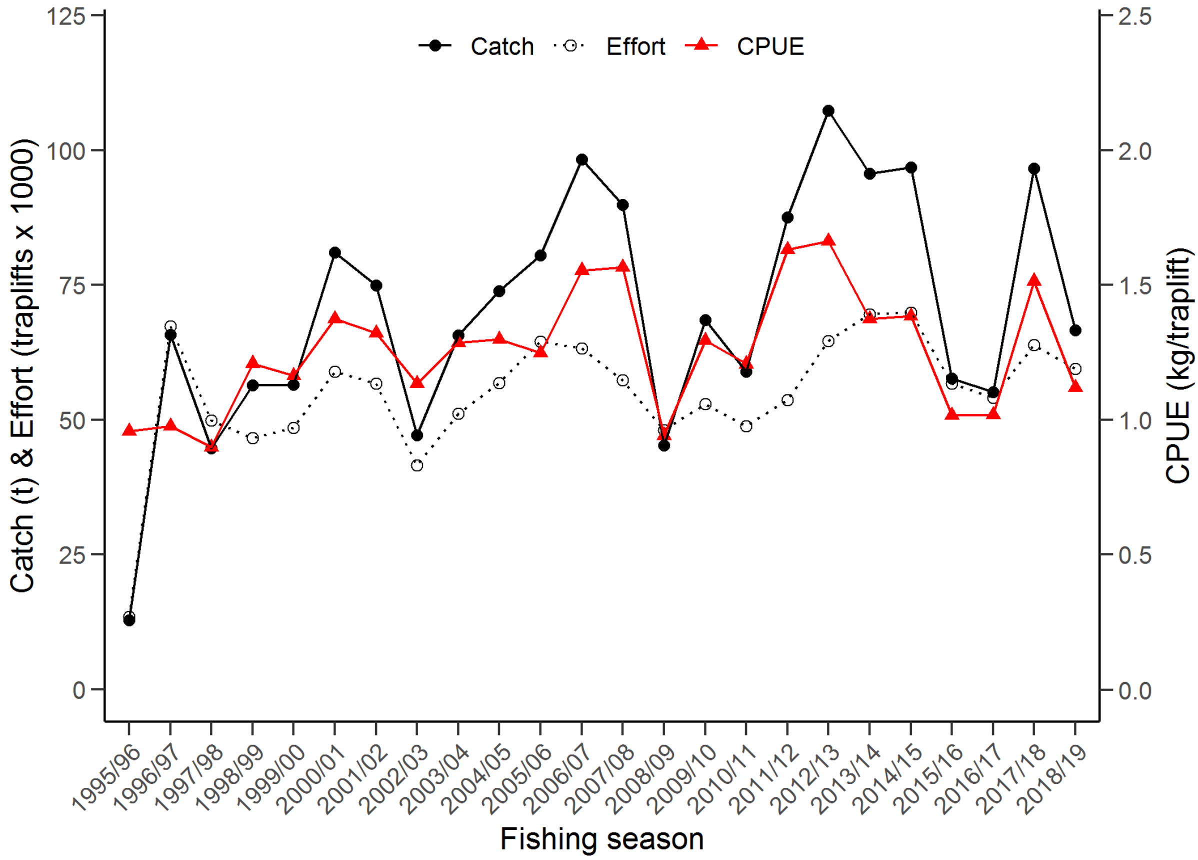


Figure 9.8 Commercial catch (t) and effort (traplifts x 1000) in the Peel-Harvey Estuary Crab Fishery since the 1995/96 fishing season (November 1 to August 31 the following year). A seasonal closure from September 1 to October 31 was introduced in 2007, which was extended to include November for the 2019/20 season.

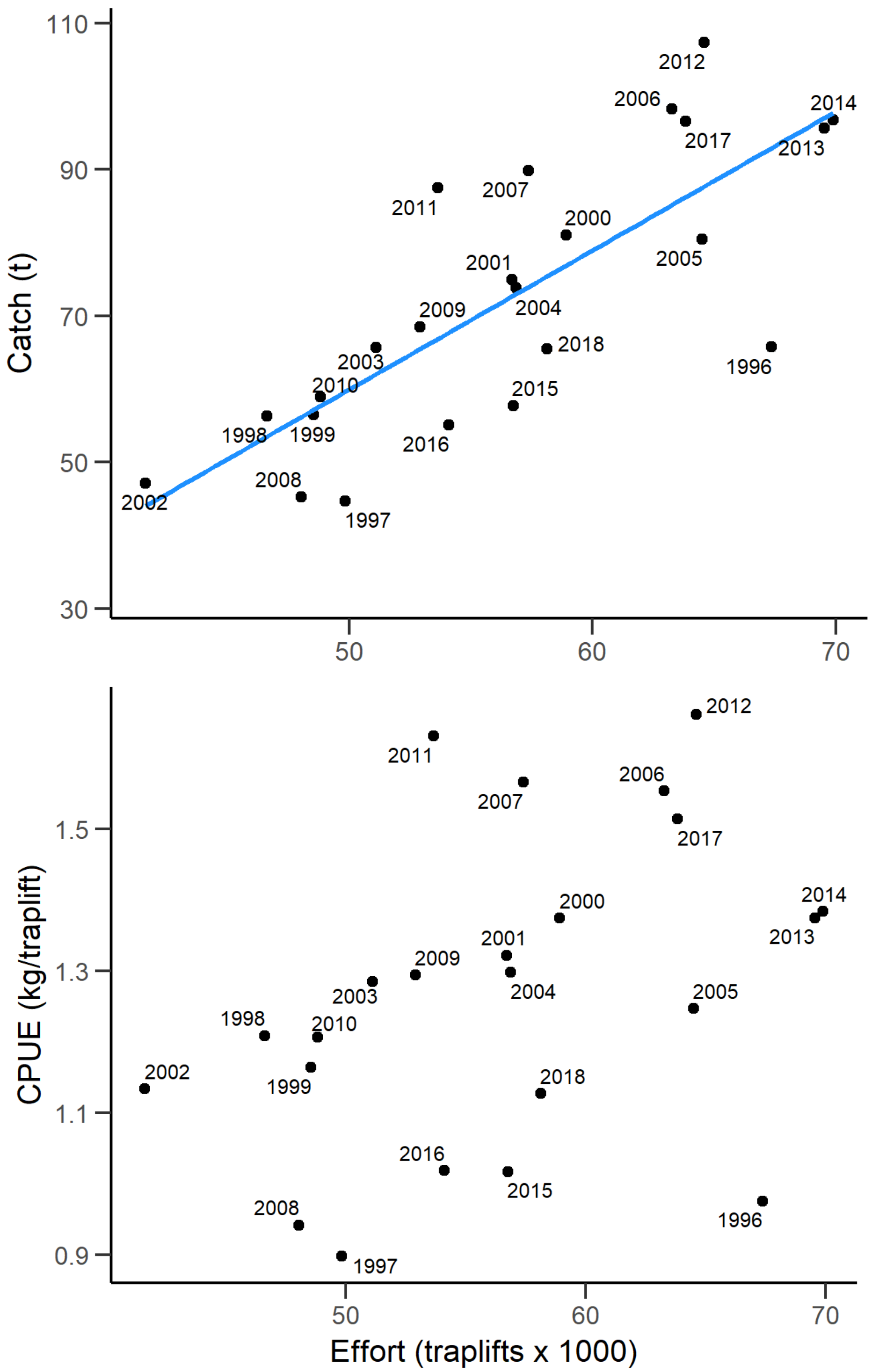


Figure 9.9 Correlation between fishing effort (no. traplifts x1000) and (a) total annual catch [R^2 = 0.61; P < 0.001], and (b) CPUE (kg / traplift) [R^2 = 0.2; P > 0.05] for the Peel-Harvey Estuary Crab Fishery each fishing season from 1996 to 2019.

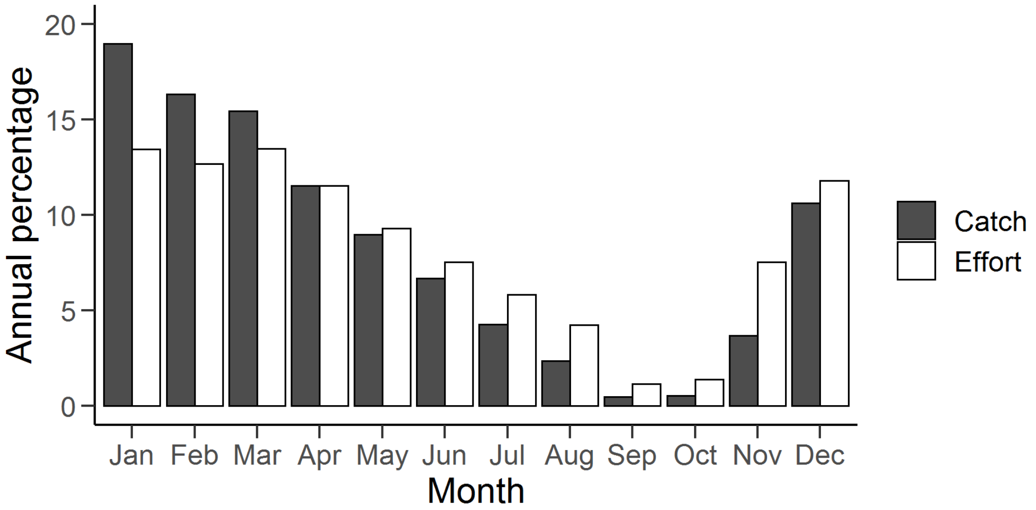


Figure 9.10 Total percentage of commercial catch (by weight) and effort (no. traplifts) each month in the Peel-Harvey Estuary Crab Fishery across the entire trap fishery period from 1995 to 2019. A seasonal closure from September 1 to October 31 was introduced in 2007, which was extended to include November for the 2019/20 season.

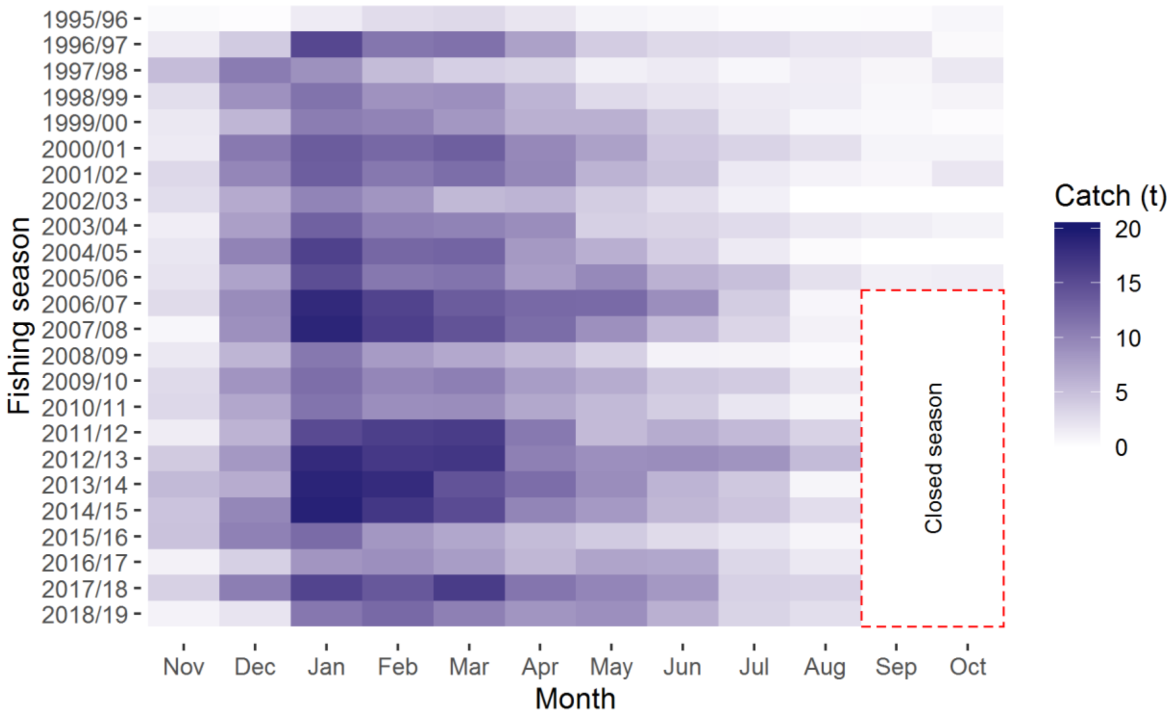


Figure 9.11 Monthly commercial catch (t) in the Peel-Harvey Estuary Crab Fishery in each fishing season from 1995/96 to 2018/19. Fishing season is defined as November 1 to October 31 prior to 2006/07, and November 1 to August 31 since 2006/07 (with a September–October closure; denoted on Figure).

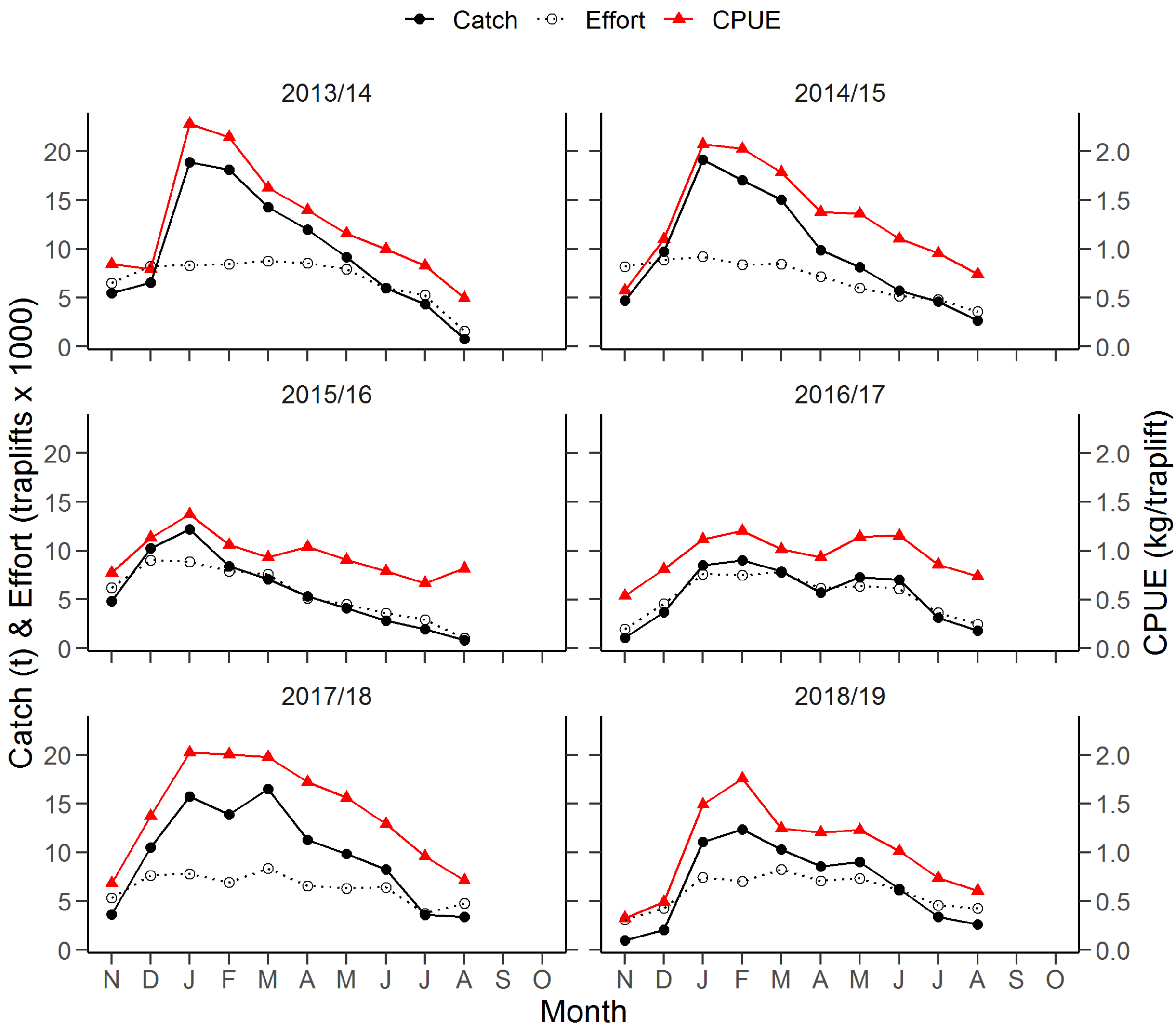


Figure 9.12 Monthly commercial catch (t), effort (traplifts x 1000) and CPUE (kg/traplift) in the Peel-Harvey Estuary Crab Fishery for each fishing season from 2013/14 to 2018/19. Fishing season is defined as November 1 to August 31 the following year.

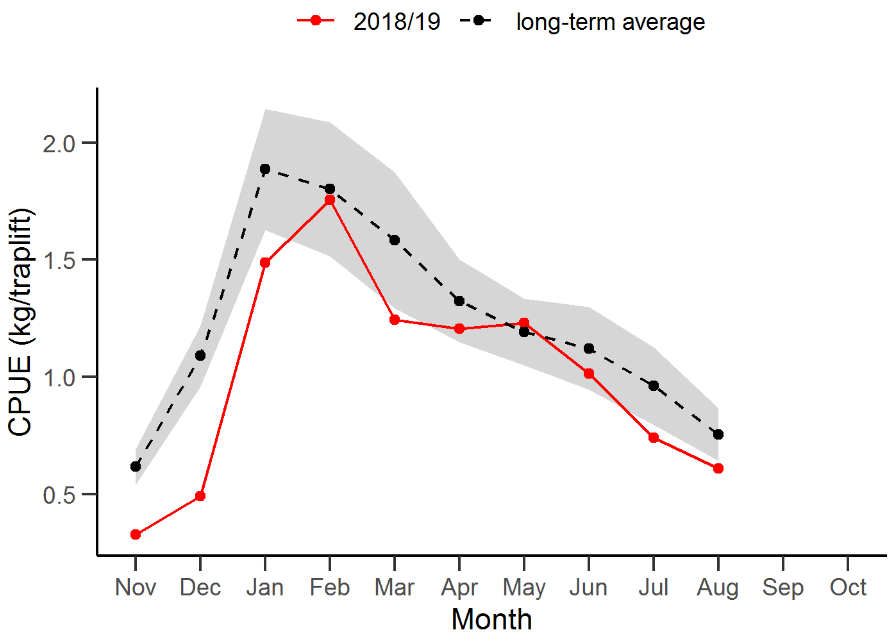


Figure 9.13 Monthly commercial catch CPUE (kg/traplift) in the Peel-Harvey Estuary Crab Fishery during the 2018/19 fishing season compared with the long-term (2007/08 to 2017/18) average. Fishing season is defined as November 1 to August 31 the following year, with a September–October closure since 2006/07.

9.3.2.2.3 Swan-Canning Estuary

Annual commercial catch in the Swan-Canning Estuary between 1976 and 2017 has ranged from 1 to 33 t (Figure 9.14). Over time effort (annual length of gill net fished) has steadily declined due to a reduction in the number of fishers operating (see also Section 6.1.3.1). Since 2008 only a single fisher has operated, and total annual effort has ranged from 4,320–99,360 metres of net (compared with up to 571,997 metres during the 1970s; Figure 9.14). Catch remained relatively stable at 8–10 t from 2008 to 2015, before declining in 2016–17 to 1–6 t, reflecting a lack of fishing effort in these years (Figure 9.14). Catch and effort in 2018 and 2019 was within these historical ranges. Overall, annual catches since 1976 are significantly correlated with total annual fishing effort ($R^2 = 0.3$; $P < 0.001$; Figure 9.15).

There has been a general increase in catch rate (nominal CPUE) over time since 1976 (Figure 9.14). Thus, prior to 1998 CPUE did not exceed 10 kg / 100 m of net, whilst since 2010 CPUE has ranged 10–24 kg / 100 m of net. There is also a significant negative correlation between total annual effort and CPUE ($R^2 = 0.46$; $P < 0.001$; Figure 9.15).

Prior to 2019 there has been no seasonal closure in place for the Swan-Canning Estuary crab fisher, however, fishing effort has been typically concentrated over the summer months, with the vast majority of catch and effort typically occurring from December to April (88% of catch and 77% of effort since 1976; Figure 9.16; Figure 9.17). In 2012, 2013 and 2016 catches peaked in February–March, before declining during late autumn and early winter. In 2015, however, catches peaked in January at 2.9 t and decreased in each subsequent month to a low of 0.05 t in July from 3 days (1440 m total net length) before fishing operations stopped for the winter period (Figure 9.18). Minimal commercial fishing occurred in 2017 with a total catch of 1.03 t from 4,320 metres of net (15 fishing days) in January and February. An unseasonal historical peak in rainfall over a 24-hour period in February flushed the majority of crabs from the estuary and the fisher did not resume fishing for the rest of the year. In 2018 minimal fishing also occurred, with minor catch and effort from February to July, as well as in December (data not shown). In 2019, catch and effort was moderate from January to April, and declined markedly during May and June (data not shown).

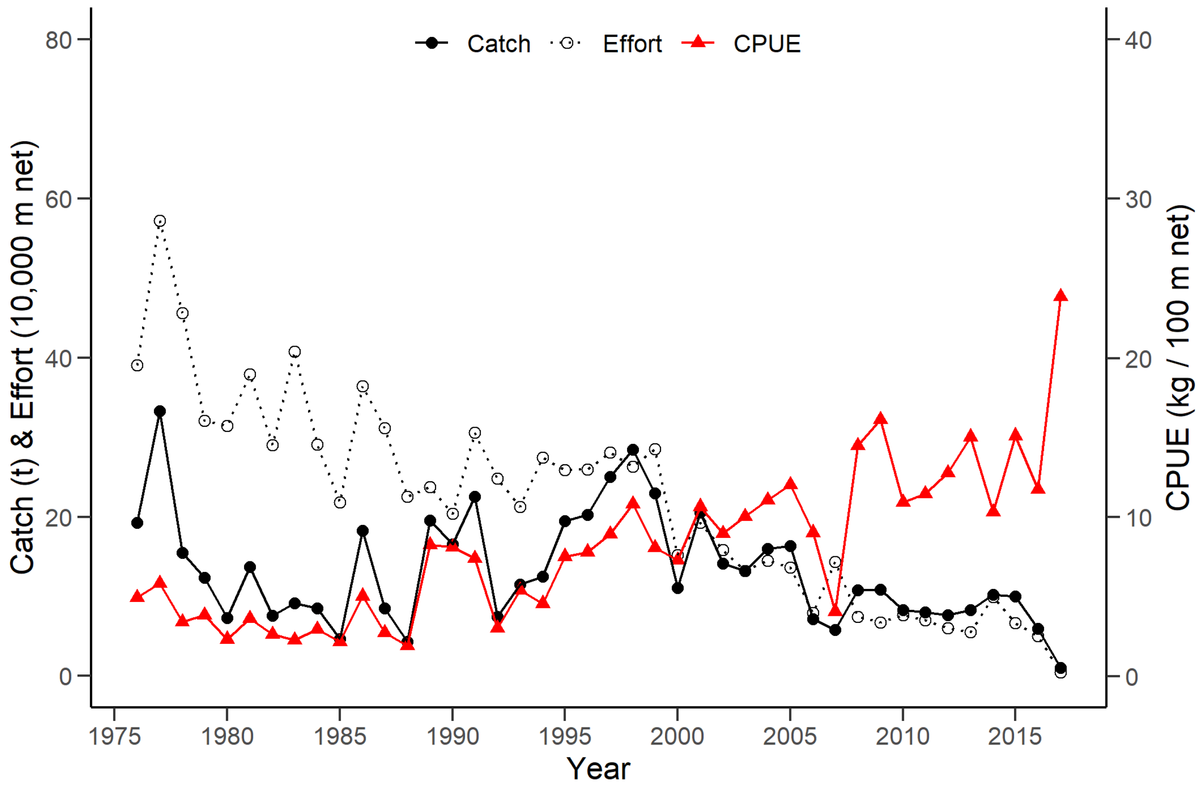


Figure 9.14 Commercial catch (t), effort (m net ×10 000) and CPUE (kg 100 m net^{-1}) for the Swan-Canning Estuary Crab Fishery from 1976 to 2017.

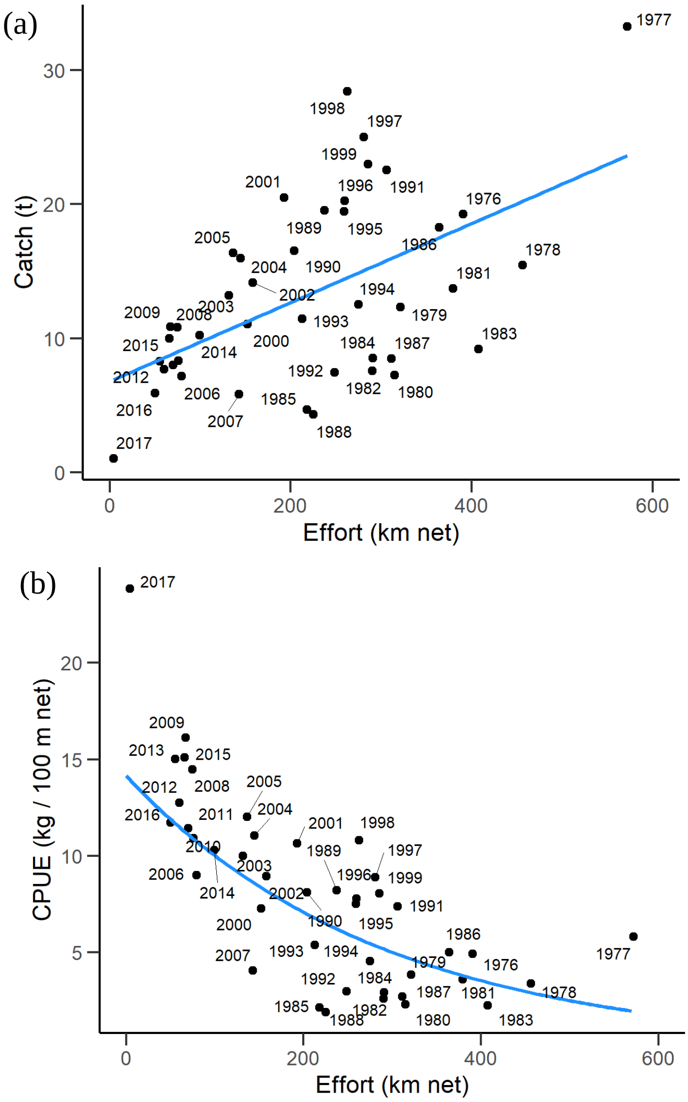


Figure 9.15 Correlation between fishing effort (km of gill net) and (a) total annual catch [$R^2 = 0.3$; $P < 0.001$] and (b) CPUE (kg 100 m net−1) [$R^2 = 0.46$; $P < 0.001$] for the Swan-Canning Estuary Crab Fishery from 1976 to 2017.

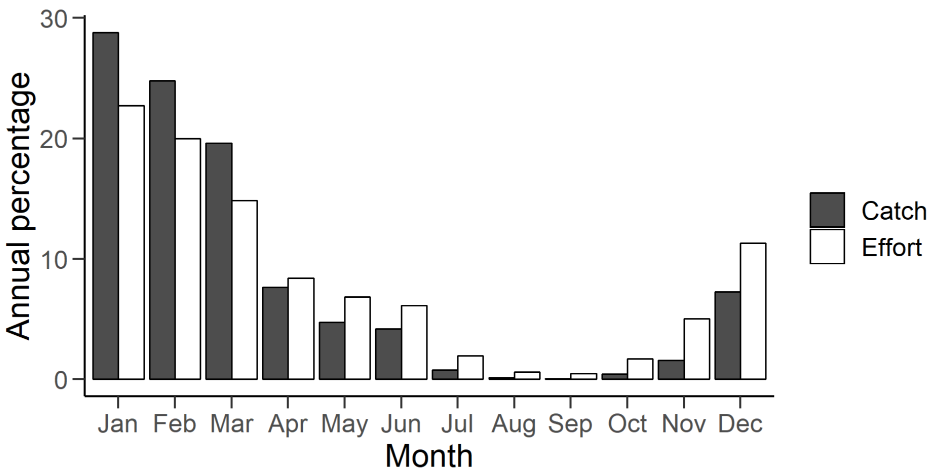


Figure 9.16 Total percentage of commercial catch (by weight) and effort (gill net length) each month in the Swan-Canning Estuary Crab Fishery from 1976 to 2019.

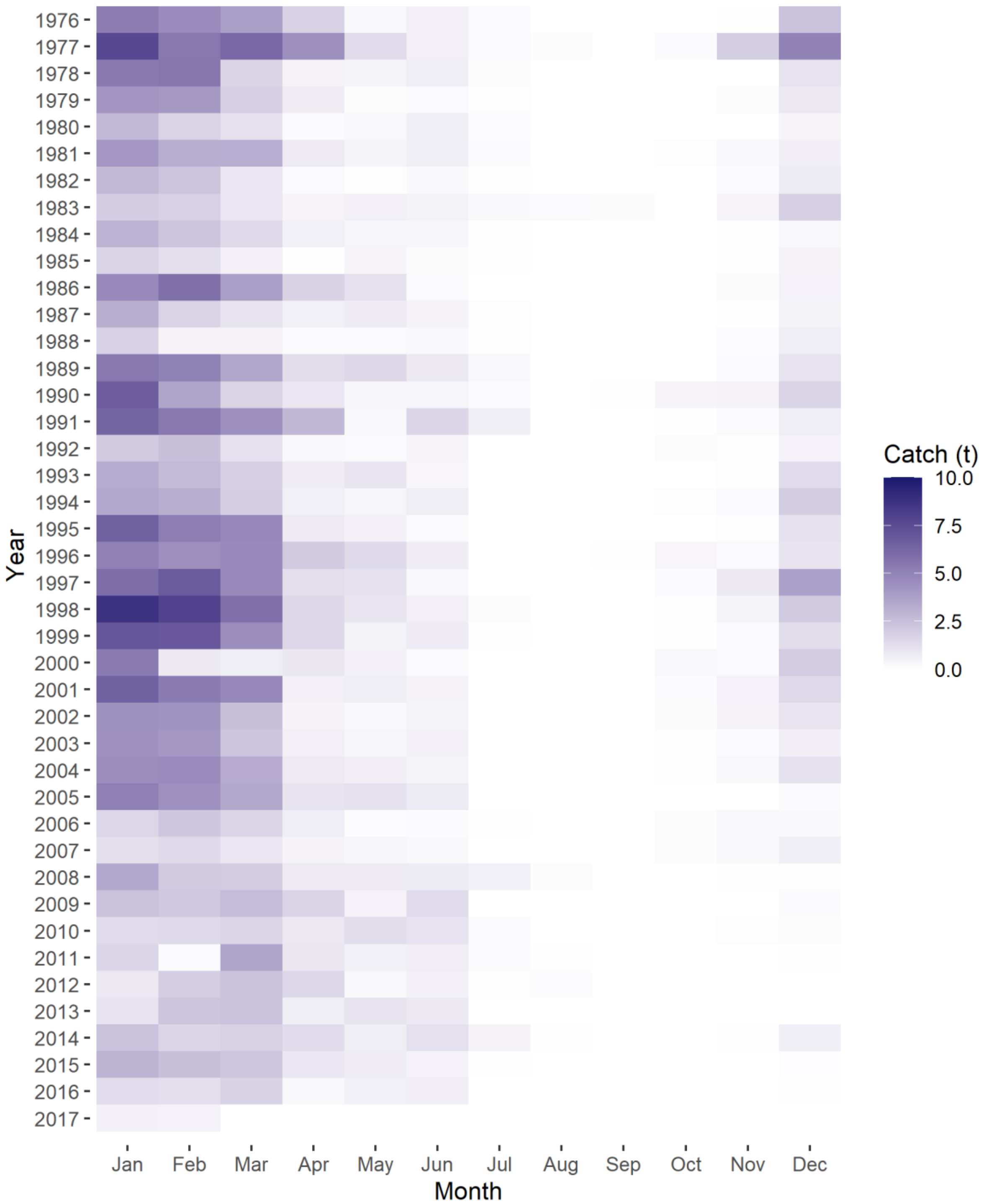


Figure 9.17 Monthly commercial catch (t) in the Swan-Canning Estuary each year from 1976 to 2017.

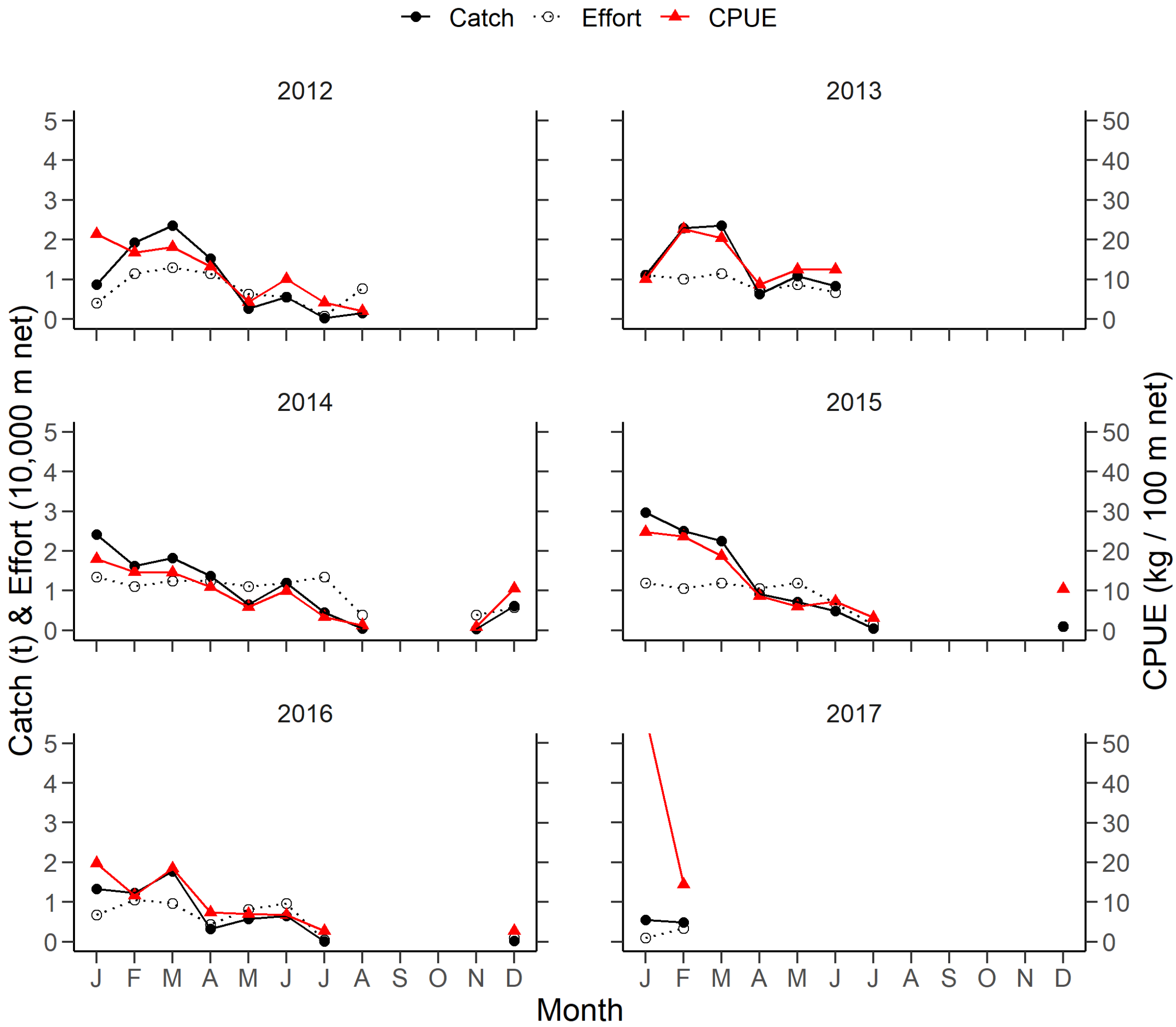


Figure 9.18 Monthly commercial catch (t), effort (m net ×10 000) and CPUE (kg 100 m net^{-1}) in the Swan-Canning Estuary Crab Fishery each year from 2012 to 2017. Note, the CPUE value for January 2017 (outside of plot limits) is 56.8 kg 100 m net^{-1}.

9.3.2.3 Recreational Catch and Effort

Most (89%) of the recreational blue swimmer crab fishing in Western Australia occurs in the WCB (Ryan *et al.*, 2019). Recent recreational catch data for blue swimmer crabs has primarily been obtained from state-wide surveys of boat-based fishers conducted during 2011/12, 2013/14, 2015/16 and 2017/18 ('iSurveys'; Ryan *et al.*, 2013; 2015; 2017; 2019). Catches were recorded in numbers of crabs, and have been converted to a total harvest weight using an average weight estimated from on-site boat ramp surveys. The estimated statewide boat-based recreational harvest of blue swimmer crabs during the 2017/18 survey period (September 2017 to August 2018) was 54 t (95% CI 45–63 t; Ryan *et al.*, 2019). This was based upon an estimated 249,112 crabs being kept at an average weight of 217 g. This is comparable with earlier estimates during 2015/16 and 2013/14 of 44 and 59 t, respectively, but notably lower than during 2011/12 where 87 t was estimated to have been caught.

From these state-wide iSurveys, finer-spatial scale estimates of boat-based recreational catch have been calculated for Cockburn Sound and the Swan-Canning and Peel-Harvey Estuaries (see Figure 9.3 earlier). Annual catches have ranged 26–46 t in the Peel-Harvey, 6–17 t in the Swan-Canning, and 6–13 t in Cockburn Sound. Note, in Cockburn Sound all fishing has been prohibited in the southern half of the embayment (approximately south of Woodman Point) since 2014, however, recreational fishing has been permitted to continue north of this point.

Based on the most recent 2017/18 iSurvey, the estimated boat-based recreational harvest for the Peel-Harvey Estuary was 35.9 t (95% CI 29.9–41.9), representing a 10 t (38%) increase from 2015/16, while catch for the Swan-Canning Estuary was 5.5 t (95% CI 3.6–7.4 t), less than half of the 2015/16 total.

Several earlier surveys prior to the iSurvey have also assessed recreational blue swimmer crab catches (see also Section 6.2). The first survey conducted in the Peel-Harvey Estuary estimated the total retained recreational catch of blue swimmer crabs in the PHE for the 12 months from 1 August 1998 to 31 July 1999 was ~289 t (Malseed and Sumner 2001), however, the uncertainty is an estimated range of 251–377 t (Johnston *et al*., 2014; Lai *et al*., 2014). The second survey estimated range for the total retained recreational catch of blue swimmer crabs for the 12 months from 1 November 2007 to 31 October 2008 was 107–193 t (Johnston *et al*., 2014). In both these surveys, the majority (~ 70 %) of the blue swimmer crab estimated catch was taken by boat-based fishers, with lower levels of catch from shore-based scoop netters and fishers operating from bridges, jetties, canals and hire house boats.

Historically, the blue swimmer crab resource of south-west WA has been fished by commercial and recreational sectors without any explicit catch share allocation between sectors. This is, in part, due to the limited data on recreational catches needed to understand changes in catch shares between these sectors over time (DPIRD, 2020). Early recreational surveys have not been comparable to the iSurvey estimates due to differences in survey methods. Recognising the naturally fluctuating stock levels of blue swimmer crabs due to variable recruitment and seasonal movements between the marine and estuarine environments, annual catch tolerance levels in Peel-Harvey Estuary and Swan-Canning Estuary by both commercial and recreational fishers have been adopted in the respective harvest strategies (DPIRD, 2020).

9.3.2.4 Conclusion

Cockburn Sound	Following conversion from gill nets to traps, commercial crab catches increased rapidly from ~150 t to peak ~350 t in 1998–2002, before progressively declining to only ~50 t in 2006, at which point the fishery was closed for 3 years due to low stock abundance. After the fishery re-opened in December 2009, despite conservative fishing levels and commercial catches not exceeding ~60 t, the commercial fishery was again closed in 2014 due to unacceptable risk level for the stock. Recreational boat-based catches from 2011/12 to 2015/16 have ranged 6–13 t (note, since 2014 recreational fishing has only been permitted north of Woodman Point).
Peel-Harvey Estuary	Commercial catches in the Peel-Harvey Estuary commercial fishery from 1996/96 to 2018/19 have ranged from 45 to 107 t and are significantly correlated with effort. However, spikes in total catches during 2001/02, 2006/07, 2012/3 and 2017/18 reflect increased catch rates in those seasons, likely resultant from warmer than average water temperatures. The 2018/19 commercial season catch was 66.5 t from 59,472 traplifts, 30 t lower than the 2017/18 total. Catches at the start of the 2018/19 season were very low, with November and December catch rates the lowest on record since 1995/96. Catch rates during January, March, July and August were also lower than the long-term average for these months. These decreased catch rates are likely attributable to cooler than average water temperatures throughout much of the season. Annual recreational boat-based catches from 2011/12 to 2017/18 have ranged 26–46 t. Based on the most recent 2017/18 iSurvey, the estimated recreational boat-based harvest was 35.9 t (95% CI 29.9–4.19), representing a 10 t (38%) increase from 2015/16. Annual catch is correlated with effort and environmental conditions, and consequently interannual variation in recreational and commercial catches has been similar.
Swan-Canning Estuary	Annual commercial catch in the Swan-Canning Estuary between 1976 and 2017 has ranged from 1 to 33 t, being highly correlated with fishing effort. Over time, effort (annual length of gill net fished) has steadily declined due to a reduction in the number of fishers operating, and since 2008 only a single fisher has operated. Catch remained relatively stable at 8–10 t from 2008 to 2015, before declining in 2016–17 to 1–6 t, reflecting a lack of fishing effort in these years. Catch and effort in 2018 and 2019 was within these historical ranges. Annual recreational boat-based catches from 2011/12 to 2017/18 have ranged 6–17 t. Based on the most recent 2017/18 recreational fishing from boat survey (iSurvey), the estimated recreational harvest was 5.5 t (95% CI 3.6–7.4 t), less than half of the 2015/16 total. Annual catch is correlated with effort and environmental conditions, and consequently interannual variation in recreational and commercial catches has been similar.

9.3.3 Catch Distribution Trends

Commercial statutory catch data (CAES returns) are submitted on a block basis (60 x 60 nm) for all commercial fisheries. Given the relatively small spatial area over which blue swimmer crab fisheries operate in the WCB, these grids are not meaningful for spatial analysis. Therefore, GPS coordinates of fishing locations obtained during monthly commercial monitoring are used to provide fine-scale spatial resolution of monthly fishing activity. Spatial recreational data has been obtained through the RAP program in the Swan-Canning Estuary.

9.3.3.1 Cockburn Sound Commercial Fishery

From 2000-2004 the spatial distribution of fishing effort (based on trap line start locations) was relatively uniform throughout Cockburn Sound and occurred across a range of water depths (Figure 9.19). In 2005-2009 and 2010-2014 fishing effort declined in the centre of the embayment, and was concentrated in shallow southern waters (near Mangles Bay) and along the eastern side of Garden Island (near Sulphur Bay). In 2015-2019, effort significantly decreased due to closure of the fishery (although monitoring continued using a chartered commercial vessel), and effort was concentrated around Mangles Bay and Sulphur Bay (Figure 9.19).

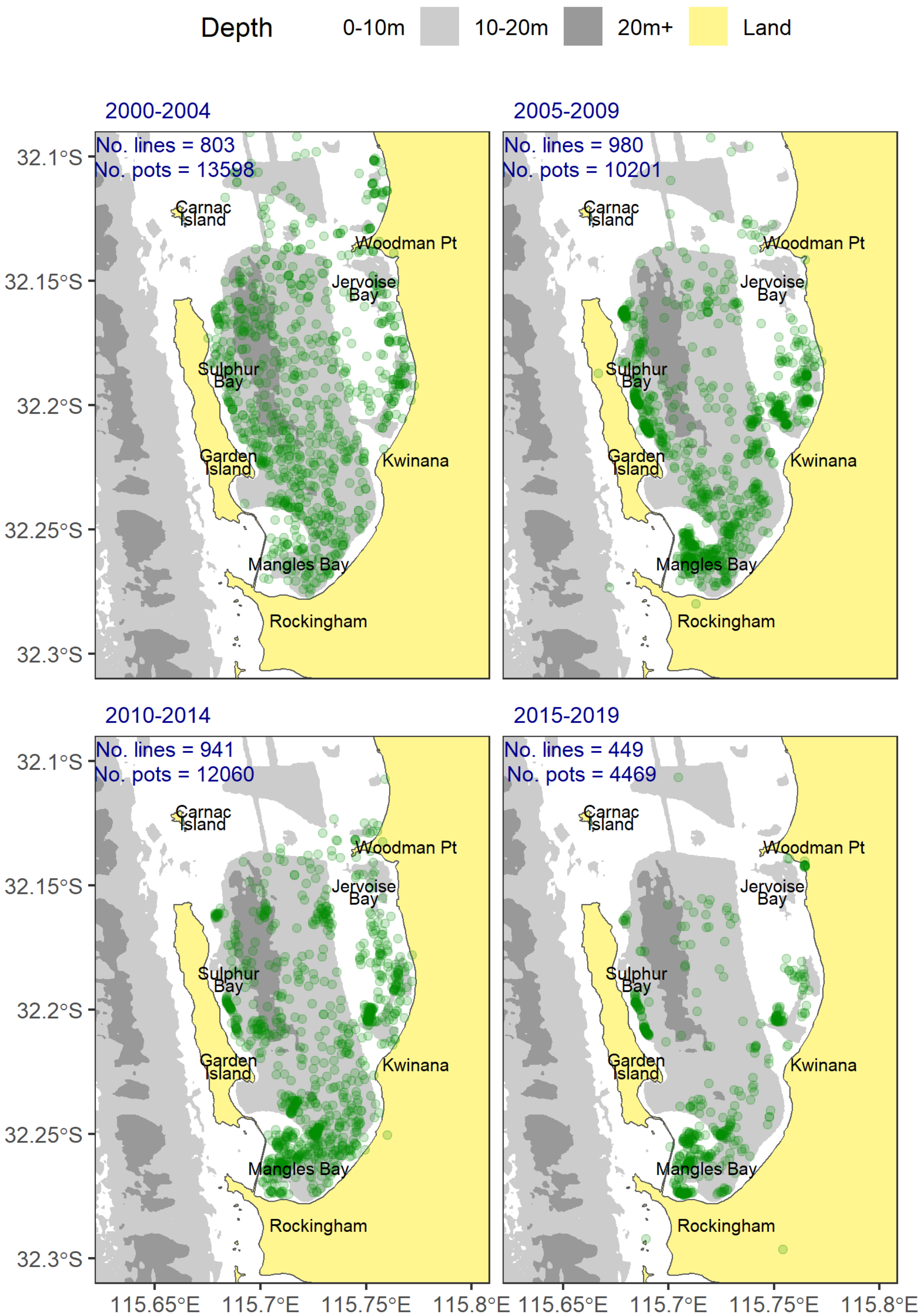


Figure 9.19. Fishing location (●) during catch monitoring surveys aboard commercial vessels in Cockburn Sound during 2000-2004, 2005-2009, 2010-2014 and 2015-2019. There have been fishing closures in 2006–2009 and 2014–2019, during which monitoring has continued on a chartered commercial vessel.

With respect to the spatial distribution of catches, high catch rates of male crabs (4-6 crabs a traplift) occurred throughout the embayment in 2000-2004, and particularly in waters between 32.23°S and 32.25°S latitude (Figure 9.20). During 2005-2009 and 2010-2014 catch rates declined in the latter area, as well as in waters further north east of Sulphur Bay (Figure 9.20). By 2015–2019, the only region of Cockburn Sound where high male catch rates occurred was in a small area of Mangles Bay. Likewise, the catch rate of female crabs has substantially declined over time throughout the embayment (Figure 9.21). Notably, the 2015-2019 female catch rates were low across all areas of Cockburn Sound including Mangles Bay. The catch rate of ovigerous females was generally highest on the western side of Cockburn Sound during 2000-2004 and 2010-15, and also adjacent to Kwinana in the earlier period (Figure 9.22). During 2005-2009 and 2015-2019 catch rates of ovigerous females were low in all areas.

This general trend of decreasing commercial catches in the deeper waters of Cockburn Sound supported fishery independent research trawling, where low abundances have been consistently recorded throughout the Sound in all regions, except the shallow waters of Mangles Bay and Jervois Bay.

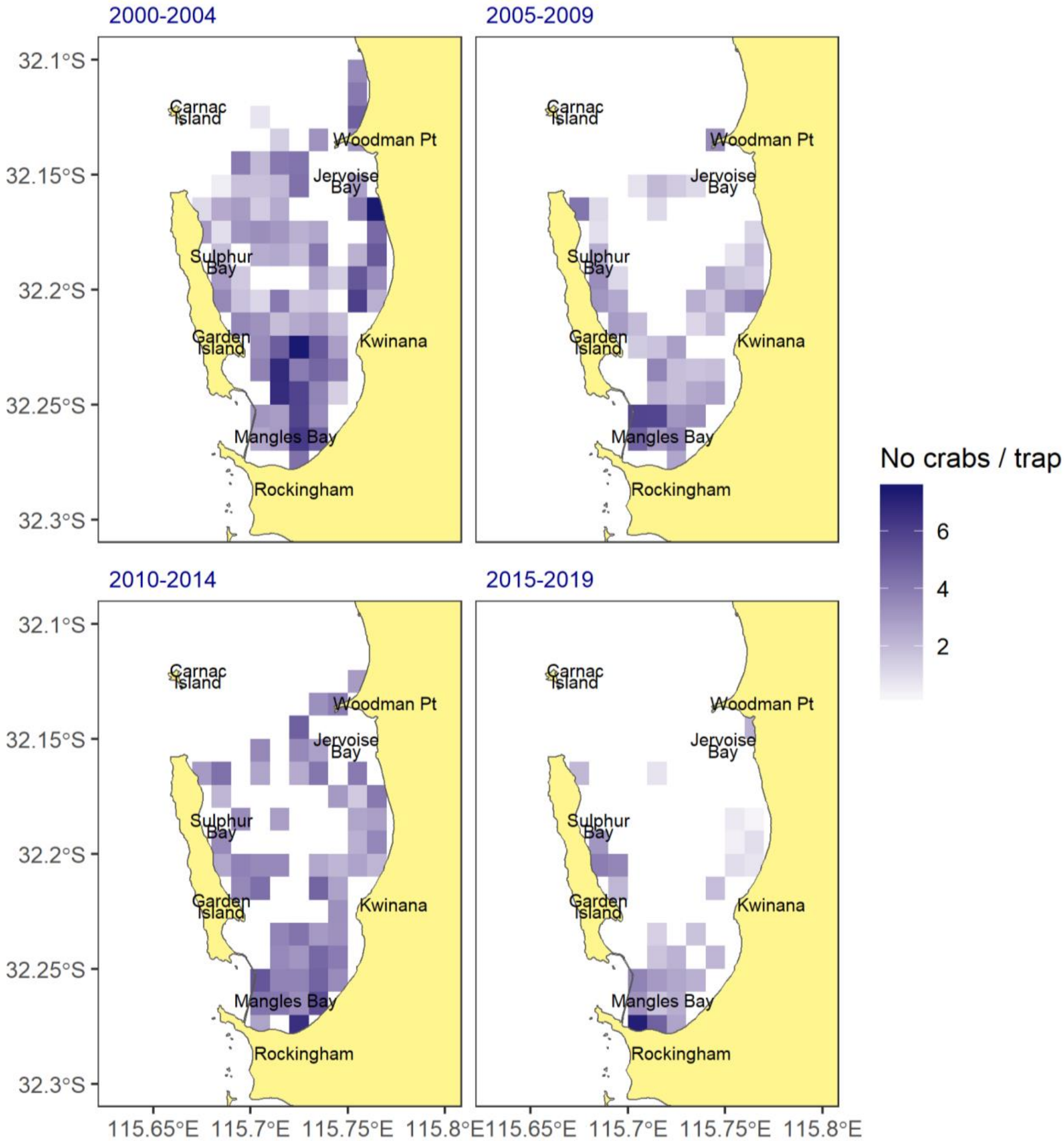


Figure 9.20. Mean commercial catch rate of male blue swimmer crabs (no. crabs / traplift) throughout Cockburn Sound from commercial monitoring during 2000-2004, 2005-2009, 2010-2014 and 2015-2019. For clarity, grids with low fishing effort (<10% based, on the total number of trips to each grid in each period) are not shown. There have been fishing closures in 2006–2009 and 2014–2019, during which monitoring has continued on a chartered commercial vessel.

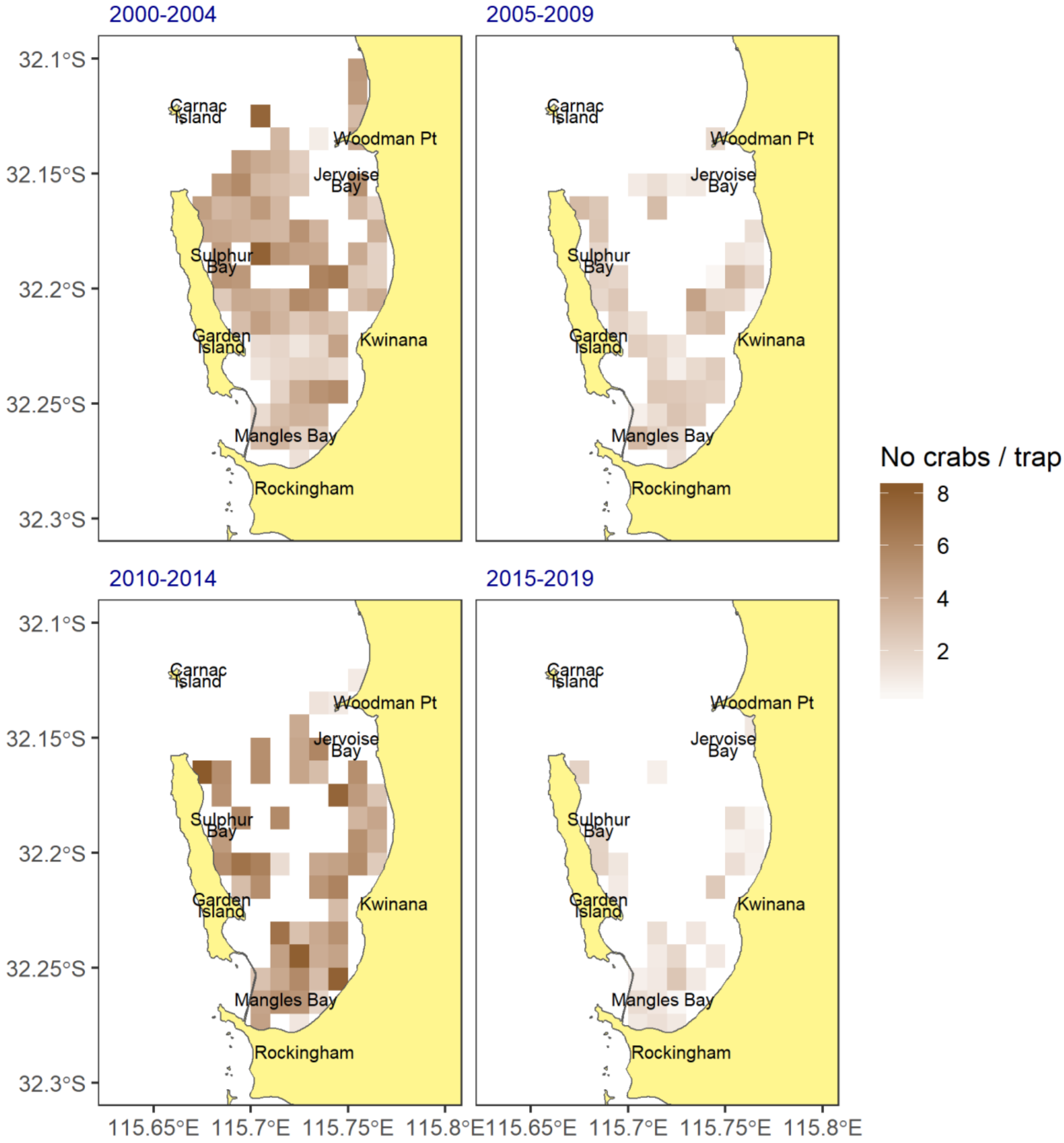


Figure 9.21. Mean commercial catch rate of female blue swimmer crabs (non-ovigerous only; no. crabs / traplift) throughout Cockburn Sound during 2000-2004, 2005-2009, 2010-2014 and 2015-2019. For clarity, grids with low fishing effort (<10% based, on the total number of trips to each grid in each period) are not shown. There have been fishing closures in 2006–2009 and 2014–2019, during which monitoring has continued on a chartered commercial vessel.

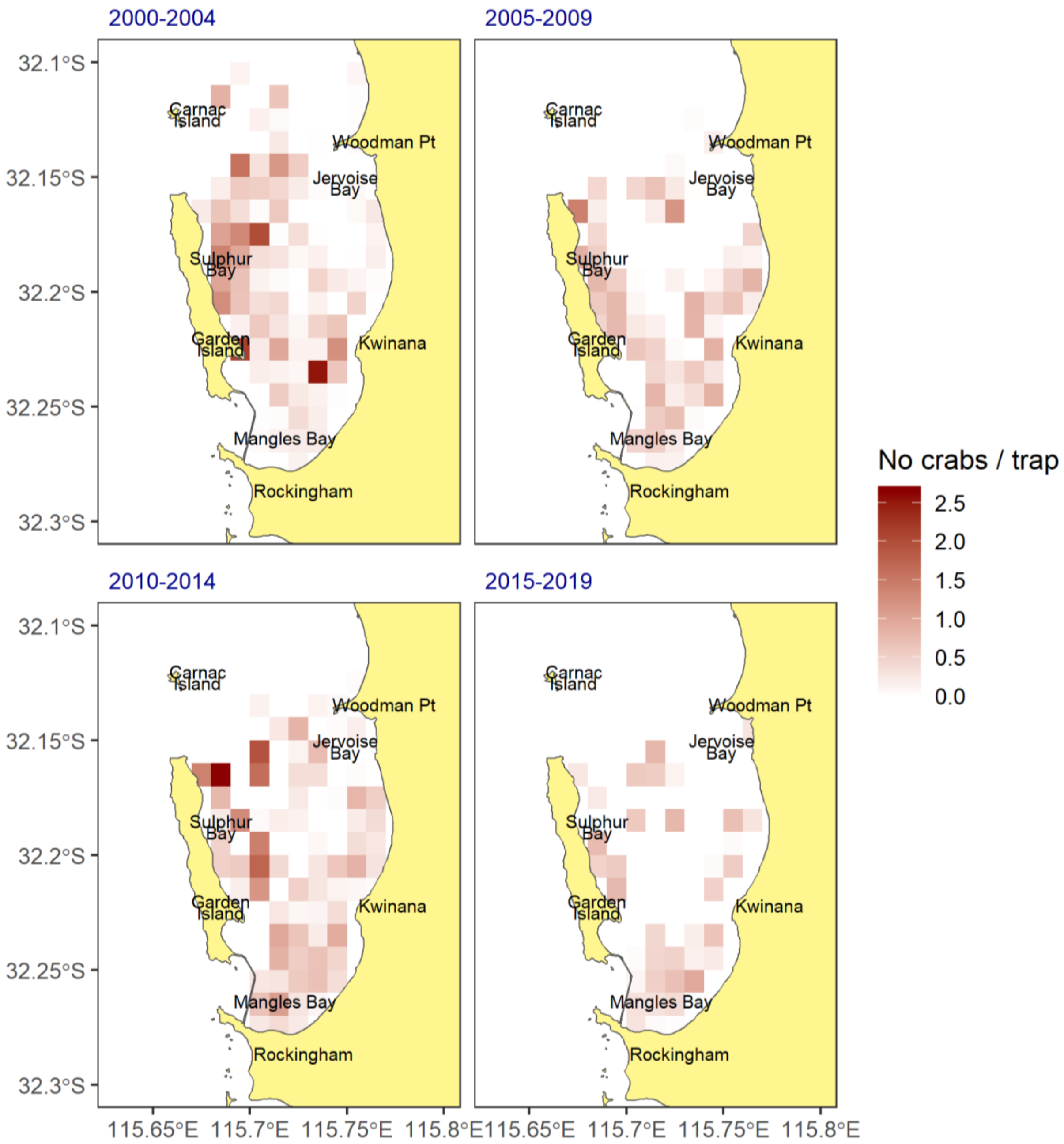


Figure 9.22. Mean commercial catch rate of ovigerous female blue swimmer crabs (no. crabs / traplift) throughout Cockburn Sound in 2000-2004, 2005-2009, 2010-2014 and 2015-2019. For clarity, grids with low fishing effort (<5%, based on the total number of trips to each grid in each period) are not shown. There have been fishing closures in 2006–2009 and 2014–2019, during which monitoring has continued on a chartered commercial vessel.

9.3.3.2 Peel-Harvey Estuary Commercial Fishery

Commercial fishing effort in the Peel-Harvey Crab Fishery occurs throughout both the Peel Inlet and Harvey Estuary, with the spatial distribution of effort varying throughout the year and corresponding with marked environmental changes in the estuary (Figure 9.23). In summer and autumn, when the system is warmest and most saline, fishing effort occurs throughout the majority of the estuary, including in southern parts of the Harvey Estuary. However, in winter, fishing effort is concentrated near the Estuary Channel and Dawesville Cut, as these waters remain warmer and more saline than other parts of the system due to marine water incursion. During spring (November), fishing activity then expands further upstream as salinity and temperature throughout the system begin to increase following their minima in winter. Little commercial crabbing occurs in the southeast region of the Peel Inlet, where the water is very shallow (generally <0.5 m). Fishing effort during the 2018/19 fishing season was in general agreement with the long-term average distribution of effort.

The density and sex ratio of crabs are strongly influenced by the time of year, reflecting the movement of females out of the system with the winter rains. The spatial distribution of male catch rates largely reflects the spatial distribution of fishing effort (Figure 9.23; Figure 9.24). However, female catch rates during spring and summer are very low throughout the system, but increase in autumn and winter, particularly in waters adjacent to the Estuary Chanel and Dawesville Cut.

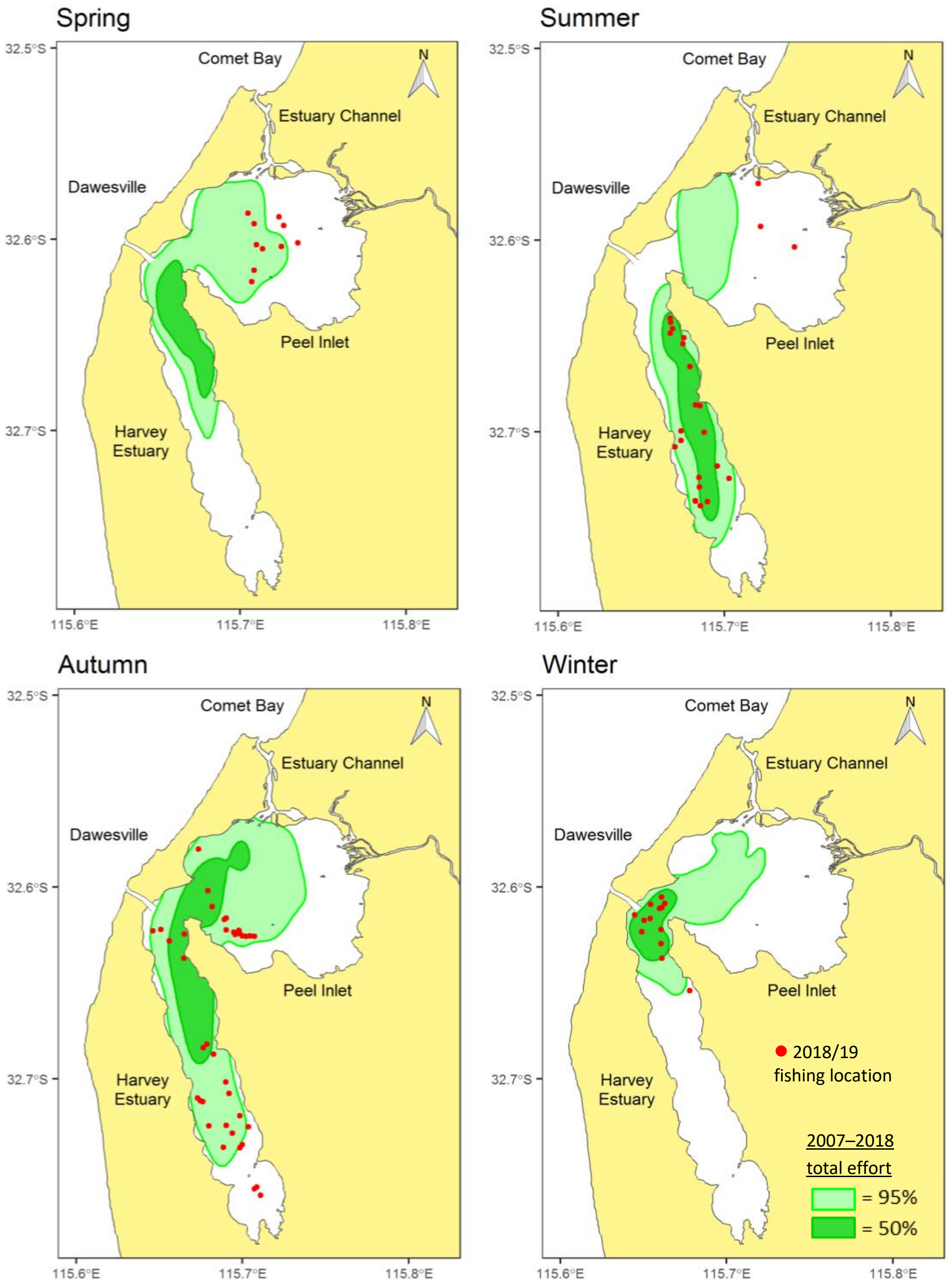


Figure 9.23. 2D kernel density estimates displaying the 50 and 95% distribution of seasonal commercial fishing effort (trap line start locations) in the Peel-Harvey Estuary for the 11 year period from 2007 to 2018 (2007/08 to 2017/18 fishing seasons). Fishing locations during the 2018/19 season are overlaid as points. Data are derived from commercial monitoring surveys and therefore only include fishing trips where an observer was present.

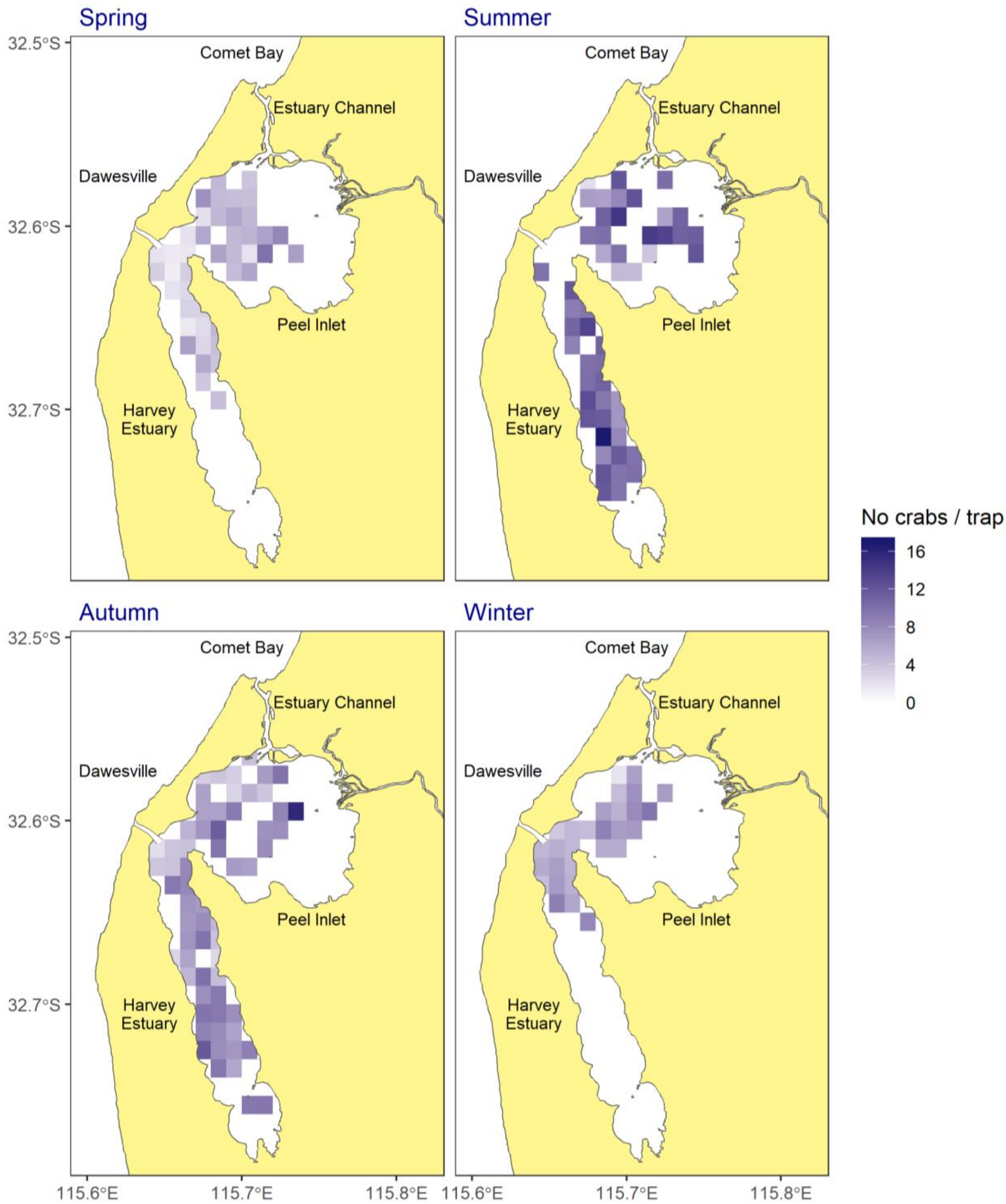


Figure 9.24. Mean commercial catch rate of male blue swimmer crabs (no crabs / traplift) throughout Peel-Harvey Estuary from 2007 to 2019 (2007/08 to 2018/19 fishing seasons). For clarity, grids with low fishing effort (<5%, based on the total number of trips to each grid in each period) are not shown.

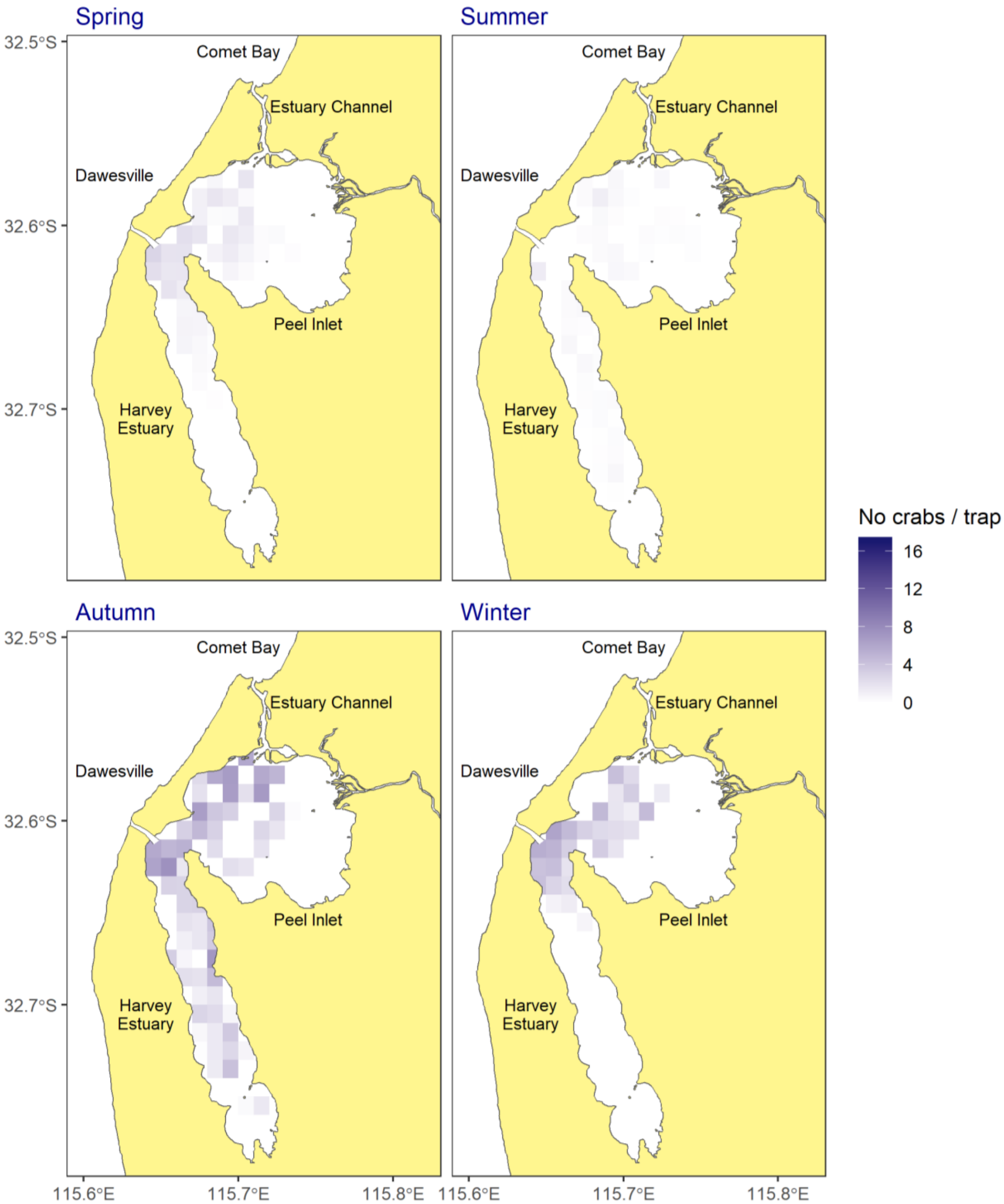


Figure 9.25. Mean commercial catch rate of female blue swimmer crabs (no crabs / traplift) throughout Peel-Harvey Estuary from 2007 to 2019 (2007/08 to 2018/19 fishing seasons). For clarity, grids with low fishing effort (<5%, based on the total number of trips to each grid in each period) are not shown.

9.3.3.3 Swan-Canning Estuary

Spatial distribution of commercial fishing activity

Commercial fishing effort in the Swan-Canning Estuary is restricted by legislation to the central basin of the estuary, from Pt Walter in the lower reaches (approx. 32.01°S, 115.79°E), to Perth Water (near Perth CBD) and Salter Point (approx. 32.03°S, 115.87°E) in the upper reaches (see section 6.1.3 for specific boundaries). Since 2007, the distribution of effort has varied seasonally, being relatively uniform throughout the estuary basin in autumn and summer, but concentrated in downstream waters adjacent to Dalkeith in winter (Figure 9.26). Minor effort has occurred during spring, with a small number of nets set throughout the central waters of the basin. As for the Peel-Harvey Estuary, this contraction of fishing effort to downstream areas during winter reflects the fact that salinity in these areas generally remains close to marine due to tidal incursion, while upstream areas transition to brackish or fresh due to freshwater flows.

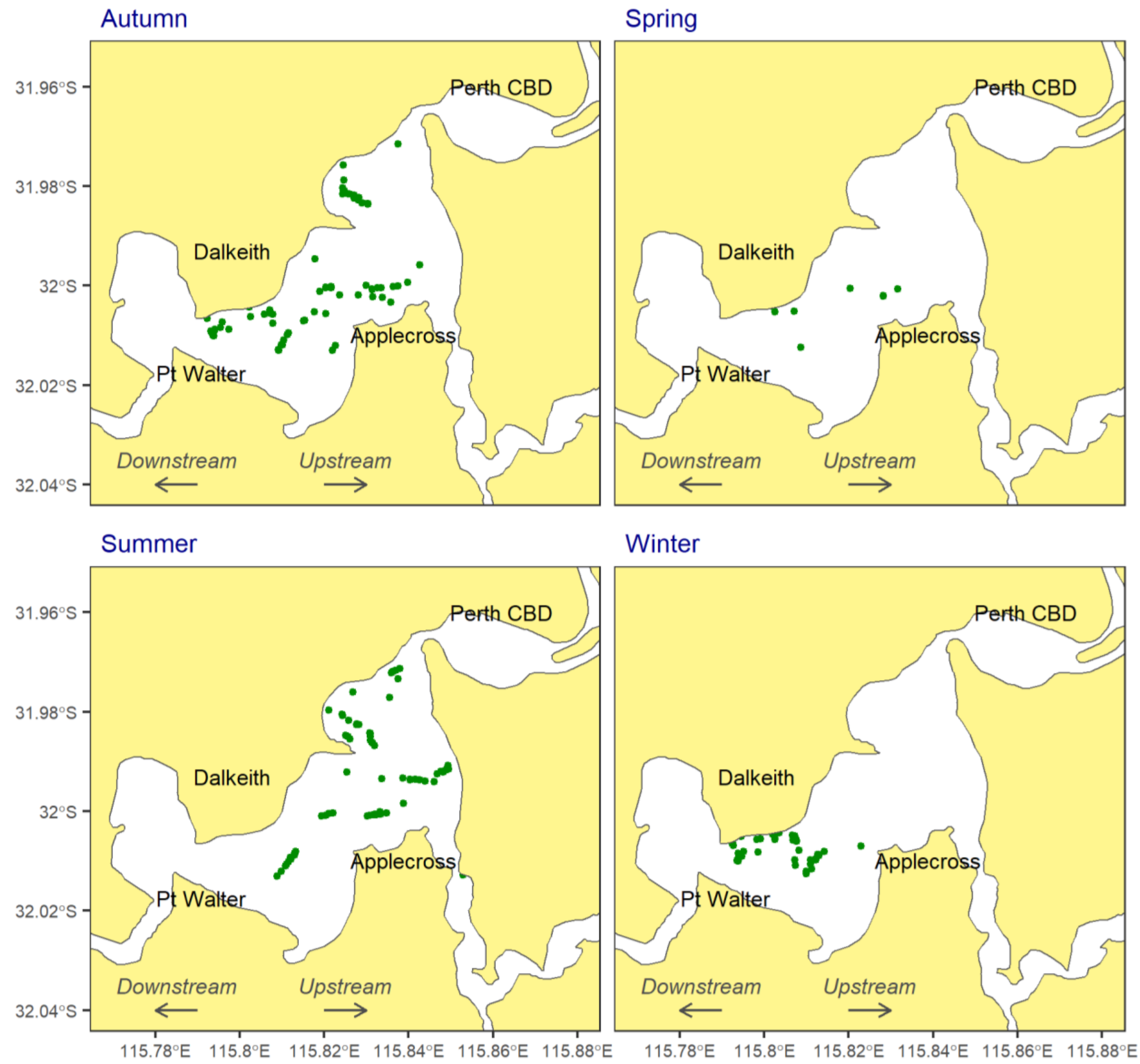


Figure 9.26 Fishing locations (●; start of net) during monitoring surveys aboard commercial vessels in the Swan-Canning Estuary each season (*i.e.* spring, summer, autumn, winter) from 2007 to 2019.

Commercial catch rates of both male and female blue swimmer crabs also vary throughout the system seasonally (Figure 9.27; Figure 9.28). For males, high catch rates have been recorded throughout the estuary basin in summer and autumn. In summer these were highest adjacent to Como Jetty (*c.* 32°S, 115.85°E) and in Matilda Bay (*c.* 31.98°S, 115.83°E), and in autumn catches were highest adjacent to Applecross (*c.* 32.01°S, 115.84°E), between Pt Walter and Dalkeith, as well as in Matilda Bay (Figure 9.27). Low catch rates of males have been recorded in spring and winter. The catch rate of females is generally low in all areas of the system throughout spring and summer, but increases substantially in the lower reaches of the system during autumn and winter (Figure 9.28).

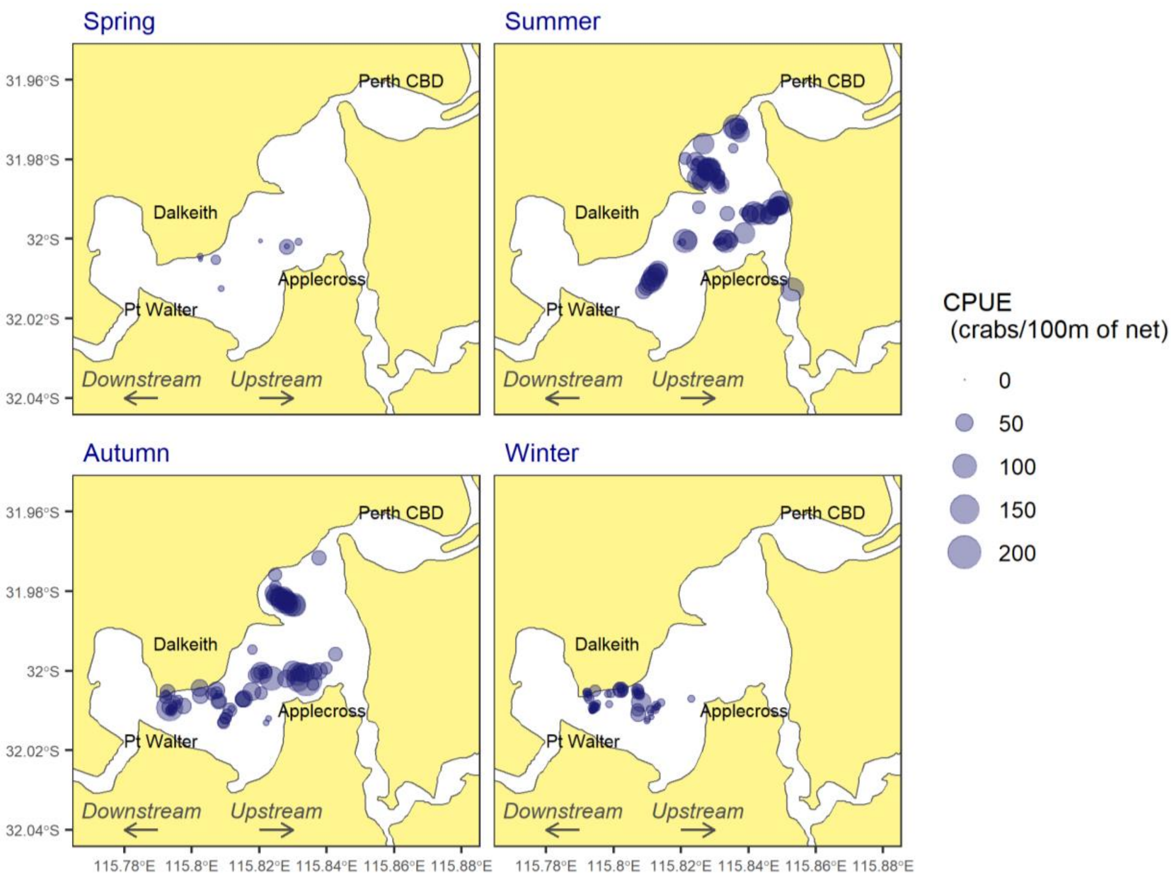


Figure 9.27 Catch rates (CPUE; crabs/100 m of gill net) of male blue swimmer crabs during monitoring surveys aboard commercial vessels in the Swan-Canning Estuary each season (*i.e.* spring, summer, autumn, winter) from 2007 to 2019.

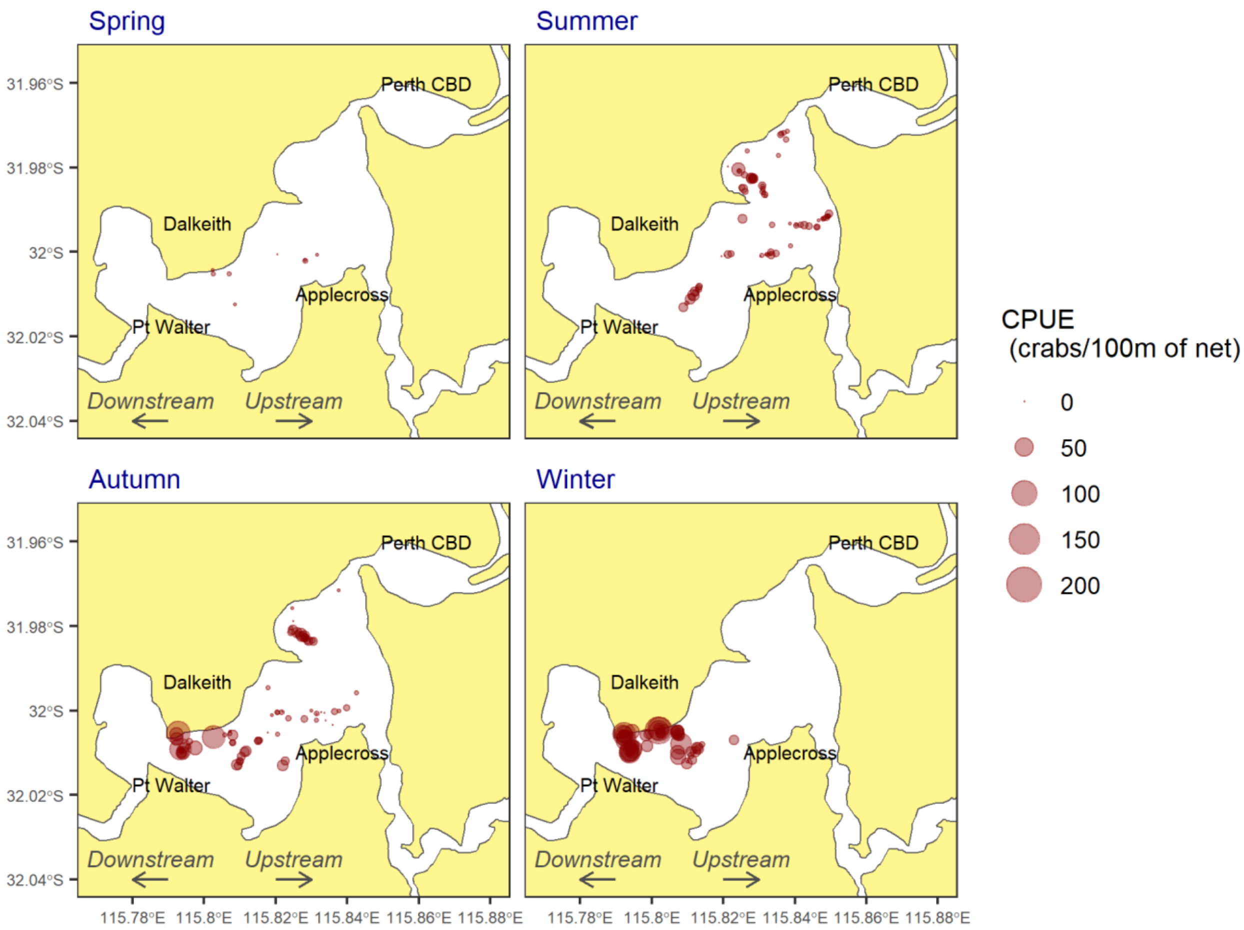


Figure 9.28 Catch rates (CPUE; crabs/100 m of gill net) of female blue swimmer crabs during monitoring surveys aboard commercial vessels in the Swan-Canning Estuary each season (*i.e.* spring, summer, autumn, winter) from 2007 to 2019.

Spatial distribution of recreational fishing activity

The majority of effort reported by recreational fishers as part of a comprehensive 3-year recreational crabbing project (2013–2016) in the SCE occurred during summer and autumn. Fishing efforts during this period occurred throughout the Swan-Canning Estuary, both in the lower reaches and extended up the Swan River as far as Maylands, and up the Canning River as far as Mount Henry Bridge. However, during winter and spring, fishing primarily occurred in the lower reaches, downstream from Point Walter (Figure 9.29). Most (*c* 88%) of this fishing activity was undertaken by boat-based fishers with a total of 564 boat-based trips. Catches during this 2013–2016 period were dominated by male crabs (~94%) in each season, with 82% of this catch above the minimum legal size of 127 mm carapace width (CW).

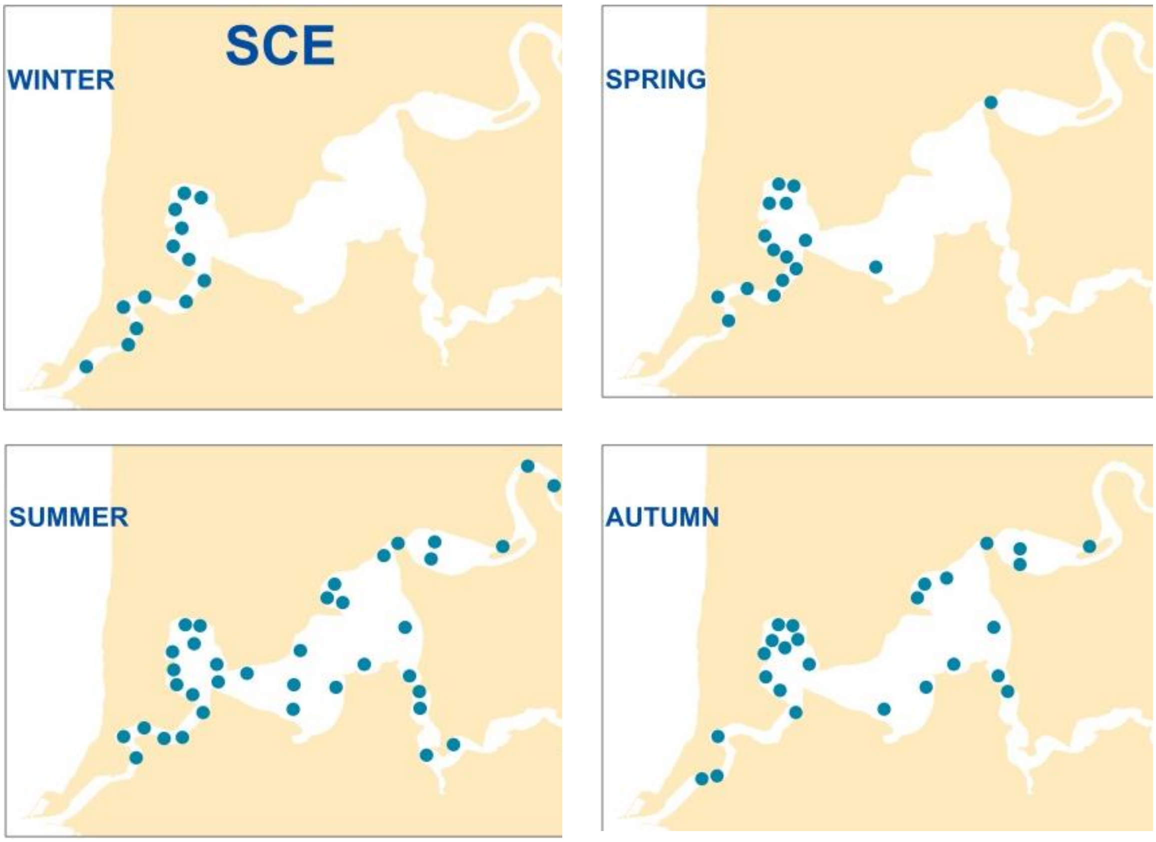


Figure 9.29 Generalised recreational crabbing locations by season for fishers in the Swan-Canning Estuary (SCE) between June 2013 and May 2016 inclusive. Data were obtained through a voluntary logbook program.

9.3.3.4 Conclusion

Cockburn Sound	The spatial distribution of commercial catch and effort in Cockburn Sound has severely contracted over time. Before ~2005, crabs were widespread throughout Cockburn Sound, with high catch rates in both shallow and deeper waters extending between the northern and southern limits of the embayment. However, in recent years, high catch rates have only occurred in shallower waters in the south-eastern areas of Cockburn Sound, *i.e.* Mangles Bay, Jervois Bay and James Point. In particular, crab abundance is very low in deeper (> 10 m) waters. Similar trends are apparent from fishery independent research trapping and trawl surveys.

Peel-Harvey Estuary	A combination of commercial and research trap data and research trawl data has shown that crab distribution throughout the Peel-Harvey Estuary is environmentally driven and heavily dependent on temperature and the timing of annual rainfall. In summer and autumn, when the system is warmest and most saline, commercial fishing effort occurs throughout the majority of the estuary, including in southern parts of the Harvey Estuary. In winter, commercial fishing effort is concentrated near the Estuary Channel and Dawesville Cut, as these waters remain warmer and more saline than other parts of the system due to marine water incursion.
Swan-Canning Estuary	Commercial fishing effort in the Swan-Canning Estuary is focused on the central basin of the estuary, with the distribution of catch and effort varying seasonally. In autumn and summer it occurs throughout the basin, but in winter is concentrated in downstream waters. Minor effort has occurred during spring. Recreational effort occurs throughout the system, being widely distributed from lower to upstream areas in summer and autumn, but concentrated in downstream areas in winter and spring. This contraction of fishing effort likely reflects the fact that salinity in downstream areas generally remains close to marine throughout winter due to tidal incursion, while upstream areas transition to brackish or fresh due to freshwater flows.

9.3.4 Fishery-Dependent Catch Rate Analyses

A key component of stock assessment for the Cockburn Sound (CS), Swan-Canning Estuary (SCE) and Peel-Harvey Estuary (PHE) blue swimmer crab fisheries is commercial catch rates derived from CAES (SCE and PHE) or on-board monitoring (CS). Trap effort is calculated as number of traplifts and catch rates as landed catch weight (kg) per traplift. Gill or set net effort is based on net length in metres (total daily length set) and catch rate calculated as kg per metre net length (or kg 100 m net^{-1}). Recreational catch rates from SCE are based on a voluntary logbook program, calculated as numbers of crabs kept or weight of crabs kept (kg) per 10 drop net pulls on each fishing occasion.

Annual catch rates for SCE and PHE have been standardised using Generalised Linear Models (GLM) to account for the effects of month and fisher (the latter based on vessel license number for commercial data and logbook number for recreational data). Models were fit using a log-normal distribution, with CPUE as the response variable, and year, month and fisher as explanatory terms (which were considered categorical variables). Estimated marginal mean values for each year (*i.e.* annual standardised values) and associated confidence limits were then calculated using the '*emmeans*' package (Lenth, 2020) in R (R Development Team, 2019). Note, that the SCE commercial harvest strategy was based only on CPUE data for the key fishing months of December to April, as this is when 88% of catch and 77% of effort has occurred since 1976 (monthly catch and effort trends are described earlier in Section 9.3.2.2).

The standardised catch rate is assumed to represent an index of abundance for *P. armatus*. This performance indicator is compared annually against reference levels, as outlined in the harvest strategy for SCE and PHE (Section 7.2; DPIRD 2015a and 2020).

9.3.4.1 Cockburn Sound

Mean annual commercial CAES nominal trap catch rates fluctuated widely between ~0.7 and 1.5 kg/trap lift in 1994–2004, before declining to their lowest levels in 2005-06 at ~0.5 kg/trap lift. Following the three year closure between 2006 and 2009, catch rates fluctuated between ~0.6-1.0 kg/trap lift with 0.7 kg/traplift in 2013/14 (see Figure 9.4). These latter catch rates, however, are not directly comparable to those prior to 2006 due to major management changes including minimum size limit changes (130 mm to 140, then back to 130 mm) and changes to temporal fishery closure periods (10 month season to 3.5 months and then to 6 months; Johnston *et al*., 2015a) and possible changes to crab spatial distribution. Due to stock levels declining to unacceptable levels, the commercial fishery was closed again in April 2014 and remains closed.

While the annual commercial CAES trap catch rate data provided evidence of an unacceptable stock depletion, the level of decline in annual catch rates prior to the 2014 closure was ameliorated by the lower levels of annual effort plus the more restricted areas and times of operation.

Commercial monitoring commenced in 1999 to collect monthly catch composition data (including during fishery closure) and provide a catch rate time series for crabs above legal size (mean monthly catch rate ± 95% confidence limits; **Figure 9.30**), which in the absence of ongoing CAES data, has been used to assess performance of the fishery.

Legal catch rates were relatively high (~ 2 kg/traplift) in 2000, 2003 and 2004, and then declined markedly to a very low level (~ 0.1 kg/traplift) in mid-2006 (**Figure 9.30**). The catch rates increased steadily during the three-year closure to above 2.5 kg/traplift but then declined again to very low levels (just above 0.1 kg/traplift) in 2014. Following closure, catch rates remained low (<0.75 kg/traplift) during 2015, before increasing in 2016 and 2017 to between 1 and 1.8 kg/traplift, and then decreased in 2018 and 2019 to <1 kg/traplift in most months.

It should be noted, however, that chartered commercial monitoring during closure periods has only been undertaken by one licence holder, fixing a maximum of 100 traps each month. The spatial distribution of effort is thus less expansive than previously occurred when multiple operators were fishing (*i.e.* effort since 2015 has focused on the southern part of the embayment as described earlier in section 9.3.3.1). Additionally, all catch from chartered monitoring is released and there is therefore no fishing mortality, which may otherwise decrease abundances of legal-sized crabs in subsequent months.

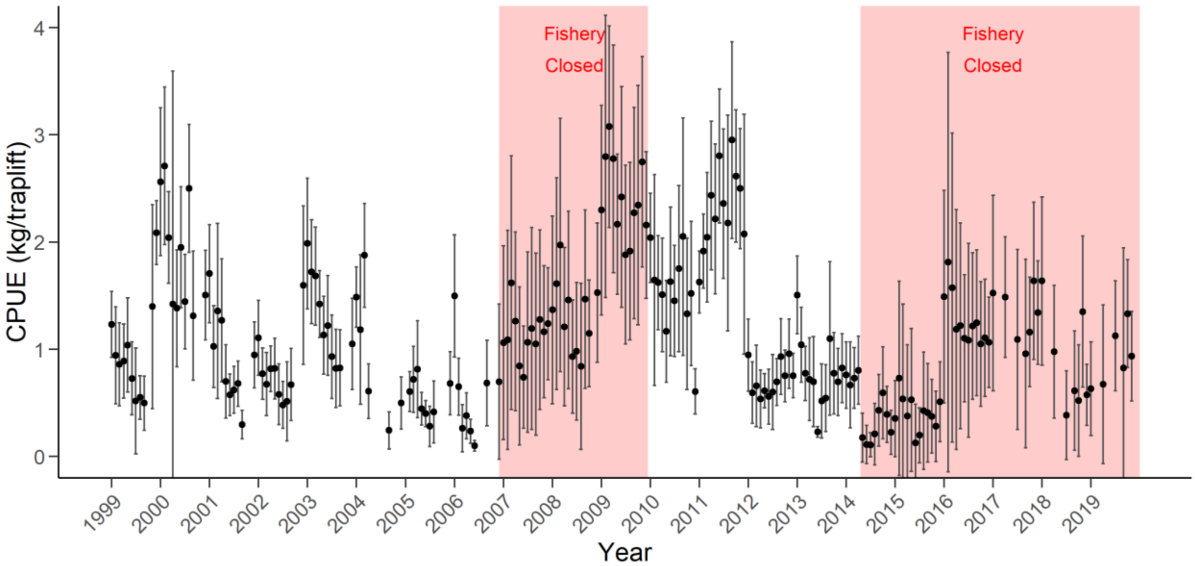


Figure 9.30. Legal (combined male and female, ≥130mm) catch rate by estimated weight (derived from length-weight relationships) from commercial monitoring surveys in Cockburn Sound. Vertical lines represent 95% confidence intervals of the mean. Shading denotes when the fishery was closed to fishing. During these periods a commercial vessel was chartered to continue monitoring.

9.3.4.2 Peel-Harvey Estuary

Standardised commercial catch rates in the PHE trap fishery have remained relatively constant over time, ranging from 0.73 to 1.42 kg/traplift (Figure 9.31). The lowest catch rates occurred during the 2008/09, 2015/16 and 2016/17 seasons (0.73–0.87 kg/traplift) and the highest catch rates occurred during 2011/12 and 2012/13 (1.33–1.42 kg traplift; Figure 9.31). During the latter two seasons water temperatures were warmer than average following a severe marine heatwave during the summer of 2010/11 (Caputi *et al.*, 2016), which likely increased abundances of legal crabs (*e.g.* greater productivity and quicker growth), as well as enhanced catchability (greater levels of feeding activity in warmer waters).

Catch rates since 2012/13 have been above the harvest strategy reference period threshold and limit of 0.73 and 0.51 kg/traplift, respectively, suggesting that the stock is being fished at sustainable levels. The 2018/19 season standardised catch rate was 0.92 kg/traplift, representing a decline from the previous 2017/18 season (1.32 kg/traplift).

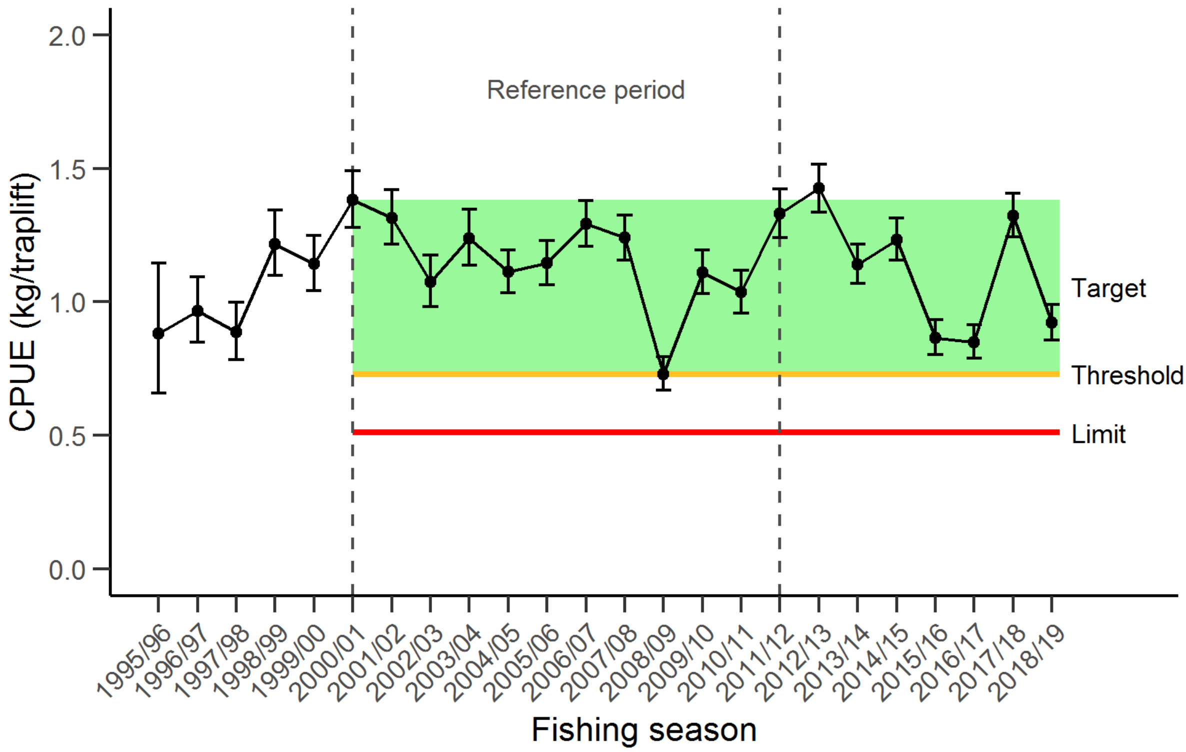


Figure 9.31. Primary performance indicator, annual standardised commercial catch rate (kg/traplift) of blue swimmer crabs in the Peel-Harvey crab fishery (Area 2 of WCEMF), with 95% confidence limits, relative to the associated reference points (target, threshold and limit) for the harvest strategy. The reference period (2000/01 to 2011/12) was a period of relative stability when the fishery was considered to have been operating sustainably. The target range extends between the maximum and minimum values of the reference period, where the latter denotes the threshold level, a proxy for the stock level at which Maximum Sustainable Yield (MSY) can be achieved. The limit is set at 70% of the threshold value (0.7BMSY). Fishing season is defined as 1 November to 31 August. Annual values have been standardised using a generalised linear model to account for effects of month and fisher.

9.3.4.3 Swan-Canning Estuary

Commercial catch rates

Standardised commercial catch rates from the SCE set net fishery have generally increased over time from 1975 to 2019 (Figure 9.32). Thus, prior to the 1993/94 season, catch rates did not exceed 6 kg 100 m net^{-1}, while since 2000/01 catch rates have ranged 7–10.8 kg 100 m net^{-1} in all but two years (*i.e.* 2006/07 and 2010/11; 5.1–6.1 kg 100 m net^{-1}). This trend of increasing catch rate over time coincides with a reduction in total commercial effort throughout the fishery, namely due to a decline in the number of licence holders (see Section 6.1.3). Fishing efficiency over time has also likely increased as technology has improved (*e.g.* less visible synthetic filament nets, depth sounders and GPS on vessels).

The harvest strategy reference period of 2008/09 to 2016/17 was therefore chosen from a relatively recent period when the fishery was single operator only. The lower threshold and limit values of this period are 6.2 and 4.3 kg 100 m net^{-1}, respectively. The 2018/19 season standardised catch rate was 9 kg 100 m net^{-1}; Figure 9.32), representing a slight decline from the previous 2017/18 season (9.9 kg 100 m net^{-1}). Both values are within the target range of the harvest strategy, suggesting that the stock is being fished at sustainable levels.

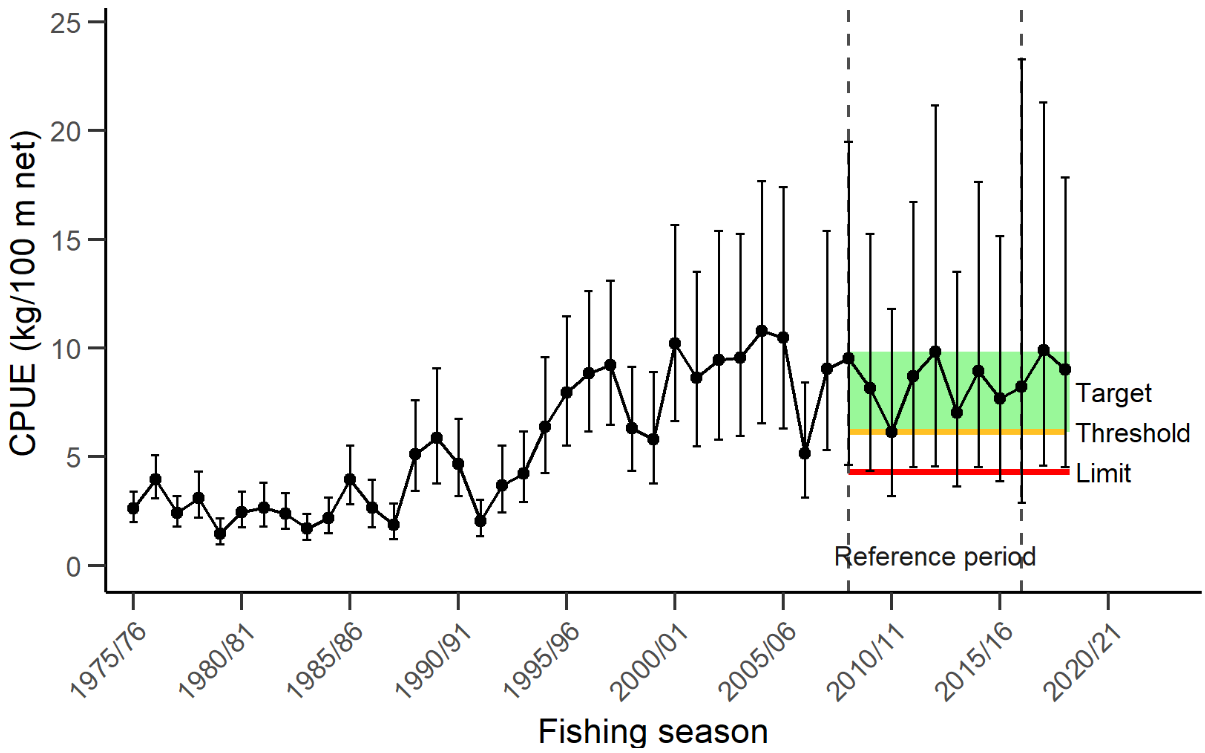


Figure 9.32. The primary performance indicator, annual standardised commercial CPUE (kg/100 m of net) for blue swimmer crab in Swan-Canning Estuary Crab Fishery (Area 1 of the West Coast Estuarine Managed Fishery (WCEMF)), and the associated reference points (target, threshold and limit) for the harvest strategy. The reference period (2008/09 to 2016/17) was a period of relative stability when the fishery was considered to have been operating sustainably. The target range extends between the maximum and minimum values of the reference period, where the latter denotes the threshold level, a proxy for the stock level at which Maximum Sustainable Yield (MSY) can be achieved. The limit is set at 70% of the threshold value (0.7BMSY). Annual values have been standardised using a generalised linear model to account for effects of month and fisher, with only data for the key fishing period of December to April each season included. Fishing season refers to a 12-month period from December to November the following year.

Recreational catch rates

Standardised recreational catch rates (based upon estimated weight of retained catch) obtained through a recreational angler logbook program show a decline in CPUE over time from 2013/14 to 2017/18 (Figure 9.33). Standardised CPUE based upon numbers of kept crabs, however, has remained relatively constant over time, with minor increase in 2014/15 and 2016/17. This suggests that a decrease in harvest weight CPUE is due to a decline in average size of crabs which occurred in the Swan-Canning Estuary between 2014 and 2018 (see section 9.3.9.3).

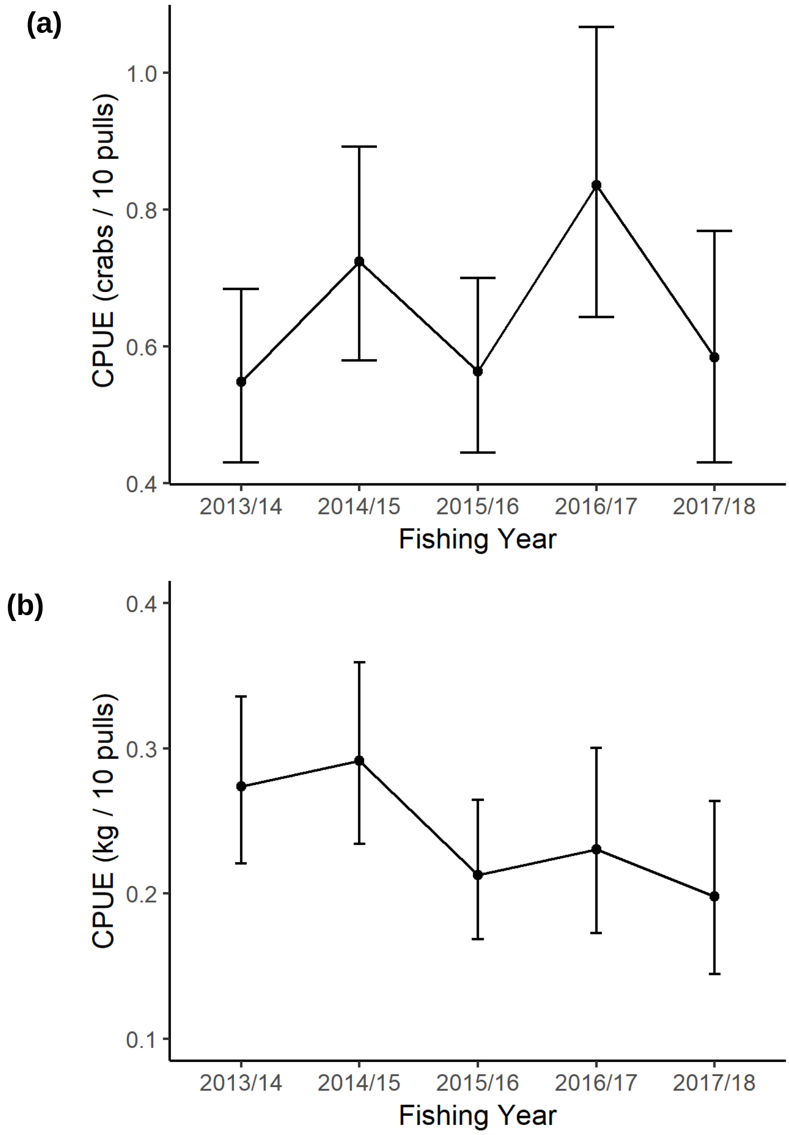


Figure 9.33. Standardised annual recreational CPUE for the Swan-Canning Estuary from 2013 to 2019 (a) by numbers of crabs kept, and (b) by harvest weight in kg / 10 drop net pulls. Fishing year refers to a 12-month period from June 1 to May 31 the following year. Data were derived from a recreational angler voluntary logbook program and were standardised using a GLM to account for effects of month and fisher.

9.3.4.4 Conclusion

Cockburn Sound	Commercial CAES trap catch rates fluctuated widely between ~ 0.7 and 1.5 kg/trap lift in 1994–2004, before declining to their lowest levels in 2005–06 at ~ 0.5 kg/trap lift. Following the three year fishery closure between 2006 and 2009, the mean annual commercial trap catch rates fluctuated between ~0.6–1.0 kg/trap lift with 0.7 kg/traplift in 2013/14. Due to stock levels declining to unacceptable levels, the commercial fishery was closed again in April 2014 and remains closed. Commercial monitoring catch rates for legal-sized crabs were relatively high (~2 kg/traplift) around 2000, 2003 and 2004. It then declined progressively to a very low level (~ 0.1 kg/traplift) in mid-2006. The catch rates increased during the three-year closure period to above 2.5 kg/traplift but then declined to very low levels (just above 0.1 kg/traplift) in 2014. From 2014 to 2015, catch rates remained low (<0.75 kg/traplift and increased to between 1 and 1.8 kg/traplift in 2016 and 2017. Catch rates again decreased in 2018 and 2019, being < 1 kg/traplift in most months. The mean monthly commercial trap catch rate data indicate an unacceptable stock depletion in the mid-2000s and in 2012–2014. Despite closure to fishing since 2014, legal catch rates remain low in 2019.
Peel-Harvey Estuary	Standardised commercial catch rates have remained relatively constant over time, ranging from 0.73 to 1.42 kg/traplift. Catch rates since 2012/13 have been above the harvest strategy threshold and limit of 0.73 and 0.51 kg/traplift, respectively. The 2018/19 season catch rate was 0.92 kg/traplift.
Swan-Canning Estuary	Standardised commercial catch rates have generally increased over time since 1975. This trend of increasing catch rate coincides with a reduction in total commercial effort (due to a decline in the number of licence holders). The 2018/19 season standardised catch rate was 9 kg 100 m net^{-1}, representing a slight decline from the previous 2017/18 season (9.9 kg 100 m net^{-1}). Both values are within the target range of the harvest strategy, suggesting that stock is being fished at sustainable levels. Standardised recreational catch rates (based upon estimated weight of retained catch) show a decline in CPUE over time from 2013/14 to 2017/18. CPUE based on numbers of kept crabs, however, has remained relatively constant over time. This suggests that abundances have remained relatively constant, but average size has declined.

9.3.5 Fishery-Independent Data Analyses

9.3.5.1 Cockburn Sound

Fishery-independent trawl catch rate data for juvenile 0+ crabs, sampled each month between April and June on small research vessels (4.5 m wide otter trawl net) are available from 2002 (see Section 8.2.4 for survey methods). Additional research trawl data collected during recruitment periods of the year (April-May) on the large research vessel *RV Naturaliste* (twin, 11 m wide nets) are available from 2007. Fishery-independent research trawl catch rates are likely to constitute the most reliable abundance index for crabs, because the data are based on standardised (fixed) survey sites employing an active fishing method.

Juvenile Index

Fishery-independent recruitment trawl survey data are used to provide an annual index of 0+ juvenile recruitment strength (Figure 9.34) and an indication of stock abundance the following season. For every sampling month of each year, crabs were allocated as juveniles (0+) or residuals (1+) according to size, using a month specific CW that separated the two-year classes (obtained from a seasonal von Bertalanffy growth curve). Juvenile abundance data (number of 0+ crabs / 100 m^2 trawled) were then analysed using a generalised linear model (log-linear distribution), with site, month and year as explanatory factors, to calculate mean annual Juvenile-index values and associated 95% confidence limits.

The index of juvenile abundance was initially >1.0 crabs/100 m^2 trawled in 2002, but declined to <0.1 crabs/100 m^2 in 2004 and 2006 (Figure 9.34). After closure of the fishery in December 2006, the index increased to >0.6 crabs/100 m^2 during 2010–12, before declining to 0.16 crabs/100 m^2 in 2013, and to 0.03 crabs//100 m^2 in 2014. From 2014 to 2019 the abundance of juveniles has remained very low (0.03–0.11 crabs/100 m^2), substantially below the harvest strategy limit of 0.4, indicating that recruitment is at unacceptable levels.

These findings from small research vessel trawling are supported by recruitment surveys using much larger trawl nets aboard *RV Naturalise* (Figure 9.35). During 2012–2015 very few crabs <100 mm were recorded in these surveys, and despite an increase in juvenile numbers during 2016 and 2017, very low abundances were again recorded in 2018 and 2019.

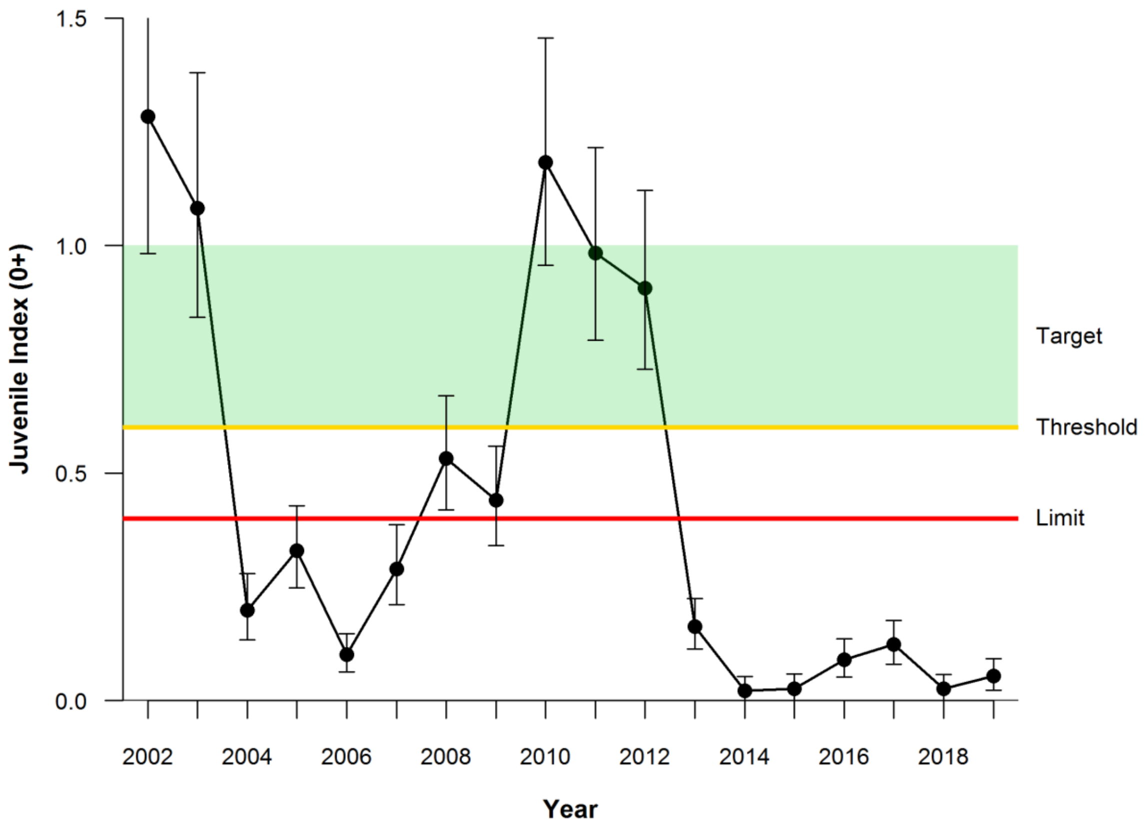


Figure 9.34. Primary performance indicator, annual standardised index of juvenile (0+) blue swimmer crabs in Cockburn Sound calculated using data from juvenile trawls conducted in April, May and June of each year at sites CBH Jetty, Colpoys Point, Mangles Bay, Jervois Bay and Garden Island North. Standardisation of catch rates was used to account for the effect of month and site with units for the index in catch rate of juvenile 0+ crabs/100 m^2 trawled. The associated reference points (target, threshold 0.6 and limit 0.4) for the preliminary harvest strategy and the 95% confidence intervals are shown. The fishery was closed between December 2006 and December 2009 and has remained closed since April 2014.

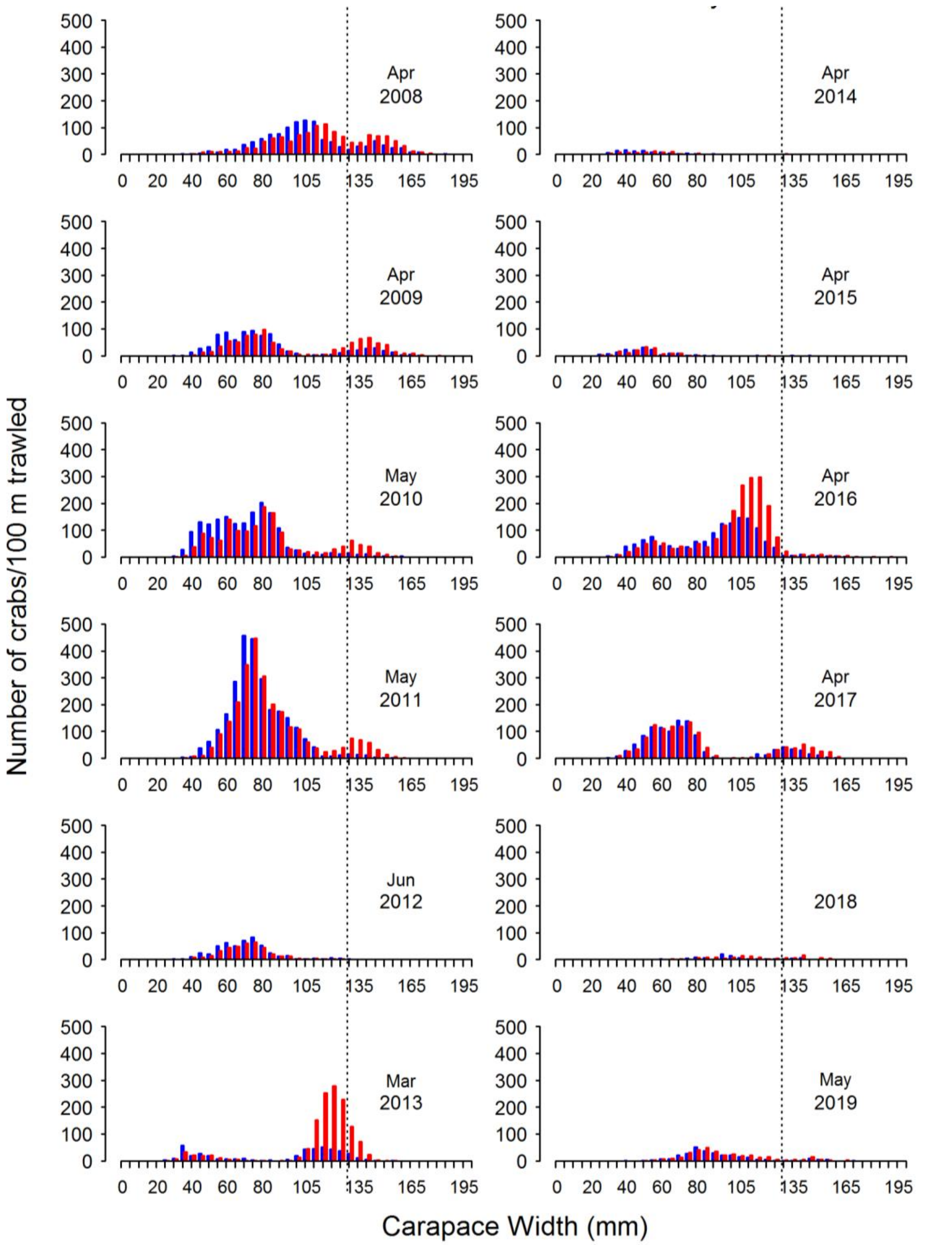


Figure 9.35. Length frequency histograms of male (blue), female (red) and ovigerous female (yellow) *P. armatus* for *RV Naturaliste* recruitment trawl surveys (April or May) from 2008 to 2019 in the Cockburn Sound. The dashed line denotes the minimum commercial size limit of 130 mm CW. The two year-classes represent juvenile (0+) and 1+ crabs. The relative abundance is comparable between years as the trawl effort (total area swept each year) is similar.

Egg Production Index

Monthly commercial trap monitoring data are used to calculate an index of egg production based on mature female abundance in September to December, *i.e.* during the main period of spawning (Figure 9.36; see Section 8.2.4 for survey methods). The index is calculated based on the catch rate of sexually mature crabs and a relationship between batch fecundity and crab size. Catch rates of sexually mature female crabs were calculated by site (*i.e.* commercial trap line location), month and year. The probability of sexual maturity of each female crab, based on CW, was used to calculate the number of sexually mature female crabs in each sample:

$$p = \frac{1}{1 + \exp\left(\frac{L - L_{50}}{a}\right)} \tag{1}$$

where L_{50} is the size at 50% maturity and a is the corresponding slope parameter of the logistic function used to model size-at-maturity. The monthly L_{50} and a values were determined for Cockburn Sound (unpublished data).

The breeding potential of female crab stocks was determined by applying batch fecundity and batch frequency models (de Lestang *et al.*, 2003a) to calculate an index of egg production (eggs per traplift). Female crabs were assigned a total potential egg production based on a batch fecundity (E, number of eggs x 1000) to CW (L) relationship (Johnston *et al.*, *in prep.*):

$$E = 1.017\exp(-6.909)L^{2.837}(1000) = 1.016L^{2.837} \tag{2}$$

where 1.017 is the bias correction factor calculated as $\exp(\sigma^2/2)$ (Beauchamp and Olson, 1973) to adjust for the mean estimate calculated in log space. A batch frequency (N) to CW (L) relationship (modified from de Lestang *et al.*, 2003a) was then used to adjust the number of eggs by the number of expected batches to estimate the total fecundity for a crab of given CW:

$$N = 1 + \frac{2}{1 + \exp\left(-\ln(19)\frac{L - 120.97}{134.77 - 120.97}\right)} \tag{3}$$

The number of eggs per sexually mature female was aggregated to calculate the number of eggs per site, and the associated number of pots used, to determine potential egg catch rate (eggs per traplift) per site and sampling occasion. These data were then analysed using a generalised linear model (log-linear distribution) with month and year as explanatory factors to calculate mean annual egg production estimates and associated 95% confidence limits.

The annual egg production index ranged from ~13–23 ($\times 10^6$ eggs/traplift) in 1999–2003 before declining to below 11 in 2004–2007, then increased to above 15 in 2008–2012 before declining progressively to its lowest level in 2015 (2.8) (Figure 9.36). The egg production index of 12 ($\times 10^6$ eggs/traplift) for 2016 was a significant increase and is at the harvest strategy limit of 12, which is based on the stock-recruitment relationship (see section 9.3.8.1).The increase in egg production for 2016, based on the commercial monitoring data, should be treated cautiously as it was based on limited spatial data. Nevertheless, this increase was also supported by the *Naturaliste* breeding stock trawl survey in 2016 where improved numbers of breeding stock were evident compared to the previous 3 years.

Despite improvement in the egg production index in 2016, this did not translate to a significant improvement in the juvenile index in 2017 (which has remained at very low levels since 2013 as described in the previous subsection). As the relative proportion of ovigerous females in 2016 appears to be similar to the low proportion observed in 2012 (**Figure 9.37**), this may have contributed to the low recruitment the following year.

Since the improvement of the egg production values in 2016, scores for this index have again declined from 2017–2019, with the 2019 value of 5.4 $\times 10^6$ eggs/traplift being less than half the limit value (Figure 9.36). This suggests that breeding stock levels are unacceptable, and the fishery remained closed for the 2019/20 season.

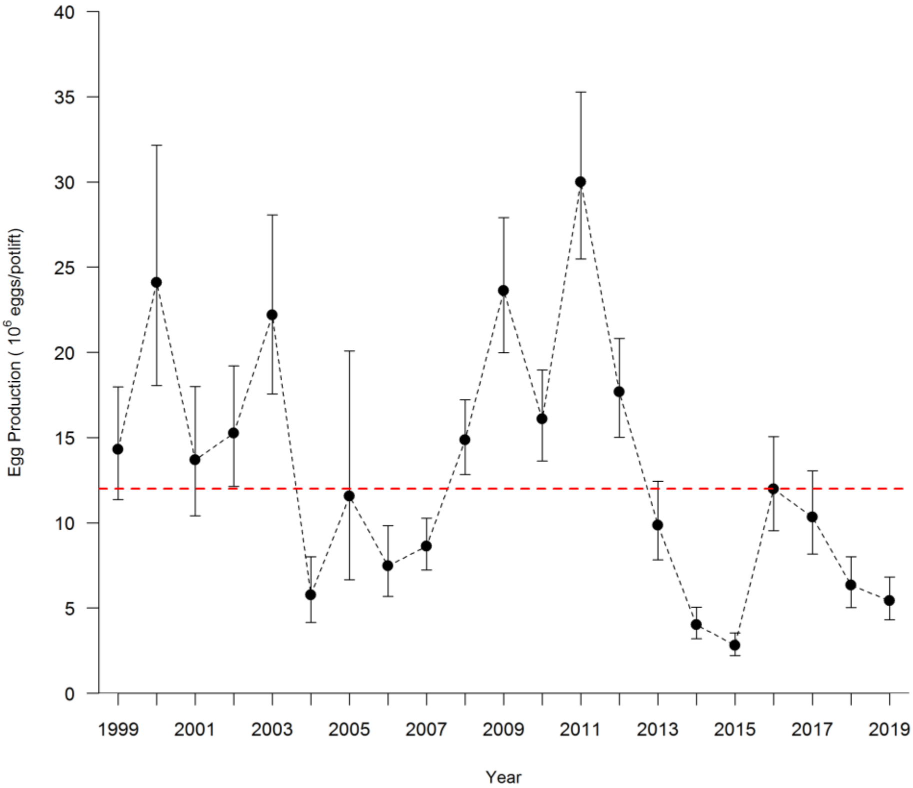


Figure 9.36. Primary performance indicator, annual egg production index (EPI; ± 95% confidence intervals) derived from commercial monitoring trap data during the peak spawning period (September to December) from 1999 to 2016. The EPI is based on a size-fecundity relationship which assumes all sexually mature females will contribute to egg production (berried). A limit of 12 (dashed red line) has been proposed for the harvest strategy based on the stock-recruitment relationship. The fishery was closed between December 2006 and December 2009 and again since April 2014.

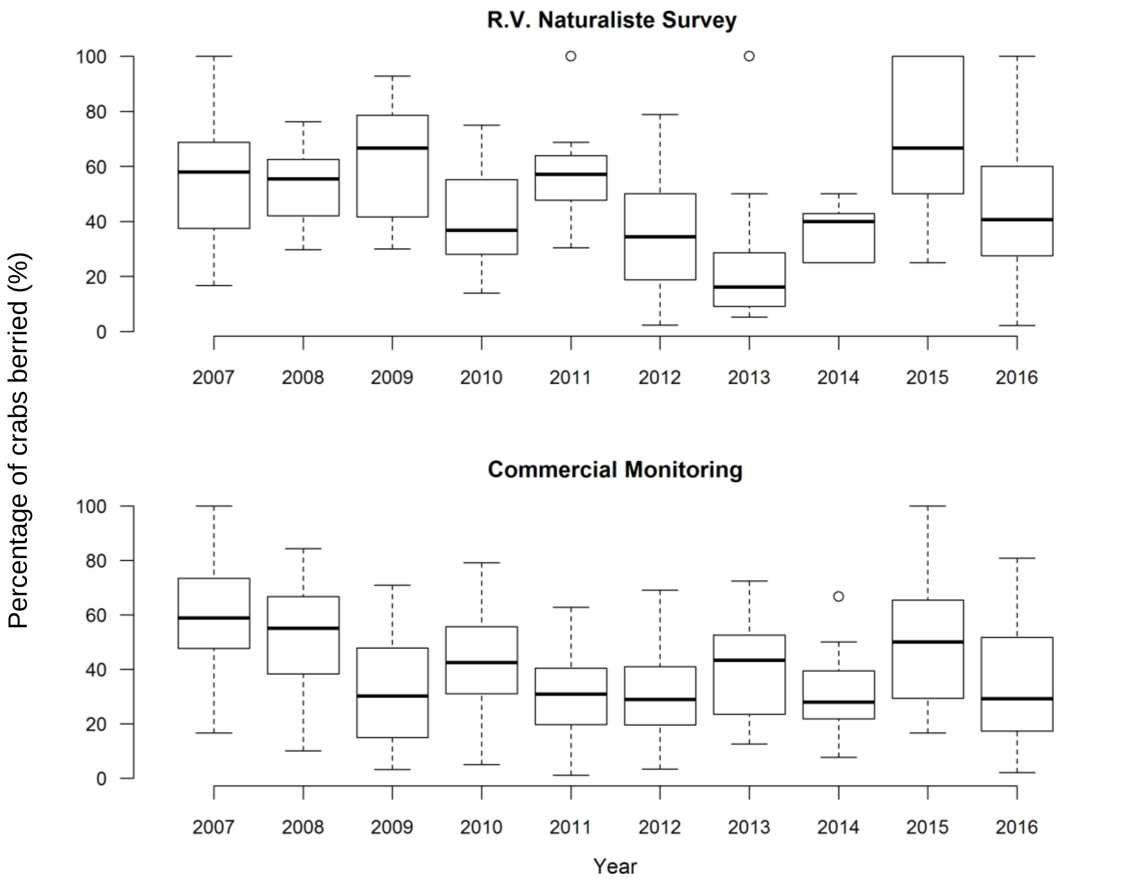


Figure 9.37. Percentage of female crabs in Cockburn Sound above the size of maturity that were berried during the spawning period (October to December) each year from 2007 to 2016. Data were obtained from (a) breeding stock surveys undertaken on the *RV Naturaliste* and (b) during commercial monitoring surveys.

9.3.5.2 Peel-Harvey Estuary

A fishery-independent trap survey has been undertaken in Peel-Harvey Estuary since 2007 (see Section 8.2.4 for survey methods). Up until 2014 this survey was undertaken monthly but in recent years it has been refined to June–Nov to develop a legal-November Index and catch prediction model for the Estuary which is described in Section 9.3.7.2.

A fishery-independent monthly trawl sampling program began in 2016 to develop a robust juvenile recruitment index for the Peel-Harvey crab fishery (see Section 8.2.4 for survey methods). Data from this trawl program also provide an indication of changes in size structure over time (see section 9.3.9.2), and are currently being modelled against key environmental variables (*e.g.* water temperature, salinity, habitat) to quantify changes in the crab population in response to changing environmental conditions.

The juvenile index for the Peel-Harvey is calculated using the abundance of juvenile crabs/100 m^2 trawled at each site on each sampling occasion during peak recruitment months of April–June (see Appendix 4). Mean annual values are derived from a generalised linear model accounting for site and month. For this analysis, female crabs are determined to be juvenile on the basis of abdominal flap morphology (fused abdominal flap), while males are determined to be juvenile if they are below the size at 50% maturity of 93 mm CW (de Lestang *et al*., 2003a).

Annual index values were highest in 2016 and 2018 (1.1 and 1.3 juveniles/100 m^2, respectively) and lowest in 2017 and 2019 (0.4 and 0.6 juveniles/100 m^2; **Figure 9.38**). A threshold and limit for this juvenile index will be developed in the future when more years of data are available.

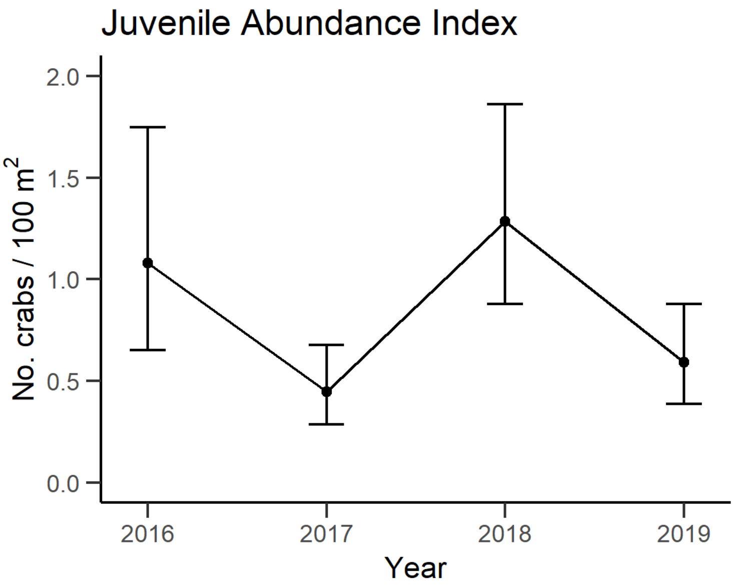


Figure 9.38. Annual standardised juvenile (0+) abundance index (± 95% confidence limits) for the Peel-Harvey Estuary derived from juvenile trawl surveys conducted in April, May and June of each year since 2016. Annual values have been standardised using a generalised linear model to account for effects of site and month.

9.3.5.3 Swan-Canning Estuary

Breeding stock surveys

Fishery-independent breeding stock surveys have been conducted during the peak spawning months of October and November in the Swan-Canning Estuary (SCE) since 2013 (see Section 8.2.4 for survey methods). From these surveys breeding stock potential is assessed through (a) catch rates of mature female crabs and (b) egg production potential. Sexual maturity was determined in the field based on abdominal flap morphology (fused *vs* loose; see Section 5.3.5 for further details), except in a very small number of cases (<2% of individuals), whereby known a size at 50% maturity of 92 mm was used. Catch rates of sexually mature female crabs (number of crabs/traplift) were calculated by site, month and year. Egg production (number of eggs/traplift) was then calculated based on the catch rate of sexually mature females and a relationship between batch fecundity and crab size, which is detailed earlier in section 9.3.5.1. Annual mean values and associated 95% confidence intervals for both metrics were estimated using a generalised linear model with year, month and site as explanatory terms.

Catch rates of sexually mature female crabs were significantly difference between years (ANOVA; $P < 0.001$), with a noticeable decline in CPUE from 3.2–4.3 crabs/traplift during

2013–2016, to 1.8 crabs/traplift in 2017 (Figure 9.39). CPUE decreased again in 2018 (*i.e.* 1.3 crabs/traplift), but increased marginally in 2019 to 2.1 crabs/traplift.

With respect to resultant egg production potential, values from 2013–2014 were essentially constant at 8.4×10^6 eggs/traplift, with a notable increase in 2015 to 13.5×10^6 eggs/traplift, before a decrease to 8.3×10^6 eggs/traplift in 2016 (Figure 9.39). There was a significant decrease in egg production during 2017 and 2018, with values in the latter year falling to as low as 1.8×10^6 eggs/traplift. In 2019, however, egg production increased to 5×10^6 eggs/traplift. This decline in egg production from 2016 to 2018 reflects not only a decrease in the abundance of sexually mature females, but also a clear decrease in the average size of crabs which occurred during this time period (detailed in Section 9.3.9.3).

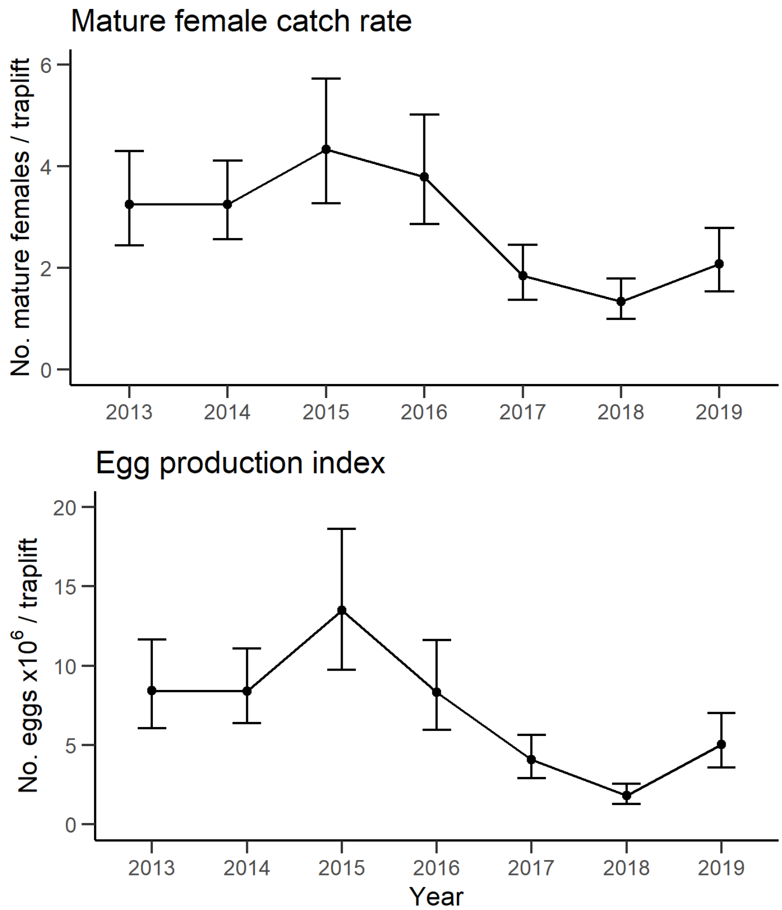


Figure 9.39. Mean annual catch rates (numbers of crabs / traplift; ± 95% confidence intervals) of sexually mature female blue swimmer crabs and their egg production potential (numbers of eggs / traplift) recorded during breeding stock surveys (October & November) in the Swan-Canning Estuary between 2013 and 2019. Annual estimates have been calculated using a generalised linear model accounting for site and month. Sexual maturity was determined from abdominal flap morphology and egg production potential is based on a size-fecundity relationship which assumes all sexually mature females will contribute to egg production.

Recruitment surveys

Fishery-independent recruitment surveys have been conducted in the Swan-Canning Estuary, during peak recruitment months (March to June) since 2014 (see Section 8.2.4 for survey methods). Initial recruitment surveys by beach seine netting were discontinued due to consistently low catches and a trawling program began in 2016. This trawl data from 2016-2019, which has been collected at 10–12 representative sites in April and May each year, has been used to develop a juvenile abundance index for the Swan-Canning Estuary. Calculation of this index is the same as for the Peel-Harvey Estuary Juvenile Index described earlier in section 9.3.5.2.

Juvenile abundance was highest in 2016 at 0.66 crabs/100 m^2 (Figure 9.40), decreasing to 0.24 crabs/100 m^2 in 2017, and further declining in 2018 and 2019 to 0.15–0.16 crabs/100 m^2. These low levels of recruitment may be reflective of low egg production in 2017 and 2018 (Figure 9.39). Given that egg production has increased in 2019, the juvenile index values for 2020 will be examined to see if there is a corresponding increase.

A threshold and limit for this juvenile index will be developed in the future when more years of data are available.

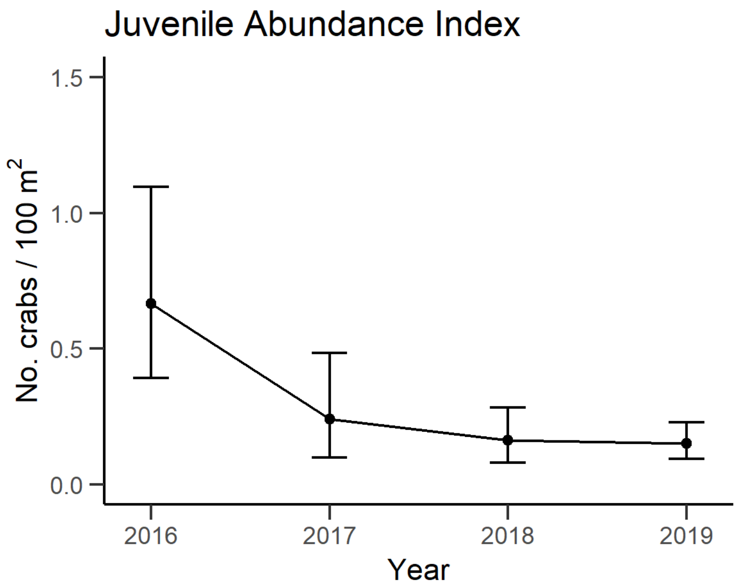


Figure 9.40. Annual standardised juvenile (0+) abundance index (± 95% confidence limits) for the Swan-Canning Estuary derived from juvenile trawl surveys conducted in April, May and June of each year since 2016. Annual values have been standardised using a generalised linear model to account effects of month and site.

9.3.5.4 Conclusion

Cockburn Sound Fishery Independent Recruitment Index	The index of juvenile (0+) abundance for Cockburn Sound was initially >1.0 crabs/100 m^2 trawled in 2002, but declined to <0.1 crabs/100 m2 in 2004 and 2006. After closure of the fishery in December 2006, the index increased to >0.6 crabs/100 m^2 during 2010–12, before declining to 0.16 crabs/100 m^2 in 2013. From 2014 to 2019 the abundance of juveniles has remained very low (0.03–0.11 crabs/100 m^2), substantially below the harvest strategy limit of 0.4, indicating that recruitment is at unacceptable levels.
Egg production index (and fishery-independent breeding stock *Naturaliste* trawl survey)	The mean egg production index increased to >15 in 2008-2012 before declining to its lowest level in 2015 (2.8). The egg production index for 2016 was a significant increase, and at the harvest strategy threshold of 12. The increase in egg production based on the commercial monitoring data, was supported by the *RV Naturaliste* breeding stock trawl survey in 2016, where improved numbers of breeding stock were evident compared to the previous three years. However, despite the improvement in the egg production index in 2016, this did not translate to a significant improvement in the juvenile index in 2017. Moreover, scores for this index again declined from 2017–2019, with the 2019 value of 5.4 ×10^6 eggs/traplift being less than half the limit value.
Peel-Harvey Estuary Recruitment index	A recruitment index for the Peel-Harvey Estuary has recently been developed using fishery independent trawl data collected from 2016 to 2019. Annual index values (abundance of juveniles/100 m^2) were highest in 2016 and 2018 (1.1 and 1.3 respectively) and lowest in 2017 and 2019 (0.4 and 0.6, respectively). A threshold and limit for this juvenile index will be developed in the future when more years of data are available.
Swan-Canning Estuary Recruitment Index	A recruitment index for the Swan-Canning Estuary has recently been developed using fishery independent trawl data collected from 2016 to 2019. Juvenile abundance was highest in 2016 at 0.66 crabs/100 m^2, decreasing to 0.24 crabs/100 m^2 in 2017, and further declining in 2018 and 2019 to 0.15-0.16 crabs/100 m^2. These low levels of recruitment may be reflective of low egg production in 2017 and 2018. Given that egg production has increased in 2019, juvenile index values for 2020 will be examined to see if there is a corresponding increase. The decline in recent years will continue to be monitored. A threshold and limit for this juvenile index will be developed in the future when more years of data are available.

Breeding stock index	Catch rates of sexually mature female crabs were similar from 2013–2016, but declined significantly in 2017 (from 3.2–4.3 crabs/traplift, to 1.8 crabs/traplift). CPUE decreased again in 2018 (1.3 crabs/traplift), but increased marginally in 2019 (2.1 crabs/traplift). Similarly, there was a significant decrease in egg production from 2016 to 2017–18, with values in the latter year falling to as low as 1.8×10^6 eggs/traplift (compared with $8.3–13.5\times10^6$ from 2013–2016). In 2019 egg production increased to 5×10^6 eggs/traplift. This decline in egg production from 2016 to 2018 reflects not only a decrease in the abundance of sexually mature females, but also a clear decrease in the average size of crabs which occurred during this time period (detailed in Section 1.3.9.3). Inter-annual variation in the breeding stock index in the Swan-Canning Estuary is apparent and the decline in recent years will continue to be monitored. A longer time series is required before the status of breeding stock can be assessed. A threshold and limit for this index will be developed in the future when more years of data are available.

9.3.6 Productivity Susceptibility Analysis

Productivity Susceptibility Analysis (PSA) is a semi-quantitative risk analysis originally developed for use in MSC assessments to score data-deficient stocks, *i.e.* where it is not possible to determine status relative to reference points from available information (Hobday *et al*., 2011; MSC, 2014). The PSA approach is based on the assumption that the risk to a stock depends on two characteristics: (1) the productivity of the species, which will determine the capacity of the stock to recover if the population is depleted, and (2) the extent of the impact on the stock due to fishing, which will be determined by the susceptibility of the species to fishing activities (see Appendix 3).

Although a valuable tool for determining the overall inherent vulnerability of a stock to fishing, the PSA is limited in its usefulness for providing stock status advice. This is because of the simplicity and prescriptiveness of the approach, which means that risk scores are very sensitive to input data and there is no ability to consider management measures implemented in fisheries to reduce the risk to a stock (Bellchambers *et al*., 2016). Consequently, the PSA is used by the Department to produce a measure of the vulnerability of a stock to fishing, which is then considered within the overall weight of evidence assessment of stock status.

The sections below outline the PSA scores for the blue swimmer crab targeted in each fishing sector; both commercial and recreational, in south-west WA.

9.3.6.1 Productivity

For the purposes of the PSA analysis, productivity scores are attributed to the species *Portunus armatus* and relevant and applicable to all fisheries. Both the commercial and recreational sectors are considered in the susceptibility scores and PSA analyses. Key factors influencing the score for productivity for *P. armatus* are short longevity (and thus low age at maturity), high fecundity, broadcast spawning strategy, and mid-trophic level (Table 1.2). Density dependence is uncertain as there is no clear evidence for either compensatory or depensatory dynamics. Therefore, a precautionary approach has been taken and moderate score allocated. The total productivity score for this species averaged 1.33 (Table 9.2).

Table 9.2. PSA productivity scores for blue swimmer crab *Portunus armatus* in all fisheries targeting the resource in the West Coast Bioregion.

Productivity attribute	Score
Average maximum age	1
Average age at maturity	1
Reproductive strategy	1
Fecundity	1
Trophic level	2
Density dependence	2
Total productivity (average)	1.33

9.3.6.2 Susceptibility

9.3.6.2.1 Cockburn Sound & Swan–Canning Estuary

Given the susceptibility scores for crab stocks in Cockburn Sound and the Swan-Canning Estuary, their commercial fisheries scored a total susceptibility of 1.88 and 1.58, respectively, and their recreational fisheries scored 1.88 (Table 9.3, see Section 6.1.1.4 and Appendix 1 for justifications of susceptibility scores). The overall weighted PSA score was 2.18, and the MSC PSA-derived score was 92 (= low risk).

Table 9.3. PSA susceptibility scores for each sector that impact on *Portunus armatus* in Cockburn Sound and Swan-Canning Estuary which for the purpose of PSA analysis have been regarded as one stock.

Susceptibility attribute	Commercial fisheries		Recreational Fishery
	Cockburn Sound	Swan-Canning Estuary	
Areal overlap	3	2	3
Vertical overlap	3	3	3
Selectivity	2	2	2
Post-capture mortality	2	2	2
Total susceptibility (multiplicative)	1.88	1.58	1.88

9.3.6.2.2 Peel-Harvey Crab Fishery

Given the susceptibility scores for crab stocks in the Peel-Harvey Estuary and adjacent coastal waters of Warnbro Sound, Comet Bay and Mandurah-Bunbury, their commercial fisheries scored a total susceptibility of 1.88 except Warnbro Sound at 1.58, and their recreational fisheries scored 1.88 (Table 9.4; see Section 6.1.2.4 and Appendix 1 for justifications of susceptibility scores). The overall weighted PSA score was 2.29, and the MSC PSA-derived score was 90 (= low risk).

Table 9.4. PSA susceptibility scores for each sector that impact on *Portunus armatus* in the Peel-Harvey Estuary (PHE) and adjacent coastal waters (Warnbro Sound; WS, Mandurah to Bunbury Developing Crab Fishery — Area 1 Comet Bay and Area 2 Mandurah to Bunbury; MBDCF) which for the purpose of PSA analysis have been regarded as one stock.

Susceptibility attribute	Commercial Fisheries			Recreational Fishery
	PHE	WS	MBDCF	
Areal overlap	3	2	3	3
Vertical overlap	3	3	3	3
Selectivity	2	2	2	2
Post-capture mortality	2	2	2	2
Total susceptibility (multiplicative)	1.88	1.58	1.88	1.88

9.3.6.3 Conclusion

Based on the productivity and susceptibility scores, the overall weighted (by fishery / sector catches) PSA scores for *Portunus armatus* in Cockburn Sound/Swan-Canning Estuary and Peel-Harvey Estuary/coastal waters were 2.18 and 2.29, respectively, which represents a low risk.

Cockburn Sound and **Swan-Canning Estuary**	The biological characteristics of *P. armatus* including rapid growth, short lifespan, high fecundity, early maturity and broadcast spawning strategy, suggest this highly productive species has a low-moderate vulnerability to fishing (productivity score 1.33). Susceptibility scores of 1.88 and 1.58 for the commercial fisheries of Cockburn Sound and Swan-Canning Estuary, respectively, and 1.88 for their recreational fisheries were based on moderate to high availability, encounterability, selectivity and post-release mortality. The overall PSA score was 2.18, with an MSC PSA-derived score of 92 (= low risk). The PSA analysis indicates that the risk of unacceptable stock depletion is low under current management arrangements and fishing effort. It assumes that the productivity of the stock is constant and not impacted by environmental conditions.
Peel-Harvey Estuary (and adjacent coastal waters including the Warnbro Sound, Mandurah-Bunbury Crab Fisheries)	The biological characteristics of *P. armatus* including rapid growth, short lifespan, high fecundity, early maturity and broadcast spawning strategy, suggest this highly productive species has a low-moderate vulnerability to fishing (productivity score 1.33). Susceptibility scores of 1.88 for the commercial fisheries of Peel-Harvey Estuary and Comet Bay-Mandurah Bunbury and 1.58 for Warnbro Sound; and 1.88 for their recreational fisheries, were based on moderate to high availability, encounterability, selectivity and post-release mortality. The overall PSA score was 2.29, with an MSC PSA-derived score of 90 (= low risk).

	The PSA analysis indicates that the risk of unacceptable stock depletion is low under current management arrangements and fishing effort. It assumes that the productivity of the stock is constant and not impacted by environmental conditions.

9.3.7 Catch Predictions

9.3.7.1 Cockburn Sound

For the Cockburn Sound commercial crab fishery, the strength of recruitment (juvenile 0+) during April–August from the previous season's spawn (September-January) and the residual stock (1+) near completion of the current fishing season (July-August) was used as an abundance index to indicate the size of the next season's catch (Johnston *et al*., 2011a; 2011b). This catch prediction was used in a decision rule framework for the management of the Cockburn Sound fishery to determine the appropriate level of fishing effort in the following season. This predictive relationship is not currently deemed appropriate due to the collapse in the fishery and the resulting change in management structure. However, a juvenile index (and egg production index) remain important indicators of the stock status and are currently used in the harvest strategy for this fishery.

9.3.7.2 Peel-Harvey Estuary

Fishery-independent trap survey data collected since 2007 have been used to develop an annual commercial catch prediction for the Peel-Harvey Estuary, which is based on the abundance of legal sized crabs in November. Catch rates of legal-sized crabs in November (t) showed a good predictive relationship with commercial catches for the following (November 1 – August 31) fishing season (t, t+1; Figure 9.41). Full details of this catch prediction model are given in Appendix 5.

The predicted commercial catch for the 2018/19 fishing season (power model) based upon the legal-November index of 1.48 was 80 t (68–94 t confidence limits and 46-139 t predictive limits; Figure 9.41). The actual catch for 2018/19 was 65.4 t, which is lower than predicted but within the latter predictive range. Contributing to this lower than predicted total annual catch was very low catch rates in November and December (CPUE lowest on recorded since 1995), which may have resulted from cooler than average water temperatures reducing overall abundances in the estuary (lower immigration from marine waters) and lowering catchability (see Section 7.3.1).

The predicted catch for the 2019/20 season is 86 t (81−104 t confidence limits) based upon a legal-November Index of 1.83.

This legal-index and catch prediction will be used in future assessments, in addition to the harvest strategy performance indicators, as a weight of evidence approach to stock assessment in this fishery.

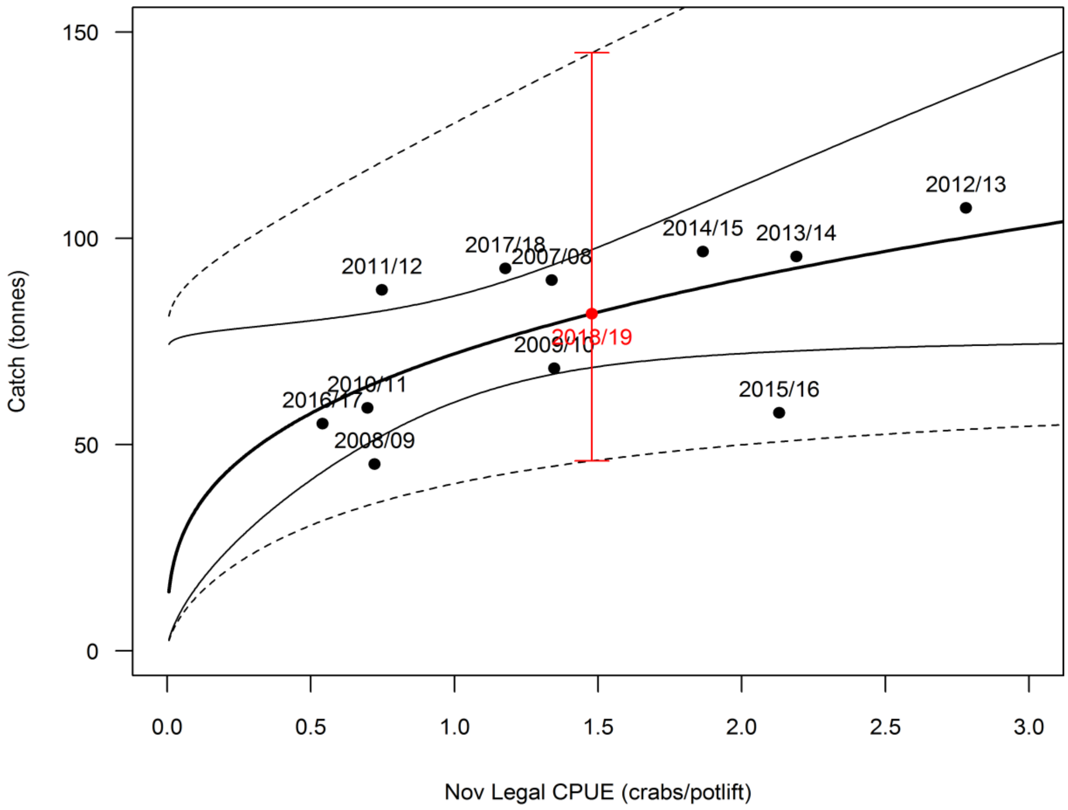


Figure 9.41. Commercial catch prediction (●) for the Peel-Harvey estuary for the 2018/19 fishing season. The solid central line is the fitted regression between fishery independent November legal CPUE and commercial catch (t) from earlier fishing seasons between 2007/08 and 2017/18. 95% confidence (thin black lines) and prediction (dashed lines) limits are also shown.

9.3.7.3 Conclusion

Cockburn Sound	The historical catch prediction is no longer used as it is no longer appropriate for this fishery. However, the juvenile index remains an important indicator of stock status.
Peel-Harvey Estuary	Fishery-independent trap survey data are used to predict annual commercial catch for the Peel-Harvey Estuary (t+1), which is based on the abundance of legal sized crabs in November (t). Based on the 2018 November legal index of 1.48, the predicted commercial catch for the 2018/19 season was 80 t (95% CL: 68–94 t). The actual catch was 65.4 t, within the predictive range. The predicted catch for the 2019/20 season is 86 t (81−104 t confidence limits) based upon a legal-November Index of 1.83. This is within the range of recent annual catch totals.

9.3.8 Empirical Stock-Recruitment Relationships

9.3.8.1 Cockburn Sound Stock-Recruitment Relationships

Historically, an important aspect considered in assessing stock status of crabs in Cockburn Sound has been the use of a stock-recruitment-environment relationship. Initially, such a relationship was derived using catch as a proxy for recruitment (de Lestang *et al*., 2010; Johnston *et al*., 2011b). Departures from the estimated stock-recruitment curve were explained by deviations in water temperature, with low temperatures in the months preceding spawning considered to be unfavourable for recruitment success.

Following the introduction of fishery closures in the mid-2000s, it was no longer possible to use catch in this relationship. Once a sufficiently long time series of juvenile recruitment data became available, the stock-recruitment relationship was recalculated based on juvenile recruitment and egg production indices.

Regression analysis was conducted on these abundance indices and environmental data obtained for the CSCMF to verify the association or relationship between the index of recruitment, *i.e.* Juvenile Index (number of 0+ crabs/100m^2), and one or more explanatory variables:

1. A measure of egg production (eggs/trap lift), during the spawning period (September to December) preceding recruitment (described earlier in section 9.3.4.1).

2. An index of chlorophyll-*a* (µg/L) during the summer period (December to March) relating to the larval period for crabs.

3. An index of water temperature (˚C) during the key spawning period *i.e.* October to December.

A linear regression model and a non-linear regression model (*i.e.* Beverton-Holt Stock Recruitment relationship) were used to explore the relationship between spawning stock and recruitment. Multiple linear regression was used to explore the additional variation explained by the environmental variables chlorophyll-*a* and water temperature. The full details of this stock recruitment relationship are given in Appendix 6. and further details of the chlorophyll-*a* index calculation are given in Appendix 7.

Although the current stock-recruitment relationship shows large variability in recruitment, there has never been a strong recruitment (>0.4 juvenile crabs/1000 m^2 trawled) when the egg production index has fallen below 12×10^6 eggs/traplift, irrespective of environmental conditions (Figure 9.42). A threshold value of 12 for the egg production index was therefore proposed for the draft harvest strategy (see Section 7.2).

Environmental variables, including water temperature during peak spawning months (Oct–Dec) and summer chlorophyll *a* index, have been shown to improve the stock-recruitment relationship. When spawning stock is at or above the threshold levels, recruitment is generally high in years with warm water temperatures (*e.g.* 2002, 2003, 2012; Figure 9.42). Additionally, the latter three years had chlorophyll *a* concentrations >1.3 µg/L.

There was an improvement in breeding stock in 2016, with an egg production index value of approximately 12, however, this did not result in a significant improvement in the 2017 0+ recruitment index (Figure 9.42). Similarly, in 2017/18, an egg production index value of approximately 10 was recorded but recruitment remained very low (<0.1).

Mean monthly water temperatures in Cockburn Sound during winter and early spring of 2016 were considerably cooler than previous years (see Appendix 8, Figure A8.3), which may have contributed to the lower proportion of berried females observed during that spawning season, and therefore, despite an improved EPI value, there was low recruitment in 2017.

The stock-recruit relationship will be updated in the near future using a refined EPI incorporating fishery-independent trawl data.

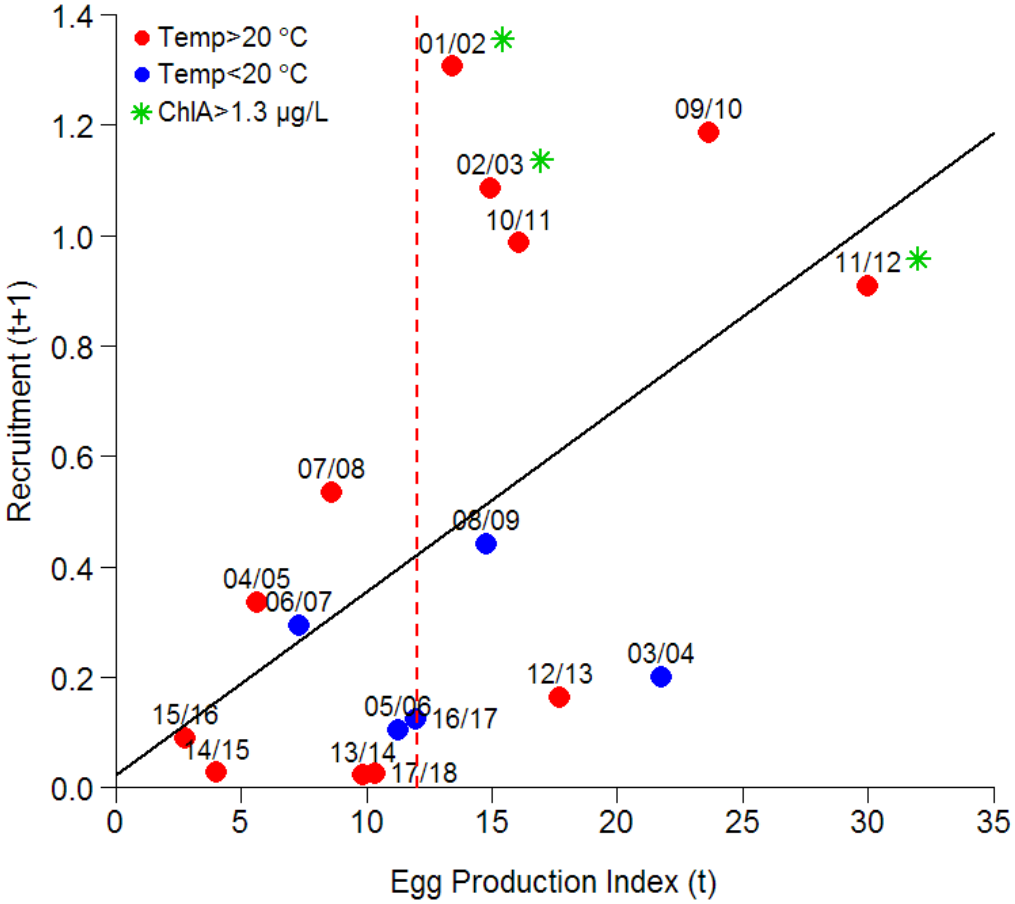


Figure 9.42. Stock recruitment relationship investigating the influence of environmental parameters (water temperature in spawning months October-December and Summer chlorophyll-a). The egg production index (10^6 eggs/traplift) is a measure in year t, with recruitment (juveniles/100m2 trawled) an index in t+1. In years with low egg production ($<12x10^6$ eggs / trapllift), low levels of recruitment were observed, irrespective of environmental conditions. An average temperature of 20°C was observed between October and December from 2001/02 – 2017/18. 95% confidence limits around the regression line are shown.

9.3.8.2 Conclusion

Cockburn Sound Stock-recruitment-environment relationship	There has never been a strong recruitment when the egg production index has fallen below 12×10^{6} eggs/traplift, irrespective of environmental conditions. A limit value of 12 for the egg production index was therefore proposed for the draft harvest strategy. Environmental variables, including water temperature during peak spawning months (Oct–Dec) and summer chlorophyll *a* index, have been shown to improve the stock-recruitment relationship. There was an improvement in breeding stock in 2016, with and EPI value of approximately 12, however, this did not result in a significant improvement in the 2017 1+ recruitment index. Similarly, in 2017/18, and EPI value of approximately 10 was recorded but 1+ recruitment remained very low (<0.1). This indicates that environment may be limiting the recruitment.

9.3.9 Trends in Size Structures

Size structure is a key component in the assessment of WCB blue swimmer stocks. Size is measured in CW, which is the distance between the tips of the two lateral spines of the carapace to the nearest millimetre. Commercial catch size data have been obtained from commercial monitoring surveys, where all crabs are measured. Fishery-independent trap and trawl surveys conducted in a standardised manner provide additional size structure information. For the Swan-Canning Estuary recreational catch size data are also available through a voluntary recreational angler logbook program.

For fishery-dependent size structure data (*i.e.* commercial monitoring and recreational logbook), annual mean size estimates have been standardised using a linear model to account for the effects of month and fisher (the latter based on vessel license number for commercial data and logbook number for recreational data). Models were fit with size (CW; mm) as the response variable, and year, month and fisher as explanatory terms (which were considered categorical variables). Estimated marginal mean values for each year (*i.e.* annual standardised values) and associated confidence limits were then calculated using the '*emmeans*' package (Lenth, 2020) in R (R Development Team, 2019).

9.3.9.1 Cockburn Sound

Commercial catch size in Cockburn Sound has been assessed since 1999 using data collected from commercial monitoring trips and chartered commercial trips during fishery closure periods. The annual average size of all crabs caught shows considerable variability over time (Figure 9.43). In 1999, mean size was 135 mm, in 2000 it was 139 mm, then 131 mm in 2001. From 2002 to 2006, mean size remained relatively constant at 135–136 mm, before increasing substantially to 143–147 mm during 2007–2009 after the closure in 2006. From 2009 to 2012 mean size then rapidly declined after the fishery opened, and in the latter year was only 129 mm, which was the first time on record average size fell below the minimum legal size of 130 mm. However, since 2012, the mean size has steadily increased, and in 2019 was 144 mm, reflecting the fact that the fishery has been closed since 2014.

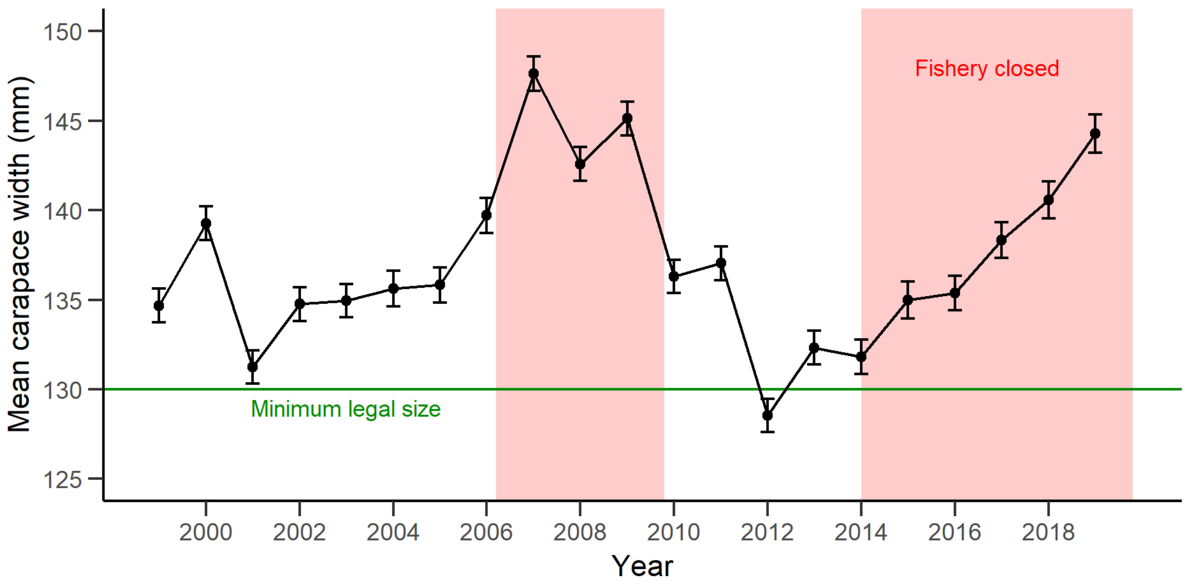


Figure 9.43. Mean standardised annual size (CW, mm; ± 95% confidence intervals) of blue swimmer crabs measured during commercial monitoring trips in Cockburn Sound from 1999 to 2019. The commercial minimum size limit of 130 mm is also shown. Annual estimates were standardised for the effects of month and fisher using a linear model. During closure periods (denoted by shading) monitoring continued aboard a chartered commercial vessel.

At a monthly scale, the average size of crabs in commercial catches generally shows a cyclic variation throughout the fishing season (Figure 9.44). In most years the size of crabs increases from the start of the season in December through to late summer and early autumn (reflecting the moult during this period) where it reaches its maximum, before declining to its minimum in late autumn and early winter. Notably, in the 2006/2007 season the mean size of crabs caught was very high throughout the year, being 142–147 mm in December/January, 148–152 mm from February to May, and 140-146 mm from June to November. In contrast, the minimum monthly size was particularly small throughout many months of 2012–2015, and regularly fell below the minimum size limit of 130 mm. In 2014–2015, the size of male crabs in particular was far smaller than during comparable months in earlier years (Figure 9.44).

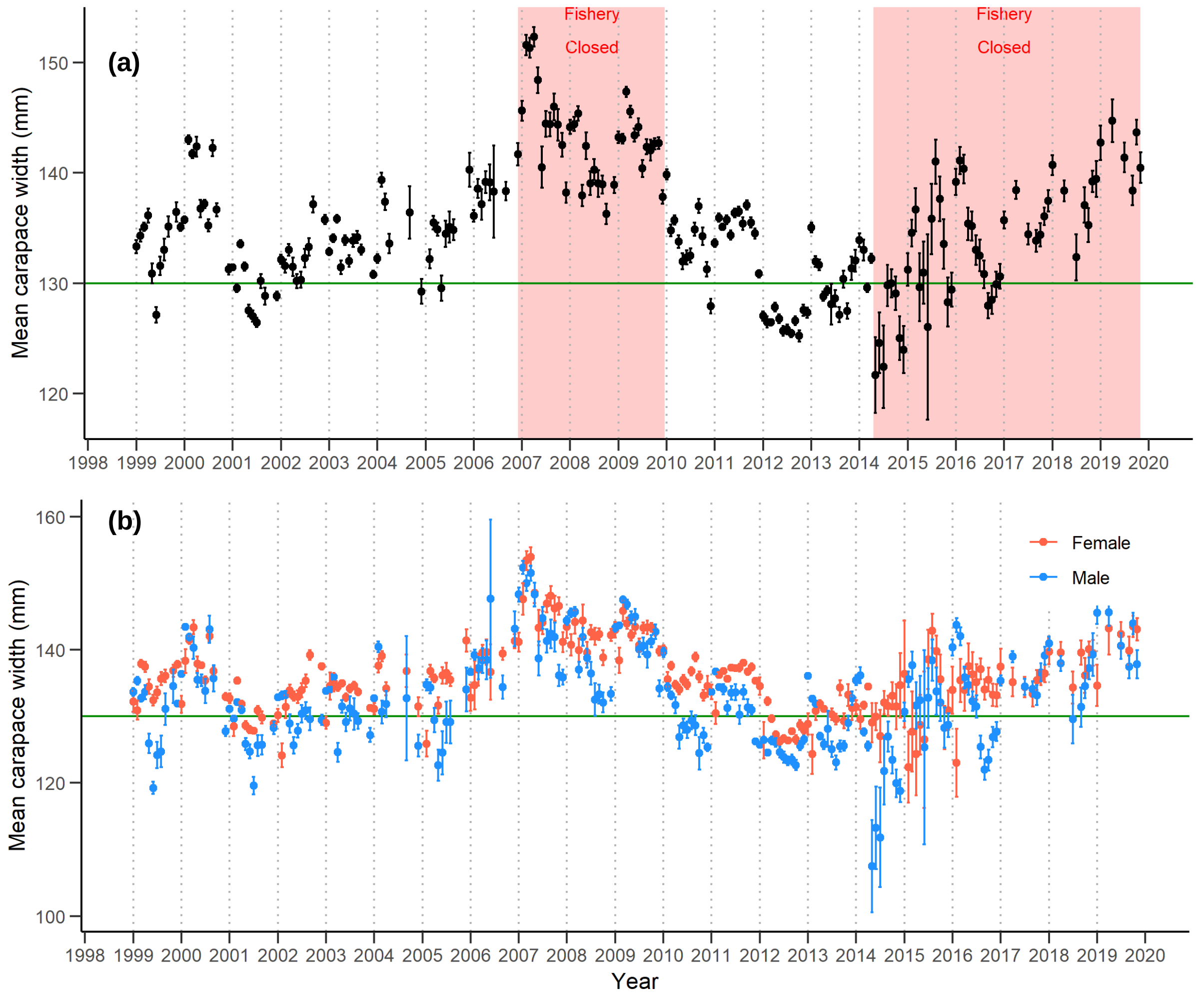


Figure 9.44. Mean monthly size (carapace width, mm; ± 95% confidence intervals) of (a) all blue swimmer crabs measured during commercial monitoring trips in Cockburn Sound from 1999 to 2019, and (b) for males and females separately. The minimum commercial size limit of 130 mm is indicated by the horizontal green line. During closure periods (denoted on plot [a]) monitoring continued aboard a chartered commercial vessel.

Size structure information collected during fishery independent research trawling (large vessel; *RV Naturaliste*) shows a similar interannual pattern to that of commercial catch size structure from 2007 to 2015. Thus, the mean size recorded during trawl surveys decreased between 2007 and 2012 (from 123 to 92 mm), before increasing from 2012 to 2015 (to 137 mm in 2015; Figure 9.45). However, the annual size decreased substantially in 2016 (107 mm) and again in 2019 (110 mm), which is in contrast to commercial catch sizes that continue to increase from 2015 to 2019 (Figure 9.43). These differences likely reflect the fact that commercial crab traps target larger animals (>130 mm), while trawling captures most size classes, and therefore the average size of trawl catches decline if a high proportion of juveniles are present. During all years except 2019 the average size of males caught in the RV Naturalise trawl survey was smaller than males (Figure 9.45).

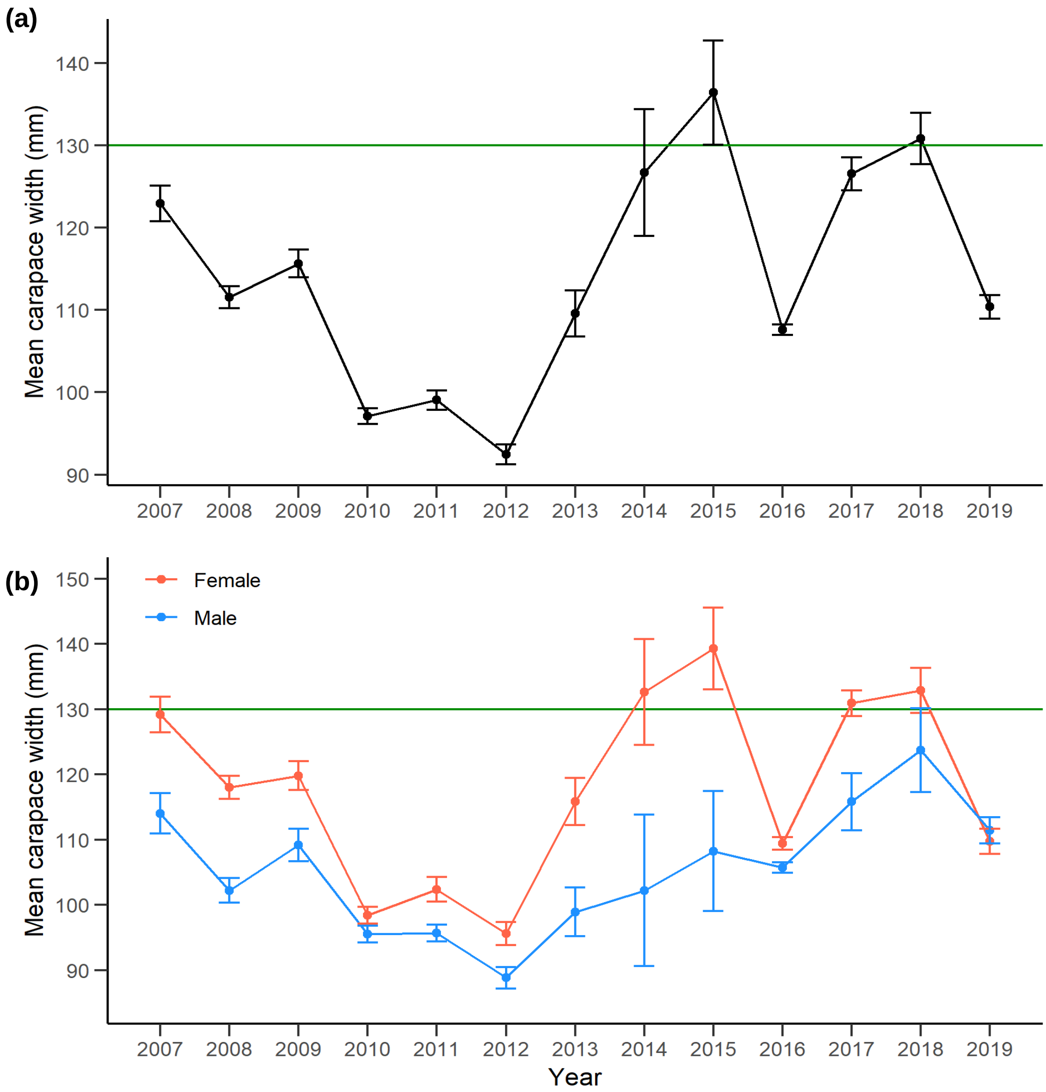


Figure 9.45. Mean annual size (CW, mm; ± 95% confidence intervals) of (a) all blue swimmer crabs, and (b) for males and females separately, recorded during *RV Naturaliste* breeding stock trawl surveys (Oct, Nov or Dec) from 2008 to 2019 in Cockburn Sound. The horizontal green line denotes the minimum commercial size limit of 130 mm CW. Fishery closure periods are denoted above in Figure 9.44a.

9.3.9.2 Peel-Harvey Estuary

The mean annual standardised size of crabs caught by commercial fishers in the Peel-Harvey Estuary between 2006 and 2019 has ranged from 127 to 136 mm (Figure 9.46). In all years the mean annual size has therefore remained at or above the minimum legal size of 127 mm. Annual mean size was significantly correlated with estuary water temperature ($R^2 = 0.6$; P = 0.003; Figure 9.47), and additionally, mean size was significantly correlated with total annual catch ($R^2 = 0.59$; P = 0.002; Figure 9.47). Thus, mean crab sizes were largest during the 2011/12 and 2012/13 fishing seasons, which is when total annual catches were also their highest as described earlier in section 9.3.2.2.2. This very large mean annual size was likely a result of enhanced growth rates, given the warm conditions which occurred in those years (annual mean temperature 19.9–20.6 °C; Figure 9.47). In contrast, 2008/09 was the coolest season since monitoring began (19° C), and had the smallest mean crab size (127 mm) and lowest total catch (45.2 t). The mean size caught during the 2018/19 season was 129 mm, which represents a notable decrease from the 2017/18 mean size of 133 mm (Figure 9.46).

The mean size caught shows clear variation throughout the year, generally increasing from November to a maximum size in late summer or early autumn, before decreasing into winter (Figure 9.48). Generally, early in the fishing season (November to January) males are larger than females, while for the rest of the season the reverse is true. In 2018/19, the mean size caught during November and December was only 120–122 mm (far below the minimum legal size), compared with 129–130 mm a year earlier during the same months in 2017/18. Likewise, the mean size caught from January to March of 2018/19 was 130 mm, while in 2017/18 it was 136-137 mm. The small size of crabs during the 2018/19 is likely resultant from cooler than average water temperatures and thus reduced growth rates.

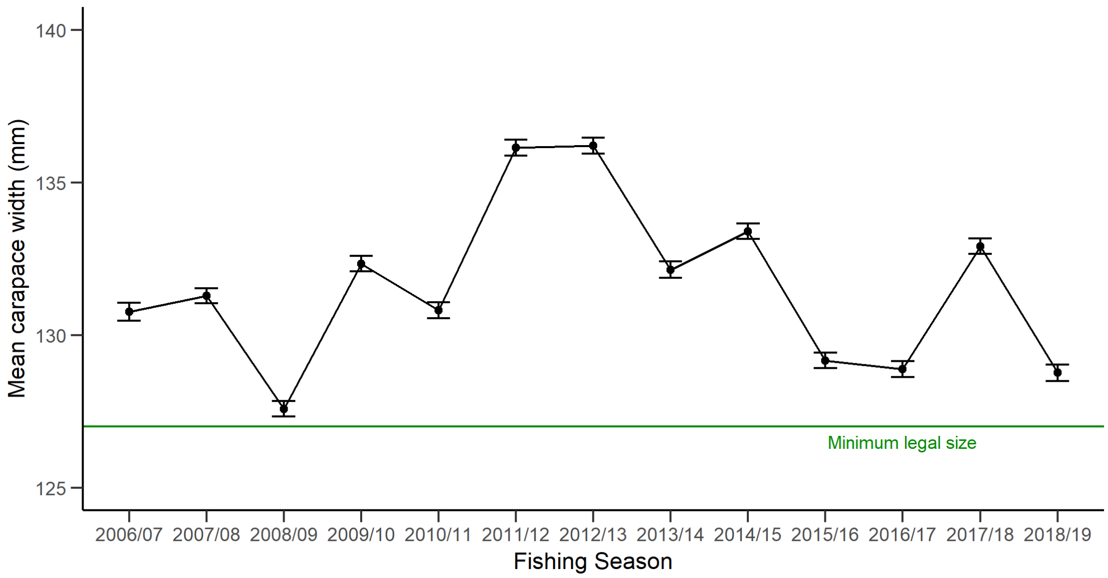


Figure 9.46. Mean standardised annual size (CW, mm; ± 95% confidence intervals) of blue swimmer crabs measured during commercial monitoring surveys in the Peel-Harvey Estuary each fishing season from 2006/07 to 2018/19. Annual estimates were standardised for the effects of month and fisher using a linear model.

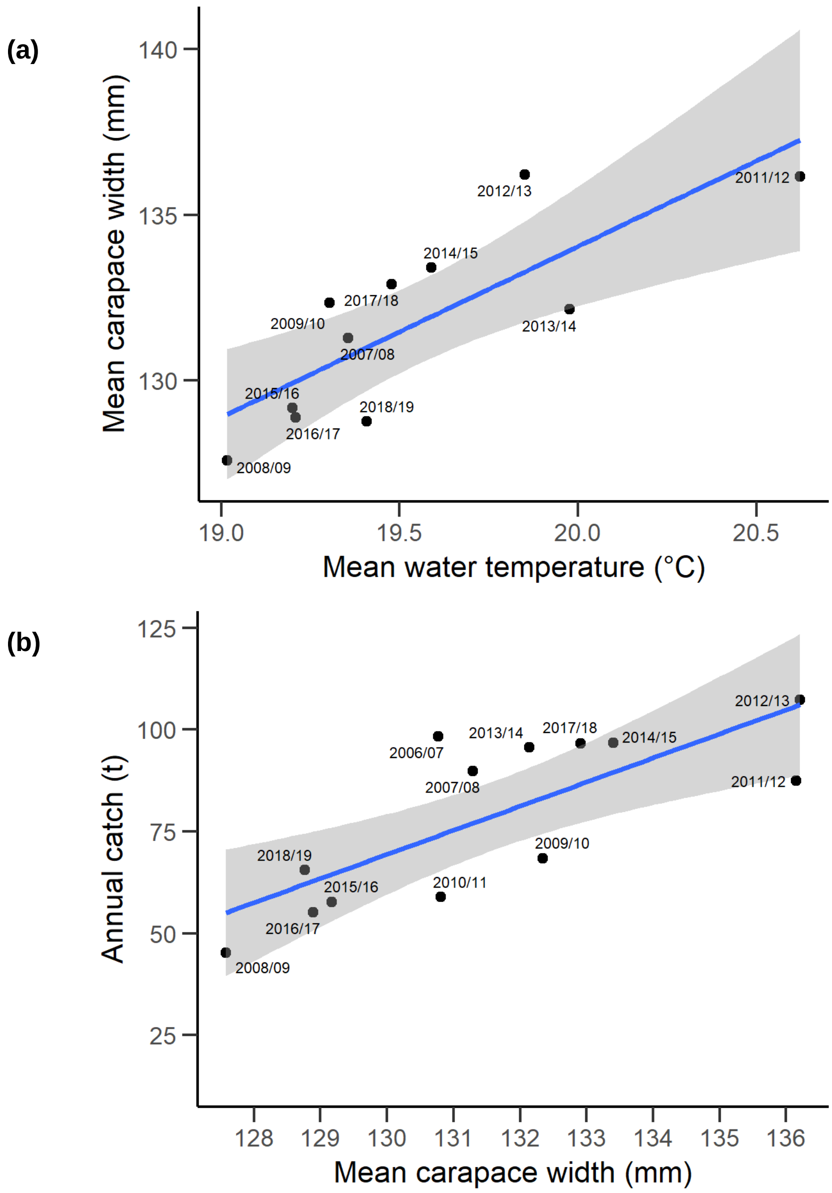


Figure 9.47. Correlation between (a) annual mean water temperature and annual mean standardised CW, and (b) annual mean standardised CW and total annual landed catch, for each fishing season from 2006/07 to 2018/19. Water temperature was recorded from two *in situ* loggers deployed in the estuary since 2007 (see Section 8.2.5). Note, data for the 2006/07 and 2010/11 seasons were not included in analysis (a) as consistent temperature data were not available.

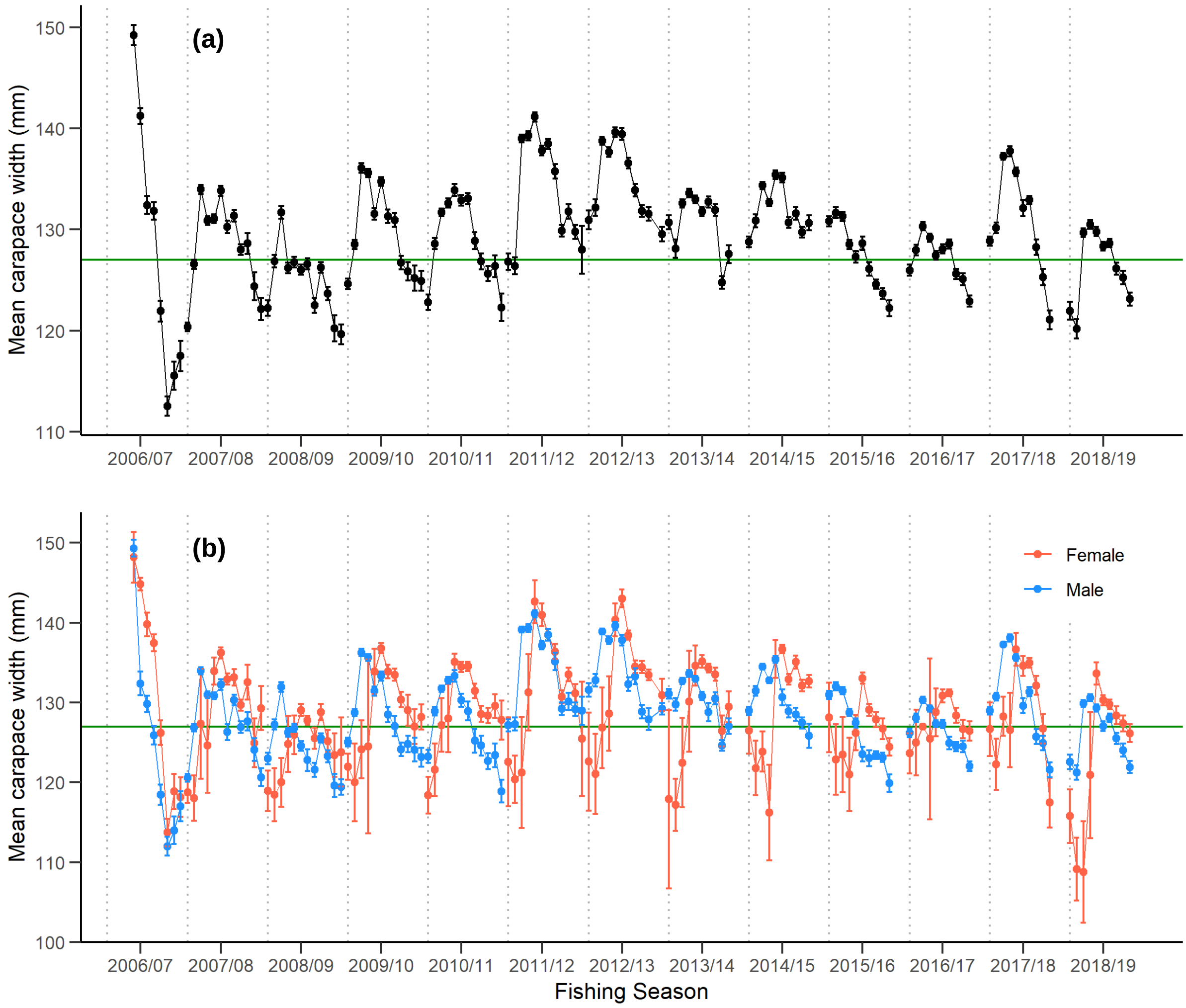


Figure 9.48. Mean monthly size (CW, mm; ± 95% confidence intervals) of (a) all blue swimmer crabs measured during commercial monitoring surveys in the Peel-Harvey Estuary from 2007 to 2019, and (b) for males and females separately. Dotted vertical lines denote the start of each fishing season (1 November – 31 August). The minimum commercial size limit of 127 mm is indicated by the horizontal green line. A spawning closure spans the months September-October.

Fishery-independent trawling and trapping, which catches a greater proportion of smaller animals than commercial gear which targets larger crabs, further shows temporal variation in size structure of crabs in the system. In trawl surveys new recruitment of juveniles (*c.* 30-50 mm) is first evident in February and March, and these crabs then grow throughout the year before approaching size at maturity in late winter and spring (Figure 9.49). The average size of crabs caught in research traps also generally increases throughout the four-month survey period from August to November (Figure 9.50). Notably, the monthly size of crabs caught in research traps during 2018 was substantially smaller than during corresponding months in 2014–17 and 2019 (Figure 9.50).

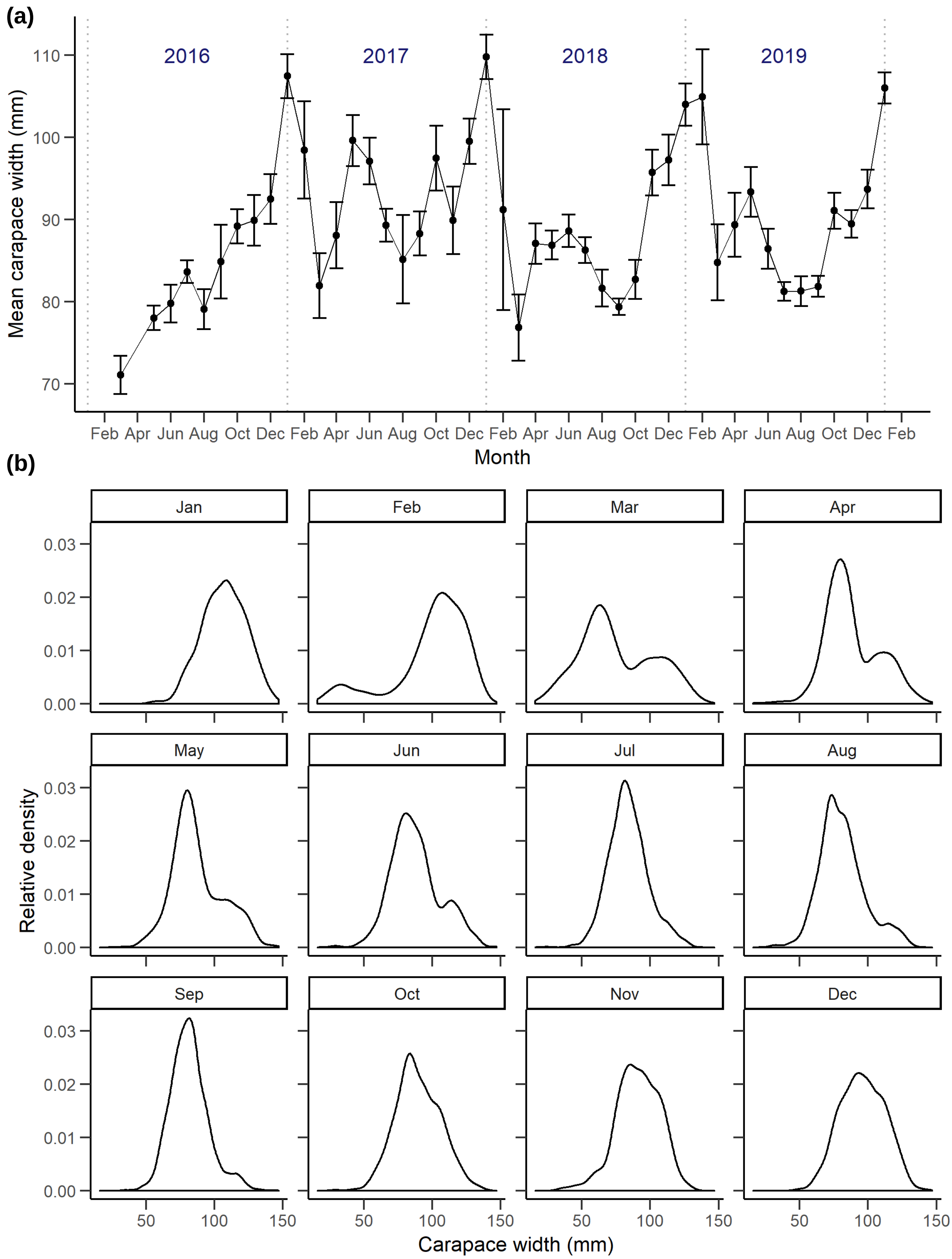


Figure 9.49. (a) Mean monthly size (CW, mm; ± 95% confidence intervals) of blue swimmer crabs recorded during-independent trawling in Peel-Harvey Estuary between 2016 and 2019, and (b), monthly size distribution determined by kernel density estimation (pooled across all four years).

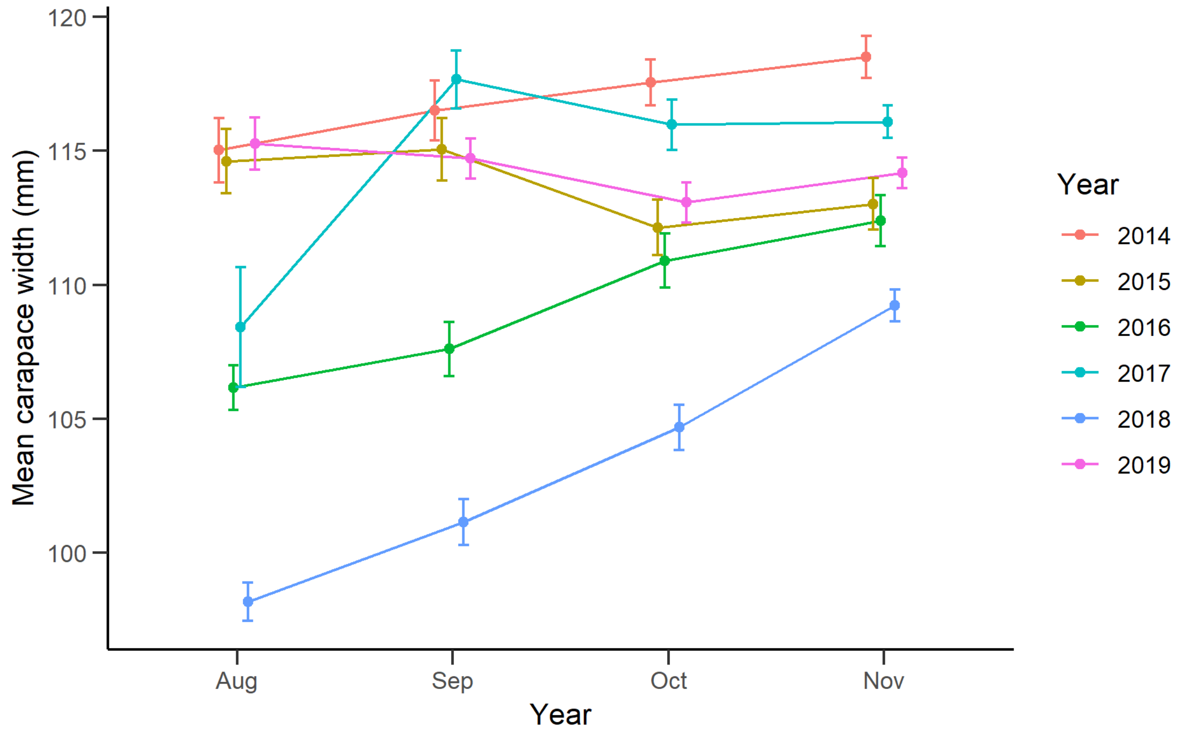


Figure 9.50. Mean size (CW, mm; ± 95% confidence intervals) of blue swimmer crabs recorded in fishery independent research trapping surveys throughout the Peel-Harvey Estuary from August to November each year between 2014 and 2019.

9.3.9.3 Swan-Canning Estuary

The mean annual standardised size of crabs caught by commercial fishers in the Swan-Canning Estuary from 2007 to 2019 has ranged 144–161 mm (Figure 9.51). This is substantially larger than the minimum legal size of 127 mm, and far larger than the average size caught in the Peel-Harvey Estuary. The annual mean size caught in the Swan-Canning Estuary, however, has showed a declining trend over time. Thus, since 2015 the annual mean size has not exceeded 151 mm, and in 2017 and 2018 was 144–145 mm. The mean size in 2019 was 150 mm, which represents a slight increase from 2017−18. It should be noted though, that only one month of size data was available for each 2017 and 2018 (Figure 9.52). The monthly mean size caught is generally largest in autumn, and smallest in November to January. The mean size of male crabs caught is larger than that of females in most months (Figure 9.52).

Recreational size composition data from 2013 to 2018 are available through a voluntary logbook program. In similarity with trends among commercial size structure data, a trend of decreasing size from 2013 to 2018 is evident (Figure 9.53; Figure 9.54). Thus, the mean annual standardised size caught during 2013–14 was 137 mm, compared with 128–129 mm in 2016/17 and 2017/18. At a monthly scale, mean size decline from 2013-2017 is clearly evident during summer and autumn (Figure 9.54), the months when most recreational catch is taken. The mean size during autumn of 2018 slightly increased from that of 2017.

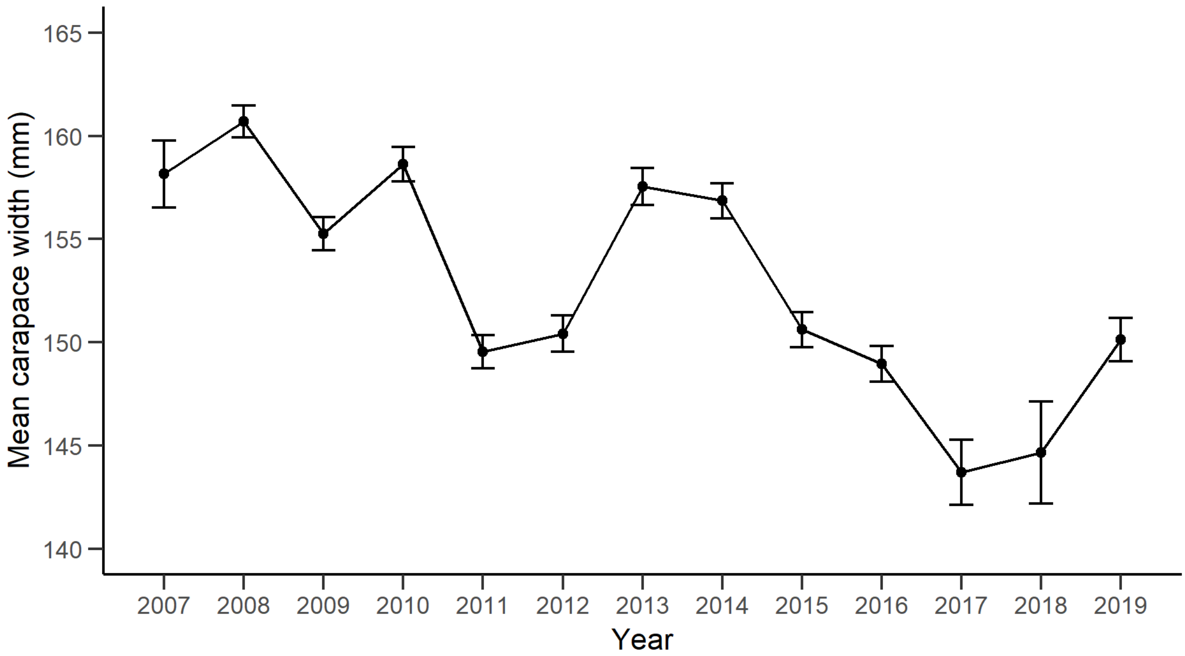


Figure 9.51. Mean standardised annual size (CW, mm; ± 95% confidence intervals) of blue swimmer crabs measured during commercial monitoring trips in the Swan-Canning Estuary each year from 2007 to 2019. Annual estimates were standardised for the effects of month and fisher using a linear model. Note, minimum legal size in this fishery is 127 mm (far below plot limits).

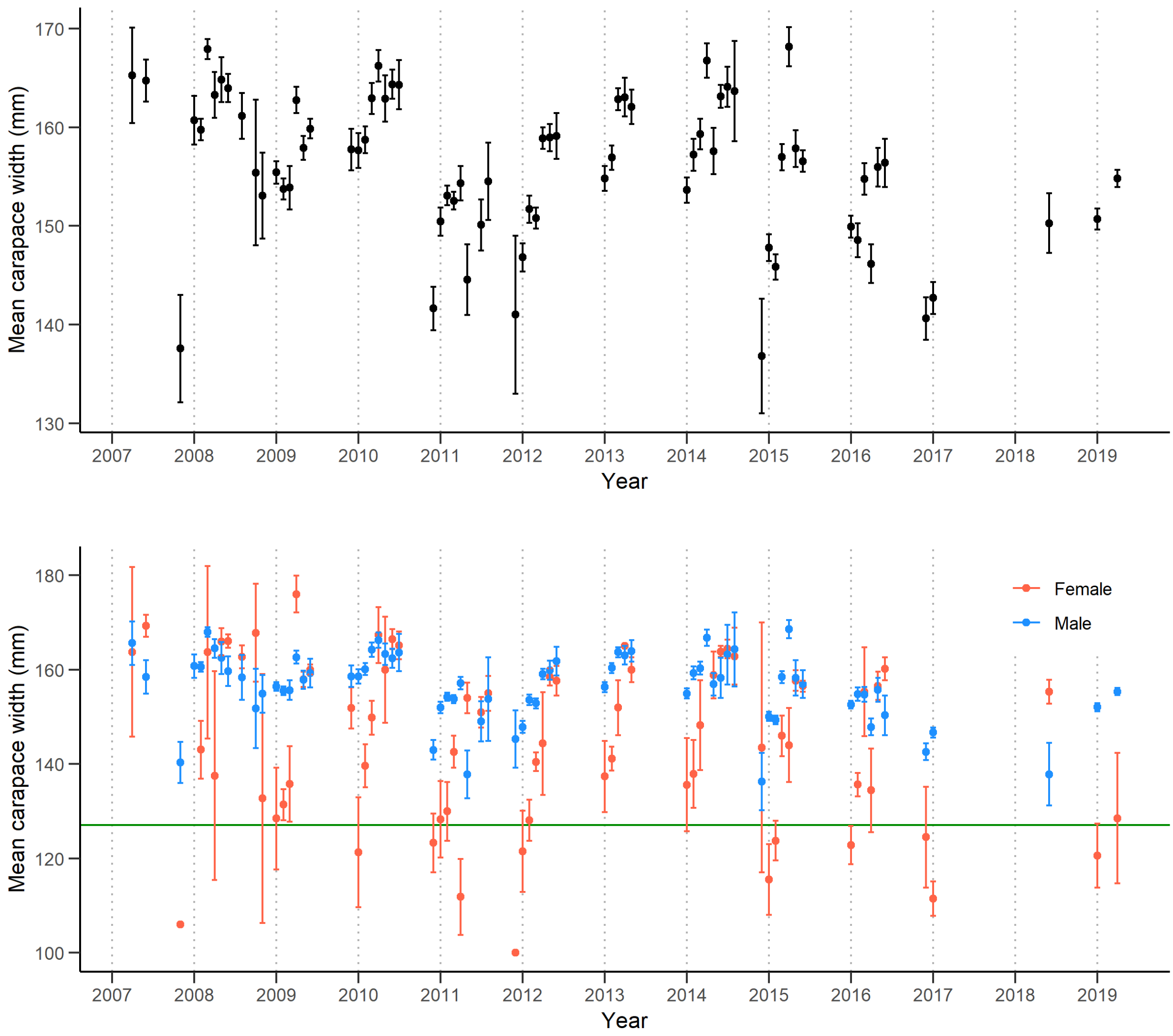


Figure 9.52. Mean monthly size (CW, mm; ± 95% confidence intervals) of (a) all blue swimmer crabs measured during commercial monitoring trips in the Swan-Canning Estuary from April 2007 to April 2019, and (b) for males and females separately. The horizontal green line denotes the minimum legal size of 127 mm.

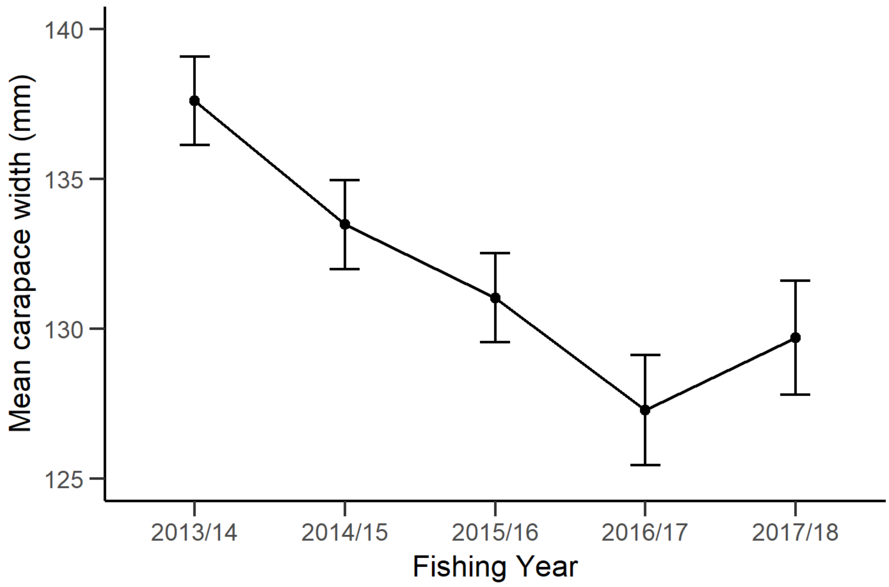


Figure 9.53. Annual standardised size (CW; ±95% confidence intervals) of blue swimmer crabs caught by recreational fishers in the Swan-Canning Estuary from 2013 to 2018. Fishing year refers to a twelve-month period from June 1 to May 31 the following year. Data were derived from voluntary logbooks and standardised for effects of month and fisher using a linear model.

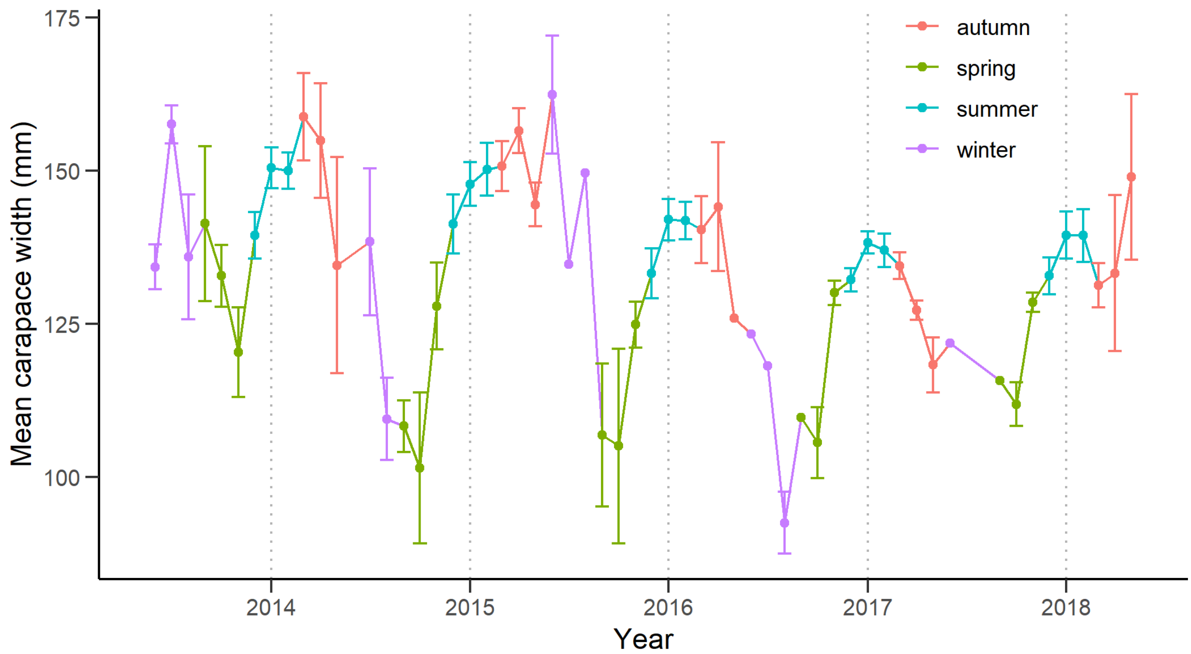


Figure 9.54. Mean size (CW; ±SE) of blue swimmer crabs caught by recreational fishers in the Swan-Canning Estuary from 2013 to 2018. Data were derived from voluntary logbooks through the research angler program (RAP).

The size of crabs caught in fishery independent research traps during the peak spawning season (October-November) from 2013 to 2019 is displayed in Figure 9.55. During 2013 and 2015 the average size (130-131 mm) was above the minimum legal size limit of 127 mm, however during all other years it was substantially lower (117–124 mm). The lowest mean annual size was during 2018, and a slight increase of size occurred in 2019, which supports the trend in commercial size data. Among individual sexes, a clear decline in the size of female crabs can be seen from 2013–15 to 2018 (drop from *c*. 137 mm to 113 mm), however, the size of males has remained relatively constant over time Figure 9.55.

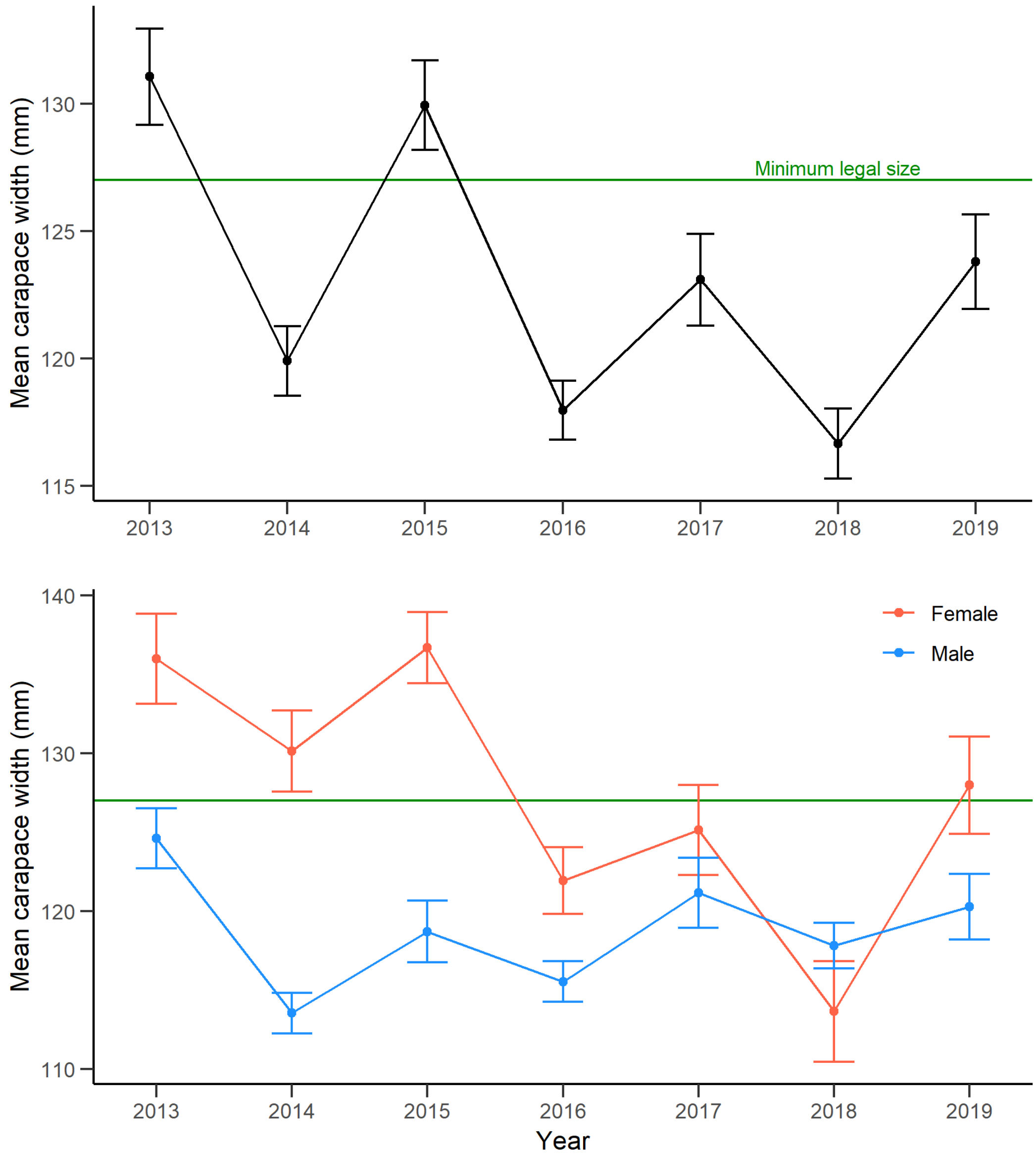


Figure 9.55. Annual mean size (CW, mm; ± 95% confidence intervals) of (a) all blue swimmer crabs, and (b) males and females separately, recorded during fishery independent trapping surveys conducted during in the Swan-Canning Estuary from 2013 from 2019 (October and November sampling only). The horizontal green line denotes the minimum legal size of 127 mm.

9.3.9.4 Conclusion

Cockburn Sound	The annual average size of crabs caught by commercial fishers in Cockburn Sound has varied considerably over time. From 2002 to 2006, the size ranged 135–136 mm, before increasing substantially to 143–147 mm during 2007–2009. From 2009 to 2012 the mean size then rapidly declined to 129 mm (below the minimum legal size of 130 mm). Since 2012, the mean size has steadily increased, and in 2019 was 144 mm. Data collected during fishery independent research trawling (breeding stock surveys, *RV Naturaliste*) also shows a mean size decline from 2007 and 2012 (decrease from 123 to 92 mm). The clear decrease in size from the late 2000s to 2012 is indicative of unfavourable environmental conditions and/or high fishing mortality. Following the fishery closure in 2014, the size of crabs caught in chartered commercial monitoring trips has steadily increased.
Peel-Harvey Estuary	The mean annual size of crabs caught by commercial fishers in the Peel-Harvey Estuary from 2007-2019 has remained relatively constant at 127–136 mm. Average size is positively correlated with temperature, and in turn, total annual catch is positively correlated with average size. In 2011/12 estuary temperatures were the warmest on record (20.6° C annual average), mean size was largest (136 mm) and total catch was highest (107.3 t). This suggests enhanced productivity occurs in the estuary under warmer conditions, resulting in larger crabs and higher total catches. The mean size caught during the 2018/19 season was 129 mm, which represents a notable decrease from the 2017/18 mean size of 133 mm. This reflects the cooler conditions which occurred during the 2018/19 season. Changes in size over time seemingly reflect environmental conditions rather than fishing pressure.
Swan-Canning Estuary	Commercial, recreational and fishery independent data show a general trend of decreasing crab sizes in the Swan-Canning Estuary from 2013–15 to 2018. The mean annual size caught by commercial fishers has ranged 144–161 mm since 2007, but since 2015, has not exceed 151 mm, and in 2017–2018 was 144–145 mm. The mean size in 2019 was 150 mm, which represents a slight increase from 2017−18. A trend of decreasing size in recreational catch (derived from a voluntary logbook) between 2013 and 2018 is also evident, with mean annual size caught falling from 137 mm during 2013–14 to 128–129 mm in 2016/17 and 2017/18. Fishery independent trapping data conducted annually during the peak spawning period (October-November) also shows clear decline in the size of female crabs from 2015 to 2018 (decrease from 137 to 114 mm). As for commercial size trends, this increased in 2019 to 129 mm. On the basis of this size decline evident among both fishery sectors, and in fishery independent data, from 2013-2018, catch for the Swan-Canning will be closely monitored. There is insufficient information to suggest whether this decline was driven by fishing or environmental conditions. An increase in mean size during 2019 suggests size within the fishery may be increasing.

9.4 Stock Status Summary

Presented below is a summary of each line of evidence considered in the overall weight of evidence assessment of the stocks that comprise the key blue swimmer crab fisheries in the WCB, followed by the management advice and recommendations for future monitoring of the species.

9.4.1 Weight of Evidence Risk Assessment

9.4.1.1 Cockburn Sound

Category	**Lines of evidence (Consequence/Status)**
Catch history	Following conversion from gill nets to traps, commercial crab catches increased rapidly from ~150 t to peak ~350 t in 1998–2002, before progressively declining to only ~50 t in 2006, at which point the fishery was closed for 3 years due to low stock abundance. After the fishery re-opened in December 2009, despite conservative fishing levels and commercial catches not exceeding ~60 t, the commercial fishery was again closed in 2014 due to unacceptable risk level for the stock. Recreational boat-based catches from 2011/12 to 2015/16 have ranged 6–13 t (note, since 2014 recreational fishing has only been permitted north of Woodman Point).
Spatial distribution trends	The spatial distribution of commercial catch and effort in Cockburn Sound has severely contracted over time. Before ~2005, crabs were widespread throughout Cockburn Sound, with high catch rates in both shallow and deeper waters extending between the northern and southern limits of the embayment. However, in recent years, high catch rates have only occurred in shallower waters in the south-eastern areas of Cockburn Sound, *i.e.* Mangles Bay, Jervois Bay and James Point. In particular, crab abundance is very low in deeper (> 10 m) waters. Similar trends are apparent from fishery independent research trapping and trawl surveys.
Commercial catch rates	Commercial CAES trap catch rates fluctuated widely between ~ 0.7 and 1.5 kg/trap lift in 1994–2004, before declining to their lowest levels in 2005–06 at ~ 0.5 kg/trap lift. Following the three year fishery closure between 2006 and 2009, the mean annual commercial trap catch rates fluctuated between ~0.6–1.0 kg/trap lift with 0.7 kg/traplift in 2013/14. Due to stock levels declining to unacceptable levels, the commercial fishery was closed again in April 2014 and remains closed. Commercial monitoring catch rates for legal-sized crabs were relatively high (~2 kg/traplift) around 2000, 2003 and 2004. It then declined progressively to a very low level (~ 0.1 kg/traplift) in mid-2006. The catch rates increased during the three-year closure period to above 2.5 kg/traplift but then declined to very low levels (just above 0.1 kg/traplift) in 2014. From 2014 to 2015, catch rates remained low (<0.75 kg/traplift and increased to between 1 and 1.8 kg/traplift in 2016 and 2017. Catch rates again decreased in 2018 and 2019, being < 1 kg/traplift in most months. The mean monthly commercial trap catch rate data indicate an unacceptable stock depletion in the mid-2000s and in 2012–2014. Despite closure to fishing since 2014, legal catch rates remain low in 2019.

Category	Lines of evidence (Consequence/Status)
Fishery Independent Recruitment Index	The index of juvenile (0+) abundance for Cockburn Sound was initially >1.0 crabs/100 m^2 trawled in 2002, but declined to <0.1 crabs/100 m2 in 2004 and 2006. After closure of the fishery in December 2006, the index increased to >0.6 crabs/100 m^2 during 2010–12, before declining to 0.16 crabs/100 m^2 in 2013. From 2014 to 2019 the abundance of juveniles has remained very low (0.03–0.11 crabs/100 m^2), substantially below the harvest strategy limit of 0.4, indicating that recruitment is at unacceptable levels.
Egg production index (and fishery independent breeding stock *Naturaliste* trawl survey)	The mean egg production index increased to >15 in 2008-2012 before declining to its lowest level in 2015 (2.8). The egg production index for 2016 was a significant increase, and at the harvest strategy threshold of 12. The increase in egg production based on the commercial monitoring data, was supported by the *RV Naturaliste* breeding stock trawl survey in 2016, where improved numbers of breeding stock were evident compared to the previous three years. However, despite the improvement in the egg production index in 2016, this did not translate to a significant improvement in the juvenile index in 2017. Moreover, scores for this index again declined from 2017–2019, with the 2019 value of 5.4 $\times 10^6$ eggs/traplift being less than half the limit value.
Productivity susceptibility analysis	The biological characteristics of *P. armatus* including rapid growth, short lifespan, high fecundity, early maturity and broadcast spawning strategy, suggest this highly productive species has a low-moderate vulnerability to fishing (productivity score 1.33). Susceptibility scores of 1.88 and 1.58 for the commercial fisheries of Cockburn Sound and Swan-Canning Estuary, respectively, and 1.88 for their recreational fisheries were based on moderate to high availability, encounterability, selectivity and post-release mortality. The overall PSA score was 2.18, with an MSC PSA-derived score of 92 (= low risk). The PSA analysis indicates that the risk of unacceptable stock depletion is low under current management arrangements and fishing effort. It assumes that the productivity of the stock is constant and not impacted by environmental conditions.
Stock-recruitment environment relationship	There has never been a strong recruitment when the egg production index has fallen below 12×10^6 eggs/traplift, irrespective of environmental conditions. A limit value of 12 for the egg production index was therefore proposed for the draft harvest strategy. Environmental variables, including water temperature during peak spawning months (Oct–Dec) and summer chlorophyll *a* index, have been shown to improve the stock-recruitment relationship. There was an improvement in breeding stock in 2016, with and EPI value of approximately 12, however, this did not result in a significant improvement in the 2017 1+ recruitment index. Similarly, in 2017/18, and EPI value of approximately 10 was recorded but 1+ recruitment remained very low (<0.1). This indicates that environment may be limiting the recruitment.

Category	Lines of evidence (Consequence/Status)
Trends in size structure	The annual average size of crabs caught by commercial fishers in Cockburn Sound has varied considerably over time. From 2002 to 2006, the size ranged 135–136 mm, before increasing substantially to 143–147 mm during 2007–2009. From 2009 to 2012 the mean size then rapidly declined to 129 mm (below the minimum legal size of 130 mm). Since 2012, the mean size has steadily increased, and in 2019 was 144 mm. Data collected during fishery independent research trawling (breeding stock surveys, *RV Naturaliste*) also shows a mean size decline from 2007 and 2012 (decrease from 123 to 92 mm). The clear decrease in size from the late 2000s to 2012 is indicative of unfavourable environmental conditions and/or high fishing mortality. Following the fishery closure in 2014, the size of crabs caught in chartered commercial monitoring trips has steadily increased.

Reasons for the current stock levels in Cockburn Sound are being investigated, and it appears that crab catch may be affected by primary productivity (summer chlorophyll *a* concentration) and water temperature, with stock levels over the past decade consistent with declines in productivity. This indicates that recent levels of stock are most likely driven by environmental influences, with catch unlikely to increase significantly until productivity increases. There has been some evidence of density-dependent growth occurring in Cockburn Sound with growth rates declining in years when stock levels and recruitment were high and increasing when stock levels and recruitment were low (Marks *et al*., 2020).

The above evidence indicated that spawning stock biomass was likely to have decreased to a point at which average recruitment levels were significantly reduced. This is primarily a result of substantial environmental changes, rather than overfishing, so the stock should not be classified as recruitment overfished. Fisheries management responded appropriately to the lower recruitment, and consequently the stock was classified as **environmentally limited**.

In 2016, the improvement in breeding stock (egg production) to threshold levels was consistent with increased commercial monitoring catch rates and improved numbers of breeding stock on *RV Naturaliste* trawl surveys compared with the 3 previous years. Unfortunately, this improvement in breeding stock did not result in a significant improvement in the 2017 juvenile recruitment index, which remains below the limit (although improved numbers of recruits were evident on *RV Naturaliste* trawl surveys). It is hypothesised that lower than average water temperatures between June and October 2016 may have contributed to the lower proportion of berried females observed during the spawning season of 2016, and therefore the low recruitment in 2017. It is also possible that current low levels of productivity in the system may have contributed to a lack of resources for crabs lowering energy reserves needed for effective egg production, not just growth. Juvenile abundances and egg production values remained at unacceptably low levels from 2017 to 2019.

All of the lines of evidence outlined above were combined within the Department's ISO 31000 based risk assessment framework (Fletcher 2015; Appendix 1) to determine the most appropriate combinations of consequence and likelihood to determine the overall current risk status to the sustainability of the stock.

Cockburn Sound Risk Matrix

Consequence (Stock Depletion) Level	Likelihood				Risk Score
	L1 Remote (<5%)	L2 Unlikely (5- <20%)	L3 Possible (20- <50%)	L4 Likely (≥50%)	
C1 Minimal	NA				-
C2 Moderate	X				2
C3 High		X			6
C4 Major				X	16

C1 (Minimal Depletion): NA – It is not plausible that fishing has had a minimal impact on this crab stock given the historical levels of fishing which have occurred.

C2 (Moderate Depletion): L1 Remote – There is a remote chance that stock will recover in the next five years given current breeding stock and recruitment levels. This may only occur if environmental conditions become more favourable, particularly during the spawning period.

C3 (High Depletion): L2 Unlikely – Whilst most performance indicators are below respective thresholds and limits, an increase in mean crab size during recent years provides some evidence of stock recovery following closure of the fishery.

C4 (Major Depletion): Likely L4 – The primary performance indicators for Cockburn Sound (recruitment index and egg production index) remain substantially below the respective limits and thresholds of the harvest strategy. Current levels of catch, recruitment and breeding stock during recent years are very low compared to historical levels. Levels of recruitment and breeding stock in Cockburn Sound is therefore considered to be unacceptable. Despite closure to fishing since 2014, the stock has not recovered, and stock decline is likely to be environmentally driven. Given their current status, it is likely that stock levels in Cockburn Sound will remain below acceptable levels within the five year assessment period.

9.4.1.2 Peel-Harvey Estuary

Category	Lines of evidence (Consequence/Status)
Catch history	Commercial catches in the Peel-Harvey Estuary commercial fishery from 1996/96 to 2018/19 have ranged from 45 to 107 t and are significantly correlated with effort. However, spikes in total catches during 2001/02, 2006/07, 2012/3 and 2017/18 reflect increased catch rates in those seasons, likely resultant from warmer than average water temperatures. The 2018/19 commercial season catch was 66.5 t from 59,472 traplifts, 30 t lower than the 2017/18 total. Catches at the start of the 2018/19 season were very low, with November and December catch rates the lowest on record since 1995/96. Catch rates during January, March, July and August were also lower than the long-term average for these months. These decreased catch rates are likely attributable to cooler than average water temperatures throughout much of the season. Annual recreational boat-based catches from 2011/12 to 2017/18 have ranged 26–46 t. Based on the most recent 2017/18 iSurvey, the estimated recreational boat-based harvest was 35.9 t (95% CI 29.9–4.19), representing a 10 t (38%) increase from 2015/16. Annual catch is correlated with effort and environmental conditions, and consequently interannual variation in recreational and commercial catches has been similar.
Spatial distribution trends	A combination of commercial and research trap data and research trawl data has shown that crab distribution throughout the Peel-Harvey Estuary is environmentally driven and heavily dependent on temperature and the timing of annual rainfall. In summer and autumn, when the system is warmest and most saline, commercial fishing effort occurs throughout the majority of the estuary, including in southern parts of the Harvey Estuary. In winter, commercial fishing effort is concentrated near the Estuary Channel and Dawesville Cut, as these waters remain warmer and more saline than other parts of the system due to marine water incursion. Commercial fishing effort in the Swan-Canning Estuary is focused on the central basin of the estuary, with the distribution of catch and effort varying seasonally. In autumn and summer it occurs throughout the basin, but in winter is concentrated in downstream waters. Minor effort has occurred during spring. Recreational effort occurs throughout the system, being widely distributed from lower to upstream areas in summer and autumn, but concentrated in downstream areas in winter and spring. This contraction of fishing effort likely reflects the fact that salinity in downstream areas generally remains close to marine throughout winter due to tidal incursion, while upstream areas transition to brackish or fresh due to freshwater flows.
Commercial catch rates	Standardised commercial catch rates have remained relatively constant over time, ranging from 0.73 to 1.42 kg/traplift. Catch rates since 2012/13 have been above the harvest strategy threshold and limit of 0.73 and 0.51 kg/traplift, respectively. The 2018/19 season catch rate was 0.92 kg/traplift.

Recruitment Index	A recruitment index for the Peel-Harvey Estuary has recently been developed using fishery independent trawl data collected from 2016 to 2019. Annual index values (abundance of juveniles/100 m^2) were highest in 2016 and 2018 (1.1 and 1.3 respectively) and lowest in 2017 and 2019 (0.4 and 0.6, respectively). A threshold and limit for this juvenile index will be developed in the future when more years of data are available.
Productivity susceptibility analysis	The biological characteristics of *P. armatus* including rapid growth, short lifespan, high fecundity, early maturity and broadcast spawning strategy, suggest this highly productive species has a low-moderate vulnerability to fishing (productivity score 1.33). Susceptibility scores of 1.88 for the commercial fisheries of Peel-Harvey Estuary and Comet Bay-Mandurah Bunbury and 1.58 for Warnbro Sound; and 1.88 for their recreational fisheries, were based on moderate to high availability, encounterability, selectivity and post-release mortality. The overall PSA score was 2.29, with an MSC PSA-derived score of 90 (= low risk). The PSA analysis indicates that the risk of unacceptable stock depletion is low under current management arrangements and fishing effort. It assumes that the productivity of the stock is constant and not impacted by environmental conditions.
Catch prediction	Fishery-independent trap survey data are used to predict annual commercial catch for the Peel-Harvey Estuary (t+1), which is based on the abundance of legal sized crabs in November (t). Based on the 2018 November legal index of 1.48, the predicted commercial catch for the 2018/19 season was 80 t (95% CL: 68–94 t). The actual catch was 66.5 t, within the predictive range. The predicted catch for the 2019/20 season is 86 t (81−104 t confidence limits) based upon a legal-November Index of 1.83. This is within the range of recent annual catch totals.
Trends in size structure	The mean annual size of crabs caught by commercial fishers in the Peel-Harvey Estuary from 2007-2019 has remained relatively constant at 127–136 mm. Average size is positively correlated with temperature, and in turn, total annual catch is positively correlated with average size. In 2011/12 estuary temperatures were the warmest on record (20.6° C annual average), mean size was largest (136 mm) and total catch was highest (107.3 t). This suggests enhanced productivity occurs in the estuary under warmer conditions, resulting in larger crabs and higher total catches. The mean size caught during the 2018/19 season was 129 mm, which represents a notable decrease from the 2017/18 mean size of 133 mm. This reflects the cooler conditions which occurred during the 2018/19 season. Changes in size over time seemingly reflect environmental conditions rather than fishing pressure.

Peel-Harvey Estuary Risk Matrix

Consequence (Stock Depletion) Level	Likelihood				Risk Score
	L1 Remote (<5%)	L2 Unlikely (5- <20%)	L3 Possible (20- <50%)	L4 Likely (≥50%)	
C1 Minimal	x				1
C2 Moderate				x	8
C3 High		x			6
C4 Major	x				4

C1 (Minimal Depletion): **Remote L1** – There is a remote chance that minimal impact on crab stocks is occurring given the level of commercial and recreational fishing activity which takes place in the Peel-Harvey Estuary and its adjacent coastal waters.

C2 (Moderate Depletion): **Likely L4** – The primary performance indicator for the Peel-Harvey Fishery (commercial standardised CPUE) has remained within the target range of harvest strategy for the past five seasons. Annual catch and size structure have remained relatively constant over time, with fluctuations correlated with effort and environmental conditions, and there is no trend in decreasing total catch over time. There is also no evidence of recruitment levels decreasing over time. There is thus a likely probability that moderate stock depletion is occurring.

C3 (High Depletion): **Unlikely L2** –Commercial standardised CPUE (the primary performance indicator for the Peel-Harvey) decreased substantially from 2017/18 to 2018/19. However, recent management changes applied to the broader south-west crab resource introduced in 2019 (extended seasonal closure during spawning period, proposed commercial fishery closures in adjacent coastal waters) will provide a greater level of breeding stock protection. Therefore, there is an unlikely chance of high (undesirable) level of stock depletion.

C4 (Major Depletion): **Remote L1** – The lower 95% confidence interval of the primary performance indicator in the Peel-Harvey (commercial standardised CPUE) does not extend below the harvest strategy limit for the 2018/19 season. Although, there is no evidence of recruitment impairment to date, given the high level of both commercial and recreational fishing effort which occurs in the Peel-Harvey, and the highly dynamic nature of estuarine environments, there is a remote possibility that major depletion would occur if environmental conditions became less favourable in future years.

9.4.1.3 Swan-Canning Estuary

Category	Lines of evidence (Consequence/Status)
Catch history	Annual commercial catch in the Swan-Canning Estuary between 1976 and 2017 has ranged from 1 to 33 t, being highly correlated with fishing effort. Over time, effort (annual length of gill net fished) has steadily declined due to a reduction in the number of fishers operating, and since 2008 only a single fisher has operated. Catch remained relatively stable at 8–10 t from 2008 to 2015, before declining in 2016–17 to 1–6 t, reflecting a lack of fishing effort in these years. Catch and effort in 2018 and 2019 was within these historical ranges. Annual recreational boat-based catches from 2011/12 to 2017/18 have ranged 6–17 t. Based on the most recent 2017/18 recreational fishing from boat survey (iSurvey), the estimated recreational harvest was 5.5 t (95% CI 3.6–7.4 t), less than half of the 2015/16 total. Annual catch is correlated with effort and environmental conditions, and consequently interannual variation in recreational and commercial catches has been similar.
Spatial distribution trends	Commercial fishing effort in the Swan-Canning Estuary is focused on the central basin of the estuary, with the distribution of catch and effort varying seasonally. In autumn and summer it occurs throughout the basin, but in winter is concentrated in downstream waters. Minor effort has occurred during spring. Recreational effort occurs throughout the system, being widely distributed from lower to upstream areas in summer and autumn, but concentrated in downstream areas in winter and spring. This contraction of fishing effort likely reflects the fact that salinity in downstream areas generally remains close to marine throughout winter due to tidal incursion, while upstream areas transition to brackish or fresh due to freshwater flows.
Catch rates	Standardised commercial catch rates have generally increased over time since 1975. This trend of increasing catch rate coincides with a reduction in total commercial effort (due to a decline in the number of licence holders). The 2018/19 season standardised catch rate was 9 kg 100 m net^{-1}, representing a slight decline from the previous 2017/18 season (9.9 kg 100 m net^{-1}). Both values are within the target range of the harvest strategy, suggesting that stock is being fished at sustainable levels. Standardised recreational catch rates (based upon estimated weight of retained catch) show a decline in CPUE over time from 2013/14 to 2017/18. CPUE based on numbers of kept crabs, however, has remained relatively constant over time. This suggests that abundances have remained relatively constant, but average size has declined.
Recruitment Index	A recruitment index for the Swan-Canning Estuary has recently been developed using fishery independent trawl data collected from 2016 to 2019. Juvenile abundance was highest in 2016 at 0.66 crabs/100 m^2, decreasing to 0.24 crabs/100 m^2 in 2017, and further declining in 2018 and 2019 to 0.15-0.16 crabs/100 m^2. These low levels of recruitment may be reflective of low egg production in 2017 and 2018. Given that egg production has increased in 2019,

	juvenile index values for 2020 will be examined to see if there is a corresponding increase. The decline in recent years will continue to be monitored. A threshold and limit for this juvenile index will be developed in the future when more years of data are available.
Breeding Stock Index	Catch rates of sexually mature female crabs were similar from 2013–2016, but declined significantly in 2017 (from 3.2–4.3 crabs/traplift, to 1.8 crabs/traplift). CPUE decreased again in 2018 (1.3 crabs/traplift), but increased marginally in 2019 (2.1 crabs/traplift). Similarly, there was a significant decrease in egg production from 2016 to 2017–18, with values in the latter year falling to as low as 1.8×10^6 eggs/traplift (compared with $8.3–13.5 \times 10^6$ from 2013–2016). In 2019 egg production increased to 5×10^6 eggs/traplift. This decline in egg production from 2016 to 2018 reflects not only a decrease in the abundance of sexually mature females, but also a clear decrease in the average size of crabs which occurred during this time period (detailed in Section 1.3.9.3). Inter-annual variation in the breeding stock index in the Swan-Canning Estuary is apparent and the decline in recent years will continue to be monitored. A longer time series is required before the status of breeding stock can be assessed. A threshold and limit for this index will be developed in the future when more years of data are available.
Productivity susceptibility analysis	The biological characteristics of *P. armatus* including rapid growth, short lifespan, high fecundity, early maturity and broadcast spawning strategy, suggest this highly productive species has a low-moderate vulnerability to fishing (productivity score 1.33). Susceptibility scores of 1.88 and 1.58 for the commercial fisheries of Cockburn Sound and Swan-Canning Estuary, respectively, and 1.88 for their recreational fisheries were based on moderate to high availability, encounterability, selectivity and post-release mortality. The overall PSA score was 2.18, with an MSC PSA-derived score of 92 (= low risk). The PSA analysis indicates that the risk of unacceptable stock depletion is low under current management arrangements and fishing effort. It assumes that the productivity of the stock is constant and not impacted by environmental conditions.
Trends in size structure	Commercial, recreational and fishery independent data show a general trend of decreasing crab sizes in the Swan-Canning Estuary from 2013–15 to 2018. The mean annual size caught by commercial fishers has ranged 144–161 mm since 2007, but since 2015, has not exceed 151 mm, and in 2017–2018 was 144–145 mm. The mean size in 2019 was 150 mm, which represents a slight increase from 2017−18. A trend of decreasing size in recreational catch (derived from a voluntary logbook) between 2013 and 2018 is also evident, with mean annual size caught falling from 137 mm during 2013–14 to 128–129 mm in 2016/17 and 2017/18. Fishery independent trapping data conducted annually during the peak spawning period (October-November) also shows clear decline in the size of female crabs from 2015 to 2018 (decrease from 137 to 114 mm). As for commercial size trends, this increased in 2019 to 129 mm.

	On the basis of this size decline evident among both fishery sectors, and in fishery independent data, from 2013-2018, catch for the Swan-Canning will be closely monitored. There is insufficient information to suggest whether this decline was driven by fishing or environmental conditions. An increase in mean size during 2019 suggests size within the fishery may be increasing.

Swan-Canning Estuary Risk Matrix

Consequence (Stock Depletion) Level	Likelihood				Risk Score
	L1 Remote (<5%)	L2 Unlikely (5- <20%)	L3 Possible (20- <50%)	L4 Likely (≥50%)	
C1 Minimal	X				1
C2 Moderate				X	8
C3 High		X			6
C4 Major	X				4

C1 (Minimal Depletion): **Remote L1** – There is a remote chance that minimal impact on crab stocks is occurring given the level of commercial and recreational fishing activity which takes place in the Swan-Canning Estuary.

C2 (Moderate Depletion): **L4 Likely** – The primary performance indicator for the Swan-Canning Estuary (commercial standardised CPUE) was within the harvest strategy target range for the past two seasons. Total commercial catch and effort has substantially decreased over the past four decades, with fisher numbers being reduced from 28 in the 1970s to one since 2008. The introduction of recent management changes (see below) will provide further protection to stocks. It is therefore likely that fishing will moderately deplete the stock within the assessment period.

C3 (High Depletion): **L2 Unlikely** – The lower 95% confidence interval of the primary performance indicator in the Swan-Canning Estuary (commercial standardised CPUE) extends below the harvest strategy threshold and approaches the limit for the 2018/19 season. There is also evidence of a decline in mean size and breeding stock (abundance of mature females and egg production) during recent years. However, both of these indices showed signs of improvement in 2019. Recent management changes (introduction of a three month closure over the peak spawning period to provide greater protection for the breeding stock, halving of recreational bag limit to five crabs to reduce fishing mortality) are expected to reduce stock depletion from both fishing sectors. It is therefore unlikely that high levels of stock depletion will occur within the assessment period.

C4 (Major Depletion): **Remote L1** – The lower 95% confidence interval of the primary performance indicator in the Swan-Canning Estuary (commercial standardised CPUE) does not extend below the harvest strategy limit for the 2018/19 season. Given the high level of both commercial and recreational fishing effort which occurs in the Swan-Canning, and the highly dynamic nature of estuarine environments, there is a remote possibility that major depletion would occur if environmental conditions became less favourable in future years.

9.4.2 Current Risk Status

9.4.2.1 Cockburn Sound

Based on the above lines of evidence, the current risk level for Cockburn Sound blue swimmer crab stocks is considered to be SEVERE (C4 × L4). The severe risk (see Appendix 2) reflects unacceptable levels of recruitment and breeding stock biomass, despite the fact that fishing has not occurred since 2014. This depletion is therefore considered environmentally driven. Current levels of recruitment remain unacceptable, likely driven by prevailing environmental conditions that make it unlikely for the stock to recover to acceptable levels in the coming season. Further consideration also needs to be given to the possibility that the permanent reduction in productivity of Cockburn Sound, due to strategic initiatives to improve water quality, has translated into a permanent reduction in this system’s carrying capacity for blue swimmer crabs. On this basis, the crab stock in Cockburn Sound is classified as **Environmentally Limited.**

9.4.2.2 Peel-Harvey Estuary

Based on the above lines of evidence, the current risk level for the Peel-Harvey Estuary blue swimmer crab stocks is considered to be MEDIUM (C2× L4). The medium risk (see Appendix 2) reflects acceptable levels of fishing mortality and recruitment. All the lines of evidence are consistent with a medium level of risk, hence the overall Weight of Evidence assessment indicates the status of the Peel-Harvey Estuary stock is adequate and that current management settings are maintaining risk at acceptable levels. Recent management changes introduced in 2019 (extended seasonal closure during spawning period, proposed commercial fishery closures in adjacent marine waters) will provide additional protection for the Peel-Harvey Estuary breeding stock. On this basis, the crab stock in the Peel-Harvey Estuary is classified as **Sustainable.**

9.4.2.3 Swan-Canning Estuary

Based on the above lines of evidence, the current risk level for the Swan-Canning Estuary blue swimmer crab stocks is considered to be MEDIUM (C2× L4). The medium risk (see Appendix 2) reflects acceptable levels of fishing mortality and recruitment. The primary performance indicator and key lines of evidence are consistent with a medium level of risk, hence the overall Weight of Evidence assessment indicates the status of the Swan-Canning Estuary stock is adequate and that current management settings are maintaining risk at acceptable levels. Recent management changes introduced in 2019 (seasonal closure during spawning period, halved recreational bag limit) will provide additional protection for the Swan-Canning Estuary crab stock. On this basis, the crab stock in the Swan-Canning Estuary is classified as **Sustainable.**

9.4.3 Future Monitoring

9.4.3.1 Cockburn Sound

Levels of recruitment and breeding stock biomass in Cockburn Sound will continue to be closely monitored through fishery independent research surveys. The validity of using *RV Naturaliste* breeding stock data for the Egg Production Index in favour of chartered commercial monitoring data (which may have biases towards certain size classes or among sexes) is being investigated. Further investigate the annual proportion of berried crabs and sex ratios to better understand changes in egg production. Using the refined egg production index, an update of the stock recruitment environment relationship will be undertaken. Key environmental variables including temperature and chlorophyll *a* will continue to be monitored to better understand their relationship with crab stocks.

9.4.3.2 Peel-Harvey Estuary

As a juvenile recruitment index has only recently been developed for the Peel-Harvey Estuary, continued monitoring using this index will allow a threshold and limit of acceptable change to be developed.

Environmental variables such as water temperature, in the Peel-Harvey Estuary have a marked impact on the commercial crab fishery, including the mean size of crabs caught and total annual catches. Currently being undertaken is analysis to quantify the influences of changing environmental conditions (*e.g.* water temperature, salinity, dissolved oxygen, tidal range) on crab populations using abundance and size data collected from fishery independent trap and trawl surveys.

Crab populations in the Peel-Harvey Estuary are considered to be dependent on breeding stock in adjacent marine waters, predominately those of Comet Bay to the north of the Mandurah Estuary Entrance Channel. To assess the breeding stock affecting recruitment into the estuary, a breeding stock survey in these marine waters during the peak spawning period is currently being developed. In turn, this will be used to develop and egg production index and with limits of acceptable change.

9.4.3.3 Swan-Canning Estuary

As a juvenile recruitment index has only recently been developed for the Swan-Canning Estuary, continued monitoring using this index will allow a threshold and limit of acceptable change to be developed.

To complement trawl surveys, the practicality of underwater visual census (UVC) using a remotely operated underwater vehicle (ROV) to survey juvenile crabs is currently being explored. It is envisaged that UVC will allow a greater diversity of habitats to be effectively sampled, including in areas of high structural complexity (*e.g.* around rocks and boat moorings) which are not able to be trawled.

The commercial fisher in the Swan-Canning Estuary has also expressed interest in trialling hourglass crab traps as a fishing method. If this is formally requested and approved and the fisher agrees to replace the gillnet with traps, detailed monitoring of trap *vs* set net catches will be required during a phase of overlap between the two gear types to determine their relative levels of fishing efficiency.

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Appendix 1

Justification for Harvest Strategy Reference Levels

The performance indicators used to evaluate the stock status of *P. armatus* in the West Coast Bioregion are egg production indices, recruitment indices and standardised commercial catch rates (see Table A1.1). For each stock, the performance indicator is estimated periodically (at least every 5 years) and compared to associated reference levels (Table A1.1). The reference levels are consistent with those used by the Department in other similar assessments and are based on internationally accepted benchmarks for a relatively short-lived invertebrate species (Mace, 1994; Caddy and Mahon, 1995; Gabriel and Mace, 1999; Wise *et al*., 2007). For commercial catch rates, the target range extends between the maximum and minimum values recorded during that reference period, where the latter denotes the threshold level assumed to represent a proxy for the stock level at which Maximum Sustainable Yield (MSY) can be achieved. Any stock size above this level is therefore consistent with meeting the objectives for biological sustainability and also satisfy stock status requirements under the MSC standard for sustainable fishing. A conservative approach has been taken to set the limit reference level at 70% of the threshold value (*i.e.* 0.7*B*MSY) and is considered to represent the level below which recruitment may be impaired (DPIRD, 2020).

Table A1.1. Performance indicators and associated reference levels used to evaluate the status blue swimmer crab *Portunus armatus* in Cockburn Sound (CS), the Peel-Harvey Estuary (PHE) and Swan-Canning Estuary (SCE).

Performance Indicator	Reference Levels		
	Target	Threshold (B_{MSY})	Limit
Egg Production Index (CS)	>12	–	12
Recruitment Index (CS)	>0.6	0.6	0.4
Commercial catch rate (PHE) [kg/traplift]	0.79–1.51	0.79	0.55
Commercial catch rate (SCE) [kg 100 m^{-1}]	6.15–9.9	6.15	4.31

Reference levels for egg production and recruitment indices for PHE and SCE are in development and will be formalised once a longer time series of data become available.

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Appendix 2

Consequence, Likelihood and Risk Levels (based on AS 4360 / ISO 31000) modified from Fletcher *et al*., (2011) and Fletcher (2015)

CONSEQUENCE LEVELS

As defined for major target species

1. Minor – Fishing impacts either not detectable against background variability for this population; or if detectable, minimal impact on population size and none on dynamics

   Spawning biomass > Target level (B_{MEY})

2. Moderate – Fishery operating at maximum acceptable level of depletion

   Spawning biomass < Target level (B_{MEY}) but > Threshold level (B_{MSY})

3. High – Level of depletion unacceptable but still not affecting recruitment levels of stock

   Spawning biomass < Threshold level (B_{MSY}) but >Limit level (B_{REC})

4. Major – Level of depletion is already affecting (or will definitely affect) future recruitment potential/ levels of the stock

   Spawning biomass < Limit level (B_{REC})

LIKELIHOOD LEVELS

These are defined as the likelihood of a particular consequence level actually occurring within the assessment period (5 years was used)

1. Remote – The consequence has never been heard of in these circumstances, but it is not impossible within the time frame (Probability of <5%)
2. Unlikely – The consequence is not expected to occur in the timeframe but it has been known to occur elsewhere under special circumstances (Probability of 5 - <20%)
3. Possible – Evidence to suggest this consequence level is possible and may occur in some circumstances within the timeframe. (Probability of 20 - <50%)
4. Likely – A particular consequence level is expected to occur in the timeframe (Probability of ≥50%)

Consequence × Likelihood Risk Matrix		Likelihood			
		Remote (1)	Unlikely (2)	Possible (3)	Likely (4)
Consequence	Minor (1)	Negligible	Negligible	Low	Low
	Moderate (2)	Negligible	Low	Medium	Medium
	High (3)	Low	Medium	High	High
	Major (4)	Low	Medium	Severe	Severe

Risk Levels	Description	Likely Reporting & Monitoring Requirements	Likely Management Action
1 Negligible	Acceptable; Not an issue	Brief justification – no monitoring	Nil
2 Low	Acceptable; No specific control measures needed	Full justification needed – periodic monitoring	None specific
3 Medium	Acceptable; With current risk control measures in place (no new management required)	Full Performance Report – regular monitoring	Specific management and/or monitoring required
4 High	Not desirable; Continue strong management actions OR new / further risk control measures to be introduced in the near future	Full Performance Report – regular monitoring	Increased management activities needed
5 Severe	Unacceptable; If not already introduced, major changes required to management in immediate future	Recovery strategy and detailed monitoring	Increased management activities needed urgently

References

Fletcher, W.J. 2015. Review and refinement of an existing qualitative risk assessment method for application within an ecosystem-based management framework. *ICES Journal of Marine Science,* **72(3),** 1043-1056.

Fletcher, W.J., Shaw, J., Gaughan, D.J. and Metcalf, S.J. 2011. Ecosystem Based Fisheries Management case study report – West Coast Bioregion. Fisheries Research Report No. 225. Department of Fisheries, Western Australia. 116 pp.

Appendix 3

Productivity Susceptibility Analysis (PSA) Scoring Tables

Productivity attribute	High productivity Low risk Score = 1	Medium productivity Medium risk Score = 2	Low productivity High risk Score = 3)
Average maximum age	<10 years	10-25 years	>25 years
Average age at maturity	<5 years	5-15 years	>15 years
Average maximum size (not to be used when scoring invertebrates)	<1000 mm	1000-3000 mm	>3000 mm
Average size at maturity (not to be used when scoring invertebrates)	<400 mm	400-2000 mm	>2000 mm
Reproductive strategy	Broadcast spawner	Demersal egg layer	Live bearer
Fecundity	>20,000 eggs per year	100-20,000 eggs per year	<100 eggs per year
Trophic level	<2.75	2.75-3.25	>3.25
Density dependence (only to be used when scoring invertebrates)	Compensatory dynamics at low population size demonstrated or likely	No depensatory or compensatory dynamics demonstrated or likely	Depensatory dynamics at low population sizes (Allele effects) demonstrated or likely

Susceptibility attribute	Low susceptibility Low risk Score = 1	Medium susceptibility Medium risk Score = 2	High susceptibility High risk Score = 3)
Areal overlap (availability) *i.e.* overlap of fishing effort with stock distribution	<10% overlap	10-30% overlap	>30% overlap
Encounterability *i.e.* the position of the species / stock within the water column / habitat relative to the position of the fishing gear	Low encounterability / overlap with fishing gear	Medium overlap with fishing gear	High encounterability / overlap with fishing gear (Default score for target species in a fishery)
Selectivity of gear type *i.e.* potential of gear to retain species	a) Individual < size at maturity are rarely caught	a) Individual < size at maturity are regularly caught	a) Individual < size at maturity are frequently caught
	b) Individual < size can escape or avoid gear	b) Individual < half the size can escape or avoid gear	b) Individual < half the size are retained by gear
Post-capture mortality *i.e.* the chance that, if captured, a species would be released and that it would be in a condition permitting subsequent survival	Evidence of majority released post-capture and survival	Evidence of some released post-capture and survival	Retained species or majority dead when released

Appendix 4

A comparison of the selectivity of research hourglass traps and a small otter trawl for sampling Blue Swimmer Crabs

Summary

- Research hourglass crab traps and a small otter trawl have been used concurrently to sample blue swimmer crabs in the Peel-Harvey Estuary from 2016 to 2020. This report compares the level of catch overlap between the two gear types, with the aim of streamlining future research surveys.
- Trawling generally caught smaller crabs than trapping (median size 84 *vs* 111 mm carapace width; CW), and was far more effective for catching juveniles from 16–90 mm CW. In contrast, traps were far more effective at catching mature crabs, and daily catch rates of legal crabs (≥ 127 mm CW) from trapping were 23–158 × higher than from trawling.
- It is proposed that monthly trawling be used to sample juvenile crabs during the peak recruitment period between February and June. This will allow the development of an annual standardised recruitment index (Juvenile Index).
- It is proposed that traps continue be used to sample larger crabs from June to November to inform catch prediction models (Legal November Index) and assessments of breeding stocks.

Background

Hourglass crab traps and otter trawls are the two main gear types that DPIRD use for fishery independent research surveys of blue swimmer crabs. Traps, as passive fishing gears, and trawls, as active fishing gears, capture crabs in different ways and therefore have inherent differences in their efficiency and selectivity for sampling populations. Previous research in the Peel-Harvey Estuary (PHE) by Bellchambers and de Lestang (2005) showed that otter trawls caught a wider size range than traps, and that traps tended to target larger crabs with almost all crabs being mature. On this basis, traps have been primarily used in breeding stock surveys (*i.e.* assessment of mature female biomass during peak spawning season) and for calculating catch rates of legal sized crabs (*e.g.* November Legal Index) in fisheries assessed by the Crab Research section, whereas otter trawling has predominately been used to sample juveniles during peak recruitment months. However, in the PHE, monthly trawling throughout all months of the year has been undertaken since 2016 in addition to monthly trapping from June to November (refined from trapping all months of the year which occurred between 2007-12).

The aim of this study was to compare the past four years of trap and trawl data from the PHE to assess the level of overlap in their sampling (*e.g.* size and sex selectivity, sampling efficiency), and to develop a sampling strategy to determine the combination of months and gear to enable a robust estimate of juveniles, legal size and spawning stock.

Methods

Trawling with a small otter trawl was undertaken at 10 sites throughout the PHE monthly from March 2016 to March 2020. Research hourglass traps were set at 15 sites (3 traps per site) each month from June to November between 2016 and 2019. Trapping was also undertaken in May 2019 as part of a crab tagging survey. These trap and trawl site locations are denoted in Figure A4.1. The otter trawl net was 3.7 m wide and 0.5 m high, and was constructed with 51 mm mesh in the wings and 25 mm mesh in the cod end. The net was estimated to have an effective fishing width of 2.4 m (*i.e.* 2/3 the net width). A three-minute-long trawl at 2.7 knots (covering approximately 250 m) was conducted at each site on every sampling occasion. Hourglass traps, which were 1.16 m in diameter, 0.5 m high and constructed from 50 mm diameter mesh, were baited with approximately 220 g of Yelloweye Mullet and set in a straight line 100 m apart for a period of approximately 24 hours. A full description of the study area and sampling gears are available in Johnston *et al*. (2014). All crabs were measured to the nearest 1 mm using Vernier callipers, with sex and maturity recorded based on visual analysis.

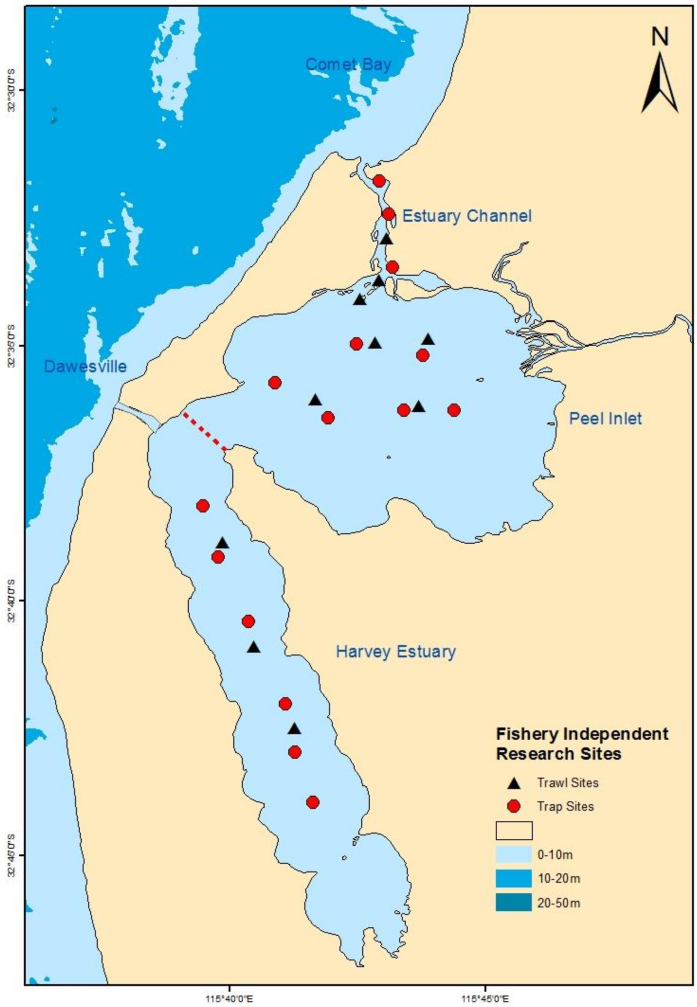

Figure A4.1 Map of the Peel-Harvey Estuary and fishery-independent research sites sampled by trapping and trawling from 2016 to 2019 (Johnston *et al*., 2014).

Size distributions of catch data were visualised using plots of Kernel Density Estimates (KDEs; Silverman, 1986). The probability density function $f(x)$ of the carapace widths was determined using the following formula, where *K* is the kernel, *h* is the smoothing parameter (bandwidth) and *n* is the number of observations.

$$\hat{f}(x) = \frac{1}{nh} \sum_{i=1}^{n} K\left(\frac{\hat{x} - x_i}{h}\right)$$

KDEs were fit and plotted using the 'ggplot2' package (Wickham, 2016) in R (R Development Team, 2019), with the bandwidth automatically chosen based upon the size range of data.

The size distribution of crabs caught in trap and trawl gear from 2016-2019 was compared overall (all sampling months), as well as for a subset of months where concurrent sampling occurred (June to November). Monthly size distributions (across all years) of each gear type were also compared.

Additionally, to assess when first recruitment was evident in the fishery, the monthly size distribution of trawl catches from January to June (the approximate known recruitment period in the PHE; Johnston *et al*., 2014) was examined by overlaying KDEs from each study year.

Sex specific size distributions and the total monthly proportion of male and female crabs caught with each gear type were also examined to assess whether size selectivity and sampling efficiency differed between sexes.

Finally, a daily catch rate and daily legal sized catch rate (crabs ≥ 127 mm) of each gear type was calculated to examine differences in the sample size that each gear type could collect within logistical and budget constraints (*i.e.* sampling efficiency). This was expressed as the mean number of crabs and legal sized crabs, respectively, caught per sampling trip within each sampling month from June to November.

Results and discussion

A total of 18,945 and 8,751 crabs were caught by trapping and trawling, respectively, during the four year study period (Table A4.1). Crabs caught in traps ranged from 45 to 198 mm CW (median 111 mm, mean 110 mm), while those in the trawl net were considerably smaller and ranged from 16 to 147 mm (median 84 mm, mean 86 mm; Table A4.1). Trapping caught more than twice as many males as females (13,309 males vs 5,636 females), while trawling caught a more even sex ratio, with only slightly less males than females (4,142 males vs 4,600 females). From June to November (when both gears were used concurrently) the smallest male crabs caught in trap and trawl gear were 67 and 24 mm, respectively, while the smallest females were 45 and 40 mm, respectively (Table A4.1).

The mode of the size distribution caught by trawling was approximately 75 to 90 mm, which was far smaller than for trapping where the peak of the size distribution was at approximately 105-120 mm (Fig A4.2). Moreover, traps caught very few crabs below 75 mm (<0.5% of crabs), while trawling caught very few crabs above 125 mm (*c.* 3% of crabs; Fig. A4.2).

Within individual sampling months there was also a clear difference in the size distribution of trap and trawl gear across all months the gears were concurrently used (Fig. A4.3). At this monthly level, trawling generally caught a wider size range of crabs, but again targeted the smaller crabs within the population than trawl gear (approximately 30–50 mm difference in modal size between gear types).

Examination of size distribution data for trawling only during January to June (Figure A4.4) showed that peak recruitment each year generally occurred in February or March (*i.e.* spike in abundance of <50 mm crabs; Fig A4.4). By May and June almost the entire population had approached maturity (*c.* 80-90 mm).

Table A4.1 Summary of blue swimmer crab size data collected from research traps and trawls in the Peel-Harvey Estuary between 2016 and 2019.

Method	Sex	n	Carapace width (mm)					
			Min	Max	Range	Median	Mean	SE
All months								
trap	all	18945	45	198	153	111	110	0.09
trap	f	5636	45	198	153	113	112	0.18
trap	m	13309	67	164	97	110	110	0.11
trawl	all	8751	16	147	131	84	86	0.21
trawl	f	4600	21	147	126	85	87	0.27
trawl	m	4142	17	145	128	84	86	0.31
trawl	u	9	16	44	28	30	31	3.17
June to November only								
trap	all	18663	45	193	148	111	110	0.09
trap	f	5480	45	193	148	113	111	0.18
trap	m	13183	67	164	97	110	110	0.11
trawl	all	5351	24	147	123	83	85	0.22
trawl	f	2752	40	147	107	83	85	0.28
trawl	m	2598	24	143	119	84	85	0.33
trawl	u	1	30	30	0	30	30	-

Sexes; m = male, f = female, u = undetermined/unknown.

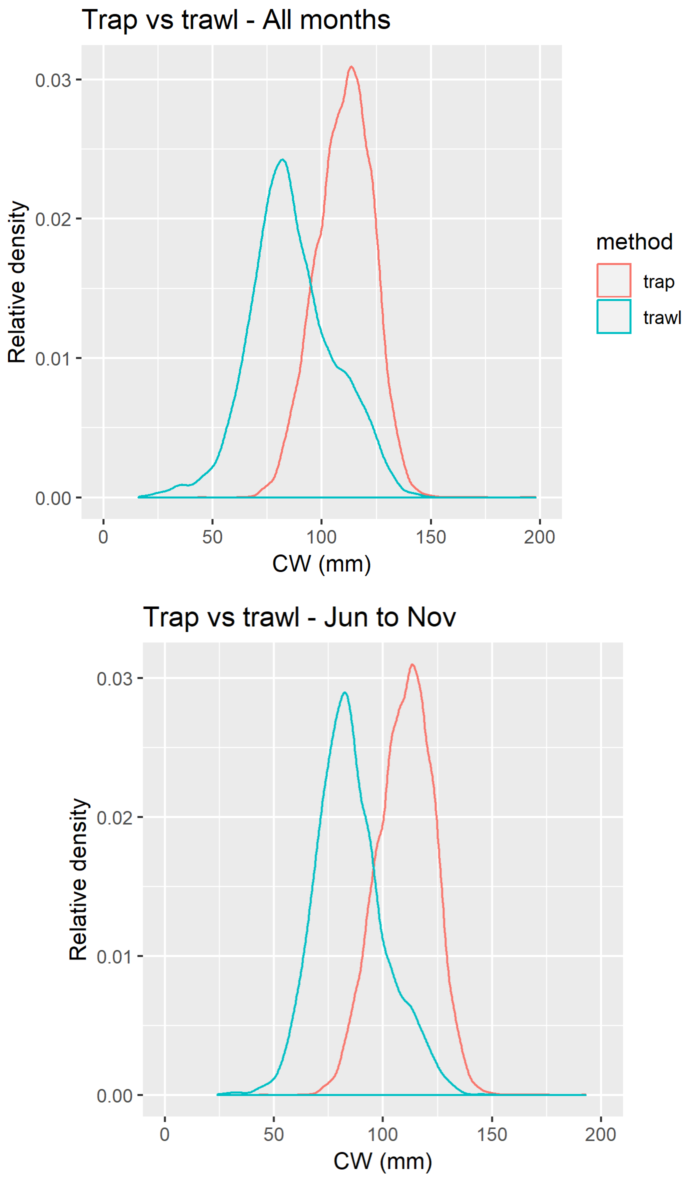

Figure A4.2 Size distribution (carapace width; CW) of crabs caught in trap and trawl gear between 2016 and 2019 (pooled across all sampling months and years [top] and pooled for Jun-Nov [bottom]).

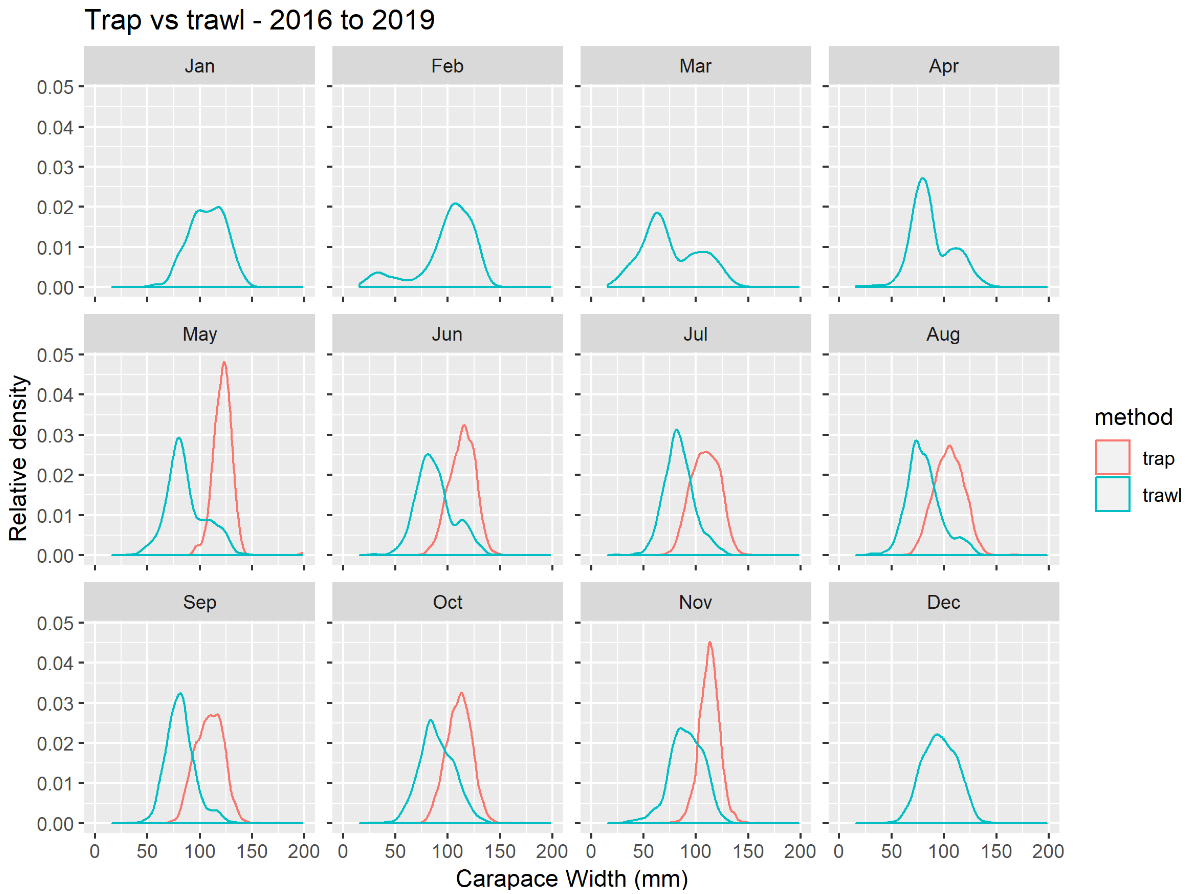

Figure A4.3 Size distribution (carapace width; CW) of crabs caught in trap and trawl gear each month between 2016 and 2019. Note, trapping was only undertaken from June to November each year, except for in 2019 when it was also undertaken in May.

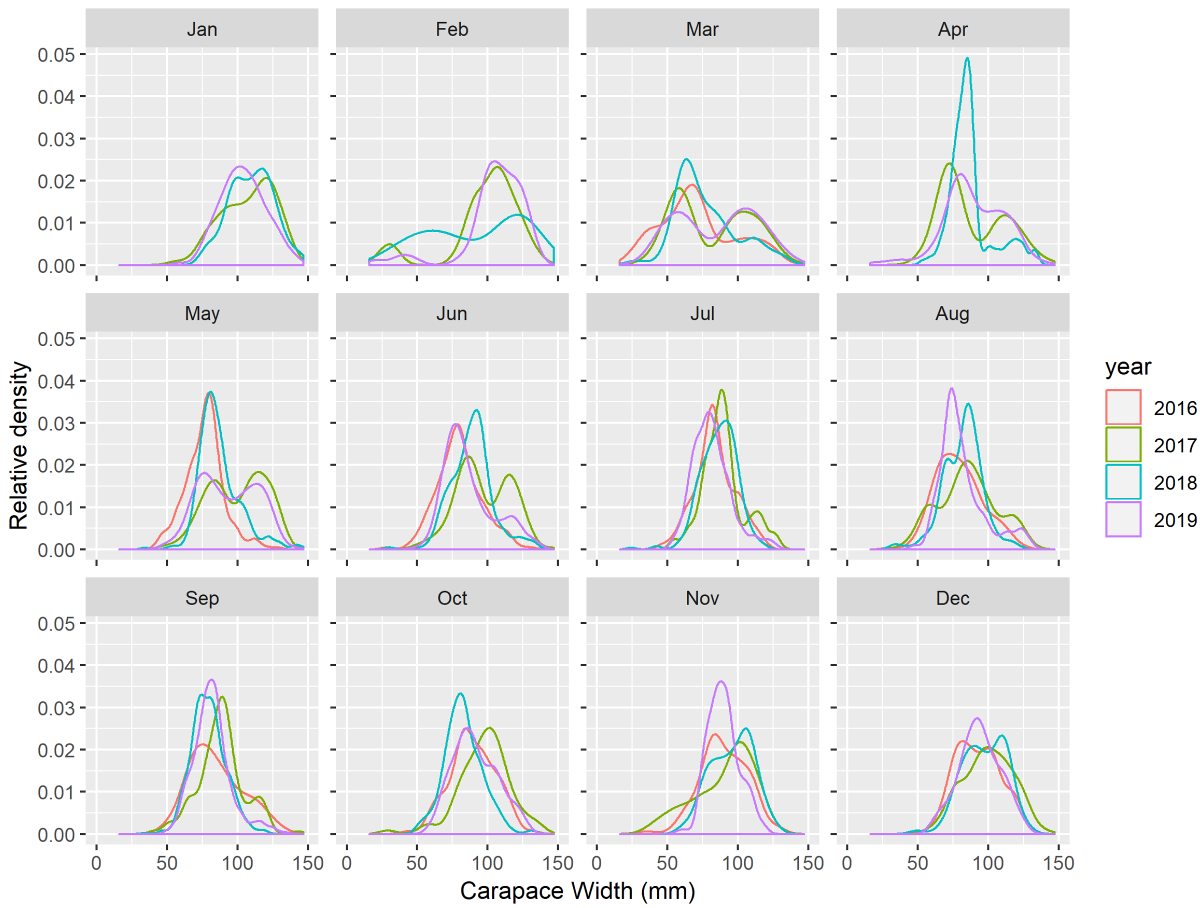

Figure A4.4 Size distribution (carapace width) of crabs caught by trawling each month and year from 2016 to 2019.

Within individual sexes, traps targeted slightly larger females than males (modal CW *c.* 118 *vs* 112 mm, respectively; Fig A4.5). The mode of the size distribution from trawling was similar between sexes, but trawling caught a slightly greater number of larger (>100 mm CW) males than females (Fig. A4.5). With respect to the overall sex ratio caught in each gear type each month, trapping caught approximately 68–72% males, while trawling caught 40–53% males (Fig. A4.5).

The maximum number of trap and trawl deployments that can be logistically undertaken within the PHE during a single sampling day (three staff working for approximately 8 hours) is 45 and 15, respectively. It should be noted that trapping also requires traps to be set the day before hauling (although this requires less time and is less labour intensive, so can therefore be undertaken by two staff). In every month trapping caught approximately 2–6 fold more crabs per sampling day than trawling (Fig. A4.6a). Thus, while trawls captured a wider size range of the population, their efficiency was far lower. Furthermore, the daily catch rate of legal sized crabs was many magnitudes higher in traps than trawl gear (29-105 crabs/day vs <5 crabs day; Fig. A4.6b). To capture a sample of 30 legal sized crabs using trawl gear would take between 7 and 60 days on the basis of the average daily catch rates displayed in Fig. A4. 6. This affirms that traps are far more suitable than trawl gear for gathering a representative sample of legal-sized crabs, such as for calculating a legal crab index for the fishery (*i.e.* Legal November Index). Traps also caught substantially higher catch rates of mature female crabs than trawl gear (Fig. A4.6d), providing clear justification for using traps as a method for conducting breeding stock surveys of blue swimmer crabs in WA (*e.g.* in Cockburn Sound and the Swan-Canning Estuary). In contrast, trawling sampled substantially more immature female crabs per day (2–9 × greater catch rates; Fig. A4.6c), confirming that trawling is more efficient for conducting juvenile surveys than traps.

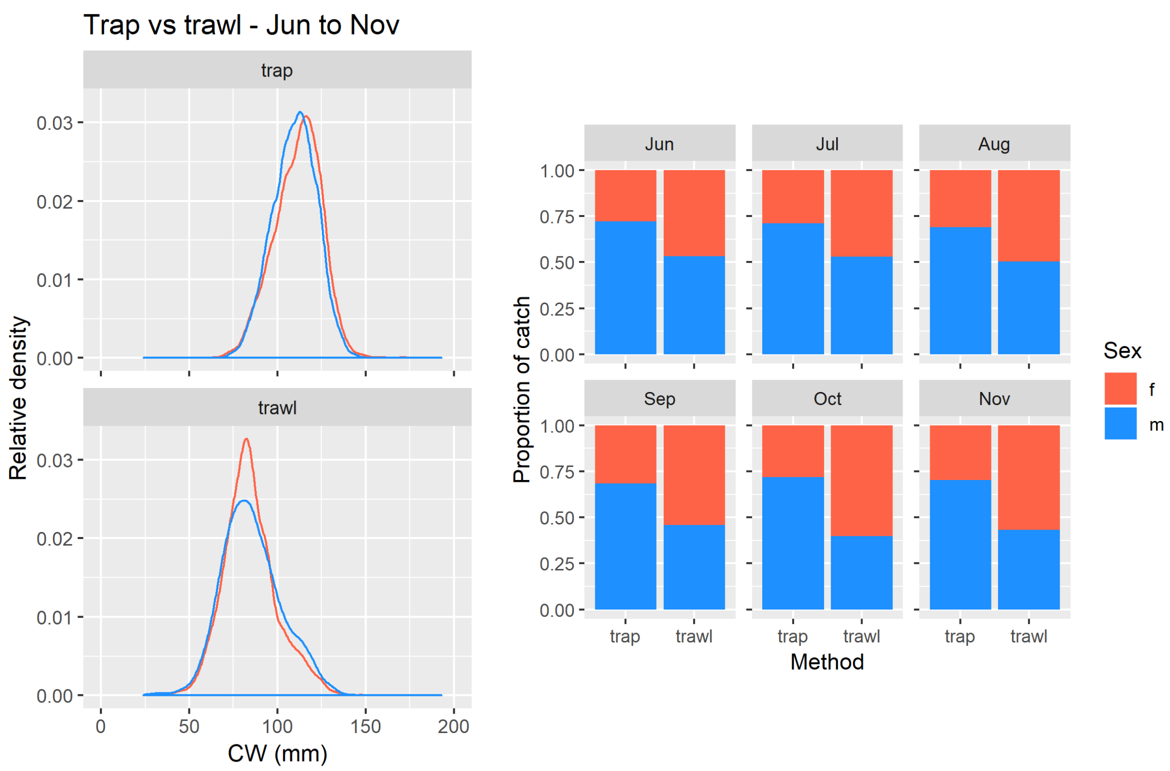

Figure A4.5 The size distribution (carapace width; CW) and relative proportion by number of individuals caught of male and female crabs in trap and trawl gear from June to November (across all study years from 2016 to 2019).

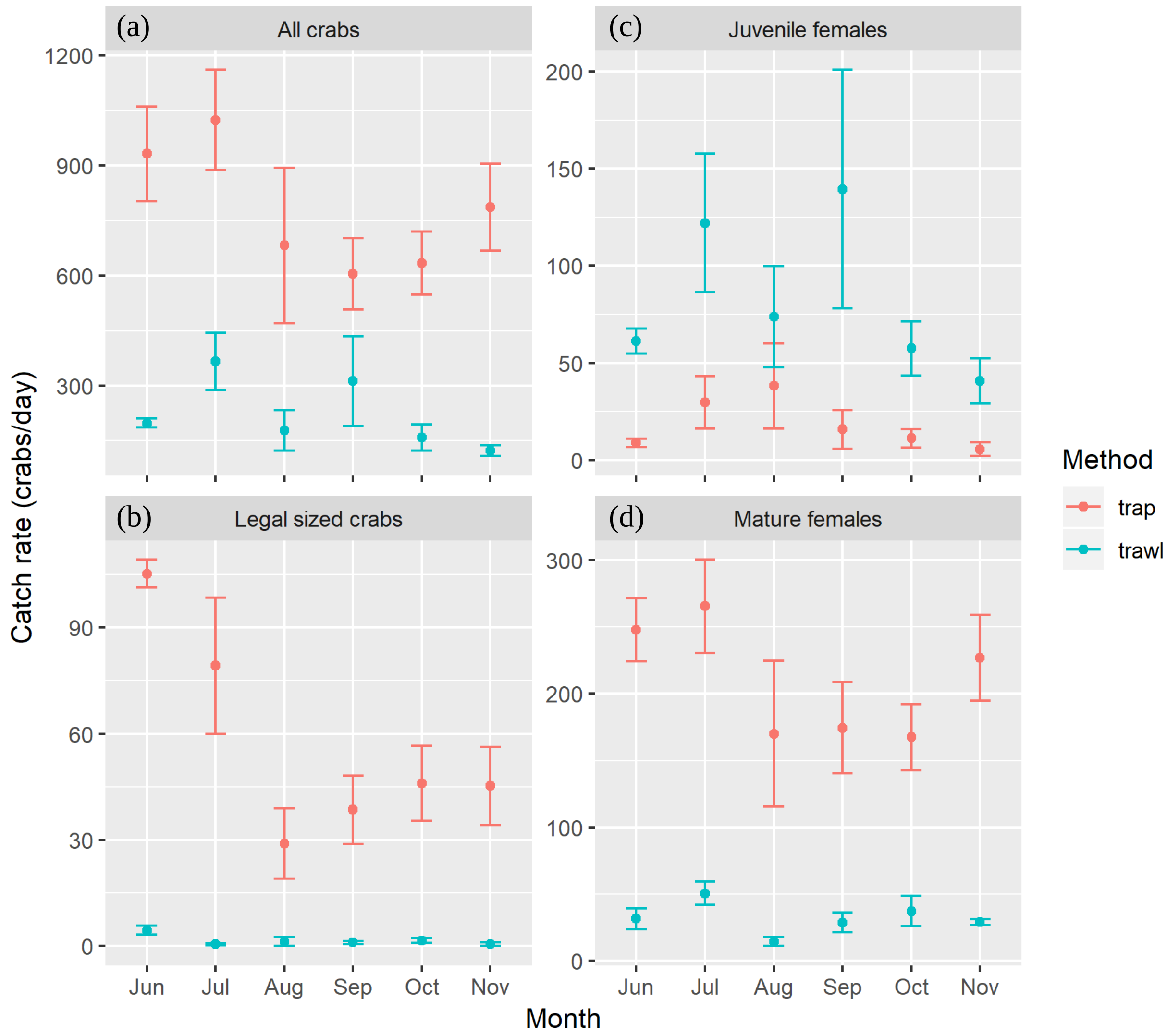

Figure A4.6 Mean ± SE daily catch rates of trap and trawl gear each month (June–November only; averaged across years) for (a) all crabs, (b) legal sized crabs (>127 mm), (c) juvenile females and (d) mature females.

Conclusions

- Trawling targets smaller crabs (< 100 mm), while trapping is far more effective for catching larger crabs. Trawling generally caught a wider size range of crabs within a given month, but at far lower catch rates (numbers of crabs per sampling day).
- Given the observed differences in the size and sex selectivity among trap and trawl gear concurrent sampling with both gear types year-round would clearly provide the best understanding of population dynamics in the PHE. However, if budget and time constraints require a reduction of sampling effort, an efficient and cost effective sampling regime can be tailored on the merits of each sampling method.
- The ability of trawl gear to sample very small juvenile crabs from 16 to 50 mm suggests that this gear type is most suitable for recruitment surveys. Trawl data from last 4 years suggests that small recruits (*i.e.* < 40 mm) are first present in trawl catches

during February, and peak initial recruitment occurs in March–April. It is recommended that monthly trawl surveys be undertaken from February to June each year to support a recruitment index.

- Very few legal crabs were caught trawling and it would require substantial sampling effort to gather a representative sample of legal sized crabs. Traps are therefore considered more suitable for legal index and it is recommended that monthly trapping from June to November continues. Trawling from July to January should be discontinued.

References

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Appendix 5

Development of the Peel-Harvey Estuary Catch Prediction Model

This analysis investigates the predictive capability of commercial catch of blue swimmer crabs in Peel Harvey in the fishing season (t/t+1) using the catch rates of legal-size (≥127 mm) crabs in November (t) calculated for fishery-independent potting surveys. A previous analysis also examined the usefulness of the catch rates of pre-recruits (115 mm to 127 mm) in November as a secondary predictor of catch, which indicated that the inclusion of pre-recruit catch rates in the analysis did not significantly improve the model and therefore has not been considered in this analysis.

Data

Commercial Catch Data

Monthly commercial catch data from October 1995 to December 2016 inclusive were analysed. The fishing season as of 2016 extends from November to the following August, although September and October were fished in earlier years. To enable comparison between seasons, this analysis only considers the commercial catch from the beginning of the season (November) to the end of August. *i.e.* commercial catch from November (t) to August (t+1).

Fishery-Independent CPUE Data

Catch rates were calculated for legal-size (≥127 mm) crabs for the fishery independent trapping surveys undertaken across three main regions of the Peel Harvey Estuary, *i.e.* Peel Inlet, Harvey Estuary and the Estuary Channel (Figure A5.1). Mean catch rates (and 95% confidence intervals) were calculated for each month sampled in each region (Figure A5.2). The mean monthly estimates for each region were then combined by calculating a weighted mean (using the relative area of each region), to produce a combined CPUE (Figure A5.3).

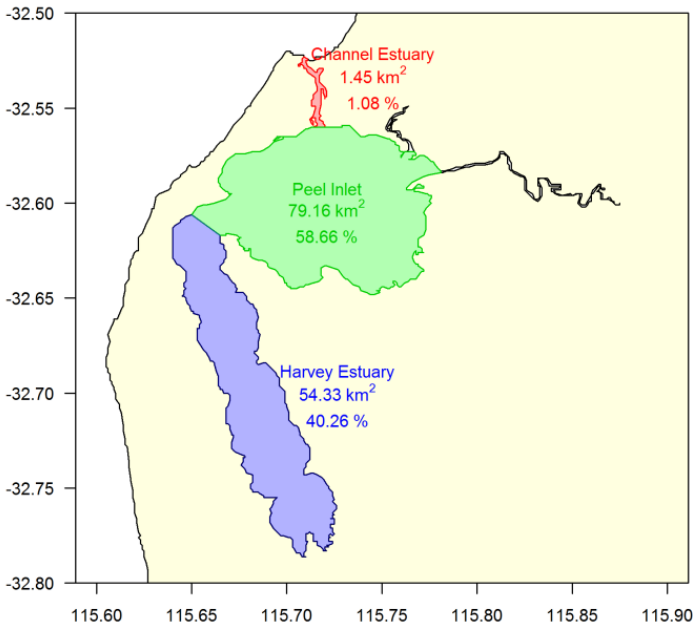

Figure A5.1 Area of three regions in Peel-Harvey BSC Fishery: Estuary Channel, Peel Inlet and Harvey Estuary.

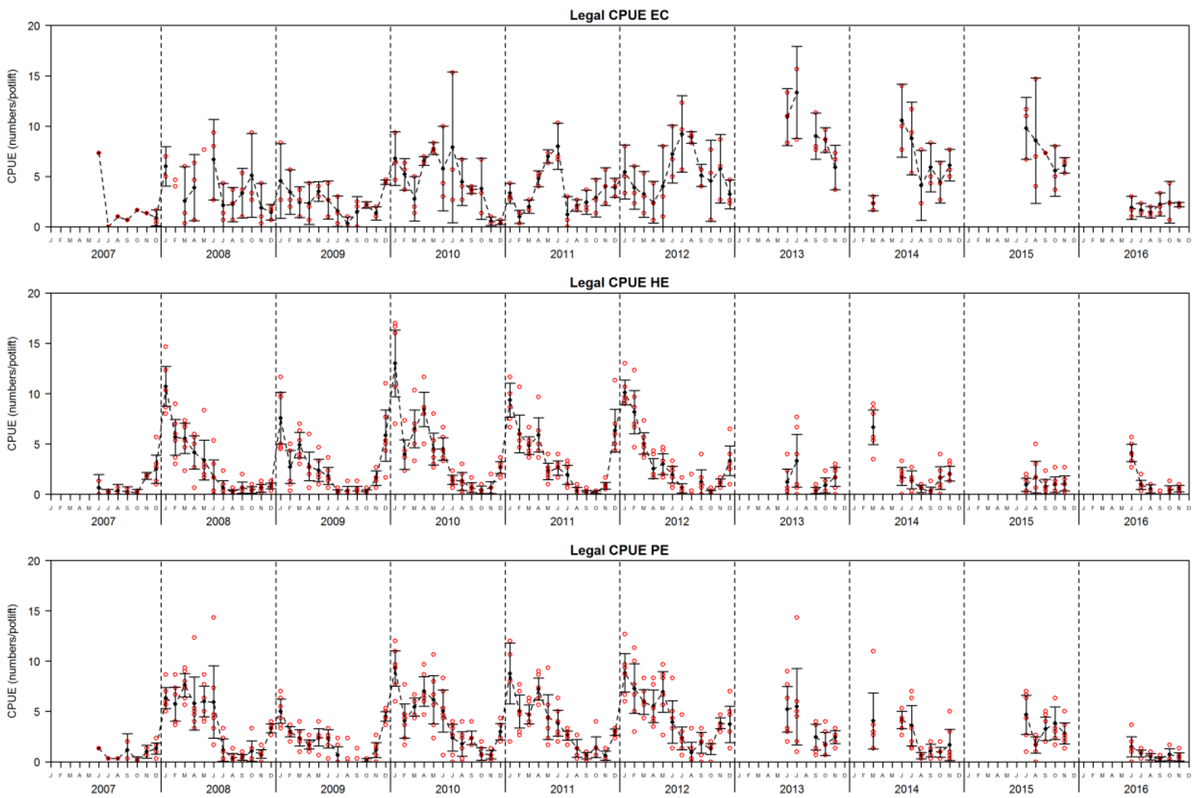

Figure A5.2 Monthly catch rates of legal size (≥127 mm) crabs calculated for fishery independent potting surveys, by region: Estuary Channel, Peel Inlet and Harvey Estuary.

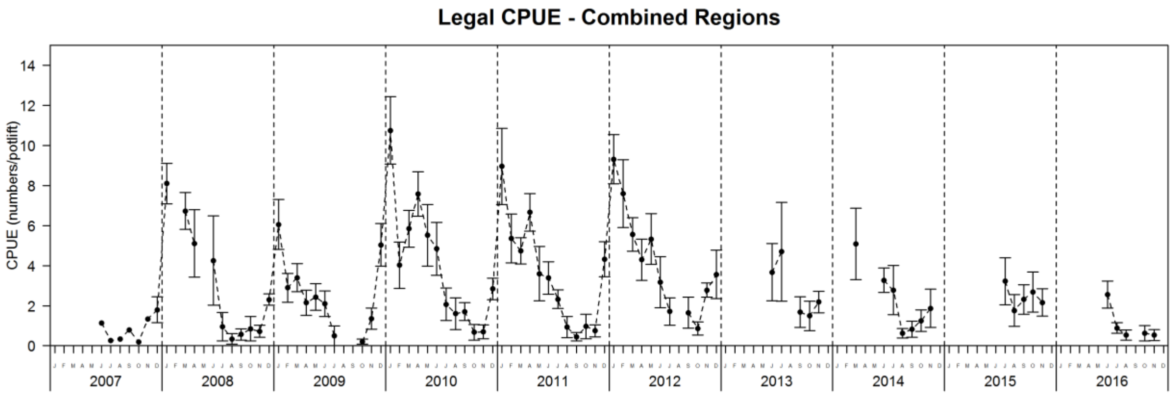

Figure A5.3 Monthly combined catch rates of legal-size (≥127 mm) crabs calculated for fishery independent potting surveys, weighted by area of each region: Estuary Channel, Peel Inlet and Harvey Estuary.

Relationship between Commercial Catch and CPUE of Legal Crabs

A previous exploratory analysis examined the relationship (linear correlation) between the CPUE in any given month from July to December and the catch (Nov-Oct) in the following season. For all months considered (July to December), only the catch rate of legal crabs in November showed a significant correlation with the catch (total catch).

Catch Prediction using November Legal CPUE

Based on results from previous analyses, the catch rate of legal size crabs in November (t) was found to be a good predictor of the subsequent commercial catch, *i.e*. the catch taken from November (t) to August (t+1). The catch prediction model used a power relationship between the catch rates and subsequent catch.

An analysis was undertaken to see if the catch (C) of blue swimmer crabs in the fishing season t/t+1 could be predicted from the catch rates of legal size crabs (U) in the previous November *i.e*. year t using the power relationship: $C_{t/t+1} = aU_t^b e^{\varepsilon}$. The regression model used to model the power relationship is given by:

$$\ln(C) = A + b\ln(U) + \varepsilon \text{, where } A = \ln(a)$$

The null hypothesis tested was that the regression coefficient (*i.e*. the slope b) was equal to zero. The results of the simple linear regression (Table A5.1) suggest that the (log-transformed) November CPUE is a good predictor of the (log-transformed) catch; $F(1, 7) = 3.4$, $p = 0.1$. Multiple R squared indicates that approximately 33% of the variation in (log-transformed) total catch was explained predicted by the (log-transformed) November catch rate of legal sized crabs.

Table A5.1 Power regression model coefficients and ANOVA table for single predictor model of catch.

```
Model Coefficients:
               Estimate Std. Error t value Pr(>|t|)
(Intercept)     4.2279    0.01020  41.468 1.24e-09 ***
log(LegalCPUE)  0.3179     0.1725   1.843    0.108*
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.2593 on 7 degrees of freedom
Multiple R-squared:  0.3266,     Adjusted R-squared:  0.2304
F-statistic: 3.395 on 1 and 7 DF, p-value: 0.1079
```

The catch prediction model and its fit to the observed catch data for each season are shown in Figure A5.4. The observed catch for each season lies within the 95% confidence interval except 2015/16, which is below the lower confidence limit. This lower than predicted catch may be due to lower temperatures and unusual rainfall conditions during the 2015/16 season which resulted in poor growth and low legal catch rates. This will be examined in future analysis.

The catch prediction model was first tested for the 2016/17 season. The legal November index for 2016 was the lowest since 2007, suggesting that legal-size stock levels were very low at the commencement of the 2016/17 season. This was reflected in the very low catch achieved in December 2016 (3.7 t). The predicted annual catch for 2016/17 using the power relationship was 58 t (95% CI: 38 t –90 t) and the actual catch was 55 t. Note, updated catch prediction analysis for more recent years is presented in section 9.3.7.2.

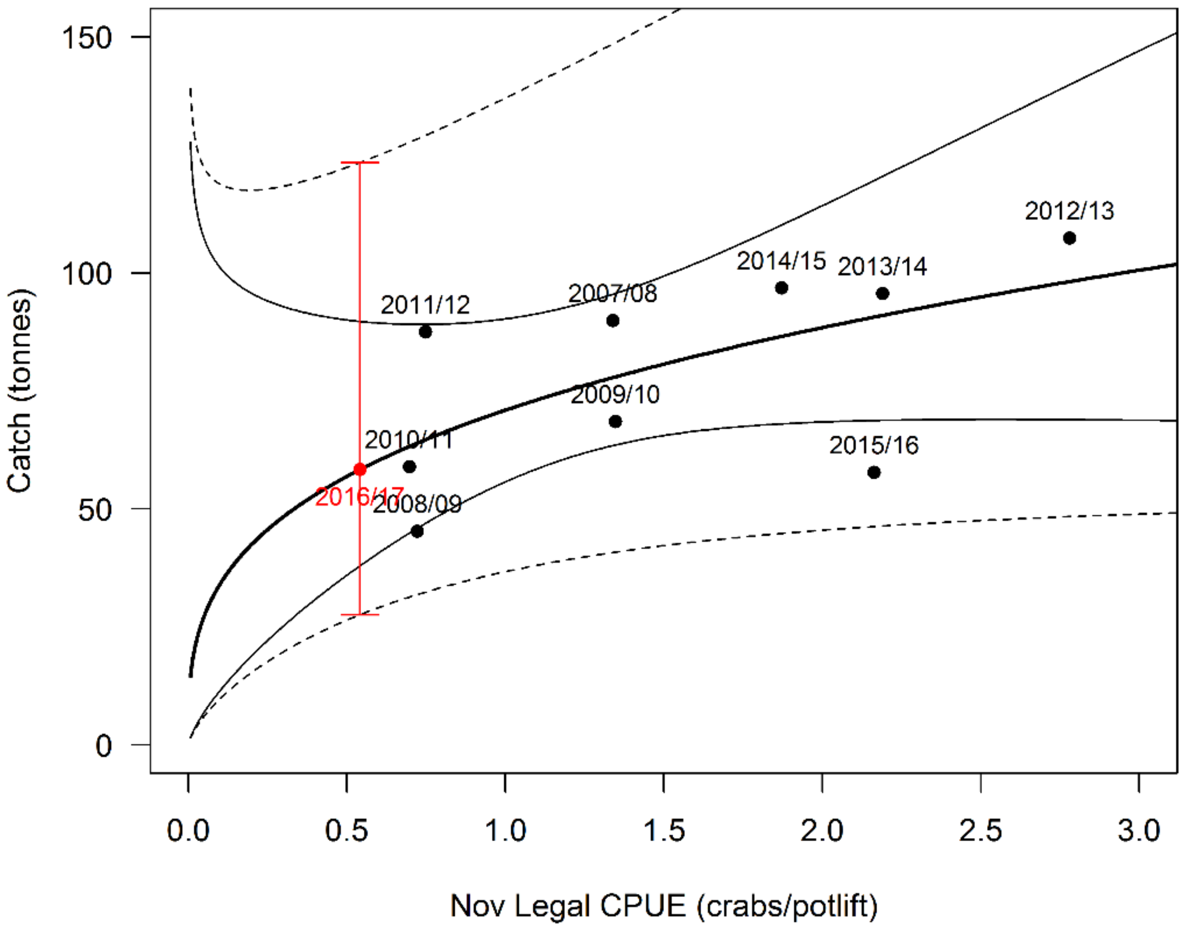

Figure A5.4 Catch prediction model using November fishery independent catch rates of legal sized blue swimmer crabs (year t) as predictor of commercial catch for the following (November-August) fishing season (year t +1) (power relationship). The solid black line indicates the fitted regression line (bias corrected for estimation in log space), and the 95% confidence limits are indicated by the black line. The dotted line indicates the 95% prediction limits. The predicted catch and its prediction limits for 2016/17 are shown in red.

Appendix 6

Development of Cockburn Sound Stock recruitment relationship

Overview

Historically, a stock-recruitment relationship was trialled for blue swimmer crabs in Cockburn Sound based on catch as a proxy for recruitment (due to the lack of a long-term direct index of recruitment) and indices of egg production (de Lestang, 2010). The historical relationship became redundant as catch can no longer be used as a proxy for recruitment due to the closures of the fishery in a number of recent years. However, data from an independent trawl survey conducted annually in Cockburn Sound during the juvenile recruitment period (April to June) provides us with 15 years of data.

The objective of this analysis was to determine the relationship between spawning stock and subsequent recruitment, and if the environmental variables chlorophyll A and water temperature could explain the variation within this relationship. These two environmental variables were used as temperature has been shown to be an important influence on spawning and recruitment in blue swimmer crabs (Johnston *et al*., 2011; de Lestang *et al*., 2010). Primary production was also thought to be an important factor influencing spawning success and juvenile survival.

Data / Methods

Regression analysis was conducted on abundance indices and environmental data obtained for the Cockburn Sound crab fishery to verify the association or relationship between the index of recruitment, *i.e.* Juvenile Index (number of 0+ crabs/100m^2), and one or more explanatory variables:

1 A measure of egg production (eggs/trap lift), during the spawning period (September to December) preceding recruitment. Note that this index is currently under review due to concerns that the index may be biased in recent years by changes in the pattern of fishing.

2 An index of chlorophyll-*a* (μg/L) during the summer period (December to March) relating to the larval period for crabs (see Appendix 7).

3 An index of water temperature (˚C) during the spawning period *i.e.* October to December.

A linear regression model and a non-linear regression model (*i.e.* Beverton-Holt Stock Recruitment relationship) were used to explore the relationship between spawning stock and recruitment. Multiple linear regression was used to explore the additional variation explained by the environmental variables chlorophyll-*a* and water temperature.

Results

Linear regression indicated that the measure of egg production during the spawning season (Sep_{t-1} to Dec_{t-1}) suggested a weak association with the subsequent recruitment in Apr_t to Jun_t and explained a significant proportion or variance in recruitment (R^2=.26, F(1,14)=4.970, p=0.043). A nonlinear regression employing the Beverton-Holt stock-recruitment relationship $R = \frac{aS}{b+S}$, where R is the recruitment from stock size S was also conducted, with similar model fit as the linear regression (Figure A6.1). Confidence intervals for the linear and nonlinear regression lines (indicating a 95% probability of the band which includes the true linear regression line of the population) were broad, and indicate the level of uncertainty of the relationship between spawning stock size and recruitment.

The relationship between the measure of egg production during the spawning season and subsequent recruitment was further analysed by incorporating the two environmental variables that were thought to influence recruitment (Figure A6.1).

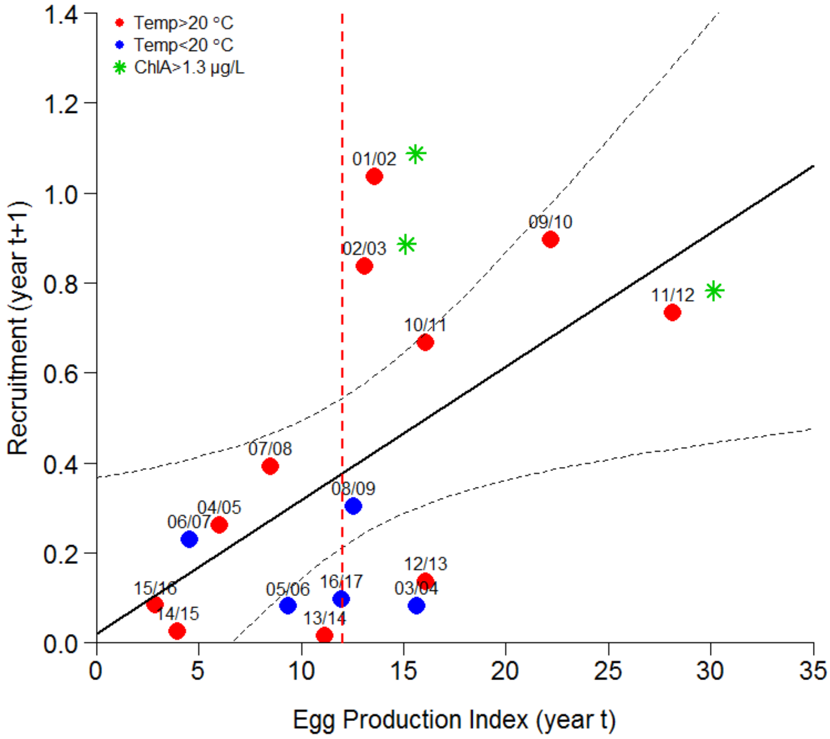

Figure A6.1. Stock recruitment relationship investigating the influence of environmental parameters (water temperature in spawning months October-December and Summer chlorophyll-*a*). The egg production index (10^6 eggs/traplift) is a measure in year t, with recruitment (juveniles/100m^2 trawled) an index in t+1. In years with low egg production (<12x10^6 eggs/traptlift), low levels of recruitment were observed, irrespective of environmental conditions. An average temperature of 20°C was observed between October and December from 2001/02 – 2015/16. 95% confidence limits around the regression line are shown.

Multiple linear regression was calculated to predict recruitment based on the egg production index, the summer chlorophyll-a index and average water temperature during the spawning season. Noting that the egg production and recruitment indices were available for seasons 2001/02 through to 2016/17, chlorophyll-a and temperature data was not available for season 2016/17 at the time of analysis. Therefore the stock-recruitment-environment analysis was limited to the seasons 2001/02 through to 2015/16. There is weak evidence that the relationship is statistically significant: $F(3,11) = 3.269, p = .063, R^2 = .47, R^2_{adj} = .33$. Predicted recruitment (numbers/100 m^2) is given by:

$$\text{Rec} = -2.761 + 0.021\,(EPI) + 0.473\,(ChlA) + 0.118\,(Temp)$$

where egg production index (*EPI*) is measured in 10^6 eggs/potlift, chlorophyll-a (*ChlA*) is measured in μg/L and water temperature (*Temp*) is measured in *°C*. However, no predictor variables were found to be significant at the 0.05 level (Table A6.1) Comparison of the stock-recruitment relationship with only egg production as a predictor variable (refitted on same years of data as those included in the multiple linear regression) against the stock-recruitment-environment relationship with the two additional predictors suggested that the inclusion of the environmental variables did not improve the regression, $F(11,13) = 2.156, p = .162$.

Stepwise regression resulted in the chlorophyll-a predictor being removed and the resulting relationship being statistically significant: $F(2,12) = 4.483, p = .035, R^2 = .43, R^2_{adj} = .33$. The *EPI* predictor variable in this model was significant at the 0.05 level, with the intercept and temperature variables significant at the 0.1 level (Table A6.2). The associated model for predicting recruitment using the egg production index and water temperature during the spawning period is given by

$$\text{Rec} = -3.136 + 0.029\,(EPI) + 0.156\,(Temp)$$

Comparison of the stock-recruitment relationship with only egg production as a predictor variable against the stock-recruitment-environment relationship with the additional water temperature variable suggested that the inclusion of the variable improved the regression, $F(12,13) = 3.429, p = .089$ (Figure A6.2).

Table A6.1 ANOVA table with Type I SS for the multiple linear regression of recruitment using the predictor variables: egg production index, summer chlorophyll-a index and average water temperature during the spawning season.

Source	DF	SS	MS	F	p-value
EPI	1	0.487	0.487	5.495	0.09
ChlA	1	0.242	0.242	2.730	0.127
Temp	1	0.140	0.140	1.582	0.234
Residuals	11	0.975	0.089		

Table A6.2 ANOVA table with Type I SS for the multiple linear regression of recruitment using the predictor variables: egg production index and average water temperature during the spawning season.

Source	DF	SS	MS	F	p-value
EPI	1	0.487	0.487	5.537	0.037
Temp	1	0.302	0.302	3.429	0.088
Residuals	12	1.056	0.088		

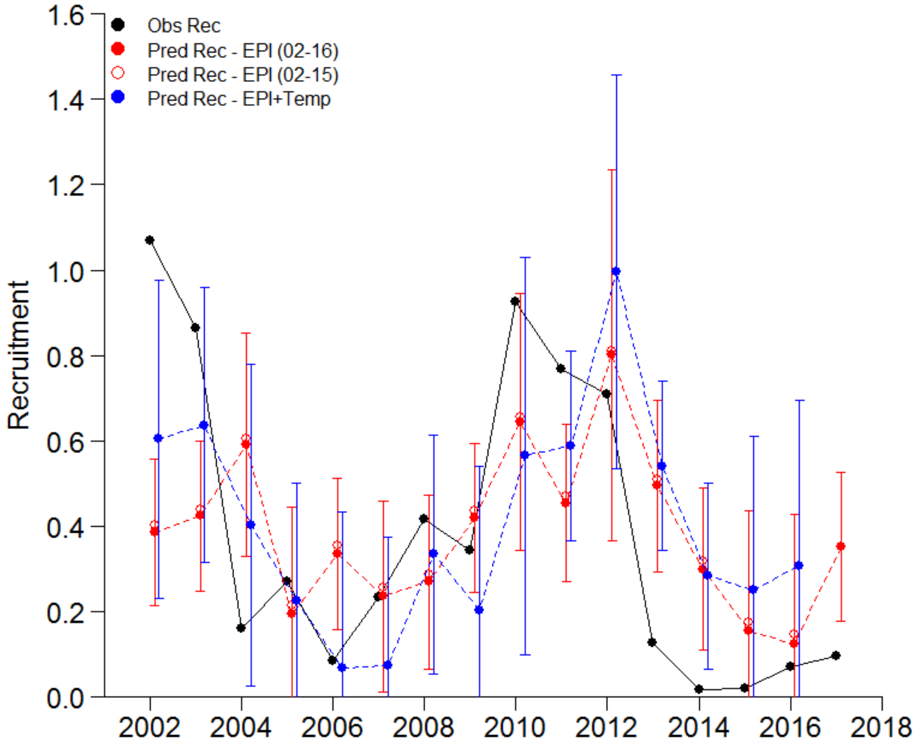

Figure A6.2 Model predictions with 95% confidence intervals for the stock recruitment relationship based on egg production index (red) and the stock recruitment-environment relationship (blue). Chlorophyll a was not used in the final analysis as it did not improve the model.

Appendix 7

Summer index for Chlorophyll *a* in Cockburn Sound

Introduction

An index of chlorophyll-*a* in Cockburn Sound was calculated from water quality data obtained from the Cockburn Sound Management Council. Water quality data was available at various sites across the area, as shown in Figure A7.1, from November 1982 to March 2016. However, as not all sites are sampled in all months or years, the analysis was limited to those sites which were sampled consistently across the time period. This means that the analysis only used data for sites: CS4, CS5, CS6/6A, CS7, CS8, CS9, CS10/10N and CS11.

Note that CS10 and CS10N were combined to form site CS10 as it appears that the site moved from CS10 to CS10N in 2002, and the sites are located quite closely together. In the 2014/15 update, site CS10 is provided (which was previously discontinued), however no spatial coordinates (*i.e.* Eastings and Northings) were provided with this updated data set so it is unclear if this is actually site CS10 or CS10N. The spatial coordinates provided for sites CS9 and CS9A showed a large spatial separation between these two sites. Therefore, they were considered as independent sites with only site CS9 being retained in this analysis as it was monitored consistently throughout the time period. Similarly, CS6 and CS6A were considered the same site so data was combined from CS6 (collected 1982/83-1996/97) and CS6A (collected 1997/98-2015/16). CS6 was used to be in line with data presented in Appendix B in the CSMC 2015/16 report.

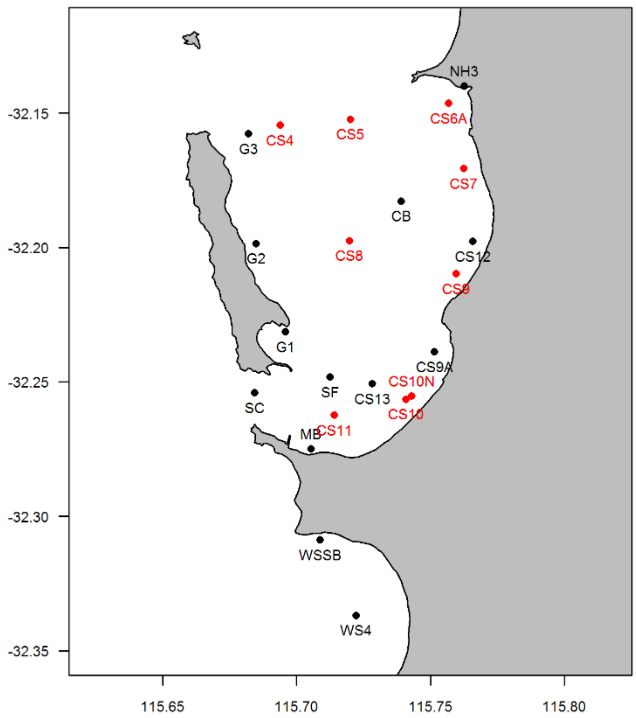

Figure A7.1 Map showing site locations of Cockburn Sound Management Council water quality data sampled during the period November 1982 to March 2016. Sites highlighted in red have been sampled consistently across the time series and have been used in this analysis.

Most sites were monitored across the summer months (December to March inclusive) throughout the time period. Some sites were sampled in late November or early April in some years, so for the purposes of modelling these observations were considered as December or March records respectively.

Method and Results

A linear model was fit to the chlorophyll-*a* data (for sites CS4, CS5, CS6/6A, CS7, CS8, CS9, CS10/10N and CS11) to investigate the effects of season (1982/83 to 2015/16 excluding 1983/84, 1987/88, 1988/89, 1993/94, 1994/95, 1995/96 and 2003/04), month (December, January, February, March) and site (CS4, CS5, CS7, CS8, CS9, CS10 and CS11). Due to the unbalanced data set, not all two-way interactions could be included in any single model. Various models were considered including the three main effects, along with either the two-way interaction of season and site or month and site. The interaction of season and site was found to be significant, whilst that of month and site was only marginally significant. However, the inclusion of either interaction term on the standardised index for the season was found to be minimal. It appears that the significance of each interaction term is due to spurious differences in some years and that generally, the trends in both season and month generally compared well between sites. Therefore, a model including only the three main effects was employed. As type I sum of squares (the commonly used sum of squares in ANOVA) are dependent on the order that factors are included in the model when data is unbalanced, type III sum of squares were also investigated (these are not order dependent) to assess the likely stability in significance levels of the various factors in the type I analysis.

The results of the type I (Table A7.1) sum of squares both conclude that all main effects were statistically significant. Least-squares means (LSM) (akin to simple arithmetic means for a completely balanced design) are presented as the standardized chlorophyll-*a* index (µg/L) for the season effect along with their associated 95% confidence intervals (Figure A7.2; A7.3). These represent the average of the monthly and site effects for each particular season.

Table A7.1. ANOVA using Type I sum of squares. $R^2 = 0.43$

	Df	SS	MS	F	Pr(>F)
Season	26	426.45	16.402	35.20	< 2.2e-16
Month	3	73.34	24.445	52.47	< 2.2e-16
Site	7	484.4	69.2	148.52	< 2.2e-16
Residuals	3187	1484.88	0.466		

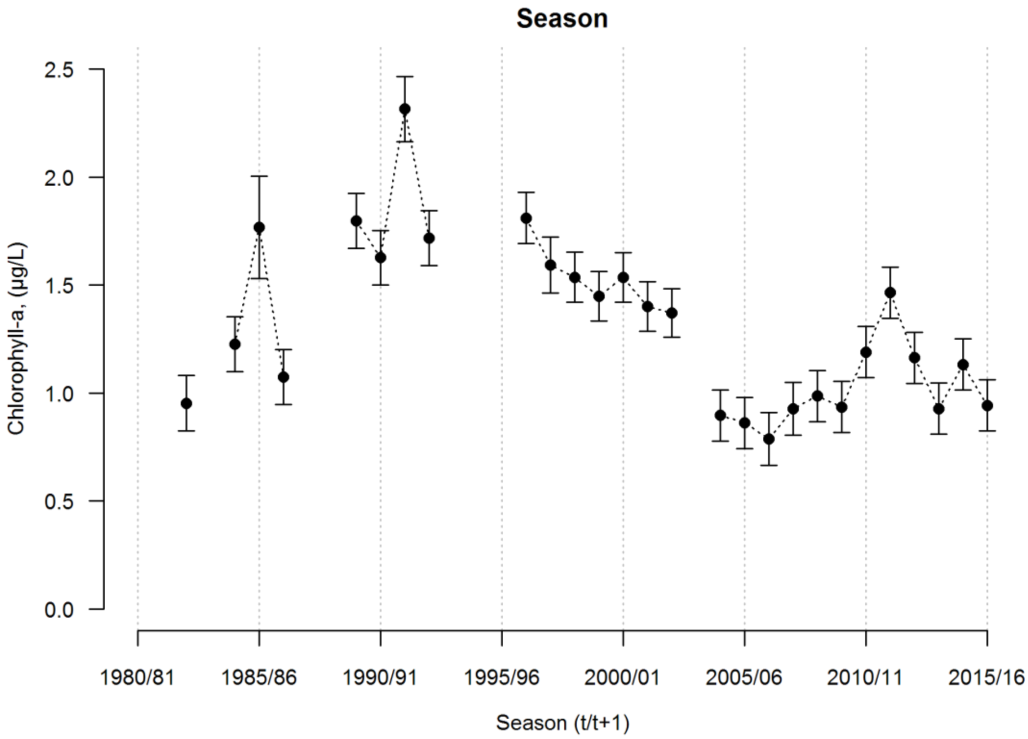

Figure A7.2 Least square means of chlorophyll-A (µg/L) for the season effect along with their associated 95% confidence intervals.

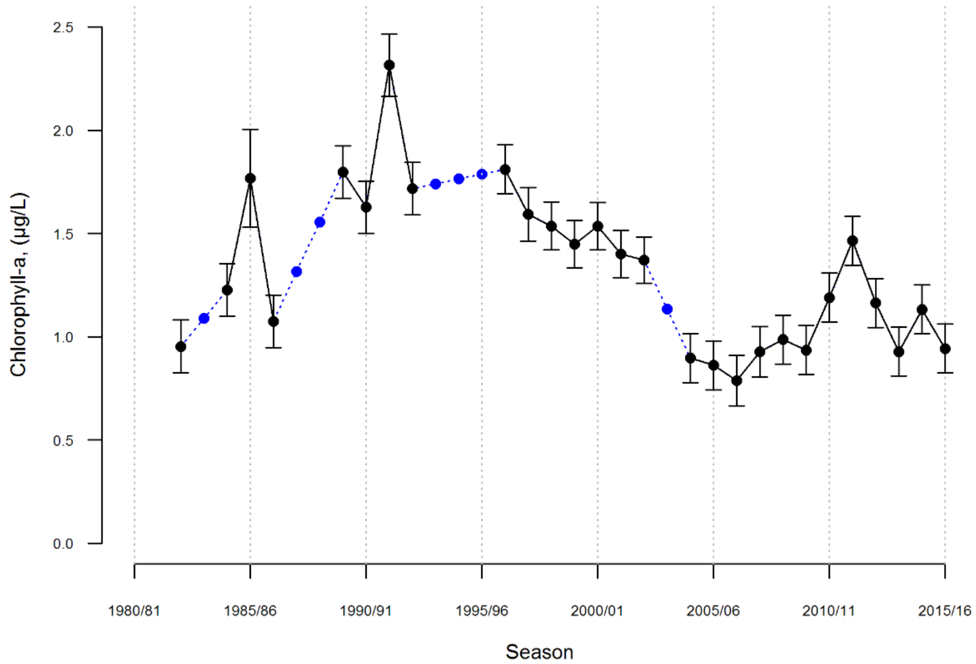

Figure A7.3 Least square means of chlorophyll-a (µg/L) for the season effect along with their associated 95% confidence intervals. A second index is also presented (indicated in blue) where missing values have been linearly interpolated from the neighbouring estimates.

Appendix 8

Water temperature and rainfall plots

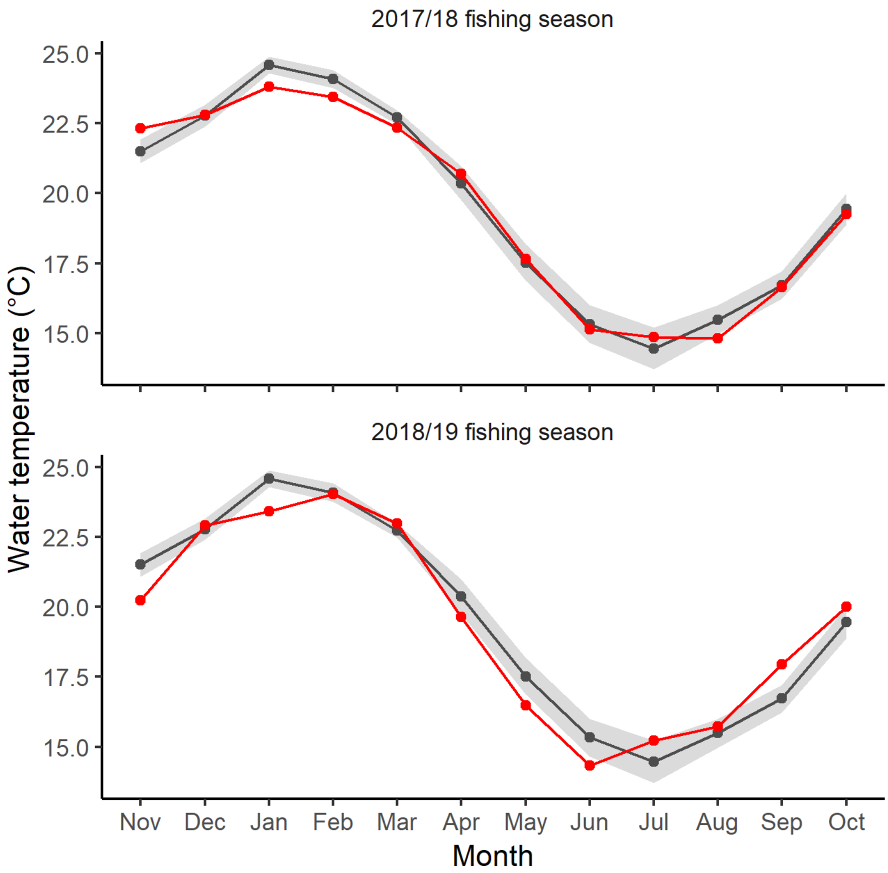

Figure A8.1 Monthly mean water temperatures recorded in the Peel-Harvey Estuary during the 2017/18 and 2018/19 fishing seasons (●) and the mean temperature (±SE; shading) each month across a ten-year period from 2007/08 to 2016/17 (●).

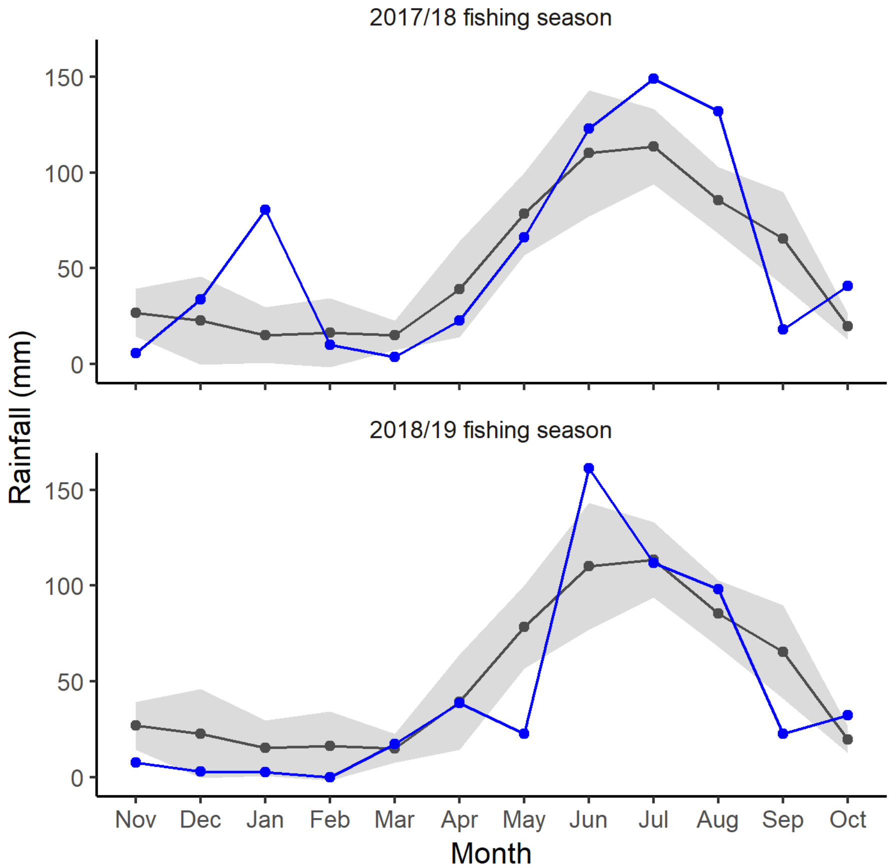

Figure A8.2 Monthly total rainfall recorded in the Peel-Harvey Estuary region (BoM Mandurah station; 009977) during the 2017/18 and 2018/19 fishing seasons (●), and the mean total monthly rainfall (±SE; shading) each month across a ten-year period from 2007/08 to 2016/17 (●). Rainfall data obtained from Bureau of Meteorology, 2019; www.bom.gov.au/climate/data.

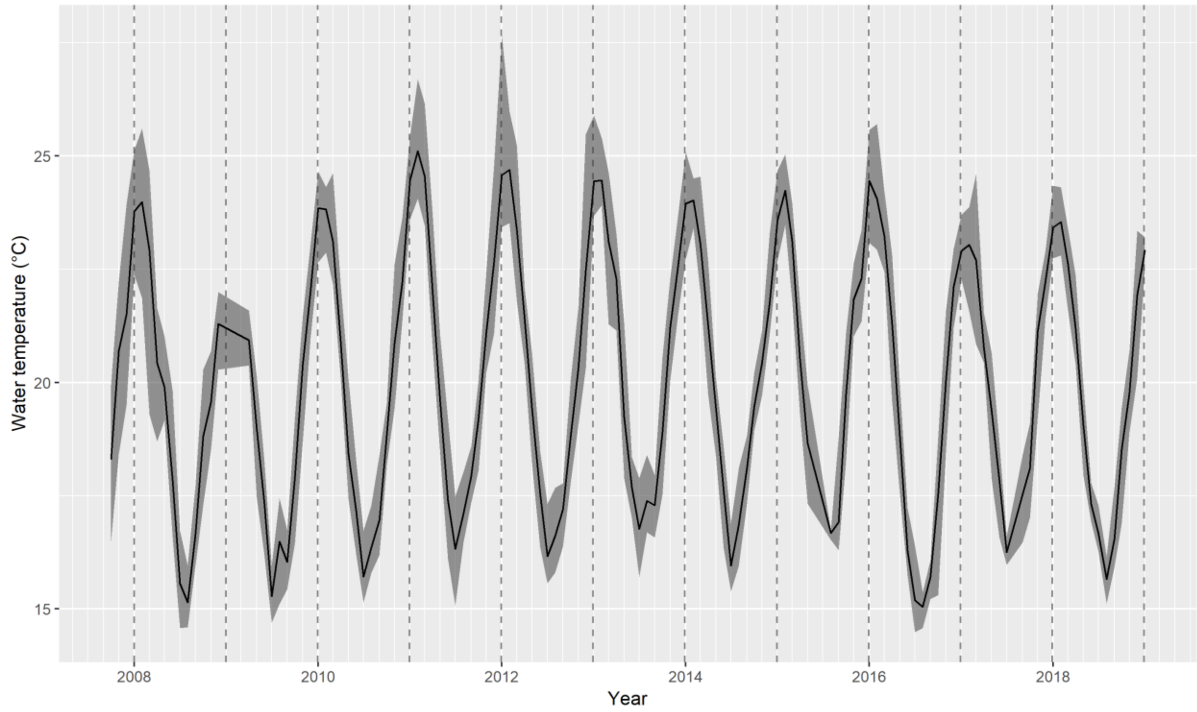

Figure A8.3 Monthly mean water temperatures recorded in Cockburn Sound from October 2007 to January 2019. Shading shows the minimum and maximum temperature recorded each month and minor axis breaks are at 2-month intervals. Data were recorded from *in situ* temperature loggers deployed at Mangles Bay (−32.271, 115.709) and Jervoise Bay (−32.189, 115.771).