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Blue Swimmer Crab (*Portunus armatus*) and Mud Crab (*Scylla serrata* and *Scylla olivacea*) Resources in the North Coast and Gascoyne Coast Bioregions, Western Australia

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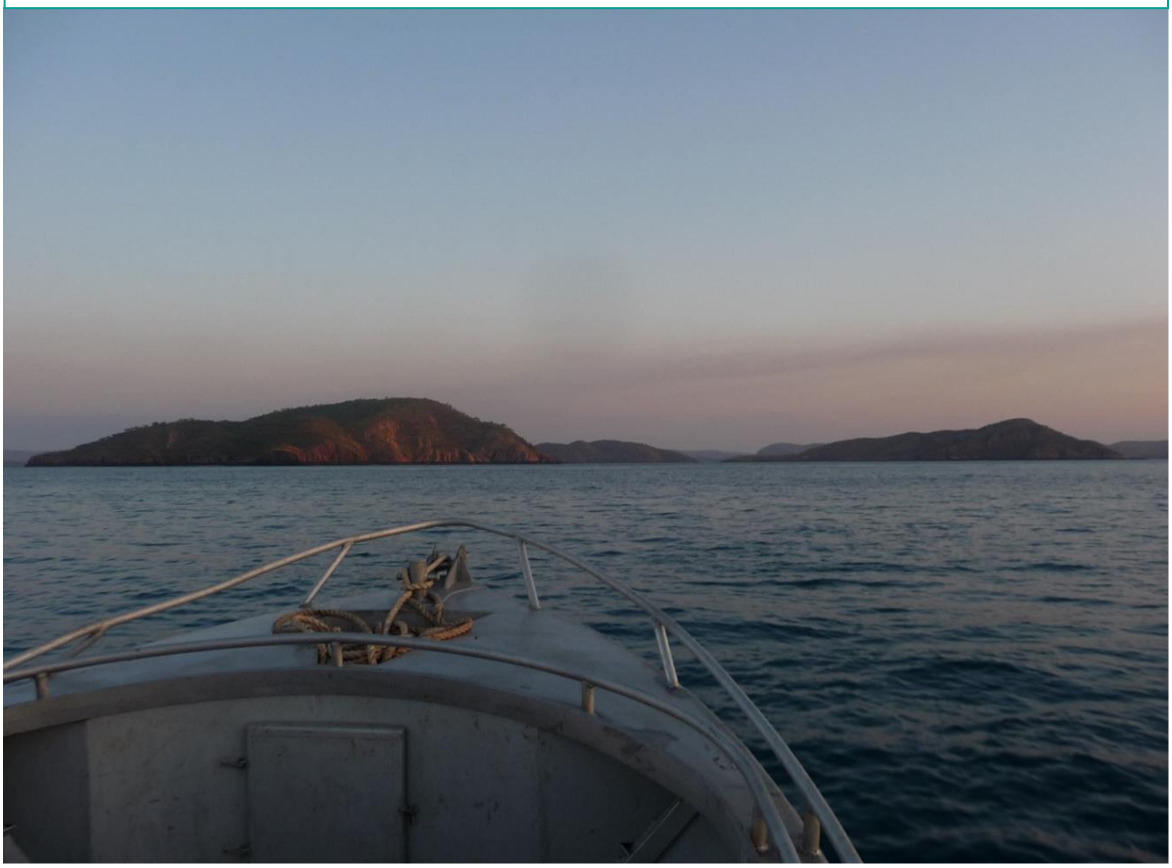
July 2020



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List of Abbreviations

ABCE	Aboriginal Bodies Corporate Exemption Holders
CW	Carapace width
DoF	Department of Fisheries, Western Australia
DPIRD	Department of Primary Industries and Regional Development, Western Australia
EBFM	Ecosystem-Based Fisheries Management
EGDCF	Exmouth Gulf Developing Crab Fishery
ESD	Ecologically Sustainable Development
EPBC	Environment Protection and Biodiversity Conservation (Act)
ETP	Endangered, threatened and protected species
FRDC	Fisheries Research and Development Corporation
FRMA	Fish Resources Management Act
GB	Gascoyne Bioregion
KCMF	Kimberley Crab Managed Fishery
KDMCF	Kimberley Developing Mud Crab Fishery
MSC	Marine Stewardship Council
NCB	North Coast Bioregion
NT	Northern Territory
PCMF	Pilbara Crab Managed Fishery
PDCF	Pilbara Developing Crab Fishery
RFBL	Recreational Fishing from Boat Licence
SAFS	Status of Australian Fish Stocks
SOI	Southern Oscillation Index
SST	Sea surface temperature
WA	Western Australia

Executive Summary

Blue Swimmer Crab

Blue swimmer crab (*Portunus armatus*) are found along the entire Western Australia (WA) coast, in a range of estuarine, inshore and continental shelf areas (<50 m). In the North Coast Bioregion (NCB), commercial fishing primarily occurs as part of the Pilbara Crab Managed Fishery (PCMF) which spans the inshore waters from Onslow through to Port Hedland, with most fishing activity taking place around Nickol Bay. The fishery was first developed in 2001 as the Pilbara Developing Crab Fishery (PDCF), with two exemption holders operating a maximum of 300 traps each. One exemption was extinguished in 2009, while the second was amended to allow for a maximum of 400 traps. This exemption was further updated in 2016 to a maximum of 600 traps, along with a seasonal closure between 15 August and 15 November to protect berried females and breeding stock. The developmental fishery transitioned to a managed fishery in 2018, with the sole licence holder currently operating two vessels. Purpose-designed hourglass traps are exclusively used in the PCMF, although prawn trawl fisheries in Onslow and Nickol Bay also retain blue swimmer crabs as by-product. Minor catches of blue swimmer crab are also taken from the Kimberley region of the North Coast (Broome to the WA/NT border) by fishers in the Kimberley Crab Managed Fishery (KCMF) which primarily targets mud crab (*Scylla* spp.; see below).

This report also contains details of commercial blue swimmer fishing activity further south in Exmouth Gulf, within the Gascoyne Coast Bioregion. Most blue swimmer crab catch in Exmouth Gulf comes as by-product from prawn trawl fisheries (up to 58 t annual catch), although dedicated trap fishing has occurred in some years since 1995. The Exmouth Gulf Developing Crab Fishery (EGDCF) operated from 2004 to 2007 and landed a total catch of 28 t during that period. The trap fishery ceased operations in 2008, before re-commencing in 2016. However, only minor catch was taken in 2016 (0.3 t) and no trap fishing has occurred since. The Exemption will be re-assessed in 2021.

Crabbing is also a very popular recreational fishing activity in WA, with blue swimmer crabs among the most important recreationally fished inshore species state-wide in terms of participation rate and numbers caught. The recreational sector primarily targets blue swimmer crabs in the north-west with drop nets or scoop nets. The 2017/18 Department of Primary Industry and Regional Development (DPIRD) survey (iSurvey) of recreational fishing in WA provided a boat-based catch estimate of 1.5 t (95% CI 1–2 t) of retained blue swimmer crabs for the NCB (approximately 2.6% of the state's recreational catch), and 5 t (95% CI 1–10 t) for the Gascoyne Bioregion (GB; 9% of the state catch) (Ryan *et al.*, 2019).

Management arrangements for the commercial and recreational fisheries include minimum size, protection of breeding females, and seasonal closures with effort controls for the commercial fishery.

The coral crab (*Charybdis ferriata*) and three spot sand crab (*P. sanguinolentus*) may also be retained as by-product in the KCMF, PCMF and EGDCF, as well as by recreational fishers.

Harvest Strategy, Monitoring and Assessment

Pilbara and Exmouth Gulf blue swimmer crab fisheries are monitored through compulsory catch and effort returns (both target and by-product species) as well as research logbooks. A commercial monitoring program was conducted between 2002 and 2008 in the PCMF to provide information on retained and discarded proportion of the stock.

The harvest strategy for the PCMF (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 (2005 to 2015, inclusive). Due to lack of catch, effort and catch rate data, a harvest strategy for EGDCF has not been developed.

Annual trap catches of blue swimmer crab from the PDCF/PCMF between 2001 and 2019 have ranged from 5.5 to 73.2 t, which is largely in line with changing effort. The 2019 catch was 19.3 t from 11,600 traplifts, within the harvest strategy catch tolerance range. This represents a decrease in total catch from 2018 to 2019 by approximately one third (10.9 t lower catch during 2019). The annual standardised catch rate for the PCMF during 2019 was 1.5 kg/traplift, which was above the harvest strategy threshold level and within the target range. On the basis of all lines of evidence, the crab stock in the PCMF is considered **sustainable**, and no changes to the management occurred for the 2020 season.

No commercial blue swimmer crab catch was reported from the EGDCF in 2019 with minimal by-product from the prawn trawl fishery in Exmouth Gulf. On the basis of this minimal catch and effort, the crab stock in the EGDCF is considered **sustainable.**

Mud Crab

Two species of mud crab, the green mud crab (*Scylla serrata*) and brown mud crab (*S. olivacea*), occur in WA. The green mud crab is predominantly found in estuarine habitats in north-western Australia from the Northern Territory (NT) border to Shark Bay, whilst the brown mud crab has a more restricted distribution limited to northern embayments, with most catches from King Sound, 200 km northwest of Broome.

The KCMF is a small fishery that targets green and brown mud crabs via the use of crab traps in coastal and estuarine waters along the Kimberley coast between Broome and Cambridge Gulf. The fishery extends from 120°E to the Northern Territory border, with fishing effort concentrated around Cambridge Gulf, Admiralty Gulf, York Sound and King Sound. There are currently three licenced commercial operators and three Aboriginal Bodies Corporate Exemption holders. In November 2018, the fishery transitioned from developing to fully managed. Fishers use either rigid rectangular or mesh round traps. Minor catch also occurs from gill net fisheries.

Recreational fishing for mud crabs in the Kimberley is focused around Cambridge Gulf, Admiralty Gulf, York Sound and King Sound, with many fishers using blunt wire hooks.

The KCMF is monitored through compulsory catch and effort returns (both target and by-product species) as well as research logbooks.

Harvest Strategy, Monitoring and Assessment

The harvest strategy for the KCMF (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 (2006 to 2015, inclusive).

Annual catch and effort ranges from 2013 to 2017 were 0.1–15.3 t and 1,644–27,020 traplifts, respectively. Total catches during 2018 and 2019, *i.e*. the first two years of operation as the KCMF, were 3.2 and 7.4 t, respectively (from 4,894 and 19,882 traplifts) and was within the harvest strategy catch tolerance range. The 2019 catch total was reported to contain 1.15 t of brown mud crabs (*S. olivacea*) and 6.27 t of green mud crabs (*S. serrata*), with 17 kg unreported. Very minor blue swimmer crab catch has also been taken from the Kimberly Developing Crab Managed Fishery (KDMCF)/KCMF, with 289 kg landed in 2015 and 56 kg landed in 2019.

The 2019 standardised catch rate of both species was 0.33 kg/traplift, which fell below the threshold of the harvest strategy, but was above the limit. Fluctuations in catch rate appear to be primarily driven by changes in effort and operators.

The 2017/18 DPIRD survey (iSurvey) of recreational fishing in WA provided a boat-based harvest estimate of 2.5 t (95% CI 2–3 t) of mud crabs for the NCB (Ryan *et al.*, 2019). This accounted for approximately 92% of the State’s recreational mud crab catch. The catch was estimated to comprise of 1.34 t of green mud crab and 1.17 t of brown mud crab.

Catch and effort has been limited to such a low level in recent years, and given the wide distribution of mud crabs throughout the Kimberley region, the stock is currently considered **sustainable**. Nevertheless, considering the proximity of the 2019 commercial catch rate to the limit reference level, catch, effort and catch rate is being monitored closely in this fishery during the 2020 season.

1. Scope

This document provides a description and assessment of the fishing activities affecting the blue swimmer crab (*Portunus armatus*) and mud crab (*Scylla spp.*) resource in the North Coast and Gascoyne Coast Bioregions of Western Australia (WA), which is currently focused on the Pilbara for blue swimmer crab and the Kimberley for mud crab. This document also incorporates information from the nearby developing blue swimmer crab fishery in Exmouth Gulf.

The commercial sector primarily captures crabs using purpose-designed traps (hourglass and ridged rectangular), and the recreational sector primarily use drop nets, scoop nets and blunt wire hooks.

The report contains information relevant to assist the assessment of the resource against Environment Protection and Biodiversity Conservation (EPBC) Act export approval requirements 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).

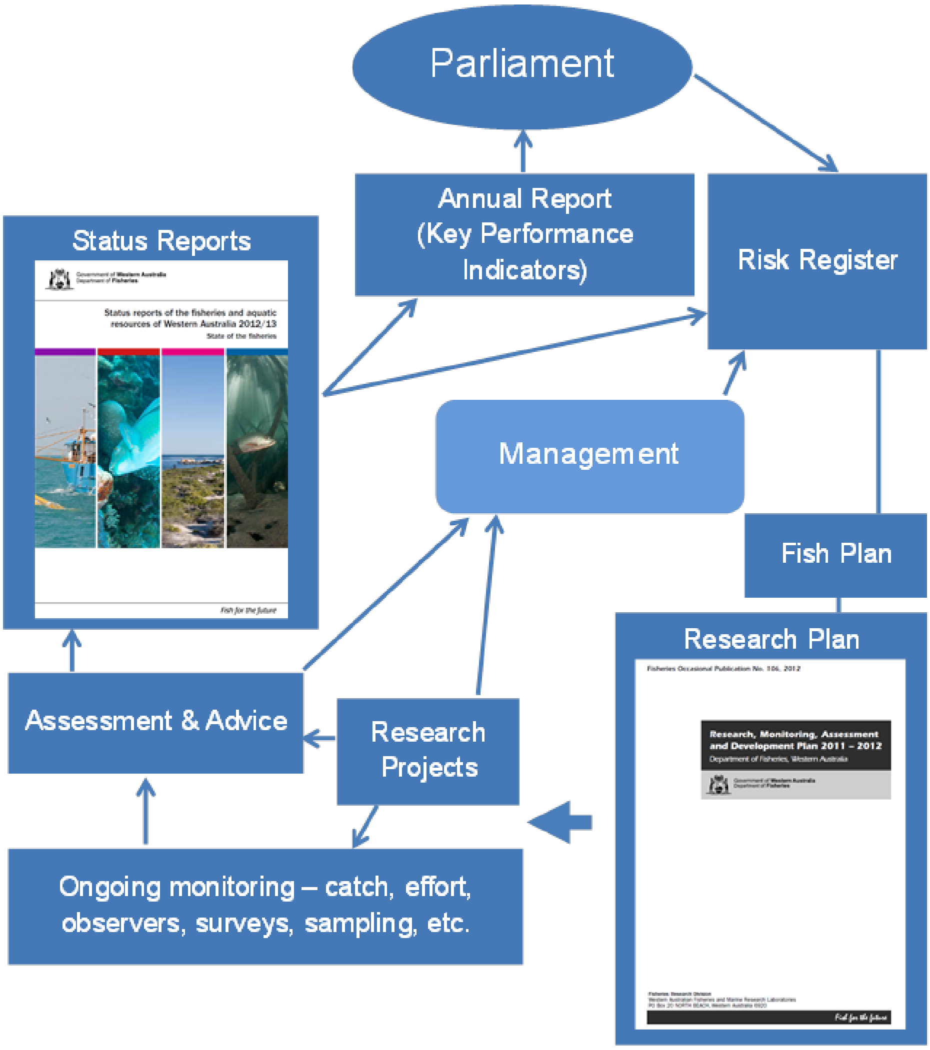


Figure 2.1. An outline of the risk-based planning cycle used for determining Departmental priorities and activities

3. Aquatic Environment

Western Australia's expansive coastline covers numerous climatic zones, from cool-temperate areas in the south through to warm tropical environments in the north. An Ecosystem-Based Fisheries Management (EBFM) approach classifies areas of the states as 'Bioregions' based upon oceanographically and climate/rainfall characteristics. Four bioregions are defined for WA's marine and coastal environments; the North Coast, Gascoyne Coast, West Coast and South Coast (Figure 3.1). Blue swimmer crabs are distributed along the entire WA coastline, however, this report focuses on fisheries in the North and Gascoyne Coast Bioregions. Commercial and recreational mud crab fishing is almost exclusively focused in the North Coast Bioregion (NCB), with only very minor catch from the Gascoyne and West Coast Bioregions.

3.1 North Coast Bioregion

The NCB extends westwards from the WA/NT border to just south of Onslow (114°50'E, 21°46'S; Figure 3.1). The region has a tropical climate and receives the majority of its annual rainfall during summer. Coastal waters typically subject to low wave energy but are seasonally influenced by tropical cyclones and severe storm activity. Marine waters are influenced by the Indonesian Throughflow and Holloway Currents which flow polewards from the Indonesian archipelago. Sea surface temperatures range 22 to 33°C. The region is macro-tidal, with tidal ranges of *c.* 2 metres in southern areas of the Pilbara to over 11 metres in the Kimberley. Consequently, the nearshore coastal waters of the Kimberley are generally turbid due to high rates of water flow. Key aquatic habitats include intertidal mudflats, mangroves and coral reef systems.

In the NCB, commercial fishing for blue swimmer crab occurs as part of the Pilbara Crab Managed Fishery (PCMF) which spans the inshore waters from Onslow through to Port Hedland, with most commercial activity taking place around Nickol Bay (Figure 3.1). The Kimberly Crab Managed Fishery (KCMF) is a small fishery that targets mud crabs via the use of crab traps in coastal and estuarine waters along the Kimberley coast between Broome and Cambridge Gulf (Figure 3.1). The fishery extends from 123° 15' E to the Northern Territory border, with fishing effort concentrated around Cambridge Gulf, Admiralty Gulf, York Sound and King Sound.

3.2 Gascoyne Coast Bioregion

The Gascoyne Bioregion (GB) is a transitionary marine environment between tropical waters of the NCB and cooler temperate waters of the West Coast Bioregion. The bioregion extends from just south of Onslow to 27°S latitude, and encompasses Exmouth, Carnarvon and Denham/Shark Bay (Figure 3.1). Sea temperatures typically range from 22 to 28°C, but in shallow embayments such as Shark Bay, may fall to as low as 15°C during winter. Summer tropical cyclones occur in the northern part of the bioregion (Exmouth region) but are infrequent in southern areas. Rainfall is limited in the bioregion and comes mostly during winter storm fronts. Key aquatic habitats include expansive seagrass beds (e.g. Shark Bay) and coral reef (e.g. Ningaloo Reef). Aquatic biota reflect the transitional marine environment and represent a mix of fully tropical and temperate species.

A developing blue swimmer crab fishery, the Exmouth Gulf Developing Crab Fishery (EGDCF) has commenced in Exmouth Gulf. A productive commercial blue swimmer crab fishery also operates within Shark Bay and the resource is reported in a separate Resource Assessment Report.

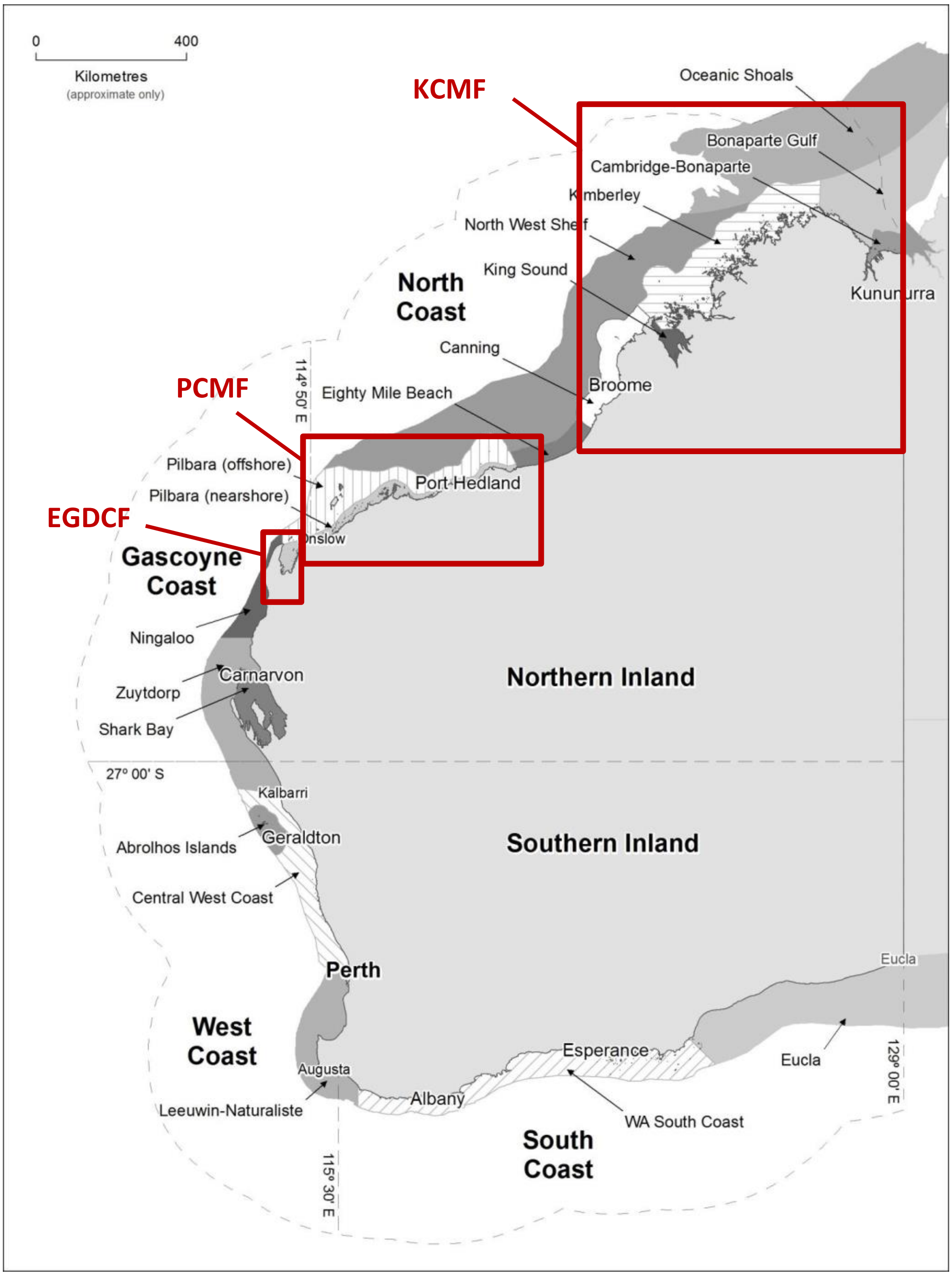


Figure 3.1. Aquatic bioregions of Western Australia and localities of the Pilbara Crab Managed Fishery (PCMF) and Kimberley Crab Managed Fishery (KCMF) within the North Coast Bioregion of WA, and the Exmouth Gulf Developing Crab Fishery (EGDCF) within the Gascoyne Bioregion of WA.

4. Resource Description

4.1 Pilbara and Exmouth Gulf Blue Swimmer Crab Resource

The blue swimmer crab (*Portunus armatus*) is targeted by commercial fishers using dedicated hourglass traps by the Pilbara Crab Managed Fishery (PCMF) along the Pilbara coast, and within the waters of Exmouth Gulf by the Exmouth Gulf Developing Crab Fishery (EGDCF). The blue swimmer crab inhabits sandy benthic habitats and is most abundant in shallow (≤ 20 m in depth) nearshore and estuarine ecosystems, but can be found in depths up to 50 m. Consequently, fishing in the PCMF and EGDCF is generally focused in inshore and estuarine areas <20 m depth. The PCMF extends from the high water mark to the 200 m isobath between longitudes 115° 5' 60" E and 120° E (approximately Onslow to Port Hedland; see section 6.1.3 for detailed boundaries of the fishery), with the majority of catch taken historically from the Nickol Bay region. The boundaries of the EGDCF mirror those of the Exmouth Gulf Prawn Managed Fishery, covering the waters of Exmouth Gulf inside a line drawn north east from Point Murat to the Muiron Islands, east north east to Serrurier Island, south south east to Locker Island and then south to the mainland (see section 6.1.3 for further details).

The single commercial fishers operating in the PCMF and EGDCF are also authorised to retain the coral crab (*Charybdis ferriata*) and three spot sand crab (*Portunus sanguinolentus*) as by-product, which reside in similar habitats to *P. armatus*. However, catches of these by-product species to date have been negligible.

It is likely that stocks of blue swimmer crabs along the Pilbara coast in Port Hedland, Nickol Bay and Onslow, as well as in Exmouth Gulf, are genetically homogenous with potential for mixing via coastal currents. Stocks of blue swimmer crabs in Exmouth Gulf are considered to be genetically distinct from stocks further south along the WA coast such as Shark Bay (Chaplin *et al.*, 2001).

Portunus armatus is a short-lived, fast growing species with a high fecundity and potential for wide dispersal and distribution of recruits. Historical commercial fishing suggests that there are commercially viable stocks of blue swimmer crabs along much of the coastline between Exmouth Gulf and Port Hedland. However, many of these areas are a substantial distance from the nearest port which makes them economically unviable to fish while there is a need to get fresh catch to market within a day or two of being caught. Furthermore, the harsh climatic conditions experienced in the region over the summer months means fishing is normally restricted to between March and November each year.

The reproductive biology and life cycle of blue swimmer crabs along the Pilbara coast and in Exmouth Gulf are likely to be similar to that in Shark Bay (*c.* 400 km south), with spawning occurring year round and growth being rapid (Harris *et al.*, 2014). Sexual maturity is reached at 10-12 months of age at about 110 mm carapace width (CW) for females and 105 mm CW for males (Chandravapan *et al.*, 2017), with both sexes attaining commercial size (135 mm CW) within 15 months (Figure 5.3). Given the species' biological traits, the highly selective hourglass traps used by commercial fishers (which target legal size and minimise by-catch and the retention of undersize crabs), and the apparent low levels of fishing pressure currently experienced in both fisheries, the risk and vulnerability to fishing of *P. armatus* in the PCMF and EGDCF is currently considered to be low. Should there be a substantial increase in commercial catch and effort in either fishery, this evaluation will be reviewed.

4.2 Kimberley Mud Crab Resource

Four species of mud crab (*Scylla* spp.) have been identified in the Indo-West Pacific region, of which the green mud crab (*Scylla serrata*) and brown mud crab (*S. olivacea*) occur in Western Australia (Keenan *et al.*, 1998). The stock structure of the mud crab population in the Kimberley has not been documented. It is unknown whether there is significant larval flow between embayments to warrant the assumption of one single stock of *S. serrata* and *S. olivacea* throughout the Kimberley. The maximum size reported for green mud crabs is between 250–280 mm carapace width (CW) and 135–139 mm CW for brown mud crabs. The green mud crab, is predominantly found in estuarine habitats in north-western Australia from the Northern Territory border to Shark Bay, but has also been found as far south as Wilson Inlet near Denmark (*c.* 400 km south of Perth) in years of strong southern coastal Leeuwin Current flow. The brown mud crab has a more restricted distribution limited to northern embayments, with most catches from King Sound, 200 km northwest of Broome.

The minimum legal size at first capture is 150 mm CW for green mud crab (*S. serrata*) and 120 mm CW for brown mud crab (*S. olivacea*). This is set well above the size at first maturity of 90–120mm CW for green and 86–96 mm CW for brown mud crab fisheries in the North Coast Bioregion (NCB; Knuckey, 1999). While there is no information on the size of functional maturity for WA mud crab stocks, it is assumed that the setting of the minimum legal size sufficiently above size at maturity would allow females to spawn at least once before reaching legal size. Consequently, breeding stock levels are expected to be adequate to maintain stocks in all current fishing areas under normal environmental conditions and at currently low levels of effort.

S. serrata and *S. olivacea* are short-lived fast-growing species with a high fecundity and potential for wide dispersal and distribution of recruits. Historical commercial fishing suggests that there is the potential for commercially viable stocks of mud crabs in suitable habitat along much of the Kimberley coastline. However, most of these areas are a substantial distance from the nearest port which makes them economically unviable to fish while there is a need to get fresh crabs to market within a day or two of being caught. Furthermore, the harsh climatic conditions experienced in the region over the summer months means fishing is normally restricted to between March and November each year. Given these biological traits, combined with the highly selective hourglass and rectangular traps used by commercial fishers (which target legal size and minimise by-catch and the retention of undersize crabs) and the relatively low levels of fishing pressure currently experienced in the fishery, the risk and inherent vulnerability to fishing of *S. serrata* and *S. olivacea* in the Kimberly Crab Managed Fishery (KCMF) is currently considered to be low.

5. Species Description

5.1 Blue swimmer crab (Portunus armatus)

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

5.1.1 Taxonomy and Distribution

The blue swimmer crab *Portunus armatus* (Figure 5.1) is a member of the family Portunidae. The scientific name was formerly *P. pelagicus* (Linnaeus, 1758; A. Milne Edwards, 1861) with reclassification occurring in 2010 (Lai *et al.*, 2010).

Blue swimmer crabs 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 is found along the entire WA coast, around the north of Australia to the south coast of New South Wales, and in the warmer waters of the South Australian gulfs (Figure 5.2). Blue swimmer crabs inhabit a wide range of inshore and continental shelf ecosystems, from the intertidal zone to at least 50 m in depth (Kangas, 2000). However, they are most abundant in sandy, muddy or algal and seagrass benthic habitats of shallow (≤ 20 m in depth) nearshore and estuarine ecosystems.

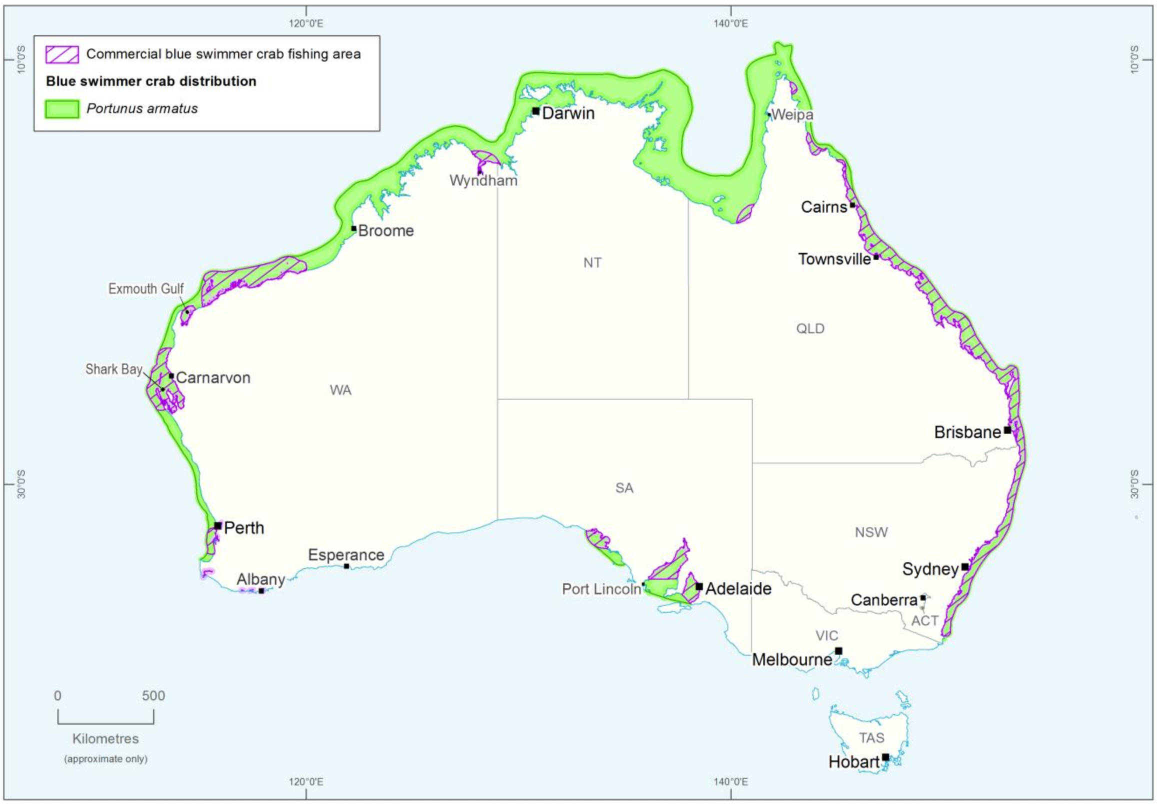


Figure 5.2. Geographic distribution (green) and commercial fishing areas (purple stripes) of the blue swimmer crab, *Portunus armatus,* in Australian waters. Note: geographic distribution information is based on areas that are assumed to be permanent, self-recruiting populations. Commercial fishing data indicated on the maps is based on current commercial fishing zones and/or commercial fishing data from Fisheries Research and Development Corporation (FRDC; Johnston *et al.,* 2016).

5.1.2 Stock Structure

In Western Australia, the Blue Swimmer Crab is fished in numerous fisheries across five regions. Assessment of stock status for Western Australia is presented at the management unit level — Shark Bay, Cockburn Sound, Peel-Harvey Estuary, WA north coast and WA south-west coast (Johnston *et al.,* 2016).

The blue swimmer crab comprises multiple management units in northern WA, which correspond to the management areas of the commercial fisheries outlined in Section 0. Therefore, the management unit employed is at the level of the fishery.

Chaplin *et al.*, (2001) reported that assemblages of blue swimmer crabs throughout WA become increasingly genetically differentiated as the geographic distance between the assemblages increase. Sezmiş (2004) further hypothesised that there were overlapping crab stocks, gene flow via larval dispersal or crab migration was largely controlled by the degree of water exchange between biogeographic regions. Along the WA coastline, crab stocks become more distinct as one moves from north to south of the State, with those in the south-west (Cockburn Sound, Warnbro Sound, Swan River, Peel-Harvey Estuary and Geographe

Bay) forming a homogenous but highly distinctive group separate to those stocks in Shark Bay and Exmouth Gulf (Chaplin *et al.*, 2001; Chaplin and Sezmiş, 2008; Sezmiş 2004).

Furthermore, stocks of blue swimmer crabs in Exmouth Gulf are considered to be genetically distinct from populations *c.* 400 km south in Shark Bay (Chaplin *et al.*, 2001). Although the genetic connectivity of *P. armatus* along the Pilbara coastline has not been assessed, it is likely that stocks in Port Hedland, Nickol Bay and Onslow are genetically similar with potential for mixing based on larval dispersal along the coast and the relatively small distances between areas (~ 200 km).

5.1.3 Life History

The sub-sections below provide an overview of the life history characteristics of blue swimmer crab stocks along the Pilbara coast and in Exmouth Gulf, with a summary of the relevant biological parameters used in stock assessments presented in Table 5.1.

A substantial amount of information exists on the biology of blue swimmer crabs in sub-tropical and temperate waters of WA. This includes studies in the marine waters of Shark Bay (Bellchambers and Smith, 2005; Chandrapavan *et al.*, 2017; Harris *et al.*, 2012; Harris *et al*; 2014), Cockburn Sound (Bellchambers *et al.*, 2005; de Lestang *et al.*, 2003a; 2010; Johnston *et al.*, 2011a; 2011b; Penn, 1977), Koombana Bay (de Lestang *et al.*, 2003a) and Geographe Bay (Bellchambers *et al.*, 2006; Harris *et al.*, 2017; Sumner and Malseed, 2004), as well as in the Leschenault and Peel-Harvey Estuaries (de Lestang *et al.*, 2003b; Harris *et al.*, 2017; Johnston *et al.*, 2014; Meagher, 1971; Potter and de Lestang, 2000; Potter *et al.*, 1983; 1998).

Comparatively, our understanding of blue swimmer crab biology in the Pilbara region and Exmouth Gulf is limited. This report therefore utilises the life history parameters developed for crab stocks in Shark Bay, approximately 400–600 km south of the fisheries in Exmouth Gulf and Nickol Bay.

Table 5.1. Summary of biological parameters for the blue swimmer crab Portunus armatus in Shark Bay, Western Australia (Chandravapan *et al.,* 2017), as an estimate of parameters for P. armatus along the Pilbara coast and in Exmouth Gulf. Natural mortality parameters for P. segnis in The Persian Gulf and Gulf of Oman, Iran (Safaie *et al.,* 2013) and P. pelagicus in Pakistani waters (Afzaal *et al.,* 2016) as no data is available for P. armatus in Australian waters.

Parameter	Value(s)	Comments / Source(s)
Growth parameters	Seasonal growth curve: $$L_j = L_\infty\left\{1 - exp\left[-k\left(t_j - t_0 + \frac{C}{2\pi}\left[S(t_j) - S(t_0)\right]\right)\right]\right\}$$	
L_∞ (mm)	Females 125.3, Males 131.3	Chandravapan *et al.,* (2017)
k (year^{-1})	Females 1.73, Males 1.79	"
t_0 (years)	Females 0.00, Males 0.00	"
C	Females 0.98, Males 1.00	"
t_c	Females 1.11, Males 0.06	"
Maximum age (years)	3	Johnston *et al.,* (2016)
Maximum size (mm)	220	
Natural mortality, M (year^{-1})	*P. armatus* – Western Australia	
	1.37 – 1.44	Hesp (unpublished)
	P. segnis – Persian Gulf:	
	Females 1.42, Males 1.47	Safaie *et al.,* (2013)
	P.pelagicus – Pakistan:	
	1.684	Afzaal *et al.,* (2016)
Length-weight parameters		$\ln(W) = a + b \ln(CW)$
a	Females -10.0843, Males -9.27173	de Lestang *et al.,* (2003)
b	Females 3.12018, Males 2.96434	"
Reproduction	Gonochoristic, external fertilisation and highly fecund	
Maturity parameters		Logistic regression
L_{50} (mm)	Females 98.8 (97.3-100.2)	Johnston *et al.,* (*in prep.*)
	Females 110, Males 105	Chandravapan *et al.,* (2017)
L_{95} (mm)	Females 124, Males 122	
Fecundity (eggs)	$\ln(BF) = 3.11 \ln(CW) - 8.37$ $r^2 = 0.91$	Johnston *et al.,* (*in prep.*)
Size-fecundity parameters		$\ln(BF) = a(\ln CW) + b$
a	3.11	Johnston *et al.,* (*in prep.*)
b	8.37	"
Spawning frequency	Multiple spawners during the spawning season, spawn every 30-60 days	Large females can produce up to 3 batches of eggs during one spawning season from a single mating event. Kangas (2000); de Lestang (2003a); Chandravapan *et al.,* (2017)

5.1.3.1 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 (de Lestang *et al.,* 2010; Kangas, 2000). In comparison, the warmer, tropical waters of Shark Bay induce spawning all year round, with a peak between July and September (Chandrapavan *et al.,* 2017; de Lestang *et al.,* 2003a; Harris *et al.,* 2012). See Section 5.1.3.5 for details on fertilisation and spawning.

The specific life history of blue swimmer crabs along the Pilbara coast and in Exmouth Gulf has yet to be determined, however, is assumed to be similar to that of populations slightly further south in Shark Bay.

A preliminary life cycle for the blue swimmer crab in Shark Bay is presented in Figure 5.3 based on analysis of data collected from commercial monitoring and fishery-independent research programs, and factory unload returns from commercial trap fishers (Harris *et al.,* 2014). Although the life cycle presented is based on the peak periods of biological activity in the Shark Bay crab stock, moulting, mating and spawning occur continuously. Consequently, this life cycle is intended to represent the majority of animals in the crab stock. This life cycle is consistent with more recent research conducted by Chandrapavan *et al.* (2017).

The peak spawning period in Shark Bay occurs from July to September. With these cooler winter months characterised by low winds and generally more stable atmospheric conditions in the Bay, which likely favour larval retention (Kangas *et al.*, 2012). 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 megalopae (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* usually 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). Induced by the warming sub-tropical waters, blue swimmer crabs moult frequently during the juvenile phase in Shark Bay and growth is rapid, with juveniles being caught in the fishery from November to February at about 6 months.

Female crabs undergo a pubertal moult in Shark Bay at around 6 – 10 months of age, with the peak mating period considered to be between March and May. Mature males moult some weeks before the maturing females, and each male carries a female clasped beneath him for

4 – 10 days until she moults and mating occurs. The mean size at maturity for blue swimmer crabs in Shark Bay is 105 mm carapace width (CW) for males and 92.4 mm CW for females (de Lestang *et al.*, 2003a). More recent analysis has determined a higher size at maturity for both males at 110 mm CW and females at 105 mm CW (Chandrapavan *et al.*, 2017).

Mature male and female crabs attain commercial size (135 mm CW) in Shark Bay between 10 – 14 months of age, with the commercial size limit set sufficiently above the mean size at maturity allowing females to spawn at least once before being available for capture.

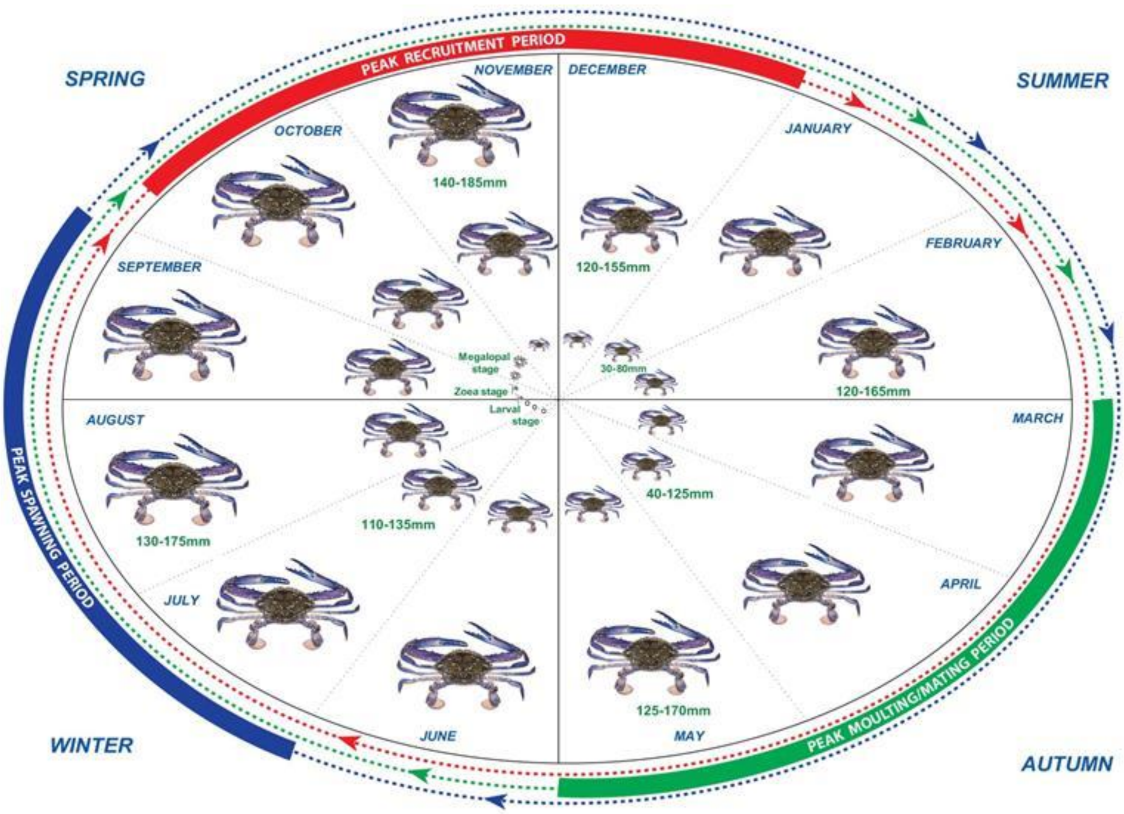


Figure 5.3. Diagram of the generalised life-cycle of blue swimmer crabs in Shark Bay (Harris *et al.,* 2014). It is assumed that this bears similarity to the life cycle of blue swimmer crabs in Exmouth Gulf and along the Pilbara Coast, for which exact details are not known.

5.1.3.2 Habitats and Movements

Blue swimmer crabs live in a wide range of inshore and continental shelf habitats, including sandy, muddy or algal and seagrass habitats, from the intertidal zone to waters of at least 50 m in depth (Edgar, 1990; Williams, 1982). 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.

Blue swimmer crab movement can be influenced by changes in temperature and salinity, often taking place in late autumn to winter from shallower to deeper waters (Aguilar *et al.*, 2008; Kangas, 2000; Potter and de Lestang, 2000). In estuaries such as the Peel-Harvey on the lower-west coast of WA, movements of crabs are also influenced by the inflow of fresh water following the onset of winter rains (Potter *et al.*, 1998). A marked decrease in water temperature and salinity over winter and spring results in crabs migrating from the upper/middle reaches of estuaries to their lower reaches or the ocean (Johnston *et al.*, 2014). 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, improved food source and increased larval distribution (Meagher, 1971; Smith, 1982). On the lower-west coast, most sub-legal crabs (i.e. <127–135 mm CW) re-enter estuaries and rivers at the end of spring and throughout summer, with males re-entering between November and January and females re-entering between January and March (Johnston *et al.*, 2014). Some legal (1+ class) crabs 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 populations in the embayments of Nickol Bay and Exmouth Gulf are likely to be self-recruiting with comparatively little immigration into, or emigration out of, the fisheries from neighbouring bodies of water. There is, however, some evidence that very high rainfall events associated with cyclone activity (usually during summer) can have a substantial effect on the inshore aquatic environment (e.g. increased turbidity, decreased salinity; Pearce *et al.*, 2003; Pinder *et al.*, 2010), which may cause crabs to migrate away from shallow inshore areas to deeper waters where conditions remain more stable.

5.1.3.3 Age and Growth

While most blue swimmer crabs will have died through natural or fishing mortality by the time they are 20 months (Potter *et al.*, 2001), some individuals in the Pilbara region and Exmouth Gulf not subjected to heavy fishing pressure may live for three to four years.

As Shark Bay is the closest crab stock to Nickol Bay and Exmouth Gulf, growth parameters estimated for Shark Bay crab stocks from data collected during trawl surveys between 2012-15 by Chandravapan *et al.* (2017) are presented (Table 5.1). Length-weight data for blue swimmer crabs in Shark Bay are presented from the study of de Lestang *et al.* (2003a) who analysed bi-monthly data collected between July 1998 and May 2000.

Growth

The growth of blue swimmer crabs in Shark Bay has been described using the seasonal growth curve of Somers (1988). From this equation, the expected length of the j^{th} crab L_j, is:

$$L_j = L_\infty \left\{1 - exp\left[-k\left(t_j - t_0 + \frac{C}{2\pi}\left[S(t_j) - S(t_0)\right]\right)\right]\right\}$$

where $\boldsymbol{t_j}$ is the age of the $\boldsymbol{j^{th}}$ crab, $\boldsymbol{L_\infty}$ is the asymptotic length (mm), $\boldsymbol{k}$ is the von Bertalanffy growth coefficient and $\boldsymbol{t_0}$ is the age of the crab with a length of zero. In Somer's model, $\boldsymbol{S(t_j) = sin[2\pi(t_j - t_c)]}$ and $\boldsymbol{S(t_0) = sin[2\pi(t_0 - t_c)]}$, where $\boldsymbol{C}$ is the seasonality amplitude parameter (which is constrained in the model to be between 0 and 1) and $\boldsymbol{t_c}$ is a parameter that determines the time of year at which growth is at a maximum or minimum, i.e. it acts to shift the growth curve to the left or right to align with the actual seasonal pattern of growth.

Growth rates for male and female blue swimmer crabs in Shark Bay are comparable (Chandrapavan *et al.,* 2017). Similarities in length frequency plots for the two sexes from seasonal data collected in Shark Bay between 2012-15 (Figure 5.4, Figure 5.5) parallel the estimated seasonal growth curves for females and males (Figure 5.6). However, the limitations of this analysis should be noted as only four months of the year were sampled.

The larval phase of spawned blue swimmer crabs extends for up to six weeks, followed by three to five month juvenile phase marked by rapid growth (Kangas, 2000). Assuming a July birth date (the start of the peak spawning period in Shark Bay), the mean lengths of 0+ and 1+ cohorts in November according to the growth model were 73 mm CW (4 months old) and 122 mm CW (16 months old), respectively, for males, and 70 mm CW (5 months old) and 115 mm CW (16 months old) respectively, for females (Figure 5.6). By February, the mean length of the 0+ and 1+ cohort had increased to 88 and 124 mm CW (i.e. 8 and 20 months), respectively for females and 87 and 119 mm, respectively for males (Chandrapavan *et al.,* 2017).

The seasonal pattern of growth of blue swimmer crabs in the subtropical environment of Shark Bay, at least in recent times, differs markedly from those in more temperate environments, as growth rates of crabs are at their maximum when temperatures are at their minima (Chandrapavan *et al.,* 2017). Conversely, in temperate environments such as in Cockburn Sound and the Peel-Harvey and Leschenault estuaries, growth is greatest during the warmer summer months (de Lestang *et al.,* 2003b). Blue swimmer crab growth in Shark Bay appears to peak around December, but then is minimal in the warmest months of the year, and again the reverse is true for this species in temperate environments. Despite this marked difference in the time of year when growth rate peaks, growth is greatest in Shark Bay at water temperatures of ~21–22ºC in winter, which is about the same as that for Cockburn Sound in December (Johnston *et al.,* 2011a) This suggests that there may be an underlying optimal temperature range for growth for *P. armatus* of around 22ºC (Chandrapavan *et al.,* 2017).

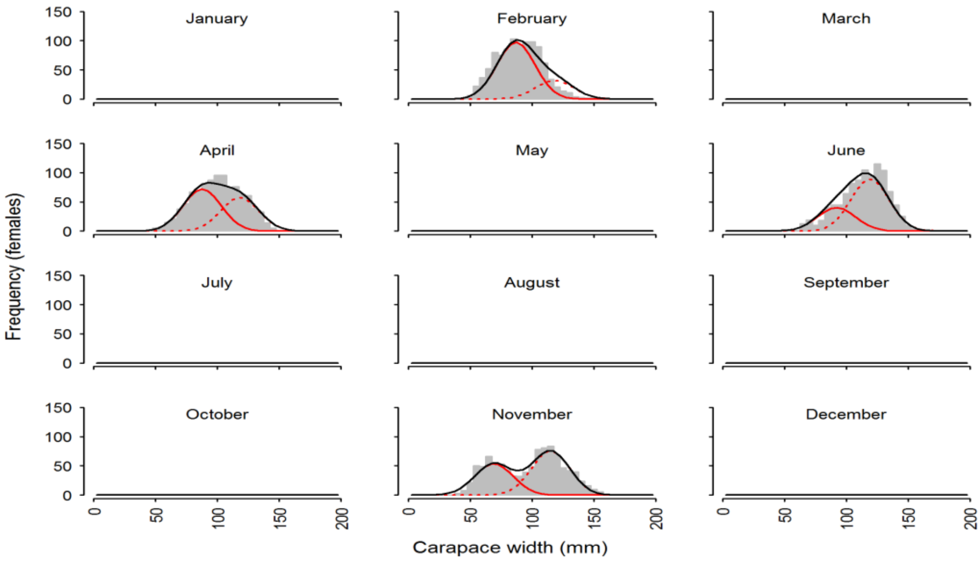


Figure 5.4. Observed monthly length-frequency distributions for female blue swimmer crabs in Shark Bay (grey bars) based on trawling surveys. The expected monthly distributions for 0+ (solid red lines) and 1+ year old (dotted red lines) females are derived by fitting a seasonal growth curve to the observed length-frequency data. The overall fits of the model to the monthly distributions (i.e. combined expected distributions for the two cohorts are also shown (black lines) (Chandrapavan *et al.*, 2017).

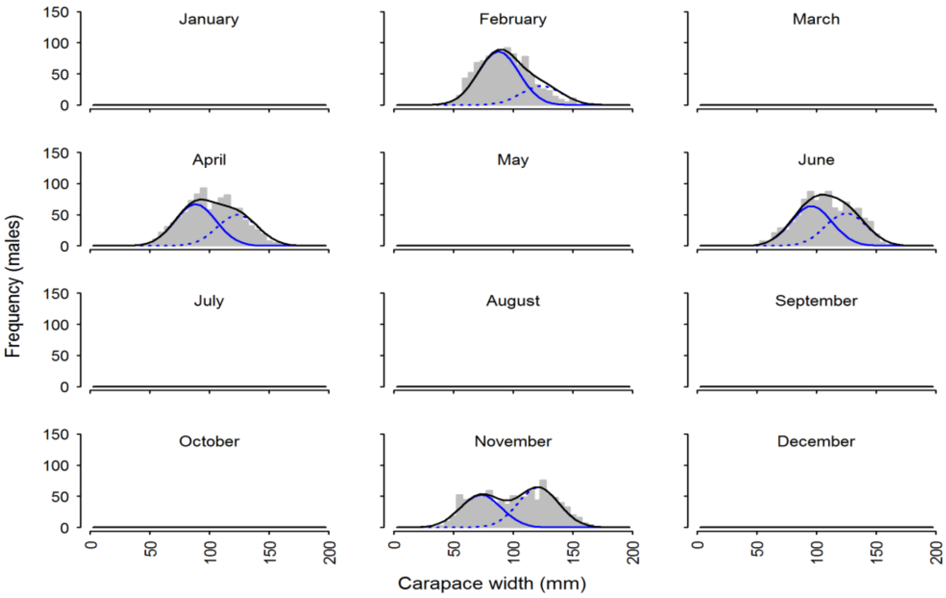


Figure 5.5. Observed monthly length-frequency distributions for male blue swimmer crabs in Shark Bay (grey bars) based on trawling surveys. The expected monthly distributions for 0+ (solid blue lines) and 1+ year old (dotted blue lines) males are derived by fitting a seasonal growth curve to the observed length-frequency data. The overall fits of the model to the monthly distributions (i.e. combined expected distributions for the two cohorts are also shown (black lines) (Chandrapavan *et al.*, 2017).

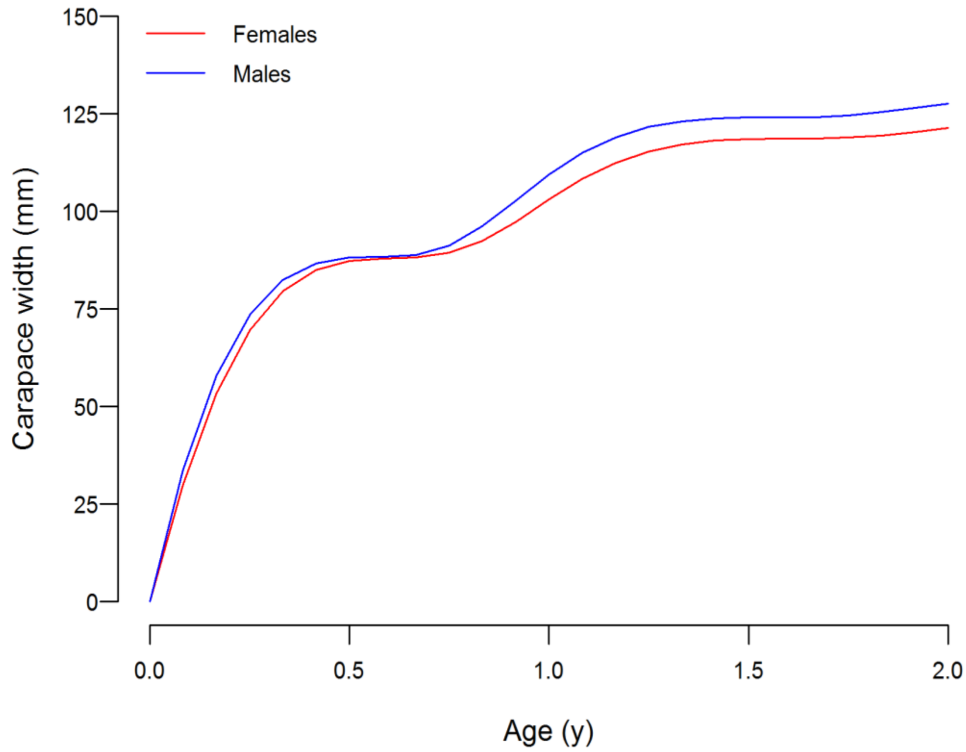


Figure 5.6. Seasonal growth curves for female and male blue swimmer crabs in Shark Bay (Chandrapavan *et al.*, 2017).

Weight-length relationship

The linear regressions describing the relationships between the natural logarithms of weights (W) in g and CW in mm for the two sexes of blue swimmer crabs in Shark Bay were significantly different (ANCOVA, $p < 0.001$) (de Lestang *et al.*, 2003a). Thus, separate regressions are presented below for each sex (Figure 5.7). The equations are:

Females: $\ln(W) = 3.12018 \times \ln(CW) - 10.08043$ ($n = 148$, mean square = 0.01843)

Males: $\ln(W) = 2.96434 \times \ln(CW) - 9.27173$ ($n = 268$, mean square = 0.01357)

where n is the sample size, and ln is the natural logarithm.

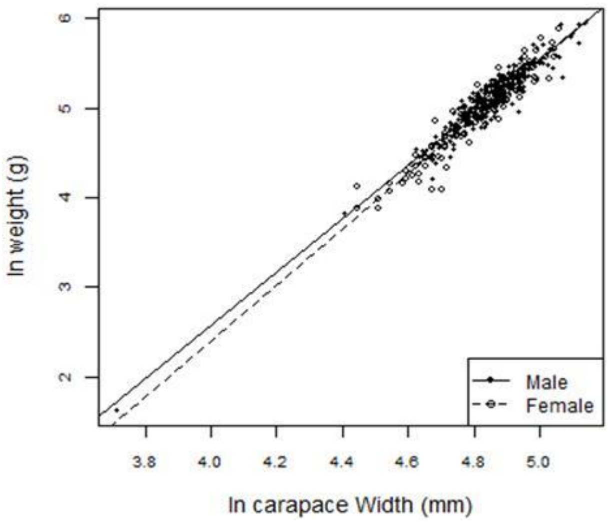


Figure 5.7 Linear relationships fitted to the natural logarithms of weight (g) vs the natural logarithms of carapace width (mm) for male (solid line, closed circles) and female (dashed line, open circles) blue swimmer crabs in Shark Bay (de Lestang *et al.,* 2003a).

Weights of crabs, of a specified sex and carapace width, may be estimated using one of the above equations (i.e. for that sex), back log-transforming the estimated values of ln(W) and correcting for bias using a multiplicative factor given by $e^{(\Delta^2/2)}$, where Δ is the standard error of the uncorrected estimates (Beauchamp and Olson, 1973). The resultant estimates of weight for each crab in the sample are shown below (Figure 5.8).

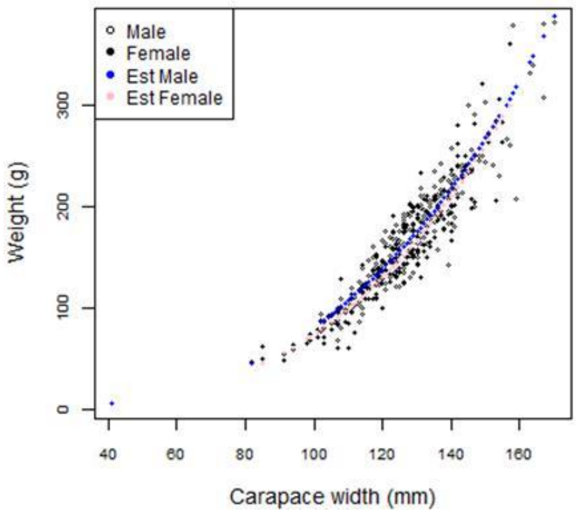


Figure 5.8. Weights (g) and carapace widths (mm) of male (open circles) and female (closed, black circles) blue swimmer crabs in Shark Bay and expected weights at each carapace width for male (blue circles) and female (pink circles) blue swimmer crabs (de Lestang *et al.,* 2003a).

These sex-specific weight-length relationships for blue swimmer crabs in Shark Bay differed significantly from those of the corresponding sex in Cockburn Sound on the lower west coast (employing data collected by de Lestang *et al.,* 2003a). Thus, crabs in Shark Bay were lighter at any given length (carapace width) than in Cockburn Sound. Possible reasons for this disparity include:

- The higher frequency of moulting that occurs in Shark Bay, increasing the likelihood of recently moulted crabs in the sample from that region; or
- The longer lateral spines on crabs in Shark Bay, and hence smaller carapaces for a given carapace width, i.e. as the measurement is from the external tips of the lateral spines on either side of the carapace.

5.1.3.4 Natural Mortality

No direct estimates of natural mortality (*M*) currently exist for *Portunus armatus*, such as those based on tagging studies. However, *M* for *P. armatus* along the Pilbara coast and in Exmouth Gulf has been indirectly estimated to be ~1.4 y^{-1} (Table 5.2), based on four equations (Hewitt and Hoenig, 2005; Hoenig, 1983, Quinn and Deriso, 1999) and using a t_{max} of three years. 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. Norriss and Crisafulli, 2010; Smith *et al.,* 2013), tend to yield conservative estimates of M, leading to more precautionary assessment advice.

Since blue swimmer crabs cannot be aged directly from hard structures, longevity has been estimated using length frequency modal progression analyses. 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). From this information a maximum age (t_{max}) of three years was used.

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	$M = e^{1.23-0.832\ln(t_{\max})}$	1.37	linear regression model, molluscs
4 Hewitt and Hoenig, 2005	$M = \dfrac{4.22}{t_{\max}}$	1.41	Simplified and approximated version of method 2

Natural mortality has also been estimated indirectly for similar species, *i.e. P. pelagicus* and *P. segnis*, in locations in the Arabian Sea, Persian Gulf and the waters surrounding Indonesia, Pakistan and Thailand, using various empirical formulas for M (see review in Afzaal *et al.*, 2016). M values ranged considerably but the vast majority lay in the range of 1.2 - 1.6 y^{-1}. In some cases, M was calculated separately for males and females, with females consistently showing a lower natural mortality rate.

5.1.3.5 Reproduction

Blue swimmer crabs are gonochoristic, *i.e.* sexes are separate and male and female reproductive organs are present in separate individuals. *Portunus armatus* exhibits sexual dimorphism, where adult males are bluer in colour, particularly on the claws and walking legs and generally have a carapace smoother in texture. Females are olive green or brown in colour with stockier chelae.

Female crabs undergo a pubertal moult in Shark Bay at around 6–10 months of age, with the peak mating period considered to be between March and May. During this pubertal moult, the abdominal flap changes from a triangular to oval shape, and from being tightly to loosely-fixed to the cephalothorax (de Lestang *et al.*, 2003a; Fisher, 1999). Mature males moult some weeks before the maturing females. Male courtship is triggered by a pheromone released by the female (Meagher, 1971), and each male carries a female clasped beneath him for 4–10 days until she moults and mating occurs. Whilst soft, females mate and retain spermatophores for a few months before spawning occurs, which is year round in Shark Bay (Harris *et al.*, 2014). The mean size at sexual maturity for blue swimmer crabs in Shark Bay is 105 and 110 mm CW for male and females, respectively (Chandrapavan *et al.*, 2017).

The release of fertilized eggs occurs approximately six months after mating in most species (Aguilar *et al.,* 2008), as the reproductive cycle of blue swimmer crab populations along the WA coast is strongly influenced by water temperature (de Lestang *et al.,* 2010). While the spawning period of blue swimmer crabs in the temperate waters of south-west WA is restricted to spring/summer (de Lestang *et al.,* 2010; Johnston *et al.,* 2011a), the warmer, tropical waters of Shark Bay induce spawning all year round (de Lestang *et al.*, 2003a; Harris *et al.,* 2014) with a peak in spawning between July and September.

Females begin this six-month period by actively feeding to build up the energy reserves needed for egg production (Warner, 1977). Eggs are extruded from ovaries through the spermatophore, where they are fertilized, and onto the pleopods, the appendages of the abdomen (spawning), where they are carried until they hatch into zoeae (Zairion *et al.,* 2015b). The eggs change in colour from yellow through brown to grey as the yolk is used up by the developing embryo and, when ready for release, are helped into the water column by fanning of the abdomen and pleopods (Warner, 1977).

While the size-fecundity relationships for blue swimmer crabs along the Pilbara coast or in Exmouth Gulf have yet to be determined, they are probably similar to that of crab stocks in Shark Bay and Cockburn Sound where this analysis has been undertaken.

The fitted linear relationship (using weighted least squares) between batch fecundity (BF) and carapace width (CW) for female crabs in Shark Bay has been determined by Chandrapavan *et al.* (2017) as

$$BF = 14.78CW - 1132$$

The number of eggs per batch ranged from 306,162 for a crab 93 mm CW to 1,322,260 for a crab 150 mm CW (Figure 5.9). In general, legal-sized females (>135 mm CW) carried 2-3 times the number of eggs of sublegal-sized females. The diameter of early Stage 1 eggs (yellow) ranged between 380−485 µm. For comparison, a smaller number of later Stage 3 eggs (grey) were also measured, the diameters of which ranged between 520-550 µm.

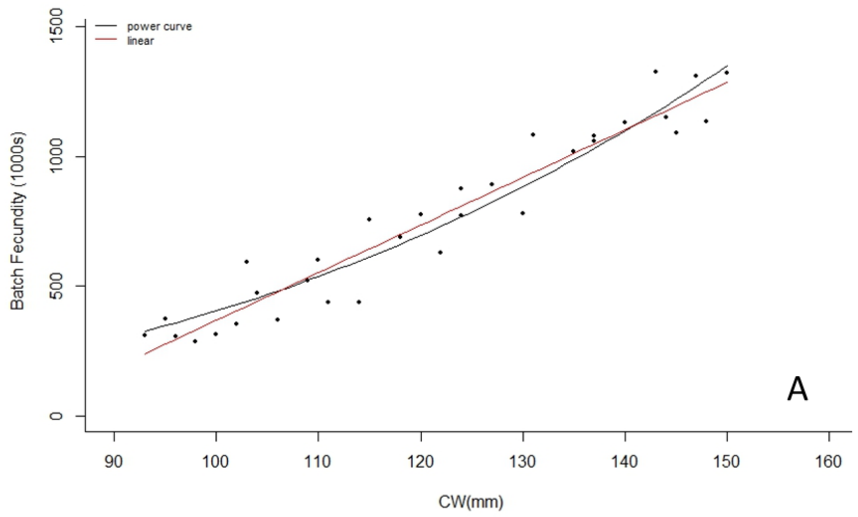


Figure 5.9. Relationships between batch fecundity and CW (mm) for 33 female crabs in Shark Bay, described by a linear regression (red line) and by a power function (black line). Note that, for this initial comparison, the relationships were derived using standard least squares regression (Chandrapavan *et al.,* 2017).

5.1.3.6 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 habitat through changes to the abundances of larval foods and predators.

The spawning season of *P. armatus* in Shark Bay, where water temperatures remain above 18ºC for a substantial part of the year, is considerably more protracted (spawns year round) than in the temperate waters of Cockburn Sound where the spawning season is restricted to spring and summer (de Lestang *et al.,* 2003a). This is also expected to be the case in Exmouth Gulf and along the Pilbara coast.

A stock-recruitment relationship has been determined for the Cockburn Sound crab fishery 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 for Cockburn Sound using egg production and juvenile recruitment and is described in full detail in de Lestang *et al.*, (2010). Briefly, over the time series there is a correlation 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 concentrations (as a proxy for primary productivity) and recruitment success. The overall stock-recruitment relationship is fairly weak and, after accounting for the effects of temperature and chlorophyll, describes approximately 52% of the variation in the data (n=16 years). The inclusion of the two environmental variables increased the percent of variation explained by the data by approximately 10%. However, in years where egg production was below 12 x 10^6 eggs/traplift, poor recruitment was observed irrespective of water temperature, indicating that there is a critical level of breeding stock required for recruitment success to occur.

Levels of recruitment to crab fisheries fluctuate considerably between years. While the causes of these variations are not fully understood, it is considered most likely to be driven by the environmental variables on spawning success and larval survival through to recruitment. The breeding stock (egg production) is not often a significant factor unless there has been a major decline in the stock due to overfishing and/or a series of poor recruitment events due to very poor environmental conditions such as what occurred in Cockburn Sound (de Lestang *et al.*, 2010; Johnston *et al.*, 2011a).

5.1.3.7 Diet and Predators

The blue swimmer crab employs an opportunistic feeding behaviour, utilising different feeding modes (Edgar, 1990; Zainal, 2017) which helps account for the success of this species in different environments. Their diet mainly consists of sessile and slow-moving invertebrates such as bivalve molluscs, crustaceans, polychaetes and brittle stars (Patel *et al.*, 1979; Williams 1982).

Studies by de Lestang *et al.* (2000) and Campbell (2017) in the Peel–Harvey and Leschenault estuaries in south-western Australia found the diet of blue swimmer crabs to be highly variable dependent on 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 bivalves, 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).

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 fish species such as the pink snapper, *Pagrus 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.

Specific studies to determine the dietary composition and predators of blue swimmer crabs along the Pilbara coastline or in Exmouth Gulf have not been undertaken.

5.1.3.8 Parasites and Diseases

Sacculina granifera Boschma is a parasitic barnacle that infects blue swimmer crabs, bringing about a number of major changes in the host crab. 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 (Figure 5.10), 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.

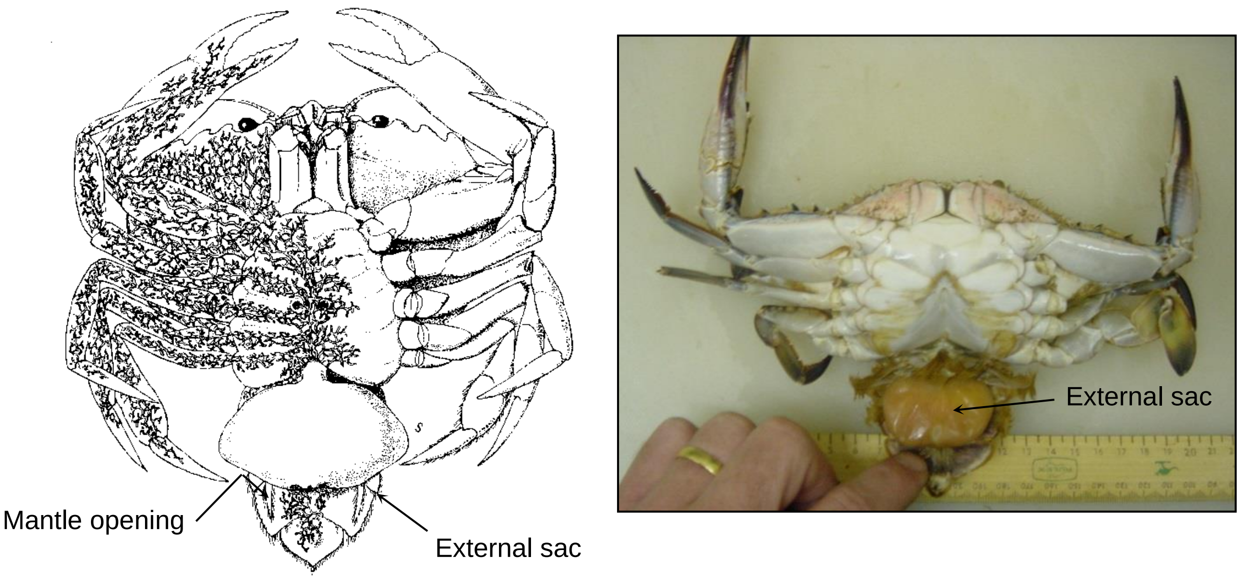


Figure 5.10. Rootlet system of Sacculina granifera (original drawing by Boas, from The Biology of Crustacea, Bang) on the left, and an infected blue swimmer crab with external sac caught in the waters off Port Hedland (Bellchambers *et al.,* 2005).

Sacculina granifera is known to have a number of effects on its crab host, including degeneration of the sex organs in both sexes and modification of the male crab to a more female form. 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. *Sacculina granifera* infestation rates of less than three per cent were encountered on commercial monitoring trips in the Pilbara Crab Managed Fishery (PCMF), so the parasite does not appear to pose any major problem to the blue swimmer crab stocks of the Pilbara coast. Neither does the presence of the parasite appear to affect the marketability of infected crabs, once the externae has been physically removed.

Prevalence of *S. granifera* in crab stocks in Exmouth Gulf has yet to be documented.

5.1.4 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 Western Australian blue swimmer crab fisheries of Cockburn Sound and Shark Bay during the last decade (Johnston *et al.,* 2011a; Chandrapavan *et al.,* 2017; 2019). These collapses are considered to have been triggered by adverse environmental conditions impacting on the spawning potential and subsequent recruitment of crab stocks that were subject to high levels of fishing pressure at the time.

Like many other blue swimmer crab fisheries, management of the Cockburn Sound Crab Managed Fishery 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. (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 rebuilding of the Cockburn Sound crab stock, the fishery was re-opened on 15 December 2009. A precautionary management approach was adopted upon re-opening the fishery, incorporating a considerably reduced fishing season for both commercial and recreational sectors, increases to the minimum commercial size limit, and commercial pot reductions. As fishery-independent surveys indicated that the stock continued to build, there was a slight easing in commercial and recreational fishing arrangements over the next four years (Fletcher and Santoro, 2015).

However, a review in December 2013 again highlighted a number of 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 (Fletcher and Santoro, 2015). An additional review of survey data in March 2014 resulted in an early closure to the fishery for both commercial and recreational sectors in that year. The fishery has remained closed since this time. Reasons for the second stock decline being investigated include combined effects of reduced levels of primary productivity within Cockburn Sound, 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 declines in abundance are believed to be substantially attributable to environmental changes, rather than fishing (Fletcher and Santoro, 2016). The blue swimmer crab stock collapse experienced in Shark Bay in 2011/12 is described in Section 7.3.1.1.

5.2 Green mud crab (*Scylla serrata*) and Brown mud crab (*S. olivacea*)

Figure 5.11. The Green mud crab, Scylla serrata. Illustration © R. Swainston (www.anima.net.au)

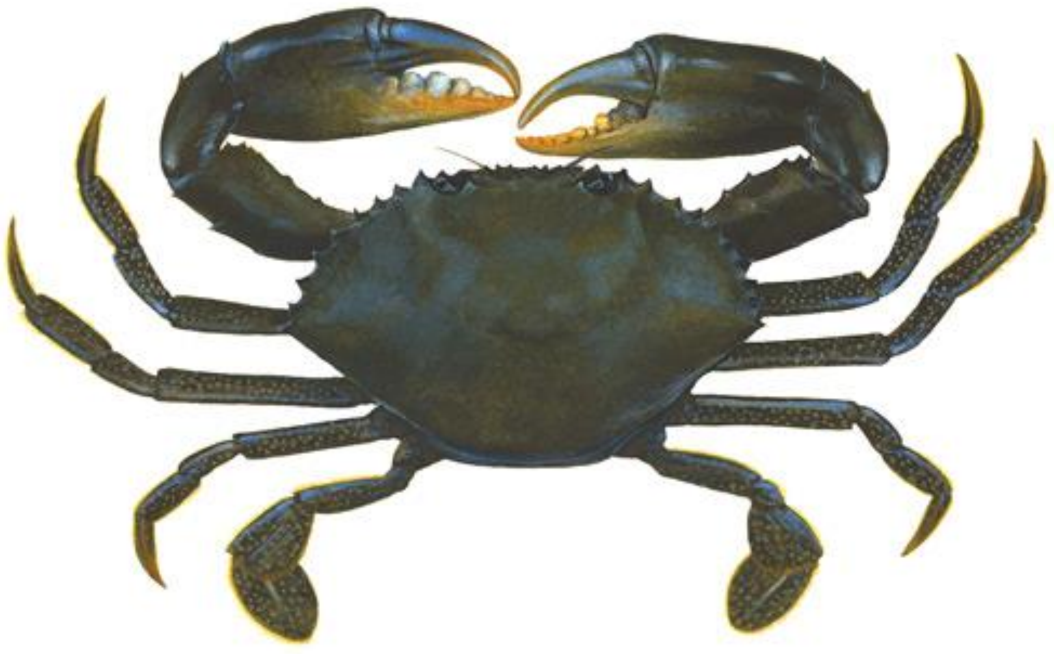


Figure 5.12. The Brown mud crab, Scylla olivacea. Illustration © R. Swainston (www.anima.net.au)

5.2.1 Taxonomy and Distribution

Two species of estuarine mud crabs, the green mud crab *Scylla serrata* (Figure 5.11) and the brown mud crab *Scylla olivacea* (Figure 5.12), occur in Western Australian waters (Keenan *et al.*, 1998).

Historically, there has been some confusion identifying *Scylla* species, however, two primary morphological characteristics have been described by Keenan *et al.* (1998) to distinguish between green and brown mud crabs in the field:

1. Frontal lobe spines. green mud crabs have high, pointed frontal lobe spines (Figure 5.13a), while brown mud crabs have low, rounded spines (Figure 5.13c).
2. Chelipeds (claws). green mud crabs have two obvious carpus spines and obvious propodus spines (Figure 5.13b), while brown mud crabs lack outer carpus spines (or just a blunt prominence in juveniles) and have reduced propodus spines (Figure 5.13d).

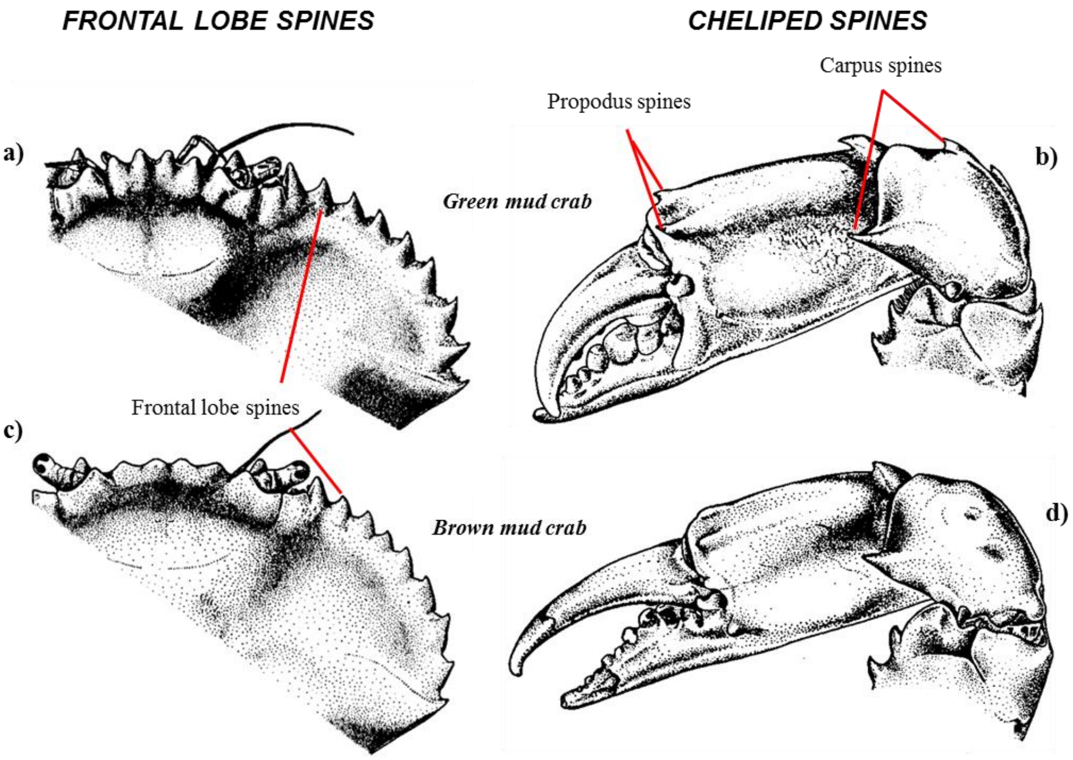


Figure 5.13. Morphological differences between the frontal lobe spines and cheliped or claw spines of the green mud crab S. serrata (a and b) and the brown mud crab S. olivacea (c and d) (adapted from Keenan *et al.,* 1998)

Prior to Keenan's revision of the genus *Scylla* in 1998, only *S. serrata* was widely recognised, and it is therefore possible that earlier catches of *S. olivacea* were recorded as *S. serrata*. For further details on mud crab taxonomy and identification see Keenan *et al.* (1998).

The green mud crab is found in estuarine habitats throughout tropical and subtropical waters of Queensland, NT, WA and northern New South Wales (Figure 5.14). Within WA, their distribution spans along the north-western coastline, from the Northern Territory border down to Shark Bay. In years of strong Leeuwin Current flow however, recruitment events have occurred resulting in localised, short-lived populations in the Swan-Canning Estuary on the lower west coast (Caputi *et al.*, 2014), and as far south as the Wilson Inlet on the south coast. The extended range of the green mud crab is thought to relate to its tolerance to lower temperatures and relatively longer larval phase (Gopurenko *et al.*, 2003).

The brown mud crab has a more restricted distribution in Australian waters (Figure 5.14), limited to a few embayments where salinity is reduced for extended periods during the monsoons (Keenan *et al.*, 1998). It is believed that brown mud crabs predominantly occur within WA and are only present in low numbers throughout the Northern Territory and Queensland. Most reported catches in WA come from within King Sound, a large coastal embayment 200 km northwest of Broome that is subject to the highest tides in Australia. The brown mud crab is thought to be more tolerant of low salinity than the green mud crab but less tolerant of lower temperatures, which is likely to contribute to their varying distributions. They are also considered to exhibit a strong preference for the intertidal zone, while green mud crabs make regular use of both intertidal and subtidal habitats up to 20 m depth offshore (Hill, 1994, Robertson, 1996).

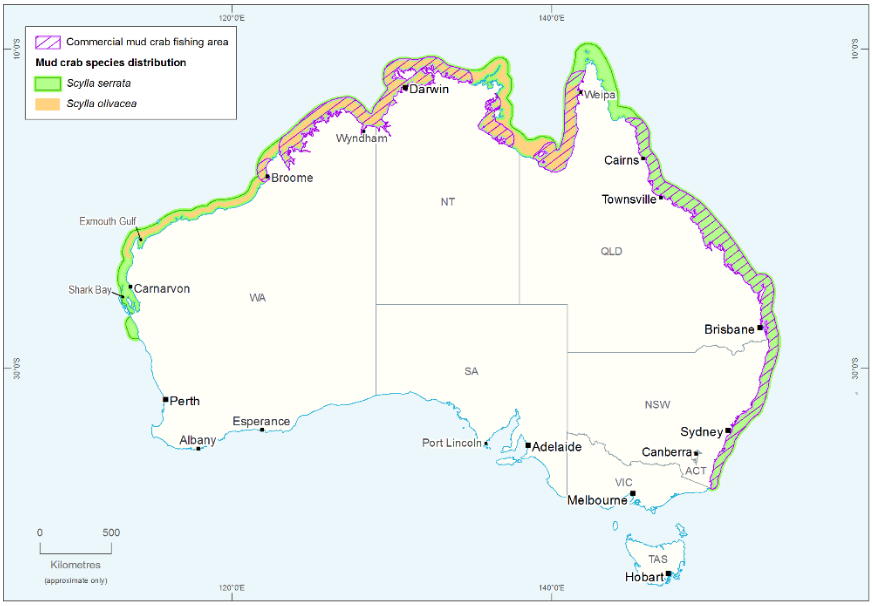


Figure 5.14. Geographic distribution for the giant mud crab, Scylla serrata (green) and the brown mud crab, S. olivacea (orange) and the commercial catch of both species combined (purple stripes), in Australian waters. Note: the distribution of S. olivacea is still poorly understood and is likely to be patchy within the range indicated. The commercial fishing areas shown are based on 2015 catch data provided by FRDC and the species are combined because catch records rarely distinguish between species (Grubert *et al.*, 2016).

5.2.2 Stock Structure

The proportion of the catch represented by the green mud crab *S. serrata* in the Western Australian mud crab fishery is uncertain, although it constitutes the majority (>99 per cent) of the commercial mud crab catch in the Northern Territory and Queensland, and the entire commercial catch in New South Wales (Grubert *et al.,* 2012).

Recent studies on the green mud crab from around the Indo–West Pacific region (Gopurenko *et al.,* 1999; He *et al.,* 2011) found two distinct genetic clades: a widespread clade comprising three separate geographic clusters (west Indian Ocean; Red Sea-South China Sea; and west Pacific, including the eastern seaboard of Australia), and an endemic north-west Australian clade, extending from WA to the tip of Cape York, Queensland. In this report, the first clade is referred to as the 'east coast' biological stock, and the second as the 'northern Australian' biological stock.

The northern Australian stock is estimated to be the earliest of the lineages for this species (He *et al.,* 2011), and therefore may contain relatively high genetic diversity. Fluctuations in paleo-oceanographic conditions including surface circulations and physical topography in the Indo-West Pacific might be responsible for the wide distribution, colonisation history and genetic divergence of this species (He *et al.,* 2011). Additionally, the migration of females offshore to spawn, coupled with a potentially long planktonic larval phase, gives the green mud crab significant capacity for dispersal (Grubert *et al.,* 2012). The lack of gene flow between the two clades in Australia though, is probably due to the constricted westward flow of waters from the Coral Sea imposed by the Torres Strait, which limits the passage of 'west Pacific larvae' into the Arafura Sea and beyond; and the southward flow of the East Australian Current (Grubert *et al.,* 2012).

The stock structure of the mud crab population in the Kimberley has not been documented. It is unknown whether there is significant larval flow between embayments to warrant the assumption of one single stock of *S. serrata* and *S. olivacea* throughout the Kimberley. *S. serrata* and *S. olivacea* are considered a single management unit in the North Coast Bioregion (NCB).

5.2.3 Life History

The sub-sections below provide an overview of the life history characteristics of *S. serrata* and *S. olivacea*, with a summary of the relevant biological parameters used in stock assessments presented in Table 5.3 and Table 5.4.

Table 5.3. Summary of biological parameters for the green mud crab Scylla serrata.

Parameter	Value(s)	Comments / Source(s)
Growth parameters	S. serrata	$L_t = L_\infty (1 - \exp(-K (t - t_0)))$
L_∞ (mm)	318.63	Thomas (1987)
K (year^{-1})	0.1327	
t_0 (years)	-1.0793	
Maximum age (years)	Approx. 4 years	Tongdee (2001)
Maximum size (mm)	250-280 mm CW	Lloris (2001)
Natural mortality, M (year^{-1})	0.8	
Length-weight parameters		W = a CW ^{b}
a	Male = 0.00001 Female = 0.0003	Grubert and Lee (2013)
b	Male = 3.625 Female = 2.903	
Reproduction	Gonochoristic, external fertilisation and highly fecund.	
Maturity		
First ovigerous	120 (female)	Tropical Australia (Hill, 1994)
L_{50} (CW)	135–140 mm (female); 140-160 mm (male)	New Caledonia and Tropical Australia (Delathiere , 1990; Knuckey, 1996; 1999)
Fecundity	2.45 – 10.75 million per batch (at 145mm CW)	Batch fecundity Davis *et al.,* (2004)
Size-fecundity parameters		BF = a CW – b
a	0.052	Davis *et al.,* (2004)
b	- 2.4	
Spawning frequency	Multiple batches spawned after single mating, with number of batches dependent on size of crab	

Table 5.4. Summary of biological parameters for the brown mud crab Scylla olivacea.

Parameter	Value(s)	Comments / Source(s)
Growth parameters		South-east India
L_∞ (mm)	Male = 148.05	Viswanathan *et al.,* (2016)
	Female = 138.80	
K (year^{-1})	Male = 0.762	
	Female = 0.856	
t_0 (years)	Male = −0.637	
	Female = −0.681	
Maximum age (years)	Approx. 4 years	Tongdee (2001)
Maximum size (mm)	Scylla olivacea 135-150 mm CW	Tongdee (2001)
Natural mortality, M (year^{-1})		
Length-weight parameters		$W = a\ CW^{b}$
a	Male = 0.079	
	Female = 0.240	
b	Male = 3.45	
	Female = 2.866	
Reproduction	Gonochoristic, external fertilisation and highly fecund	
Maturity parameters		
L_{50} (mm)	86 mm (female)	Malaysia Ikhwanuddin *et al.,* (2011)
Spawning frequency	Multiple batches spawned after single mating, with number of batches dependent on size of crab	

5.2.3.1 Life Cycle

The main events in the life cycle of the green mud crab are illustrated in Figure 5.15. It is thought the brown mud crab has a similar lifecycle. The spawning period in northern Australia occurs around November and December, when ovulating females migrate offshore. Egg incubation in this species is estimated to take 10-17 days. At spawning, planktonic zoea larvae emerge from the eggs. These individuals then go through a series of up to 5 moults in ~3 weeks (depending on water temperature and salinity), during which time they are transported back to the estuarine environment by tidal currents. The final larval stage (megalopa) will settle onto suitable substrate and moult into juvenile crabs after 5-12 days of settling. Sexual dimorphism becomes apparent as the size and form of the limbs develop once the crab reaches ~100 mm CW (Heasman, 1980). Female pubertal moult occurs at ~130 mm CW.

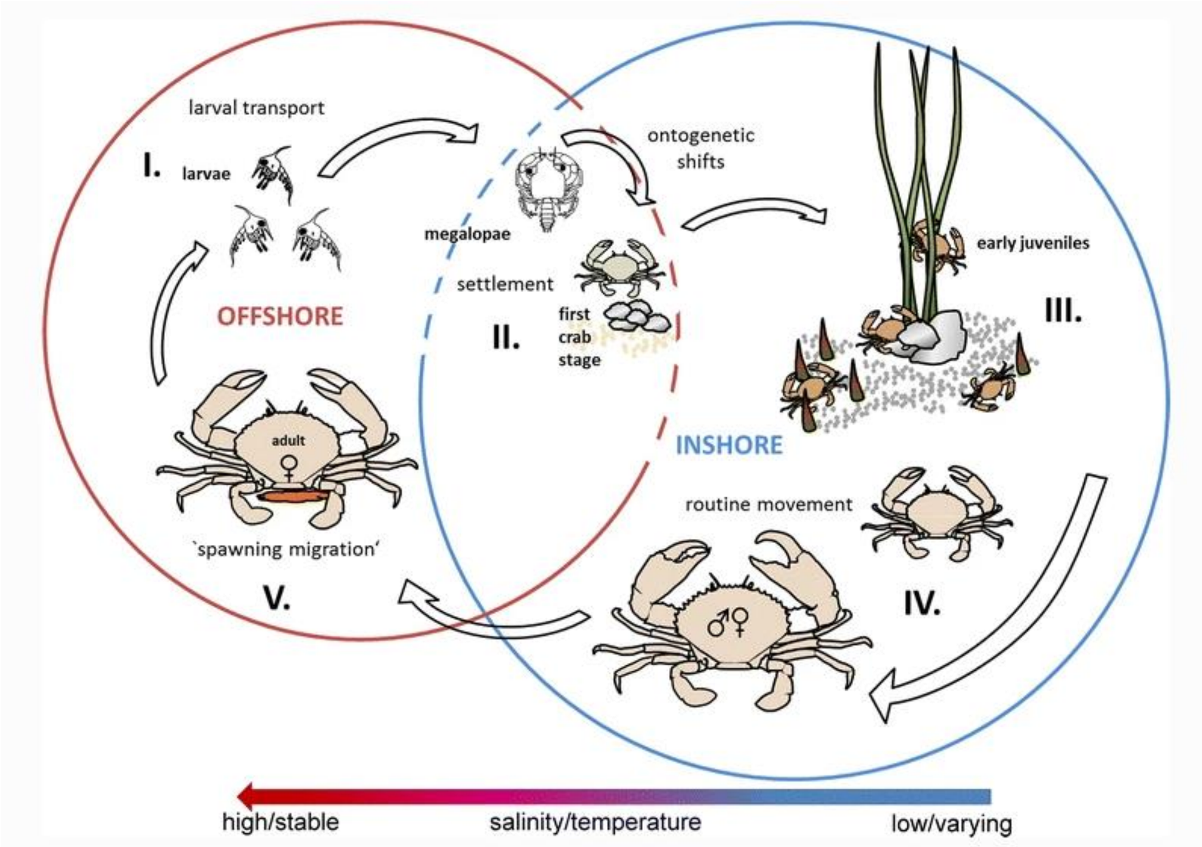


Figure 5.15. Schematic representation of the life cycle of the green mud crab Scylla serrata (Alberts-Hubatsch *et al.,* 2016).

5.2.3.2 Habitats and Movements

Green mud crabs spend most of their life cycle within subtidal and intertidal areas associated with sheltered tropical/subtropical estuaries and embayments, and are mainly found in areas of muddy substrate accompanying mangrove vegetation (Brown, 1993). Juvenile crabs tend to be found among the more protected, mangrove areas, sub-adults in the intertidal and subtidal zone (but feed preferentially in shallow waters), while adults remain in deeper, subtidal waters (Hill *et al.*, 1982). In contrast, adults of the brown mud crab have been considered to exhibit a stronger, but not exclusive preference for the intertidal zone (Hill, 1994; Robertson, 1996). Burrows of 1-2 m in length are also utilised, particularly in warmer months or during vulnerable mating or moulting periods (Brown, 1993). Mud crabs have a relatively restricted home range and there is limited movement between neighbouring bays or estuarine systems (Hyland *et al.*, 1984).

Ovigerous female green mud crabs migrate 10-30 km offshore, in depths of 20-40 m (but up to 95 km offshore and max of 300 m) to release their eggs and it is suggested that they return to the coast after spawning (Brown, 1993; Hill, 1994). It has been proposed that this migration provides an oceanic environment more tolerable to the pelagic larval stages, allows greater opportunity for larval dispersal, and reduces exposure to predators (Fratini and Vannini, 2002).

5.2.3.3 Age and Growth

No age and growth parameters have been determined for mud crabs in WA. The maximum size reported for the green mud crab elsewhere is 250–280 mm CW or 2–3 kg (Lloris, 2001), whereas the maximum size of the brown mud crab is 135–150 mm CW (~1.5 kg) (Tongdee, 2001). Green mud crabs are estimated to live up to four years of age.

Mud crabs can increase in size between moults quite rapidly (up to 30 mm) and tend to grow faster (i.e. moult increments are shorter) in warmer waters, but attain a smaller final size than those in higher-latitude waters. Growth is also strongly seasonal, with faster growth occurring in warmer months (Figure 5.16). Water temperature has been suggested to have a more pronounced effect on intermoult duration than moult increment (Heasman, 1980).

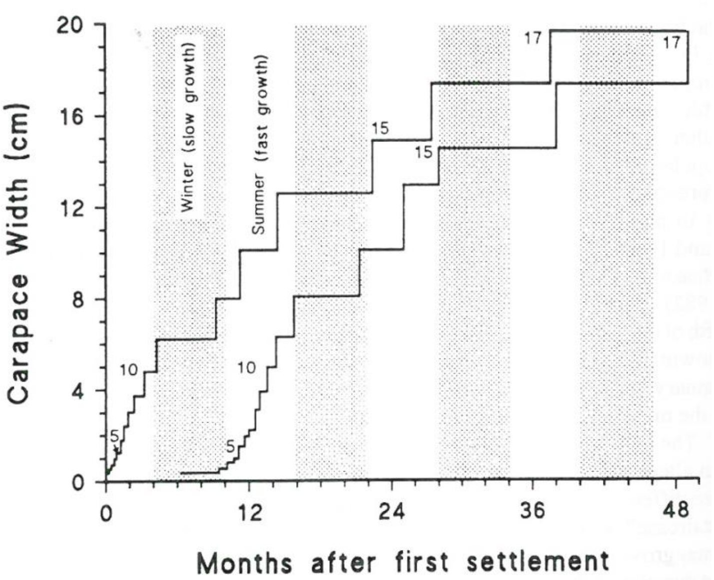


Figure 5.16. Growth patterns of green mud crab Scylla serrata in Queensland (Brown, 1993, but after Fielder and Heasman, 1978).

Thomas (1987) looked at age and growth parameters of green mud crabs using several methods based on modal progression and each of the techniques yielded similar mean sizes at a given age class (Table 5.5). The von Bertalanffy equation used was:

$$L_t = 318.63\ (1-e^{-0.1327(t + 1.0793)})$$

Table 5.5. Mean size (carapace width in mm) attained by the green mud crab Scylla serrata in different years of life as determined by various methods (Thomas, 1987).

	o	I	II	III
Months mode curve		112.0	151.5	187.5
Probability plot technique	81.5	117.0	157.0	182.0
von Bertalanffy growth equation		118.0	162.0	180.0

Weight-length relationships (using wet weight; *W* and *CW*) determined for male and female green mud crab (*S. serrata)* in the Northern Territory by Grubert and Lee (2013) are as follows:

Males: $W = 0.00001 \times CW^{3.625}$

Females: $W = 0.0003 \times CW^{2.903}$

These are also illustrated in Figure 5.17. The males sampled ranged from 108-196 mm and 220-1851 g, while females ranged from 111-200 mm and 195-1261 g. Males were therefore heavier relative to their carapace width compared to females; this difference in length-weight relationship between sexes became more apparent as carapace width increased. The observed pattern is probably due to the allometric growth of the chelae as males reach ~130 mm CW (Knuckey, 1999). Much of the variability in weight for a given carapace width for both males and females may be due to the inclusion of crabs with missing appendages as well as those in different moult stages (Grubert and Lee, 2013).

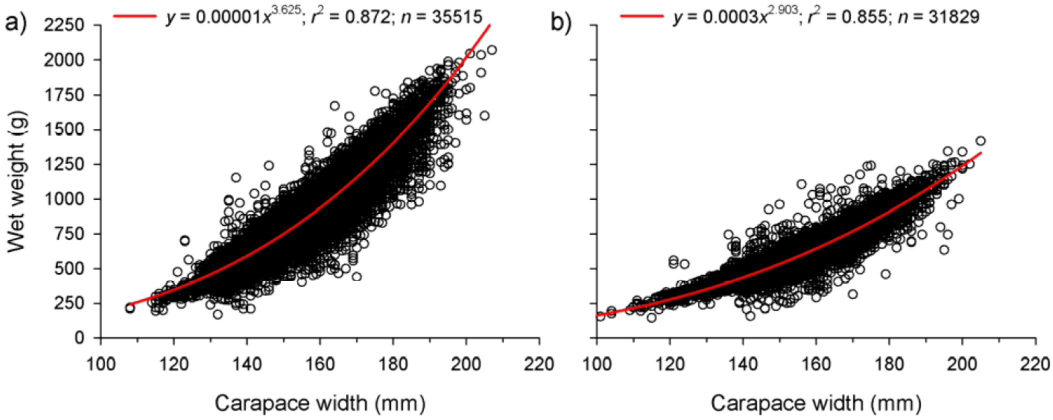


Figure 5.17. Length-weight relationships for male (a) and female (b) green mud crab *Scylla serrata* sampled from commercial catch in the Roper River, NT (Grubert and Lee, 2013).

Weight-length (*W-CW*) relationships for brown mud crab (*S. olivacea*) in Thailand were determined by Jirapunpipat (2008) and are as follows:

Males: $W = 0.079 \times CW^{3.45}$

Females: $W = 0.240 \times CW^{2.866}$

These relationships are illustrated in Figure 5.18.

As with green mud crabs, males of brown mud crabs are generally heavier than females at any given carapace width.

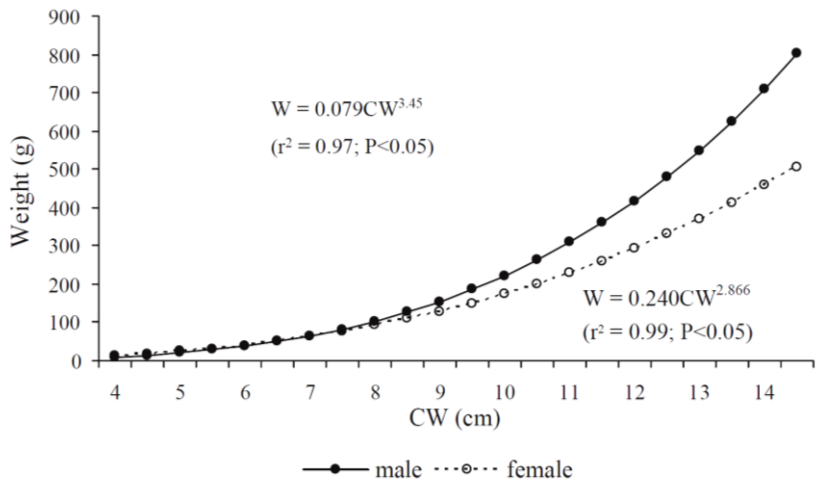


Figure 5.18. Length-weight relationship of male and female brown mud crabs *Scylla olivacea* in Thailand (Jirapunpipat, 2008).

5.2.3.4 Natural Mortality

There are no estimates of natural mortality for *S. serrata* or *S. olivacea* in WA. In the NT, Knuckey (1999) applied three methods from Beverton and Holt (1957), Pauly (1980) and Rikhter and Efanov (1976) and from these, estimated natural mortality for *S. serrata* to be around 1.2 year^{-1}. This relatively high figure reflects the relatively short lifespan of the species, which tend to be largely governed by recent recruitment levels (which, unlike longer-lived species, are not buffered by the build-up of year-classes). Grubert and Lee (2013) estimated natural mortality (M), to be around 0.8 for both sexes, using the simple equilibrium model.

5.2.3.5 Reproduction

Mating occurs around September/October in northern Australia and within ~48 hours after a moult, when the female's carapace is soft. Coupling is initiated a few days before moulting however, where the male cradles the female. Once the female has moulted, the male will transfer sperm packages (spermatophores) into the female's sperm receptacle (spermathecum) (Brown, 1993). This process can take place for several hours. The female will then remain in the protection of the male for several days until her new shell becomes hard. Transferred sperm packages remain viable for up to 7 months (Brown, 1993; Knuckey, 1999).

In northern Australia, green mud crabs reach sexual maturity at 12-18 months (Knuckey, 1999). Size at maturity differs between sex and location and can be difficult to standardise within the literature as methods defining 'maturity' are not consistent. For example, some studies used physiological criteria such as presence of gonads, while others determined functional maturity through behavioural observations or presence of mating scars. Size at 50% maturity for females has been previously documented at 90-120 mm CW (Hill, 1975; Heasman *et al.,* 1985; Prasad and Neelakantan, 1990; Robertson and Kruger, 1994). More-recent studies however, carried out after the re-classification of the *Scylla* genus, have indicated female size at maturity is 131-138 mm CW (Knuckey, 1999). The transition of males from immature to physiological maturity (i.e. presence of spermatophores), probably occurs from 110 mm CW (Heasman *et al.,* 1985; Knuckey, 1996; 1999), although they may not be large enough to compete successfully for mates until achieving fully adult morphology (e.g., large claws) upon reaching carapace widths of 140–160 mm (Heasman *et al.,* 1985; Knuckey, 1999; Perrine, 1978).

Studies on brown mud crabs carried out in Ranong Province, Thailand and Sarawak, Malaysia have found female size at maturity to be 86-96 mm CW (Ikhwanuddin *et al.,* 2011; Jirapunpipat, 2008; Moser *et al.,* 2002; Tongdee, 2001).

Green mud crabs are highly fecund, with females producing 2-10 million eggs per batch. Furthermore, spawning multiple times after a single mating may be a normal occurrence for larger crabs and females can mate more than once per season (Brown, 1993; Heasman, 1980). Davis *et al.*'s (2004) study in a South African estuary contains one of the few examinations on size-fecundity relationships the green mud crab. A weak but significant correlation between size and fecundity was found (R^2 = 0.18, y = 0.052x – 2.4, *p* = 0.026; Figure 5.19).

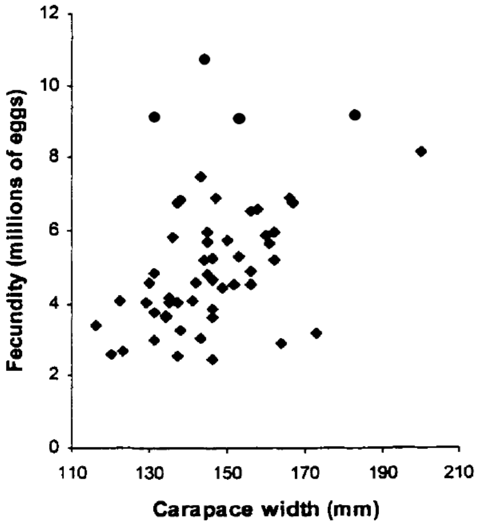


Figure 5.19. Size-fecundity relationship of the green mud crab Scylla serrata in South Africa (R2 = 0.18, y = 0.052x – 2.4, p = 0.026, Davis *et al.,* 2004). Fecundity defined here as number of eggs per female per batch (N = 60).

5.2.3.6 Factors Affecting Year Class Strength and Other Biological Parameters

The extensive migrating behaviour observed in ovigerous females allows offspring to recruit further from the habitat of their parents (Hill, 1994) and may be a contributing factor to the widespread distribution of the species.

Temperature and salinity as well as the interaction between the two parameters have been found to affect the survival and development of mud crab larvae (Nurdiani and Zeng, 2007). Highest survival in the megalopal stage occurred at water temperatures of 25°C and salinity of 35, while larval duration tended to increase with decreasing temperature and increasing salinity (Nurdiani and Zeng, 2007).

Populations of *S. serrata* have in recent years been recorded in the south-west of Australia almost 1000 km south of their usual range limits (Gopurenko *et al.,* 2003). This appears to have been due to the strength of the south-flowing Leeuwin Current. Meynecke *et al.,* (2012a) examined the correlations between the Southern Oscillation Index (SOI), rainfall, river flow and sea surface temperature (SST) on the commercial harvest of *S. serrata* in the Northern Territory. A combination of SOI, rainfall/river flow and SST explained 30 – 70 % of the variability in commercial catches, emphasising the importance of climatic events on mud crab harvest. Also, catch rates were more strongly linked with mean summer SST at higher latitudes and rainfall at lower latitudes. Mud crabs could potentially benefit from increased water temperatures at higher latitudes due to increased growth rates and reproductive activity, while higher rainfall could lead to increased productivity and therefore, food supply (Grubert *et al.,* 2012). Alternatively, habitats vulnerable to climate change such as seagrass or mangroves are vital to megalopae and juvenile stages of *S. serrata* (Meynecke *et al.,* 2012b; Webley *et al.,* 2009). Recruitment success and juvenile survival may therefore be indirectly affected by climate change through the availability of seagrass and mangrove habitats.

5.2.3.7 Diet and Predators

No studies on the diet of mud crabs have been carried out in WA, however, due the extensive aquaculture industry of *S. serrata* in south-east Asia, considerable research into the diet of mud crabs (mainly *S. serrata*) has been undertaken in the latter region (e.g. Jayamanne and Jinadasa, 1991; Millamena and Quinitio, 2000; Pavasovic *et al.,* 2004).

Muds crabs are highly opportunistic in their feeding behaviour, adopting predatory, scavenging and cannibalistic strategies. Mud crabs generally predate on sessile or slow-moving benthic invertebrates including attached and burrowing bivalves and small crabs, locating their prey by means of chemoreception (Hill, 1976; 1979). Their diverse diets often feature crustaceans such as other crab species (or smaller, weak and injured crabs of the same species), bivalve molluscs and sometimes small live fish or shrimps.

It has been found that adult *S. serrata* feed mainly on molluscs while juveniles feed on crustaceans (Jayamanne and Jinadasa, 1991). Diet did not appear to vary seasonally in these study regions. Crabs feed at night but only at high tide during the day (Jayamanne and Jinadasa, 1991).

Studies on predation of mud crabs in WA waters have yet to be undertaken. However, it is presumed that the planktonic larval stage can be eaten by small fish, while the post-larvae and juvenile stages are preyed on by larger fish and elasmobranch species that live in mangrove areas. Adult mud crabs are considered to have fewer predators. However, anecdotal evidence suggests that turtles, sting rays, crocodiles and large fish, such as barramundi and sharks, prey on adult mud crabs.

5.2.3.8 Parasites and Diseases

Loxothylacus ihlei is a rhizocephalan parasite of the green mud crab. Similar to other sacculinid infections, *L. ihlei* stunts the growth of individuals and induces feminisation.

Studies from mud crab populations in the NT indicated prevalence of the infection was relatively low (2.1%) and smaller individuals were most affected by the parasite (Knuckey *et al.,* 1995), however, there have been no surveys done on its prevalence in WA. Various other diseases affecting green mud crabs have been identified through studies carried out in Queensland, including those affecting the shell and egg development (see Andersen *et al.,* 2000; Kvingedal *et al.,* 2006), as well as *Octolasmis*, a barnacle infecting the gills of older crabs, studied in Thailand populations (Jeffries *et al.,* 1992).

5.2.4 Inherent Vulnerability

The mud crab is a highly fecund species with a short life span (see Section 5.1.3.3) and is therefore generally considered to have a low inherent vulnerability to fishing. Furthermore, the size of maturity is less than the legal size so that this provides some level of protection to the spawning stock. However, recruitment of this species can be significantly influenced by changes in environmental conditions (see Section 7.3.1). Therefore mud crab catches can fluctuate between years as a consequence of impacts on the stock that may not necessarily be primarily related to fishing pressure.

While there have been no identified stock collapses in the mud crab fishery in WA, there have been reported declines in recent years in mud crab stocks in the Northern Territory. The Northern Territory mud crab fishery is divided into two management units: the Arafura-West Mud Crab Fishery (AWMCF) and the Western Gulf of Carpentaria Mud Crab Fishery (WGCMCF). Annual commercial catches in the AWMCF ranged between 106–149 t (at an average of 124 t) for the decade spanning 2005–14, with the catch in 2015 equating to 85 per cent of the long-term average (Grubert *et al.,* 2016). Catch rates from 2005–14 were more variable, ranging from 0.3 kg per pot-lift–0.7 kg per pot-lift (average 0.5 kg per pot-lift), with the relatively low catch rate experienced in 2015 (0.3 kg per pot-lift) being a function of increased fisher competition in a few key areas following effort displacement from the WGCMCF. Consequently, the AWMCF management unit is currently classified as a sustainable stock (Grubert *et al.,* 2016).

However, there has been a decline in the annual commercial mud crab catch from the WGCMCF over recent years. After increasing from 152 t in 2006 to a peak of 419 t in 2009, the annual catch steadily declined to 81 t in 2015 (Grubert *et al.,* 2016). Mud crab catch rates are positively correlated with environmental variables, with wet season rainfall showing the strongest correlation at lower latitudes (Mayneke *et al.,* 2012). Monsoonal rainfall across many catchments emptying into the Gulf of Carpentaria has been lower than average for much of the past 5 years, coinciding with a period of predominantly neutral or negative values of the Southern Oscillation Index that began in early 2012. This has been associated with a decline in mud crab availability and catch rates (Grubert *et al.,* 2016). A size-age-sex stock synthesis model applied to pooled commercial catch and effort data showed an emerging trend of lower stock size and subsequent low recruitment, suggesting that the stock was approaching an overfished state by the end of 2015 (Grubert *et al.,* 2016). Additional analysis involving a delay-difference modelling approach (using an assumed catchability q of 0.25–2.0 x 10^{-3}) indicated that overfishing (defined as F/F_{MSY} >1) was not currently occurring, but may have occurred between 2009 and 2012. However, if there have been changes in fishing practices (such that q exceeds 2.0×10^{-3}), there is an increased risk that overfishing is occurring at present while unfavourable environmental conditions are constraining recruitment. The above evidence indicates that the current level of fishing pressure may cause the stock to become recruitment overfished. Consequently, the WGCMCF management unit is currently classified as a transitional–depleting stock (Grubert *et al.,* 2016).

The most common method of capture is by baited pots/traps positioned close to mangrove estuarine environments, shallow water embayments and tidal creek systems. The main risks to nearshore habitats come from oil and gas resource development and the expansion of port facilities, plus periodic cyclones.

6. Fishery Information

6.1 Commercial Fishery

6.1.1 Overview

Blue swimmer crab

Blue swimmer crabs have been targeted by commercial fishers using purpose-designed hourglass traps along the Pilbara coast since 2001, with the majority of catch historically taken from the Nickol Bay region. They have also been retained as by-product by the Onslow and Nickol Bay trawl fisheries since the early 1980s, although annual trawl catches have generally been low (< 3 t; Figure 6.1).

Exemptions to use hourglass traps to fish commercially for blue swimmer crabs in Exmouth Gulf were issued in October 2003 and June 2004. However, limited fishing was undertaken using either of the Exemptions and they were not renewed upon expiry in 2009. A further five-year Exemption to fish commercially for blue swimmer, three spot sand and coral crabs using hourglass traps in Exmouth Gulf was issued in August 2016.

The sections below provide more detailed information about the main commercial sectors that target blue swimmer crabs along the Pilbara coast and in Exmouth Gulf, *i.e.* The Pilbara Crab Managed Fishery (PCMF) and the Exmouth Gulf Developing Crab Fishery (EGDCF).

Mud crab

Brown and green mud crabs have been fished commercially in coastal and estuarine waters between Broome and Cambridge Gulf (near the Northern Territory border) since 1994. Commercial fishing with purpose-designed crab traps has been occurring since 2006, with the majority of fishing effort concentrated around York Sound, King Sound, Cambridge Gulf and Admiralty Gulf.

The sections below provide more detailed information about the main commercial sector that targets mud crabs in the north of WA, i.e. The Kimberley Crab Managed Fishery (KCMF).

6.1.2 History of Development

Pilbara Crab Managed Fishery

In 2001, Exemptions were issued to two Cockburn Sound crab fishers permitting them to use hourglass traps to target blue swimmers along the Pilbara coast, and retain the coral crab (*Charybdis ferriata*) and the three spot sand crab (*Portunus sanguinolentus*) as byproduct.

Exemption 1 allowed for fishing from the high water mark to the 200 m isobath between longitudes 115° 5' 60" E and 120° E (approximately Onslow to Port Hedland) other than closures around Onslow, Karratha and Port Hedland. This Exemption provided for two fishing units, with a maximum of 200 crab traps per unit. The Exemption set a maximum of 200 traps that could be used in Nickol Bay, with a total of 400 traps that could be used at any one time in the fishery. Current fishing activities relating to this Exemption are presented in Section 6.1.2.

Exemption 2 provided for one fishing unit with a maximum of 200 traps, with fishing limited from the high water mark to the 200m isobath between longitudes 117 E and 120 E, (approximately Point Samson to Port Hedland). On appeal, the boundaries of Exemption 2 were extended in 2003 to coincide with those of Exemption 1, other than the waters of Nickol Bay (i.e. fishing allowed between longitudes 115°E and 116 45'E and between longitudes 117°E and 120°E). Following Departmental approval in 2005, Exemption 2 was leased to another trap fisher who operated intermittently over the next three years. However, no fishing was undertaken using this exemption after July 2007, with the fisher citing logistical difficulties and high cost associated with the remoteness of the fishery. Exemption 2 was extinguished in 2009.

As with most developing fisheries, annual catches in the Pilbara Developing Crab Fishery (PDCF) grew rapidly in line with increases in fisher knowledge, gear development and fishing effort during the years following inception, from 10 t from 19,200 traplifts in 2001 to 64 t from 68,500 traplifts in 2003 (Figure 6.2). The annual catch and effort then fell over the next two years to 32 t from 32,700 traplifts in 2005, as one fisher ceased operating citing diminishing economic returns.

The variability inherent in the crab stocks in the region was evident when the highest catch on record in the fishery was reported in 2006 (73 t from just 35,970 traplifts; 1.94 kg/ traplift), followed by one of the lowest catches the following year (11 t from 18,000 traplifts; 0.58 kg/traplift). The peak catch in 2006 was associated with five cyclonic events in the summer of 2005/06 in the Pilbara that resulted in the highest rainfall recorded in the Nickol Bay region since 1934 (see Section 7.3.1.2). It is thought this rainfall potentially increased the catchability of crabs in the Nickol Bay region.

The catch then remained steady at around 29 t between 2008 and 2010, before declining in line with effort as the sole remaining fisher focused on other commercial activities in the region. Subsequent annual catches have varied between 6 t from 8,100 traplifts in 2012 to 49 t from 43,760 traplifts in 2017 (Figure 6.2). The fishery attained managed status in 2018, gazetted as the PCMF. Annual total catches of 30.2 and 19.3 t from 30,220 and 19,327 traplifts were reported for 2018 and 2019, respectively (CPUE = 1.0 and 1.67 kg/traplift; Figure 6.2).

In addition to the PCMF, the Onslow and Nickol Bay Prawn Managed Fisheries also have a history of retaining blue swimmer crabs. Between 1991 and 2004, the prawn trawler fleets retained a combined total of between 1 and 6 t annually (Figure 6.1). However, retention of blue swimmer crabs by the trawl fleets has diminished to less than one tonne annually in recent years. Negligible catch of blue swimmer crabs (<0.19 t in any given year) is taken by other commercial fishing methods (e.g. set nets) in the Pilbara region.

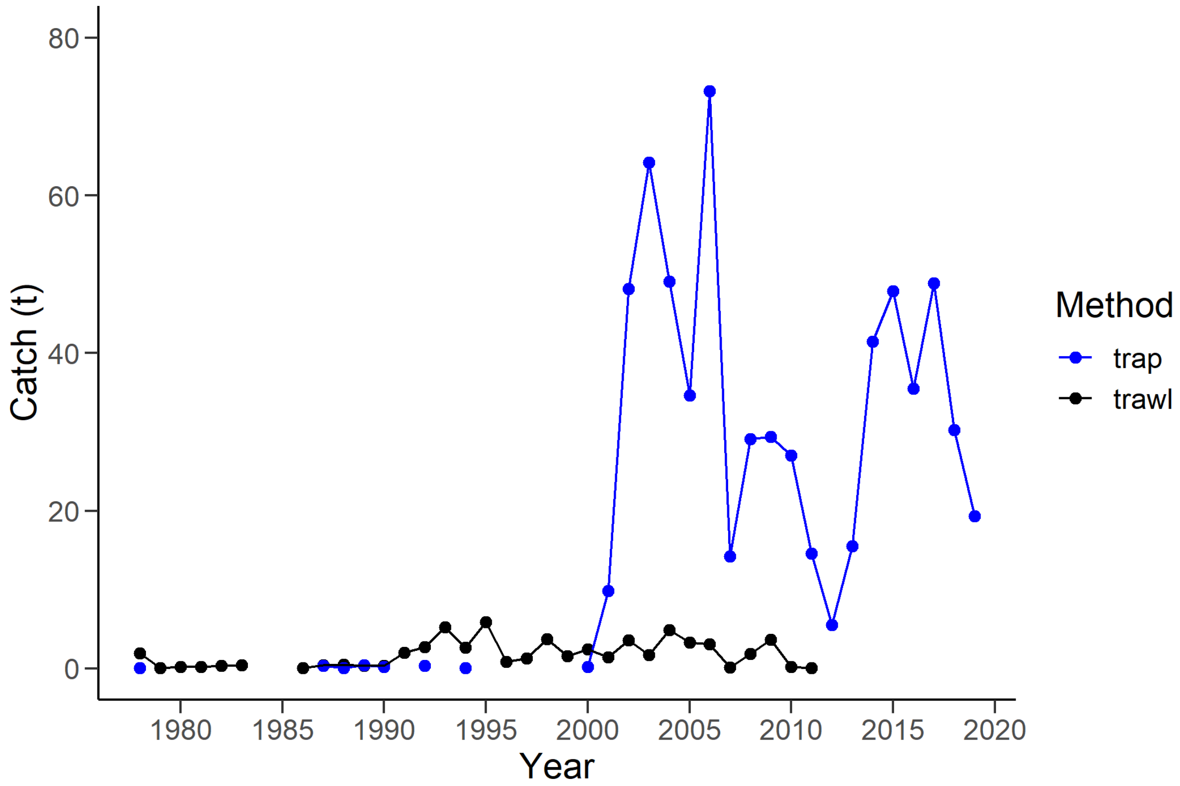


Figure 6.1. Annual commercial blue swimmer crab catch (tonnes) in the Pilbara region of Western Australia by trap and trawl fishing from 1978 to 2019.

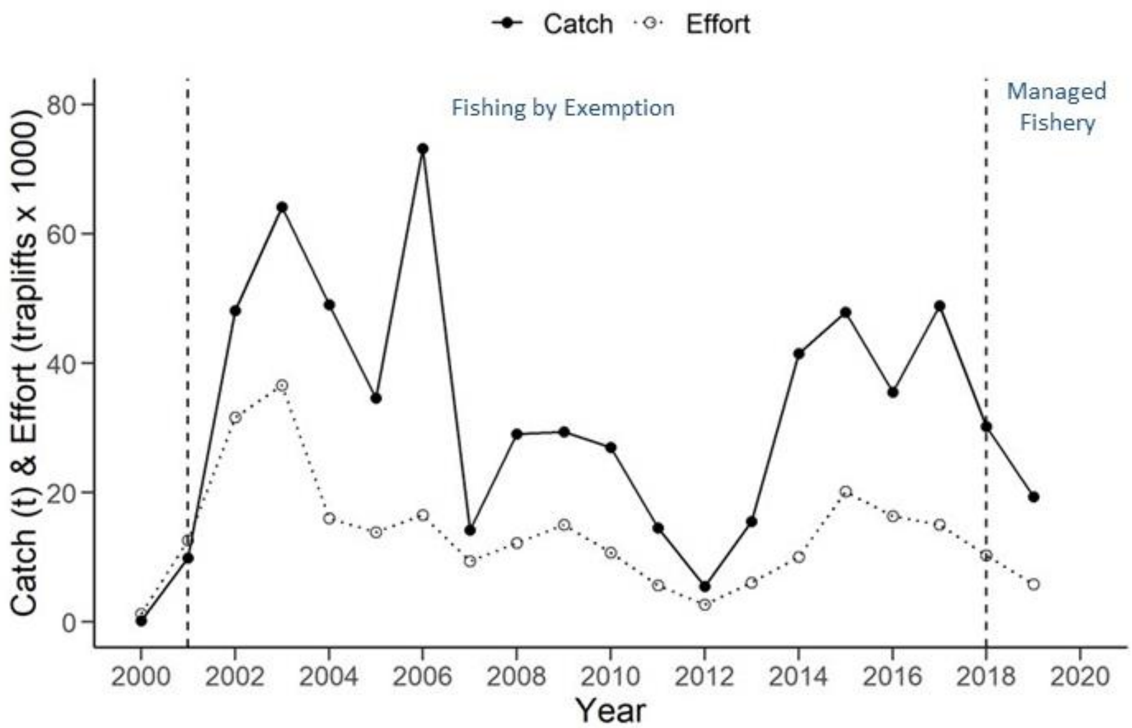


Figure 6.2. Annual commercial blue swimmer crab catch (tonnes) and fishing effort (traplifts x 1000) in the Pilbara Crab Developing (PDCF) and Managed (PMCF) Fisheries between 2000 and 2019.

Exmouth Gulf Developing Crab Fishery

Between 1995 and 2001, the use of crab traps to fish commercially for blue swimmer crabs in Exmouth Gulf was authorised through permissive conditions on Fishing Boat Licences. A limited amount of commercial trap fishing took place during this period, with annual catches ranging from 0.2–8.5 t (Figure 6.3).

Since 2003 access to the EGDCF has been granted via Exemption. Exemptions to use (a maximum of) 200 hourglass traps to fish commercially for blue swimmer crabs in the waters between North West Cape and 115° 06.5' E longitude (Onslow) were issued in October 2003 and June 2004. The latter exemption was amended in March 2006 to increase the maximum number of traps that could be used to 300 to give the Exemption holder a greater opportunity to develop an economically viable operation.

However, limited fishing was undertaken using either Exemption. A combined total catch of 28 t was taken over the five year period from 2004 to 2008, with annual catch and effort ranging from 4−10 t from 8,400−14,800 traplifts, respectively (Figure 6.4). Consequently, the two Exemptions were not renewed upon their expiry in 2009.

A new Exemption to fish commercially for blue swimmer, three spot sand and coral crabs using purpose-designed traps in Exmouth Gulf was issued in June 2016. However, only limited fishing has occurred to date with the trap fisher retaining just 0.3 t of crab from 852 traplifts during 2016. Current fishing activities relating to this Exemption are presented in Section 6.1.2.

In addition to the EGDCF, trawlers in the Exmouth Gulf Prawn Managed Fishery have a history of retaining blue swimmer crabs as a byproduct of their trawl activities. The trawl fleet has retained between 6 t and 43 t of blue swimmer crabs per year between 1993 and 2010 (Figure 6.3). However, the annual catch can vary widely dependent on factors such as the distribution and amount of fishing effort, the abundance of target prawn species, and changing environmental conditions. Trawl catch peaked at 58 tonnes in 2011, associated with flooding events and the marine heat wave in 2010/11.

However, in recent years there has been a substantial reduction in the annual trawl catch of blue swimmer crabs to an average of 4 t between 2012 and 2016 (Figure 6.3). There was a considerable restructure of the trawl fleet during 2012. The company that operates the fleet in Exmouth Gulf restructured its operations, reducing the fleet from 9 to 6 trawlers. In addition, the remaining vessels were converted freezer boats to facilitate the processing of catch at sea and negate the need to return to port every day. This restructure led to reduced trawl effort in the Gulf, and may have had an impact on the retention of blue swimmer crabs as frozen crab is less attractive to the market.

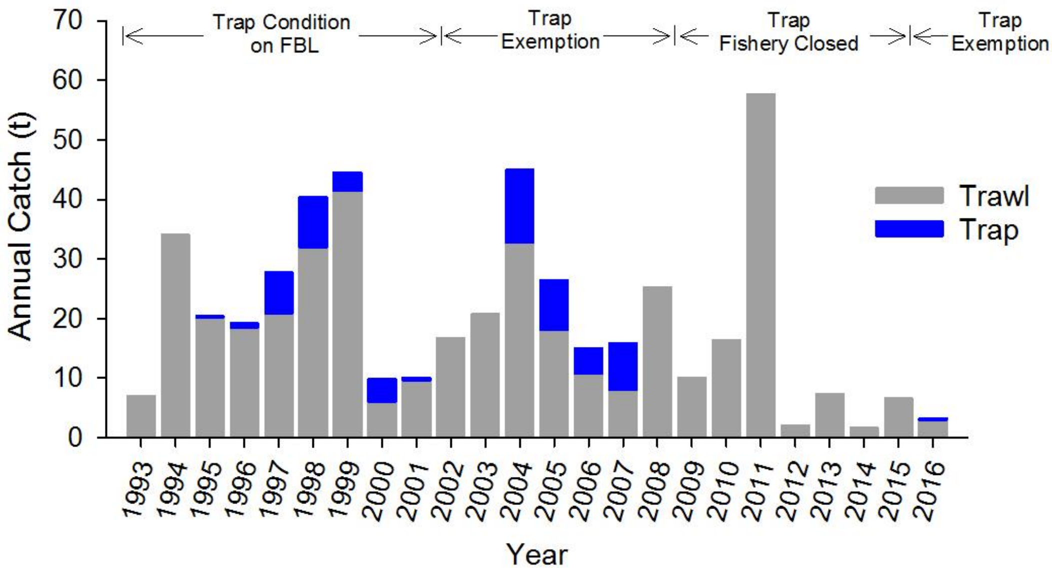


Figure 6.3 Annual commercial blue swimmer crab catch (tonnes) for trap fishers in the Exmouth Gulf Developing Crab Fishery and trawl fishers in the Exmouth Gulf Prawn Managed Fishery between 1993 and 2016. Note, no trap catch has been reported since 2016 and only negligible trawl catch has occurred (not shown).

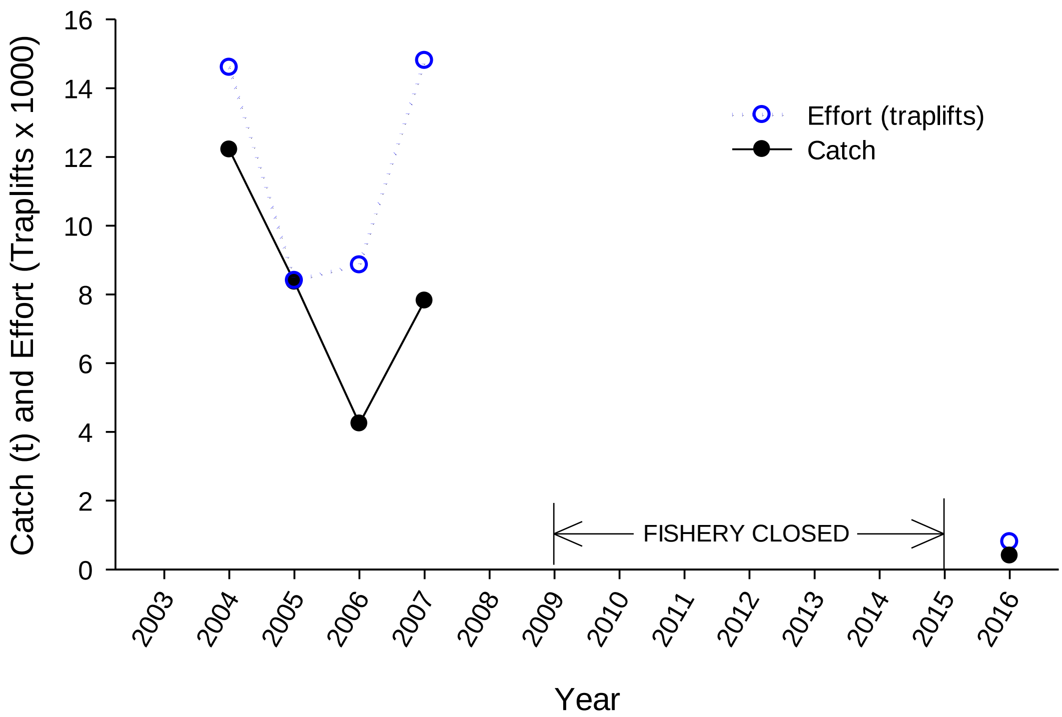


Figure 6.4 Historical annual commercial catch (tonnes) and fishing effort (traplifts x 1000) for the Exmouth Gulf Developing Crab Fishery between 2003-16.

Kimberley Crab Managed Fishery

Management arrangements for targeting mud crabs in the Kimberley region was first formalised in 1989, with the Minister of Fisheries approving a policy to allow Aboriginal communities to apply for authorisations to commercially fish for mud crabs, as well as Bêche-de-mer and trochus in their localised areas. From 1994 to 2005, commercial fishing for mud crabs was authorised through permissive conditions on Fishing Boat Licences. However, annual trap catch and effort for mud crabs remained low during this period, ranging between 0.1–2.8 t, and 447–5,250 traplifts, respectively (Figure 6.5). This was due either to the unviability of the fishery, the limitations of permissive conditions, or operators concentrating their efforts on other commercial fisheries.

Exemptions granting access to the Kimberley Developing Mud Crab Fishery (KDMCF) replaced the permissive conditions in 2006, issued under Section 7(3)(c) of the Fish Resources Management Act 1994 for 'the exploration or development of fisheries or the development of fishing technology'. Annual catch and effort in that year reached 9.3 t from 18,720 traplifts (Figure 6.5), with the majority of catch and effort attributed to the extensive exploratory efforts of a single fisher.

Catch and effort remained fairly stable during 2007–09 (~ 5-6 t from ~ 4,000–8,000 traplifts), before declining significantly to just 0.3 t from 274 traplifts in 2011 (Figure 6.5). This decline was due to a lack of effort by the majority of fishers, with one Exemption not being renewed. From this point, annual catch and effort in the KDMCF rapidly increased to peak at 15.3 t from 27,020 traplifts in 2015. However, annual catch and effort declined significantly in 2016 to just 609 kg from 1,664 traplifts (Figure 6.5). This represented the entire commercial catch of mud crab for WA in that year, with the majority of catch landed in Admiralty Gulf. Most of this catch (505 kg) was reported as brown mud crab (*S. olivacea*), with the remaining catch (104 kg) not identified to species level (*Scylla* spp.). The KCMF attained managed status in late 2018. Annual total catches of 3.2 and 7.4 t from 4,894 and 19,882 traplifts, respectively, were reported for 2018 and 2019 (CPUE = 0.66 and 0.37 kg/traplift; Figure 6.5)

There are currently three licences issued to commercial operators (600 trap limit), and three Exemptions issued to Aboriginal groups (total of 210 traps currently allocated of a maximum 600 traps). Further details of these current fishing activities are given in Section 6.1.3.

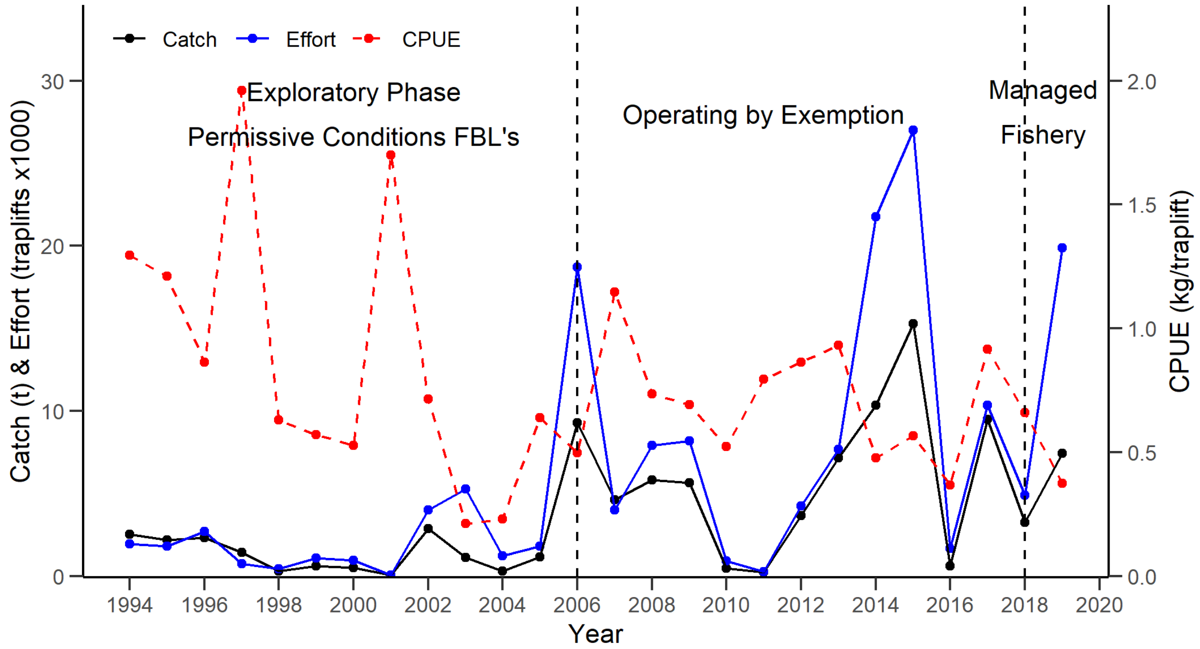


Figure 6.5 Historical annual commercial catch (tonnes), fishing effort (traplifts × 1000) and CPUE (kg/traplift) for trap fishers capturing mud crab in the Kimberley Managed Crab Fishery (formerly developmental fishery) between 1994 and 2019.

6.1.3 Current Fishing Activities

Pilbara Crab Fishery

A summary of key attributes of the current PCMF and the fishing fleet is provided in Table 6.1.

Table 6.1. Summary of key attributes of the Pilbara Crab Managed Fishery (PCMF) during 2019

Attribute	
Fishing methods	Hourglass crab traps
Fishing capacity	600 traps
Annual catch range	5.5 to 48.9 t (2010 to 2019)
Number of licenses	1
Number of vessels	2
Size of vessels	One 10 m vessel, one 17 m vessel
Number of people employed	4
Value of fishery	Level 1: <$1milion (2019 value; 19.327 t at approx. $6.16/kg beach price = $ 119,054)

There is currently one licence to fish commercially for blue swimmer, coral and three spot sand crabs in the PCMF. An increase of 200 traps (total 600 traps) was allocated in 2016, with the traps able to be used across two vessels. As a precautionary measure to this increase in traps numbers, an annual season closure between 15 August and 15 November (inclusive) was implemented to protect berried and mated pre-spawning female crabs.

The spatial boundaries and closure areas of the PCMF are displayed in Figure 6.6 and detailed in *Management Paper No 290 — Draft Management Plan for the Pilbara Crab Managed Fishery* (DPIRD, 2018). However, only a small portion of the area (<10%) is currently being fished, with most activity centred on and around Nickol Bay (Figure 6.6).

Markets for catch from the PCMF are primarily dependent on the state of the local WA market. While the catch has historically been sold through eastern states markets, recent declines in the WA total catch of blue swimmer crabs have made local markets more attractive with the catch currently transported to processors in Perth.

Commercial catch from the PCMF was approved for international export by the Australian Government Department of Environment and Heritage under the Environment Protection and Biodiversity Conservation Act (1999) in February 2006. However, no catch was exported between 2006 and 2011 and export approval was discontinued in August 2012.

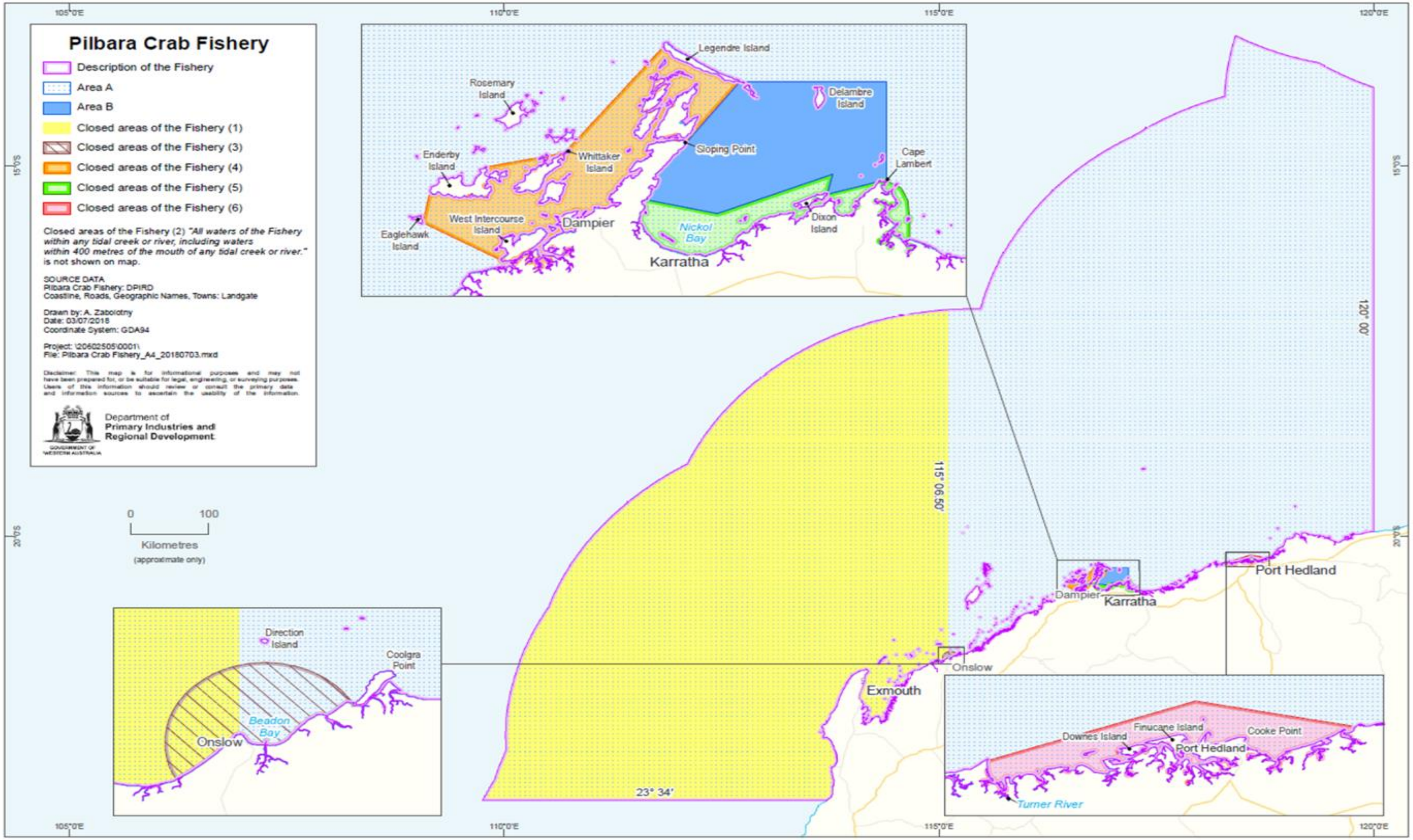


Figure 6.6. Boundaries and management zones of the Pilbara Crab Fishery.

Exmouth Gulf Crab Developing Fishery

A summary of key attributes of the current EGDCF and the fishing fleet is provided in Table 6.2.

Table 6.2. Summary of key attributes of the commercial Exmouth Gulf Developing Crab Fishery in 2019.

Attribute	
Fishing methods	Hourglass crab traps
Fishing capacity	300 traps
Number of exemptions	1
Number of vessels	1
Size of vessels	10.65 m
Number of people employed	2
Value of fishery	Level 1: <$1milion

There is currently one Exemption to fish commercially for blue swimmer, coral and three spot sand crabs in the EGDCF. The endorsement allows for the use of a total of 300 crab traps that can be operated from a single vessel and is valid for five years. A small amount of exploratory fishing was conducted in 2016, with 316 kg of blue swimmer crab landed from 852 traplifts (Figure 6.3). No catch has been reported from the EGDCF since 2016.

The crab catch from the EGDCF is sold through local markets.

The spatial boundaries and closure areas of the EGDCF are displayed in Figure 6.7 and detailed in the Instrument of Exemption.

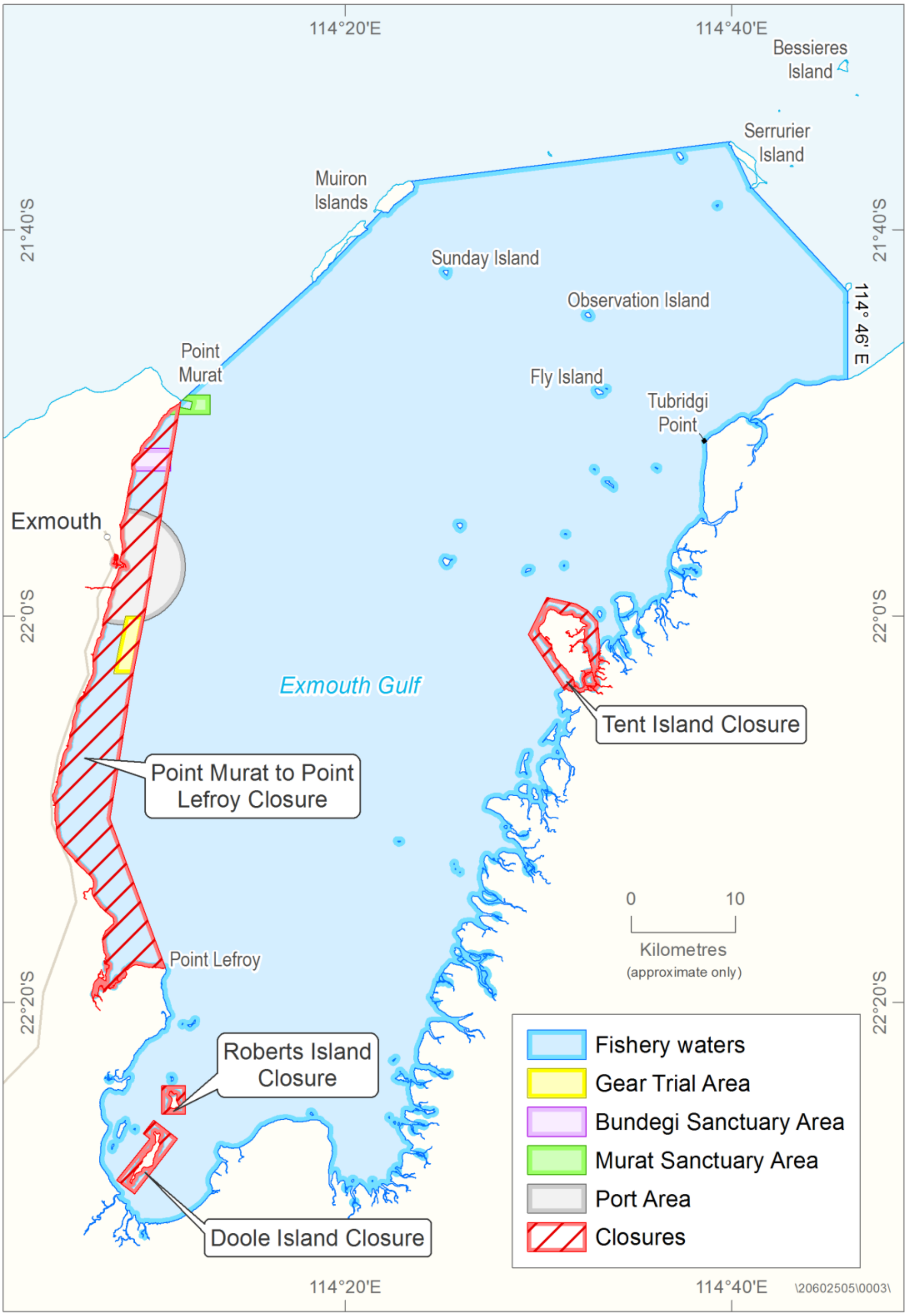


Figure 6.7. Boundaries and management zones of the Exmouth Gulf Developing Crab Fishery.

Kimberly Mud Crab: Commercial Fishery

A summary of key attributes of the current Kimberley Crab Managed Fishery and the fishing fleet is provided in Table 6.3.

Table 6.3. Summary of key attributes of the commercial Kimberley Crab Managed Fishery in 2019

Attribute	
Fishing methods	Rectangular and hourglass rigid traps
Fishing capacity	600 traps
Number of licences	3 (maximum of 6 operators)
Annual catch range	0.2 to 15.3 t (2010 to 2019), 2019 = 7.4 t
Number of vessels	4 (note, fishers typically use 1–2 smaller auxiliary vessels known as 'dories' to deploy and retrieve traps)
Size of vessels	Larger 'motherships' – up to 17 m Auxiliary vessels ('dories') – 4 to 6 m
Number of people employed	12-20
Value of fishery	Varies depending on catch and effort each year. 2019 estimate = $229,849; *Level 1 < $1 million* The average beach price for green (uncooked) mud crabs in the Kimberley was around $31/kg (value is based on a small proportion of total catch from an individual processor).

The KCMF (Figure 6.8) is currently a small fishery that uses purpose-designed crab traps to target the green mud crab (*Scylla serrata*) and the brown mud crab (*S. olivacea*) between Broome and Cambridge Gulf, with fishing effort concentrated around Cambridge Gulf, Admiralty Gulf, York Sound and King Sound (Johnston *et al.*, 2015a).

There are currently three commercial licences, each allocated 200 traps (600 trap total fishery allocation). Licence holders are able to lease or sell traps in units of 100, allowing for up to 6 commercial operators in the fishery.

The fishers generally operate between March to November to avoid summer and associated cyclone events, with May to September being the most productive months. Commercial operators generally fish on a part-time basis with most operating other endorsements including Kimberley Gillnet and Barramundi Managed Fishery Licences and fishing boat charters. Operators tend to fish remote waters for long periods of time from large mother ships, using small dinghies known as dories to enter mangrove estuaries with crab traps that are generally serviced each daylight high tide.

Catch is understood to be sold fresh locally when fishing occurs in close proximity to town centres, and frozen when fishing in remote locations for sale at local domestic markets.

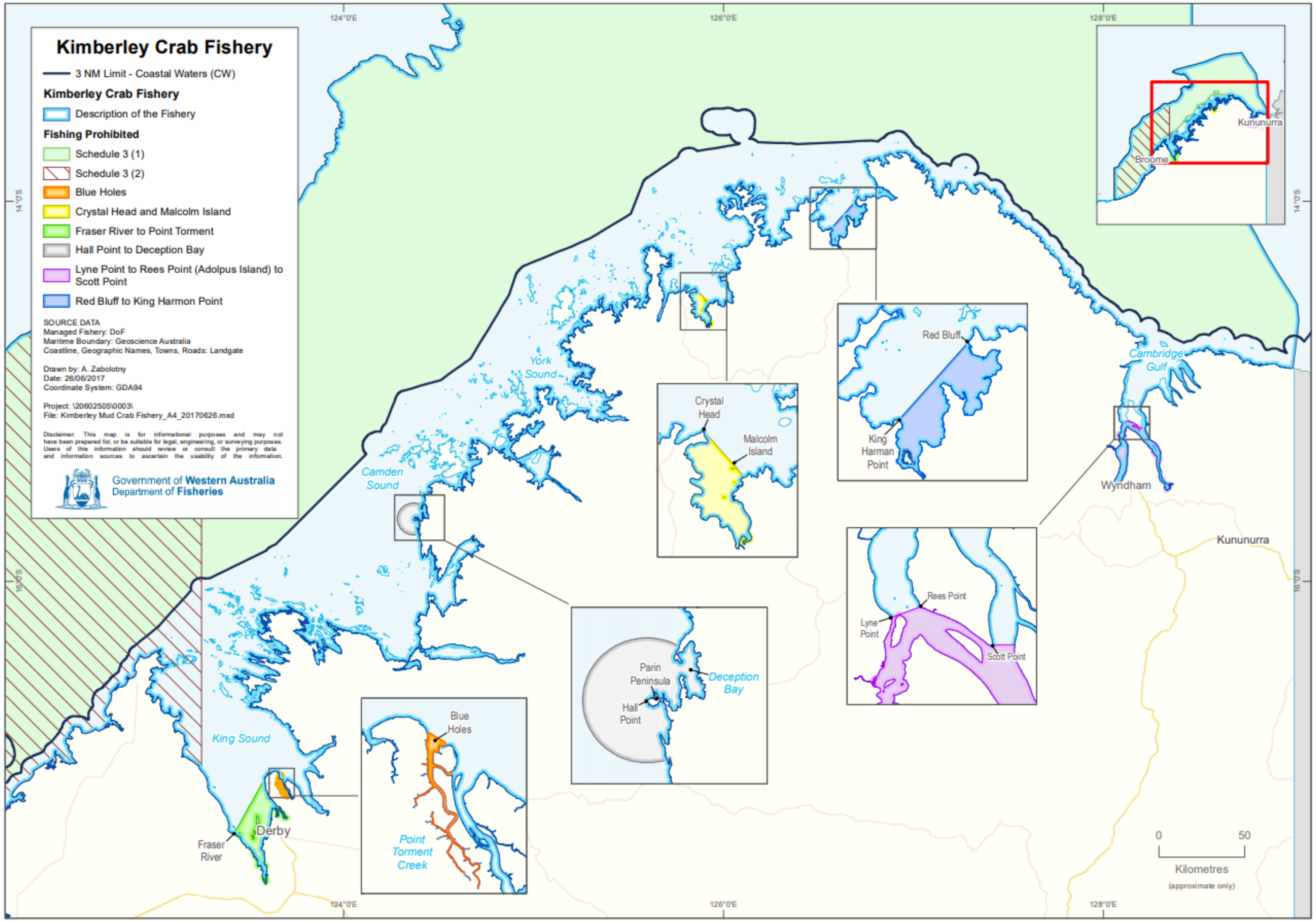


Figure 6.8. Boundaries of the Kimberley Crab Managed Fishery and its management for Commercial Licence holders.

Kimberley Mud Crab: Commercial activities by Aboriginal groups

Three Aboriginal groups have exemptions (Aboriginal Bodies Corporate Exemption Holders; ABCE) to take portunid crabs at commercial scale within the boundaries of the KCMF (Table 6.4); the Emama Nguda Aboriginal Corporation, the Milari Aboriginal Corporation and the Jabirr Jabirr Aboriginal Community. These groups are allocated differing trap quantities based upon their requirements and consultation with management. Currently 210 traps are allocated, with a maximum allowable allocation of 600 traps. Further exemptions and trap allocations can be granted to other Aboriginal groups on request. Fishing activities occur from boats (Licenced Fishing Vessels and occasionally unregistered vessels) and shorebased locations. Each Aboriginal group has a designated area of operation as outlined below.

Table 6.4. Summary of key attributes of mud crab fishing activities by Aboriginal Bodies Corporate Exemption Holders in the Kimberly region of the North Coast Bioregion during 2019.

Attribute	
Fishing methods	Rectangular and hourglass rigid traps
Fishing capacity	600 traps (210 traps currently allocated)
Number of exemptions	3 (access to other corporations can be granted on request)
Number of vessels	Unknown. Fishers may also operate from shore.
Size of vessels	Unknown
Number of people employed	Unknown
Value of fishery	Varies depending on catch and effort each year *Level 1 < $1 million* Average beach price for green (uncooked) mud crabs is around $31/kg. Aboriginal corporations may also trade and barter product adding value to the local communities that cannot be estimated.

The fishery boundaries for the Emama Nguda Aboriginal Corporation in the KCMF encompass the waters of King Sound within 2 nautical miles of the high water mark, east of a line running between the southernmost point of Valentine Island and the westernmost point of the southern peninsula of Point Osborne (Figure 6.9), excluding:

all the waters bounded by a line commencing at the southern shore of the mouth of the Fraser River and following the mainland generally south easterly then northerly along the high water mark, to the point locally known as Point Torment, north of Derby, and then in a straight line back to the point of commencement;

all waters of the creek, and within a 500m radius of the mouth of the creek known locally as Blue Holes, north of Derby.

The fishery boundaries for the Milari Aboriginal Corporation in the KCMF encompass the waters, creeks and tributaries of Camp Inlet, south of a line drawn in an easterly direction along the geodesic from the intersection of 16º 56.207’ south latitude and the high water mark on the western side of Inlet Entrance (122º 28.112’ east longitude) to the intersection of 16º 56.207’ south latitude and the high water mark on the eastern side of Inlet Entrance (122º 29.135’ east longitude) (see Figure 6.10).

The area of operation for the Jabirr Jabirr Community encompasses all WA waters including rivers, tidal creeks, tributaries and pools, between 16°59.72’ south latitude and 17°21.35’ south latitude and extending to the outer limit of the coastal waters of the State (Figure 6.11).

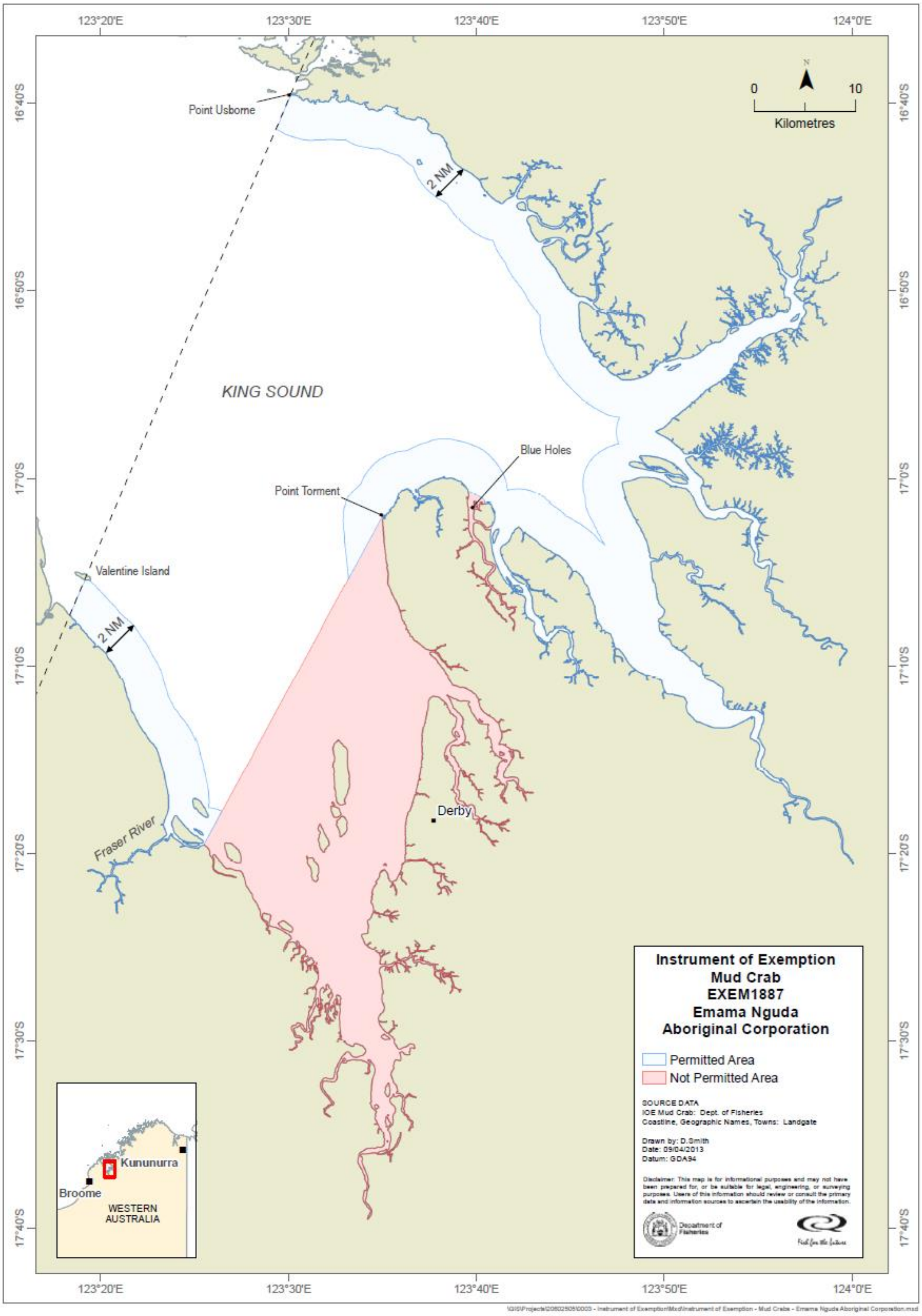


Figure 6.9. Kimberley Mud Crab areas of operation for the Emama Nguda Aboriginal Corporation.

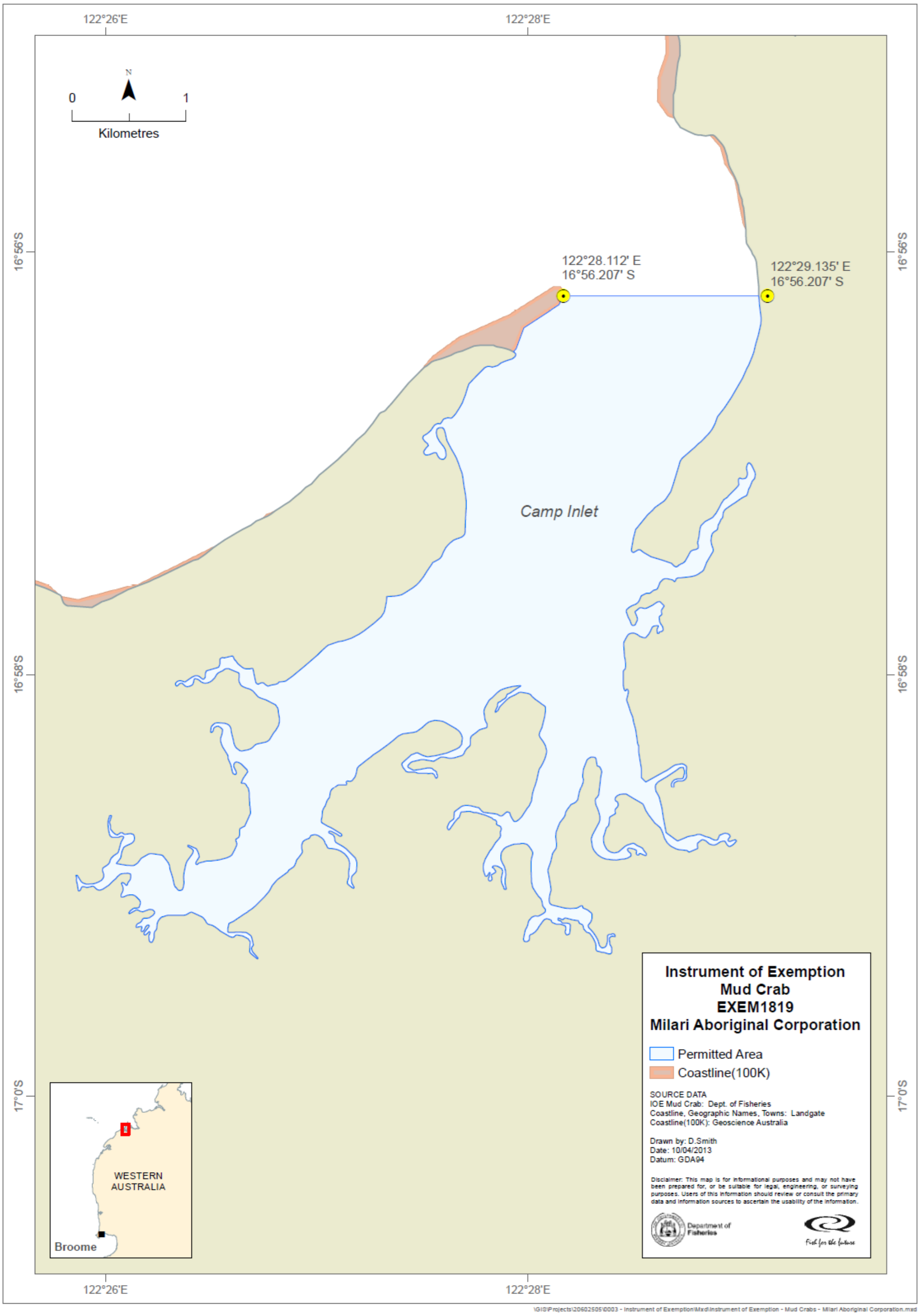


Figure 6.10. Kimberley Mud Crab areas of operation for the Milari Aboriginal Corporation.

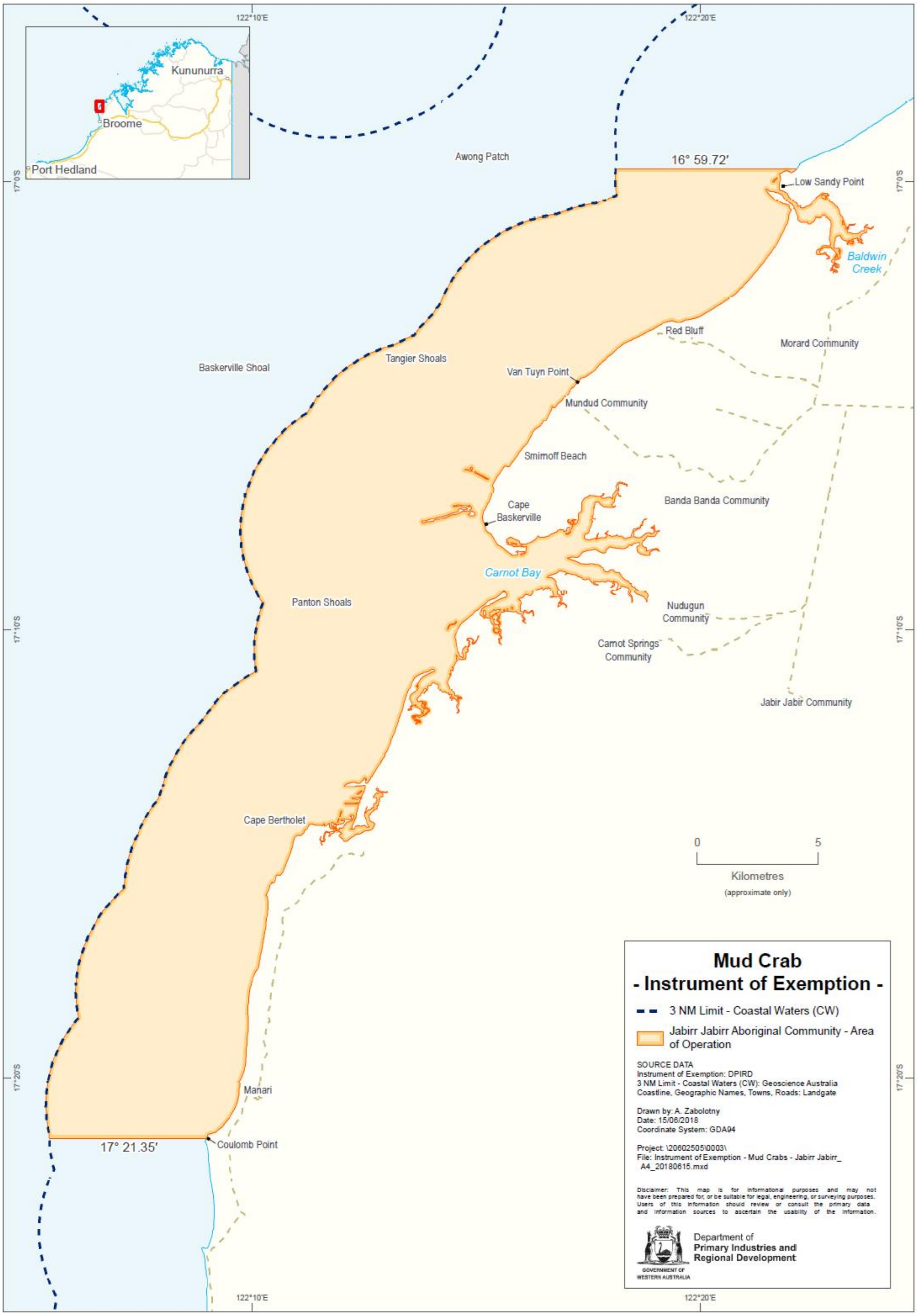


Figure 6.11. Kimberley Mud Crab areas of operation for the Jabirr Jabirr Aboriginal Community.

6.1.4 Fishing Methods and Gear

Blue swimmer crab

Commercial fishers in the PCMF and EGDCF use purpose-designed ‘hourglass’ crab traps for targeting blue swimmer crabs (Figure 6.12). These are netted enclosures comprising two rings which are separated from one another, either through the use of a positively buoyant upper ring (known as a pneumatic ring) and a weighted lower ring (Figure 6.12a), or by three to four rigid vertical struts (Figure 6.12b). The waist of the trap is constricted such that it resembles an hourglass. Traps are usually collapsible and may have one, two or three pairs of opposing side entry funnels.

Historically, given the developmental nature of both fisheries, there have been no restrictions on the size of traps or mesh size. Most fishers used traps approximately 1 – 1.3 m in diameter with 75 mm (3 inch) mesh, as this mesh size has proven most efficient in retaining legal crabs while allowing undersize crabs to escape. However, prior to use, the design of crab traps must be approved by the Department of Primary Industry and Regional Development (DPIRD). Following a submission from the trap fisher in the Pilbara, approval was given by the Department of Fisheries (DoF), WA, in May 2017 to use commercially produced hourglass crab traps imported from Queensland. These traps are similar to those currently used, but do not have the upper pneumatic ring and are held open by four plastic supports; and have four separate funnel-type entry gaps around the centre (Figure 6.12). Furthermore, a comparative study of catchability between the two types of traps showed that the Queensland traps, which are enclosed in 50 mm (2 inch) mesh, retained significantly more undersize crabs and bycatch species (e.g. finfish). Consequently, the fisher is required to install 75 mm mesh panels on the imported traps to address this issue.

Since the PCMF attained managed status, hourglass traps in that fishery must now conform to the following specifications; no more than 1200 mm diameter, no greater than 550 mm trap height and mesh size ≥ 75 mm.

The traps may be set individually attached to a surface float, or set in lines with traps joined by no less than 20 m of rope between each trap and with surface floats located at each end of the line of traps. Surface floats must be branded or stamped with the Licenced Fishing Boat number of the relevant authorised boat. Each trap can only be pulled once in every 24 hours.

The fisher in the PCMF uses baited pots to capture target crab species. When available (approx. two-thirds of the time), the fisher uses locally caught mixed whole fish sourced from the Nickol Bay Prawn Managed Fishery (NBPMF). The NBPMF has been recognised as meeting the national *Guidelines for the Ecologically Sustainable Management of Fisheries* since 2004. The fisher reported using approx. 600 kg per week when using this bait, equating to approx. 86 kg of bait per day (Table 6.5).

Other bait used when local fish was not available includes North Sea herring (*Clupea harengus*), locally-caught pilchards (*Sardinops* spp.) and scaly mackerel (*Trachurus declivis*). During 2009–2010, the fisher used approx. 70 kg per day of mixed herring and pilchards. Since 2011, these species have been replaced with scaly mackerel (approx. 70 kg per day), which is caught by the exemption holder using a separate endorsement he holds for netting in Cockburn Sound, frozen and transported north (Table 6.5). In 2012, 2178 kg of bait was used in the PCMF. No data on bait type or quantity exists for the EGDCF.

Table 6.5. Annual catch, effort and bait used by Exemption Holder in the Pilbara Crab Fishery 2008 – 2016*. Days fished with each bait type are an estimate based on usage rates indicated by the fisher (i.e. 66 % usage of mixed fish and 33 % usage of herring/pilchard or scaly mackerel). Conversion rate indicates the amount of bait used (kg) to catch one kg of crab.

Year	Total Days Fished	Effort (traplifts x 1000)	Catch (kg)	Bait Type	Days Fished with each Bait Type	Amount of Bait used per Day (kg)	Total Bait Used (kg)	Conversion Rate
2008	122	35.8	29078	Mixed Fish	81	86	6994	0.2
				Herring/Pilchard	41	70	2847	0.1
2009	150	45.0	19403	Mixed Fish	100	86	8600	0.4
				Herring/Pilchard	50	70	3500	0.2
2010	107	32.1	27015	Mixed Fish	71	86	6134	0.2
				Herring/Pilchard	36	70	2497	0.1
2011	57	16.2	14558	Mixed Fish	38	86	3268	0.2
				Scaly Mackerel	19	70	1330	0.1
2012	27	8.1	5518	Mixed Fish	18	86	1548	0.3
				Scaly Mackerel	9	70	630	0.1
2013	61	8.275	15542	Mixed Fish	61	86	5246	0.3
2014	101	23.41	41500	Mixed Fish	101	86	8686	0.2
2015	202	42.485	47891	Mixed Fish	202	86	17372	0.4
2016	139	44.46	35498	Mixed Fish	139	86	11954	0.3

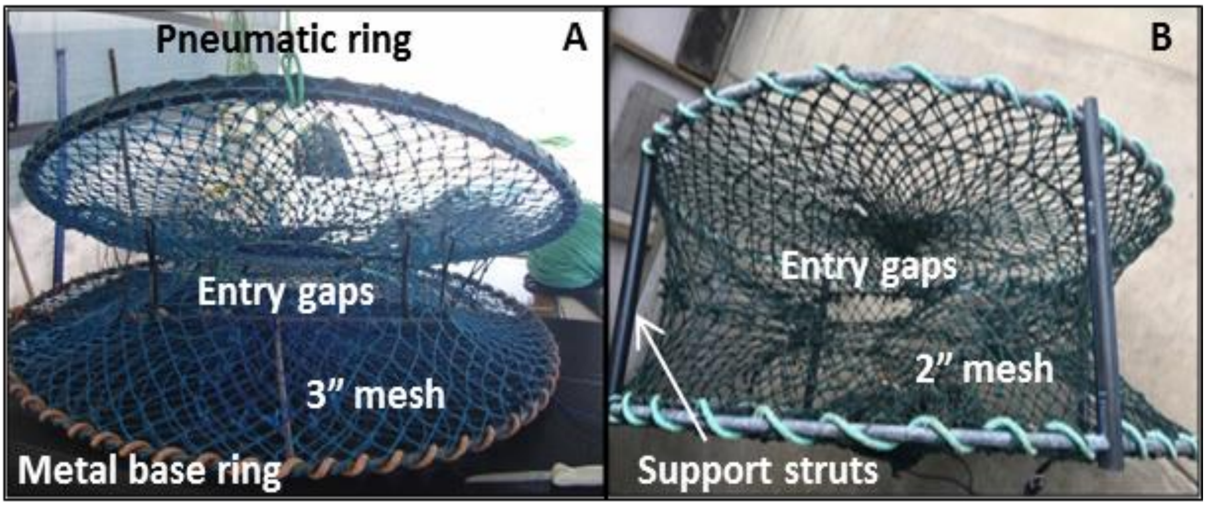


Figure 6.12. Commercial hourglass crab traps used in the Pilbara and Exmouth Gulf Developing Crab Fisheries. A) Traps traditionally used in the PCMF and EGDCF; B) Traps imported from Queensland that are now also used in the PCMF.

Mud Crab

Operators in the KCMF tend to fish remote waters for long periods of time from large mother ships, using small dinghies known as dories to enter mangrove estuaries. The KCMF uses purpose-designed crab traps that target larger (legal sized) mud crabs, with the overall trap design and large mesh size allowing sub legal mud crabs and non-targeted by catch species opportunity to escape the trap.

There are two styles of crab trap permitted for use in the KCMF, a rectangular trap and a round trap. The rectangular design must not exceed 1000 mm length, 600 mm width and 300 mm height (external measurements), and must have a minimum mesh size of 50 x 70 mm. Rectangular traps are usually constructed from rigid metal mesh (e.g. steel) and have 2 openings for crabs to enter (Figure 6.13). Round traps are constructed with flexible nylon mesh (minimum 50 mm diameter knot to knot) and must not exceed 500 mm high; 1200 mm diameter, and have no more than four (4) openings for crabs to enter the trap (Figure 6.14). Management regulations further stipulate that round traps constructed with mesh <75 mm must also have at least 2 escape gaps (circular, >90 mm diameter or rectangular, 140 mm wide and 40 mm high).

Any crab trap that is used in the KCMF must be (a) attached a surface float upon which is branded or stamped in legible characters the Licensed Fishing Boat number of the authorised boat which is being used to fish in the Fishery; or (b) be attached to another crab trap, to which a surface float of a type mentioned in (a) above must be attached at each end of the line of crab traps.

All traps set by operators in the KCMF must be pulled and emptied at least once in any 48 hour period, with crab traps generally checked each daylight high tide. Fishers are required to report all lost traps to the Department.

Fishers in the KCMF use a variety of bait (Table 6.6). Some of the fishers in the KCMF also hold licences to fish in the Kimberley Gillnet and Barramundi Managed Fishery (KGBF) and may use fish frames and/or heads from barramundi or threadfin captured under their KGBF licences. Other bait is purchased from local suppliers.

Fishers use approximately 300 to 750 g of bait per trap, depending on the bait being used. In 2012, fishers used 162 kg of a mixture of horse, beef and barramundi frames and 1463 kg of threadfin and barramundi heads (Table 6.6).

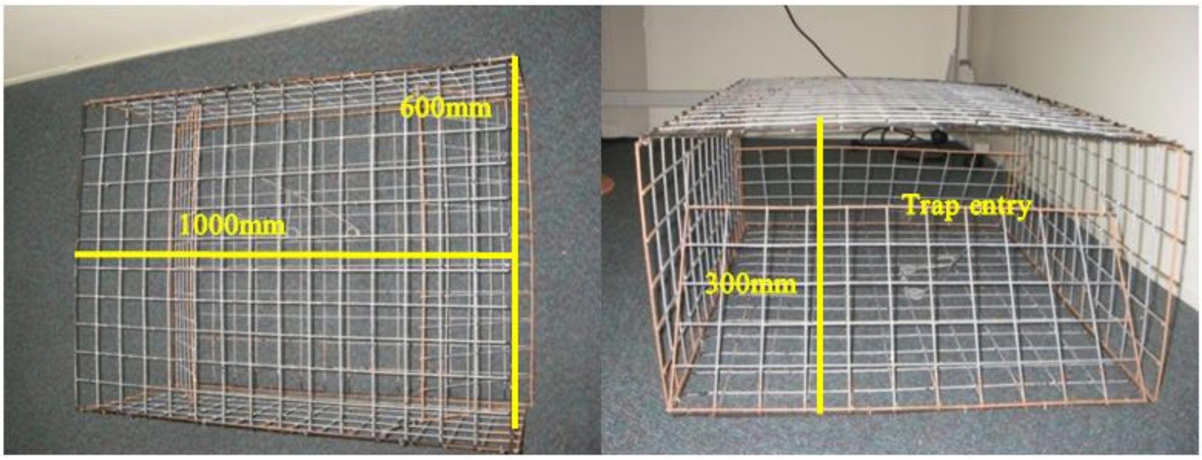


Figure 6.13. Rectangular trap design used in the Kimberley Crab Managed Fishery. Sizes vary slightly between exemption holders.

Figure 6.14. Round trap design used in the Kimberley Crab Managed Fishery. Sizes vary slightly between exemption holders.

Table 6.6. Annual catch, effort and bait used in the Kimberley Developmental Crab Fishery from January 2006 to June 2017. Conversion rate indicates the amount of bait used (kg) to catch one kg of crab. No bait data have been collected since the fishery transitioned to Managed status in 2018.

Year	Total Days Fished	Average No. of Traps per Day	Total No. of Traps per Year	Total Catch (kg)	Bait Type	Bait Used per Trap (g)	Total Bait Used per Year (kg)	Conversion Rate
2006	112	80	4580	2932	Horse, Beef, Barramundi frames, Threadfin and Barramundi heads	300-750	2063	0.7
	67	210	14070	6361	Slimy Mackerel	500	7035	1.1
2007	100	40	4000	4599	Threadfin and Barramundi heads	750	3000	0.7
2008	46	70	3220	3366	Horse, Beef and Barramundi frames	300	966	0.3
	60	30	1800	2143	Threadfin and Barramundi heads	750	1350	0.6
	12	200	2400	297	Slimy Mackerel	500	1200	4.0
2009	61	100	6100	4356	Horse, Beef and Barramundi frames	300	1830	0.4
	65	30	1950	1293	Threadfin and Barramundi heads	750	1463	1.1
	45	40	896	468	Bull and Donkey Meat	-	337	0.7
2010	17	15	274	218	Bull and Donkey Meat	300-500	128	0.6
2011	28	82	2296	2814	Donkey Meat	500	689	0.2
2012	65	30	1950	855	Horse, Beef and Barramundi frames	300	585	0.7
	99	69	7650	7136	Threadfin and Barramundi heads	750	5738	0.8
2013	167	98	21745	12872	Horse, Beef and Barramundi frames	750	16309	1.3
2014	220	114	27020	15266	Horse, Beef and Barramundi frames	70	20265	1.3
2015	50	33	1664	609	Horse, Beef and Barramundi frames	750	1248	2.0
2016	34	133	6800	6300	Horse, Beef and Barramundi frames	750	5100	0.8
2017*	112	80	4580	2932	Horse, Beef and Barramundi frames	750	2063	0.7

6.1.5 Susceptibility

Blue swimmer crab

The Pilbara coastline spans more than 400 km, with suitable habitat for blue swimmer crabs found in the embayments and estuaries of most of this area and up to several kilometres out to sea. However, effort in the fishery is relatively low and most activity is centred on and around Nickol Bay. Consequently, only a small portion of the distribution of the exploited stock (<10%) is currently being fished.

The EGDCF covers some 40,000 km^2, most of which is suitable habitat for blue swimmer crabs. However, the low level of effort currently being expended in this fishery means that only a small portion of the distribution of the exploited stock is currently being fished.

The purpose-designed hourglass traps used in the PCMF and EGDCF deploy on the ocean floor, and are retrieved to the surface by a rope attached to a surface float. Consequently, the encounter-ability of the targeted blue swimmer crab stock is high as they are primarily a benthic dwelling species. Furthermore, traps are also baited increasing the likelihood of crabs to encounter and enter the traps. Traps are selective for both adult and juvenile crabs, however, the 3 inch mesh size used allows the majority of undersize crabs and by catch to escape.

The Nickol Bay, Onslow and Exmouth Gulf Prawn Managed Fisheries are all trawl fisheries where blue swimmer crabs are taken as byproduct. Trawl fleets use demersal otter trawl gear for Tiger, King and Endeavour prawns with higher opening headrope for mid water schooling species such as banana prawns (fliers). Therefore there is a high encounterability of blue swimmer crabs by trawl gear as crabs in the substratum and those that swim up into the water column during trawling would be captured.

Blue swimmer crabs can survive out of water for up to several hours provided that their gills remain moist. As regulations stipulate that PCMF and EGDCF commercial trap fishers must return berried and undersize crabs to the water within 5 minutes of being landed, mortality rates of non-retained catch are extremely low.

Mud crab

The KCMF spans some 12,000 km of Kimberley coastline, with suitable habitat for the green mud crab, and to a lesser extent brown mud crab, likely to cover much of this area. However, effort in the fishery is very low with most activity concentrated around Cambridge Gulf, Admiralty Gulf, York Sound and King Sound. Consequently, only a small portion of the distribution of the exploited stock (<10%) is likely to be currently fished.

The purpose-designed crab traps used in the KCMF deploy on the bottom of creek beds and tributaries, and are retrieved to the surface by a rope attached to a surface float. Consequently, the encounter-ability of the targeted mud crab stock is high as they are primarily a benthic dwelling species. However, the configuration of traps and mesh size used allows the majority of sub-legal mud crabs and non-targeted bycatch species the opportunity to escape the trap.

Mud crabs can survive out of water for up to several days provided that their gills remain moist. As regulations stipulate that operators in the KCMF must ensure that totally protected crab or any fish other than crab are released to the waters from which it was taken within 5 minutes of being landed, and not pull any trap before the totally protected crab or fish is released to the waters from which it was taken, mortality rates of non-retained catch are extremely low.

6.2 Recreational/Charter sector

6.2.1 History of Development

Blue swimmer crab

Recreational fishing for blue swimmer crabs has been undertaken in bays and estuaries along the Pilbara coast for decades, with most effort historically centred in coastal waters around the town sites of Onslow, Karratha and Port Hedland.

Although not regarded as a major recreational crab fishery, recreational fishing for blue swimmer crabs has been undertaken in the nearshore waters of Exmouth Gulf for decades, with most effort historically centred in coastal waters around the town site of Exmouth and along the western shore of the gulf.

Boat or shore-based recreational fishers targeting blue swimmer crabs in WA may use hand-held scoop nets, a blunt wire hook, drop nets, or collect crabs by hand.

A 12-month creel survey of recreational boat-based and shore-based fishing in the Gascoyne bioregion of Western Australia was conducted between April 1998 and March 1999 (Sumner *et al.*,, 2002). The survey provided a total recreational blue swimmer crab catch estimate for boats launched from public boat ramps in the bioregion over the 12-month period of 3,870 retained crabs (SE ± 1,154 crabs) and 2,892 released crabs (Sumner *et al.*,, 2002), equating to ~1 t retained catch by weight (at 250g per crab). However, all of this catch was recorded in Shark Bay with no blue swimmer crabs captured by either boat or shore-based fishers surveyed in Exmouth Gulf.

A similar creel survey was conducted along the Pilbara coast (Onslow to Broome inclusive) between December 1999 and November 2000 (Williamson *et al.*, 2006). The creel survey estimated the recreational catch of blue swimmer crabs along the Pilbara coast between December 1999 and November 2000 to be 22 t, with most of the catch (19 t) taken from Nickol Bay (Williamson *et al.*, 2006). This represented the majority of the catch from Nickol Bay in that year, as commercial operations targeting blue swimmer crabs in the area did not begin until the following year. However, it should be noted that the boat-ramp surveys were conducted between 10 am – 6 pm at all boat ramps other than the three surveyed around Dampier (which were also sampled between 6 am – 10 am). Given that a recent survey in Cockburn Sound during the 2009/10 crab season found that more than half of the recreational catch came from the period between 5.30 – 9 am (Johnston *et al.*, 2012), it is possible that the recreational catches presented for the Pilbara coast and Nickol Bay are under-estimated.

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 in the NRFS, with a national harvest of approximately 3.9 million crabs (Henry and Lyle, 2003). Harvest levels were greatest in Western Australia (57% of total). The majority of the harvest was taken using pots or traps (78%) with hand collection, nets, and line fishing accounting the bulk of the remainder. Just over half (52%) of the blue swimmer crabs were captured in estuarine waters, coastal waters contributed a further 46% and there was only a very minor (2%) offshore harvest component. Boat fishing activities accounted for the majority of the crabs harvested (77%) (Henry and Lyle, 2003).

A boat-based biennial recreational fishing survey (i-Survey) conducted by DPIRD since 2011/12 uses three complementary components to collect information on fishing catch, effort, location and other demographic information: off-site phone diary surveys, on-site boat ramp surveys and remote camera monitoring. These surveys between 2011/12 and 2017/18 have estimated annual recreational harvests of blue swimmer crabs in each the NCB and GB to be from 1–5 t (Ryan *et al.*, 2019).

Mud crab

Fishing for mud crabs represents an iconic recreational fishing experience in the Kimberley region, with fishing occurring primarily in shallow waters of associated mangrove tidal creeks and near shore embayments in and around the townships of Broome, Derby (King Sound) and Wyndham (Cambridge Gulf). Consequently, the species is considered to have a high community value.

A 12-month creel survey of recreational boat-based and shore-based fishing was conducted along the Pilbara coast (Onslow to Broome inclusive) between December 1999 and November 2000 (Williamson *et al.*, 2006). The estimated total recreational catch of mud crab in the Pilbara during the 12-month survey period was 49,500 crabs, with 25,500 (21 t) crabs retained and 24,000 released. The majority of this catch were green mud crabs, with 19,000 (17 t) retained and 13,500 released, compared to 6,500 (4 t) brown mud crabs retained and 10,500 released. The majority of mud crabs were taken by boat-based fishers, accounting for 93% and 99% of all green and brown mud crabs, respectively (Williamson *et al.*, 2006).

A national survey of recreational and indigenous fishing was conducted in Australia during 2000–01 by Henry and Lyle (2003). A total of about 0.8 million mud crabs were harvested, the greatest quantity taken in Queensland (71%), with Western Australia (12%), the Northern Territory (10%) and New South Wales (6%) of secondary importance. Pots and traps were the primary capture method for mud crabs, accounting for 92% of the catch. A relatively small component of the catch was taken using lines and hand collection (using hooks or gaffs). Based on harvest proportion, boats represented main fishing platform used to capture mud crabs (74%), with the fishery concentrated in estuarine (74% of the harvest) and to a lesser extent inshore coastal waters (24%) (Henry and Lyle, 2003).

Mud Crab in the North Coast was steady at 2.5 t (95% CI 2–3) in 2017/18 compared with 2.5 t (95% CI 2–3) in 2015/16, but lower than 6.5 t (95% CI 5–8) in 2013/14 and 7 t (95% CI 5–9) in 2011/12 (Ryan *et al.*, 2019). North coast mud crab represented 92% of the estimated statewide total. The average weight of crabs retained by recreational fishers in the North Coast Bioregion (NCB) was determined to be 0.607 kg and 1.09 kg for brown (*S. olivacea*) and green (*S. serrata*) mud crabs, respectively (Ryan *et al.*, 2019).

The charter fishery has operated since 2001, and occasionally targets mud crabs in the Kimberley region. Tour participants must adhere to DPIRD charter fishing regulations, which replicated existing recreational daily bag and size limits. However, fishing tour legislation has recently changed so that specific boundary and operational rules are now dependent on the tour operator's licence. The number of charter fishing tours where maximum bag limits may be taken by tour participants has been reduced, with the focus now on fishing eco-type tours where fish species can be caught and consumed during the course of the tour only. Operators are required to record the retained catch and effort from their charter operations on a DPIRD daily trip return sheet for each day fished along with a monthly cover sheet (see Section 8.2.2 for example of data sheets). As the Kimberley region is highly susceptible to cyclonic events between November and April, charter fishing operators tend to operate between April and November in order to provide clients with the most favourable fishing conditions. From 2006 to 2015, between 15 and 25 charter vessels (annual mean of 19 vessels) operated annually in the Kimberley region and reported fishing for mud crabs between 111 and 201 charter fishing trips (annual mean of 154 fishing trips) per year. Annual retained catches of mud crab by charter operators over this period ranged from 614 to 1,396 crabs (annual mean of 1,032 mud crabs), compared with a range of 236 to 1,270 crabs released.

6.2.2 Current Fishing Activities

Blue swimmer crab

Recreational fishing for blue swimmer crabs in Western Australia is managed through a series of input and output controls. As with the commercial sector, the principal management tool employed to sustain an adequate breeding stock involves maintaining minimum size limits well above the size at sexual maturity such that every female crab has at least one spawning season to produce eggs. The State minimum legal recreational size limit is set at 127 mm carapace width (CW), which is substantially above the size at 50% maturity in the region of 105 and 100 mm for males and females, respectively (Chandravapan *et al.*, 2017). Further protection is provided to the breeding stock through a ban on keeping berried females.

Shore-based recreational crabbers, fishers on non-powered vessels and divers are subject to a possession limit of 20 crabs per fisher per day in the Gascoyne Bioregion (GB) and NCB of Western Australia. 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. In the GB and NCB the licence entitles fishers to a maximum catch of 40 crabs per powered boat per day when there are two or more people on-board holding RFBLs (or one person’s maximum daily bag limit of 20 if only one licensed fisher is on board).

There are no specific seasonal or spatial closures for recreational fishers targeting blue swimmer crabs in the NCB or GB, other than designated marine reserves.

NCB and GB blue swimmer crab fisheries are considered to provide a high social amenity to recreational fishing and diving.

Mud Crab

Recreational and charter fishing for mud crab represents an iconic fishing experience in northern WA. The recreational catch of mud crabs in the Kimberley region is considered to be relatively low due to the small regional population and large area of coastline. Nevertheless, the fishery is of significant importance to local communities and tourist operators. The recreational and charter fishery has a high social value with many tourists and seasonal visitors interested in experiencing line fishing for sport fish such as barramundi and capturing large mud crabs synonymous with the Kimberley region.

Minimum size limits are the same as the commercial fishery (150 mm CW for green mud crabs and 120 mm CW for brown mud crabs) and egg-bearing females must be returned to the water. A total of 5 legal-sized mud crabs are permitted to be retained per fisher per day or 10 mud crabs per boat when 2 or more people are on board a powered vessel and both hold a valid RFBL.

6.2.3 Fishing Methods and Gear

Blue swimmer crab

Restrictions govern the gear types that can be used to take blue swimmer crabs in Western Australia. Boat or shore-based recreational fishers can legally catch crabs by:

- Hand (*e.g.* while diving or snorkelling).
- Wire hook – hand-held blunt, wire hooks must not be capable of piercing the crab.
- Drop net – no wider than 1.5 metres in diameter. There is a maximum limit of 10 drop nets per person or 10 drop nets per boat, regardless of how many people are aboard.
- Scoop net – hand-held wire or plastic scoop nets must be bowl-shaped, made of rigid mesh that is not capable of entangling a crab, have an internal diameter no bigger than 375 mm and a depth of no more than 210 mm.

The primary methods used by recreational blue swimmer crab fishers in north-western Australia are drop netting and scoop netting (Figure 6.15). Recreational fishers targeting blue swimmer crabs with drop nets use a wide variety of baits, including whole fish (e.g. mullet, herring, pilchards), fish parts (head, frames, wings), chicken necks or carcasses and beef spleen.

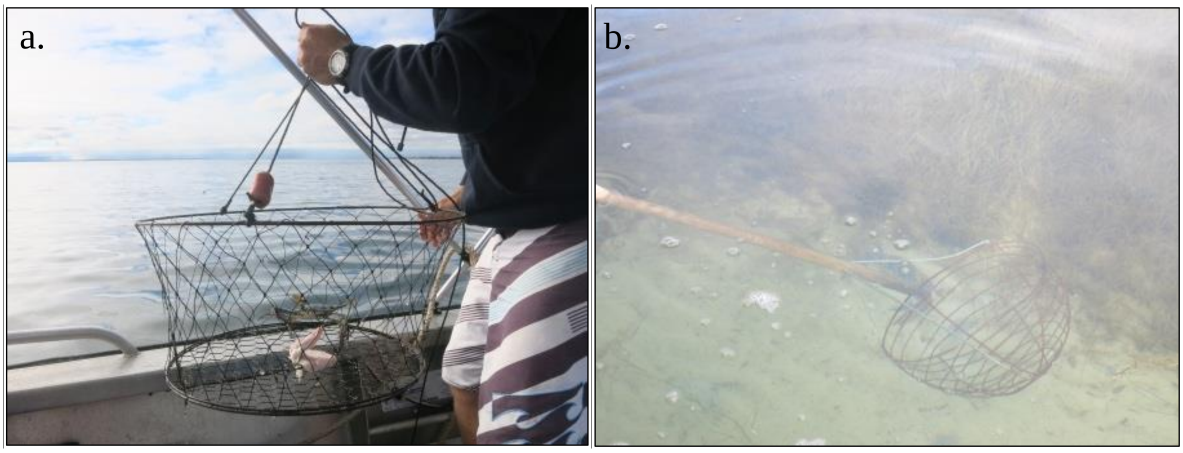


Figure 6.15. The primary methods used by recreational blue swimmer crab fishers in the North and Gascoyne Coast Bioregions of Western Australia. (a) drop net (b) scoop net.

Mud crab

Recreational fishers and charter operators utilise a variety of methods to target mud crabs, including drop nets (maximum of 10 drop nets per boat or per shore-based fisher), scoop nets and by hand/hook. Drop nets are generally deployed from vessels, with scoop and hand/hook collection being used by shore based fishers. An RFBL is required if fishing from a powered vessel.

Fish and fish frames, or combinations of chicken, kangaroo, horse and camel meat are commonly used by recreational fishers to bait drop nets when fishing for mud crabs.

6.2.4 Susceptibility

Blue swimmer crab

As recreational effort in the fishery is considered to be comparatively low in the Pilbara and Exmouth, only a small portion of the distribution of the exploited stock (<10%) is assumed to be fished.

All three recreational crabbing methods used in WA bring fishers into immediate contact with the target species. SCUBA divers, snorkelers and fishers using scoop nets interact directly with their target crabs, while drop nets are designed to lie flat on the benthos where most crabs dwell. Consequently, the encounter-ability of fishers with their target species using any permitted method is high. However, this immediate contact means that divers, snorkelers and scoopers can select against berried or undersize crabs at the point of capture.

Blue swimmer crabs can survive out of water for up to several hours provided their gills remain moist. As regulations stipulate that recreational fishers in WA must return berried and undersize crabs to the water immediately before attempting to catch another crab, mortality rates of non-retained catch are extremely low.

Mud crab

As the vast majority of the Kimberley coastline is extremely remote, recreational fishing for mud crabs tends to be confined to the shallow waters of mangrove tidal creeks and near shore embayments in and around the townships of Broome, Derby (King Sound) and Wyndham (Cambridge Gulf). Consequently, only a small portion of the distribution of the exploited stock is assumed to be fished by recreational fishers and charter tour operators.

All three recreational mud crabbing methods used in WA bring fishers into immediate contact with the target species. Fishers using scoop nets and wire hooks interact directly with their target crabs, while drop nets are designed to lie flat on the benthos where most crabs dwell. Consequently, the encounter-ability of fishers with their target species using any permitted method is high.

However, this immediate contact means that fishers using scoop nets and hooks can select against berried or undersize crabs at the point of capture. Similarly, crabbers using drop nets are able to return undersized and berried female crabs immediately after being landed.

Mud crabs can survive out of water for up to several days provided that their gills remain moist. Consequently, survival rates post capture are likely be high due to the short time set and pull of drop nets and quick turnover of scoop/hand hook combined with shallow water depth reducing handling times. The only foreseeable issue would be due to fishers practising upsizing (exchanging larger caught animals with smaller retained ones to maintain bag limits). As regulations stipulate that recreational crabbers in WA must ensure that totally protected crab or any fish other than crab are released to the waters from which it was taken within 5 minutes of being landed, and not pull any drop net before the totally protected crab or fish is released to the waters from which it was taken, mortality rates of non-retained catch are extremely low.

6.3 Customary Fishing

No regulated customary fishing for blue swimmer crabs occurs in either the Pilbara Region or in Exmouth Gulf. While some customary fishing for blue swimmer or mud crabs is likely to occur in the Kimberley Region as a source of sustenance for local communities, there is no data reported to DPIRD for this traditional fishing.

A nation-wide study in 2000/01 by Henry and Lyle (2003) reported on the indigenous catch of blue swimmer and mud crabs in northern Australia (Broome in WA to Cairns in Queensland). The survey estimated that the harvest of mud crabs by indigenous fishers from Broome (WA) to Cairns (Queensland) between July 1st 2000 and June 30th 2001 was 108,000 crabs, with 9,015 of these captured in the Kimberley region of WA. Of the 108,000 mud crabs harvested by indigenous fishers, 66% were caught in inshore waters (<5 km but >500 m from coastline) compared to 34% from coastal waters (<500 m from coastline but < 1 km up river). The pattern of this recreational harvest reflected the distribution of mud crabs in tropical and subtropical waters. The major portion of the indigenous mud crab harvest was taken by hand collection methods (63,000 crabs) (58% of total) and spears (29,000 crabs)

(27%). The survey also estimated 2,119 blue swimmer crabs were caught by indigenous fishers in northern Australia, with 592 of these crabs caught in the Kimberley region of WA over the 12-month survey period (Henry and Lyle, 2003).

6.4 Illegal, Unreported or Unregulated Fishing

There is no known Illegal, Unreported or Unregulated (IUU) fishing of either blue swimmer crab or mud crab stocks in the NCB or in Exmouth Gulf. The management arrangements for the NCB and GB are enforced regularly by DPIRD’s Fisheries and Marine Officers in the district offices. Compliance is monitored via both at-sea and on-land inspections, with the majority of checks being carried out on land at the point of landing (boat ramps).

Current risks to enforcement are considered to be low for NCB crab fisheries and in Exmouth Gulf.

7. Fishery Management

7.1 Management System

Blue swimmer crab

Both the Pilbara Crab Managed Fishery (PCMF) and Exmouth Gulf Developing Crab Fishery (EGDCF) are managed under an input control system, primarily through the regulation of vessel and trap numbers. Supplementary controls cover retainable species and associated minimum size limits, gear specifications and seasonal and daily time restrictions. Refer to 6.1.3 for details of management specific for each fishery.

The principal management tool employed to ensure adequate breeding stock in both fisheries involves maintaining the minimum size limit well above the size at sexual maturity. The legal minimum size for both the PCMF and EGDCF is 135 mm carapace width (CW); well above the size at 50% sexual maturity in the region (*i.e.* 105–110 mm CW in Shark Bay; Chandrapavan *et al.*, 2017).

Mud crab

The Kimberly Crab Managed Fishery (KCMF) is managed under an input control system, primarily through the regulation of vessel and trap numbers. Supplementary controls cover retainable species and associated minimum size limits, gear specifications and seasonal and daily time restrictions. Refer to 6.1.3 for details of management.

The principal management tool employed to ensure adequate breeding stock in both fisheries involves maintaining the minimum size limit well above the size at sexual maturity. The legal minimum size for green mud crab is 150 mm carapace width and 120 mm for the brown mud crab; well above the size at sexual maturity (90-120 mm carapace width and 86-96 mm for green and brown mud crab, respectively).

7.2 Harvest Strategy

Pilbara Crab Fishery

A draft harvest strategy for the PCMF 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. However, a draft harvest strategy for the EGDCF has yet to be developed as there is insufficient data due to the minimal and sporadic fishing undertaken by the Exemption holders in this fishery to date.

The harvest strategy design for the PCMF is based on a constant proportion strategy where the annual catch of the targeted resource varies in proportion to variations in stock abundance. To achieve this, blue swimmer crabs in the PCMF are assessed annually by comparing commercial catch rates and commercial catch against reference points (Table 7.1). These reference points are calculated from commercial catch and effort data over a reference period when the effort levels in the fishery were stable.

The reference levels for the assessment of the blue swimmer crab resource and associated ecological assets has been based on the period of relative stability in the commercial fishery between 2005 and 2015 (Figure 9.23).

The primary performance indicator to achieve management objectives for the PCMF is the annual standardised commercial trap CPUE, as is used to assess the status of stocks in many blue swimmer crab fisheries in WA. The CPUE is collated from statutory monthly commercial trap catch and effort returns for the region of Nickol Bay (CAES blocks 2016 and 2017), as this area provides the longest time series to judge the performance of the fishery (Refer to Section 9.3.4; Table 7.1). This performance indicator will be applied across the whole fishery. However, should the focus of the fishery move out of Nickol Bay then CPUEs for other areas will be developed to determine if multiple indicators were beneficial for management of the overall fishery.

Annual catch tolerance levels have been developed for the PCMF (Table 7.2) (see DPIRD, 2020) 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 (2005–2015).

Table 7.1. Summary of the performance indicators, reference levels and control rules for the Pilbara Crab Managed Fishery (PCMF) and Kimberley Crab Managed Fishery (KCMF).

Management Objective	Performance Indicator(s)	Reference Levels	Control Rules
To maintain spawning stock biomass of *P. armatus* stocks above B_{MSY} to maintain high productivity and ensure the main factor affecting recruitment is the environment.	1. Annual standardised commercial catch rate (kg/traplift) of *P. armatus* in PCMF 2. Annual standardised commercial catch rate (kg/traplift) of mud crabs *Scylla spp*. in KCMF	**Target:** PCMF: 0.5–1.9 kg/traplift. KCMF: 0.4–0.9 kg/traplift	Continue management aimed at achieving ecological, economic and social objectives.
		Threshold: PCMF: 0.5 kg/traplift KCMF: 0.4 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% of the current harvest level to return stock to the target level.
		Limit: PCMF: 0.3 kg/traplift KCMF: 0.3 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) are required to rebuild the stock to the target level within two generation times (i.e. informing the recovery strategy for the stock).

A summary of the approach used to determine the reference levels is presented in Appendix 1.

Table 7.2 Annual catch tolerance ranges (in tonnes, t) for Pilbara Crab Managed Fishery (PCMF) and Kimberley Crab Managed Fishery (KCMF) which incorporates Aboriginal Body Corporate Exemption holders (ABCE).

Fishery	Catch tolerance range
KCMF & ABCE (*Scylla spp.*)	5–30 t
PCMF (*Portunus armatus*)	20–73 t

Exmouth Gulf Developing Crab Fishery

Since Exemptions were first issued in 2003, commercial fishing for blue swimmer crabs by trap fishers in the EGDCF has been sporadic and exploratory in nature. Consequently, a draft harvest strategy for this fishery has yet to be developed as there has not been a suitable period of relative stability in catch and effort to be able to set reference levels for the assessment of this blue swimmer crab resource and associated ecological assets.

Until a harvest strategy is developed, nominal commercial blue swimmer crab catch and effort for both the trap and trawl fisheries in Exmouth Gulf will be used in a weight-of-evidence approach to assess the crab resource in this fishery.

Kimberley Crab Managed Fishery

A draft harvest strategy for the KCMF 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 (Table 7.1).

The range of years considered for development of performance indicators was 2006 to 2015 which is the current management operating under exemptions (Figure 9.25).

The primary performance indicator to achieve management objectives for the KCMF is the annual standardised commercial trap CPUE. CPUE for the KCMF is collated from statutory monthly commercial trap catch and effort returns (Table 7.1).

The current catch tolerance ranges used to assess annual fishery performance based on the current stock status and control rules have been calculated from the fishery’s maximum and minimum catches between 2006 and 2015 including an additional 10% (of minimum catch) to generate the tolerance range (Table 7.2). If the status of the resource changes such that the control rules trigger additional management adjustments, the tolerance range for each of these fisheries must also be adjusted accordingly.

Given the highly dynamic nature of fisheries it is often not possible to predict precisely what catch or effort will be generated when a given set of management arrangements are applied. For input (effort) managed fisheries, tolerance levels define what level of catch or discrepancy against the harvest control rules is acceptable. This provides a mechanism to more consistently and pragmatically determine whether the intended ‘harvest levels’ are being successfully achieved by the current management arrangements (Fletcher *et al.*, 2016). This process is secondary to the application of harvest control rules for ecological sustainability, and its purpose is to annually evaluate and report on fishery performance.

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, market influences, non-WA managed fisheries, and other activities.

7.3.1 Environmental Factors

Levels of recruitment to many crab fisheries fluctuate considerably, primarily due to environmental influences (e.g. water temperature and rainfall) on spawning success and larval survival through to recruitment. The relationship between environmental factors, recruitment and catch in the PCMF, EGDCF and KCMF may be evaluated in the future as data becomes available.

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 El Niño Southern Oscillation (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. Marine heatwaves have also been identified in the north-west coast of Australia (Chandrapavan *et al.,* 2019).

Blue swimmer crab

Blue swimmer crabs are rated a high risk to climate change due to their sensitivity to water temperature changes. 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 months of August and September prior to spawning (de Lestang *et al.,* 2010; Johnston *et al.,* 2011b). Conversely, it is possible that elevated water temperatures in sub-tropical locations such as Shark Bay can have a deleterious effect on spawning and recruitment. Anecdotal evidence suggests growth patterns of crabs in the sub-tropical waters of Shark Bay are notably different to those in the temperate waters of south west WA so future increases in temperature will lead to variations in growth patterns. It is likely elevated temperatures will increase growth and influence size at maturity over future generations.

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. Sensitivities to climate change will also differ depending on the particular ecosystem the crabs inhabit. Changes in rainfall and sea level rises may negatively impact shallow coastal habitat and lead to a reduction in suitable nursery areas for juvenile blue swimmer crabs. Predictions have also indicated a lower frequency of cyclonic events, but increased severity, which may affect crab stocks in the north-west of WA. Resultant flooding events may affect blue swimmer crab recruitment and breeding stock levels in areas such as the Gascoyne and Pilbara.

Changes in rainfall and sea level rises may also negatively impact seagrass habitat leading to a reduction in suitable nursery grounds for juvenile crabs.

In late 2011, blue swimmer crab (*Portunus armatus*) stocks in Shark Bay were found to be at historically low levels due to an apparent recruitment failure and mortality of adult stock. The cause of the low recruitment to the fishery in 2011/12 was a combination of a very cool winter in 2010 followed by the heat wave in the summer of 2010/11 (Caputi *et al.*, 2015). However, there was also heavy fishing pressure on the breeding stock in the years leading up to the marine heatwave but there is no evidence that this contributed to the collapse (Chandrapavan *et al.*, 2017; 2019).

Mud crab

Mud crabs represent a species that may potentially benefit from moderate climate change in some areas (Welch *et al.*, 2014). It is possible that increased water temperatures at higher latitudes might increase growth rates and reproductive activity, while greater rainfall in the tropics might increase primary and secondary productivity, thereby providing more food for juvenile crabs. However, any such benefits are only likely to occur within the physiological tolerances of the particular developmental stage affected (Grubert *et al.*, 2016).

The effects of climate change are likely to differ between mud crab fisheries in WA, Northern Territory and Queensland based on the large latitudinal and longitudinal range of this species. Sensitivities to climate change will also differ depending on the particular ecosystem the crabs inhabit. Long term climate change predictions indicate that rainfall in northern WA will decrease over time potentially increasing hypersaline areas in shallow mangrove estuaries along the Kimberley coast. Such a rise in hyper-salinity may lead to increased mortality of juveniles and adults as mud crabs do not tolerate high levels of salinity. Changes in rainfall and sea level rises may also negatively impact mangrove habitat and lead to a reduction in suitable nursery areas for juvenile mud crabs (Meynecke *et al.*, 2012b). Predictions have also indicated a lower frequency of cyclonic events, but increased severity. Resultant flooding events may affect mud crab recruitment and breeding stock levels.

7.3.1.2 Cyclonic activity

Cyclonic activity and subsequent severe rainfall has been linked with changes in blue swimmer crab catches in north-western Australia. In the PCMF, the highest catch and catch rate on record coincided with an unprecedented five cyclonic events over the 2005–06 summer that generated the highest rainfall recorded in the Nickol Bay region since 1934 (BoM, 2016; Figure 7.1). It is thought the high rainfall and subsequent freshwater runoff ‘flushed’ crabs from shallow nearshore areas further offshore, where they were then open to exploitation by the commercial trap fisher.

It is likely that similar environmental factors also play a significant role in variability of crab stocks in Exmouth Gulf. In 2011, a record high trawl catch of blue swimmer crab (58 t) from the Exmouth Gulf Managed Prawn Fishery was reported which coincided with flooding events and the 2010/11 marine heatwave.

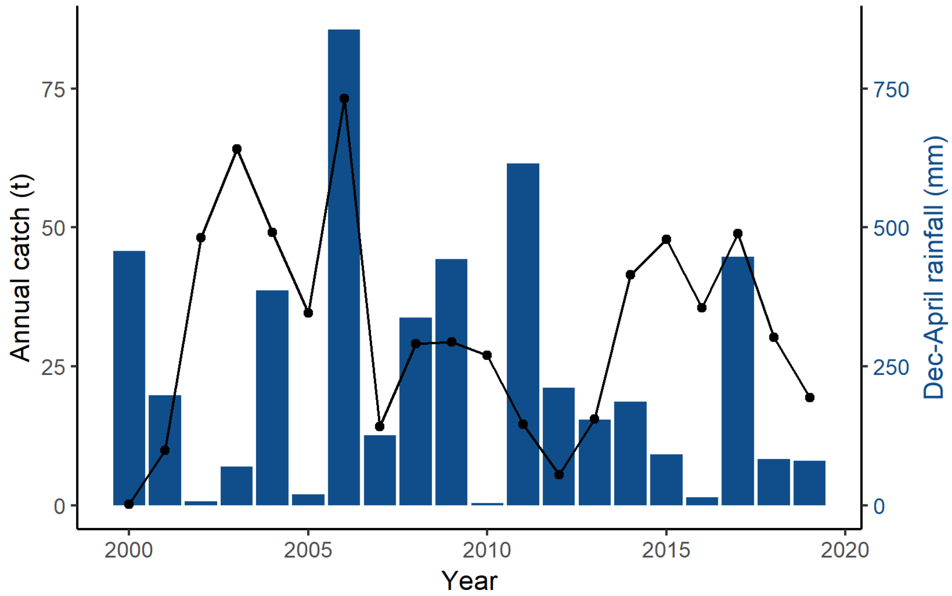


Figure 7.1. Annual blue swimmer crab catch (t) for the Pilbara Crab Fishery (points) and annual (December-April) rainfall at Karratha weather station (bars) from 2000 to 2019.

Mud crab

Depending on location, commercial mud crab catch rates generally show positive correlations with environmental factors such as rainfall and sea surface temperature (Meynecke *et al.*, 2012b). Catch rates are more strongly linked to sea surface temperatures at higher latitudes and rainfall at lower latitudes.

A Fisheries Research and Development Corporation (FRDC) project on the relationship between environmental conditions and mud crab catches in the Northern Territory demonstrated the influence of rainfall and cyclonic flooding events on catch levels (Meynecke *et al.*, 2012b). There are usually distinct fishing seasons in the KCMF due to the environmental influence of cyclones and associated strong winds, high rainfall and localised flooding events. As cyclone season is generally November to April, fishing is normally between April and November to avoid these unfavourable environmental conditions.

7.3.1.3 Water temperature, wind, rainfall, lunar illumination and tide height

Commercial daily catch rates of blue swimmer crabs in Nickol Bay from 2004 to 2016 have been modelled against a suite of key environmental variables using Generalised Additive Models (GAM) (Johnston *et al.*, 2020). These key predictor variables included water temperature (SST), wind speed and direction, rainfall (daily, weekly, monthly), lunar illumination and maximum daily tide height. Water temperature, wind speed, tidal height and rainfall had a positive effect on CPUE, with the former two variables having the greatest magnitude of effect (*c.* 50% increase in CPUE from low to high environmental values; Figure 7.2). The effect of lunar illumination on CPUE was relatively minor, but slightly lower catch rates did occur at lunar illuminations above 75%.

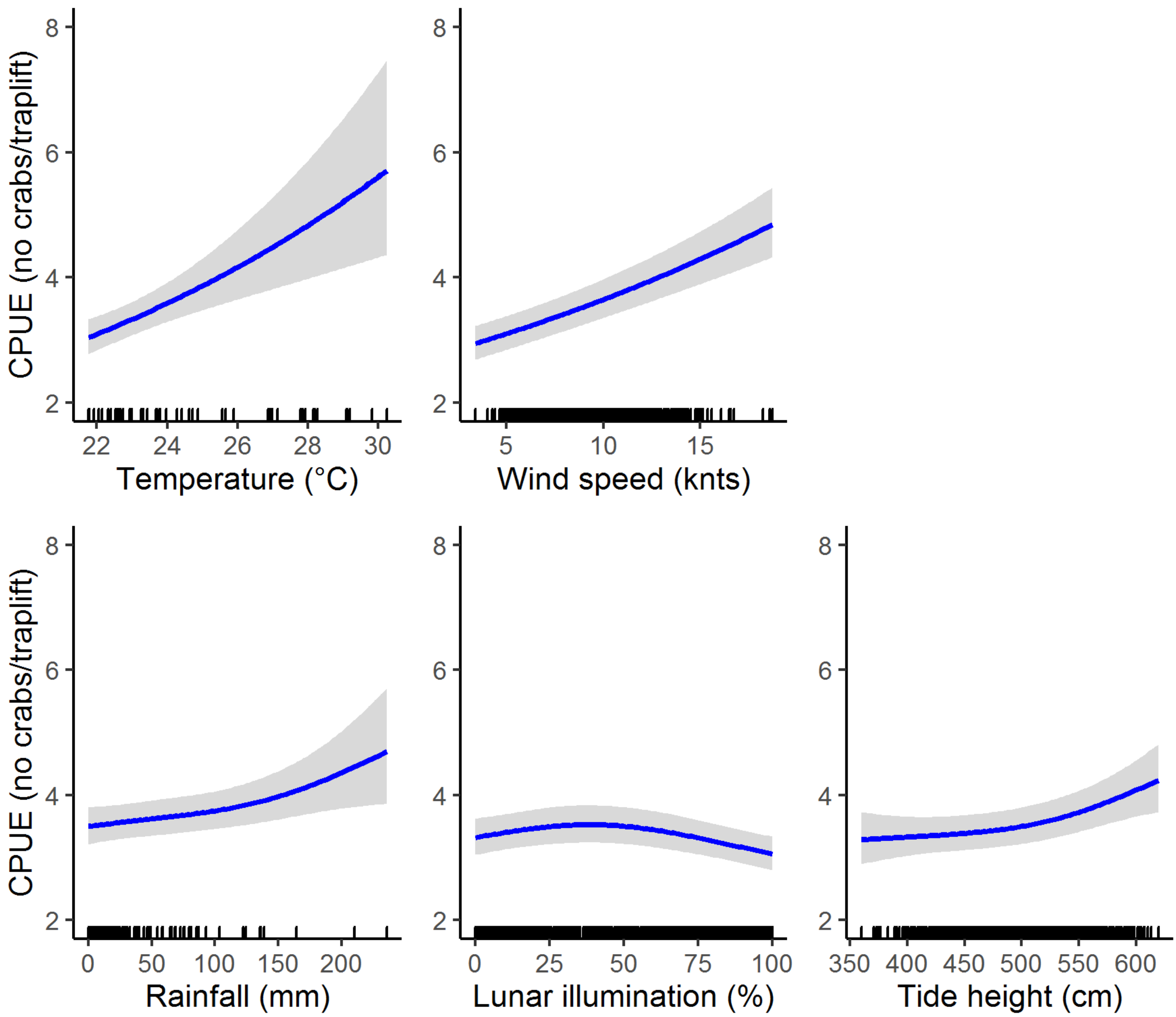


Figure 7.2. Environmental influences on commercial blue swimmer crab CPUE (no. crabs / trap lift) in Nickol Bay from 2004 to 2016 as predicted by Generalised Additive Models. Rainfall refers to the total amount of rainfall 30 days prior to the fishing event. Effects were plotted with other environmental variables held at their median values (lunar illumination = 48.9%, rainfall = 2.8 mm, wind speed = 8.44 knt, temperature = 23.7 °C, tide = 502 cm). Month and year were fixed at July and 2016, respectively. Shaded areas display 95% confidence limits and inward tick marks on the x-axis show the values of explanatory variables. (Johnston *et al.*, 2020).

7.3.1.4 Eutrophication

Eutrophication represents a problem in nearly every estuarine and marine embayment fishery along the coast in the West Coast and South Coast Bioregions (Smith, 2006; Veale *et al.*, 2014; Johnston *et al.*, 2015b). However, it is not considered to be a significant issue in the North Coast Bioregion (NCB) or Exmouth Gulf due to the dynamic hydrological properties associated with the flushing effect of spring tides, and reduced agricultural and industrial inputs, compared with southern WA.

7.3.2 Introduced Pest Species

The extremely high level of international shipping that operates in the NCB poses a high risk that an introduced pest may be introduced. Consequently, the Department of Primary Industry and Regional Development (DPIRD) has implemented a targeted IMP monitoring and inspection program. No introduced pest species that may affect crab stocks have been reported for the PCMF or EGDCF.

7.3.3 Market Influences

Blue swimmer crab

The average beach price for trap caught blue swimmer crabs across all Western Australian fisheries for 2019 was around $6.16/kg. Markets for catch from the PCMF are primarily dependent on the state of the local WA market. While the catch has historically been sold through eastern states markets, recent declines in the WA total catch of blue swimmer crabs have seen an increase in the WA beach price making local markets more attractive. Consequently, the catch is currently transported to processors in Perth.

Commercial catch from the PCMF was approved for international export by the Australian Government Department of Environment and Heritage under the Environment Protection and Biodiversity Conservation Act (1999) in February 2006. However, no catch was exported between 2006 and 2011 and export approval was discontinued in August 2012.

The remote location of the EGDCF caused logistical difficulties for the original two Exemption holders to get their crab catch to market, impacting on the financial viability of their fishing operations. However, the current Exemption (commenced in 2016) has been issued to a large fishing company that has operated a trawl fleet in the Exmouth Gulf Prawn Managed Fishery for many years. Consequently, they have substantial infrastructure in place to process and market their crab catch.

Mud crab

Historically the mud crab fishery has had a high community value, but a low commercial value due to the small annual catch. Commercial fishers travel vast distances due to the remoteness of their operations and stay in the vicinity for several weeks before returning to unload catch. In this scenario crabs are frozen and generally sold to local markets although live product may also be sold at premium prices.

The average beach price for green (uncooked) mud crabs in the Kimberley for 2019 was around $31/kg (value is based on a small proportion of total catch from an individual processor). Aboriginal corporations may also trade and barter product adding value to the local communities that cannot be estimated.

7.3.4 Non-WA Managed Fisheries

Given the nearshore proximity characterising blue swimmer crab and mud crab fishing occurring well within the 3 nautical mile extent of coastal waters, fishing in commonwealth waters at the 12 nautical mile limit would be unlikely to impact local mud crab fishing.

7.3.5 Other Activities

The main risks to nearshore habitats in the Pilbara and Kimberley regions come from oil and gas resource development and the expansion of port facilities, plus periodic cyclones and associated local flooding events.

There is a current business plan application to establish multispecies aquaculture facilities in the Beagle Bay area of the Kimberley region driven by representatives from the Milari Aboriginal Corporation. Mud crab, sea cucumber, black-lipped oyster and giant clam aim to be the key aquaculture species trialled on the Dampier Peninsula WA.

8. Information and Monitoring

8.1 Range of Information

There is a range of information available to support the assessment and harvest strategy for the blue swimmer crab (See Table 8.1) and mud crab (see Table 8.2) resources of the North and Gascoyne Coast Bioregions of WA.

Table 8.1 Summary of information available for assessing blue swimmer crab stocks in the Pilbara Crab Managed Fishery and Exmouth Gulf Developing Crab Fishery.

Data type	Fishery-dependent / independent	Purpose / Use	Area of collection	Frequency of collection	History of collection
Pilbara Crab Managed Fishery (PCMF)					
Commercial catch and effort statistics (CAES) Method; trap	Dependent	Monitoring of commercial catch and effort trends, calculation of catch rates and the area fished	Pilbara coast: CAES block	Monthly	Since 2002
Commercial monitoring surveys Method; trap	Dependent	Commercial catch composition	Pilbara coast: latitude and longitude;	Annual	2002 – 2008 NB. No sampling in 2007
Daily logbook data Method; trap	Dependent	Annual catches and catch rates as indicators of abundance; Spatial analyses of catch and effort	Pilbara coast; Some detailed latitude and longitude; Some transect only	Daily by trapline	Since 2002 (incomplete)
Recreational catch and effort estimates Method: creel survey and phone diary, remote camera and onsite boat ramp survey	Dependent	Monitoring of recreational catch and effort trends	Pilbara coast North coast bioregion	Single survey Biennial	1999/2000 Since 2011/12
Exmouth Gulf Developing Crab Fishery (EGDCF)					
Commercial catch and effort statistics (CAES) Method; trap	Dependent	Monitoring of commercial catch and effort trends, calculation of catch rates and the area fished	Exmouth Gulf: CAES block	Monthly	Since 2003
Daily logbook data Method: trap	Dependent	Annual catches and catch rates as indicators of abundance; Spatial analyses of catch and effort	Exmouth Gulf; Detailed latitude and longitude;	Daily by trapline	Since 2003 (incomplete)
Recreational catch and effort estimates Method: phone diary, remote camera and onsite boat ramp survey	Dependent	Monitoring of recreational catch and effort trends	Gascoyne bioregion	Biennial	Since 2011/12

Table 8.2. Summary of information available for assessing the Kimberley Crab Managed Fishery (KCMF).

Data type	Fishery-dependent or independent	Purpose / Use	Area of collection	Frequency of collection	History of collection
Commercial catch and effort statistics (CAES) Method: trap	Dependent	Monitoring of commercial catch and effort trends, calculation of catch rates and the area fished	Kimberley coast CAES block	Monthly	Since 1994
Daily logbook data Method: trap	Dependent	Annual catches and catch rates as indicators of abundance; Spatial analyses of catch and effort	Kimberley coast; Some detailed latitude and longitude; Some transect only	Daily by trap line	Since 2006 (not mandatory from 2018)
Recreational catch and effort estimates	Dependent	Monitoring of recreational catch and effort trends	Kimberley coast	Single survey	1999/2000
			North coast bioregion	Biennial	Since 2011/12
Charter catch and effort statistics	Dependent	Monitoring of charter catch and effort trends	Kimberley coast	Monthly (daily return)	Since 2001
Biological information	Independent	Patterns of growth and reproduction, stock structure	Camden Sound, Mud Bay, Doubtful Bay, Walcott Inlet, Secure Bay, Leadline Creek and Horizontal Falls.	Pilot study by DoF (2011)	Oct - 2015

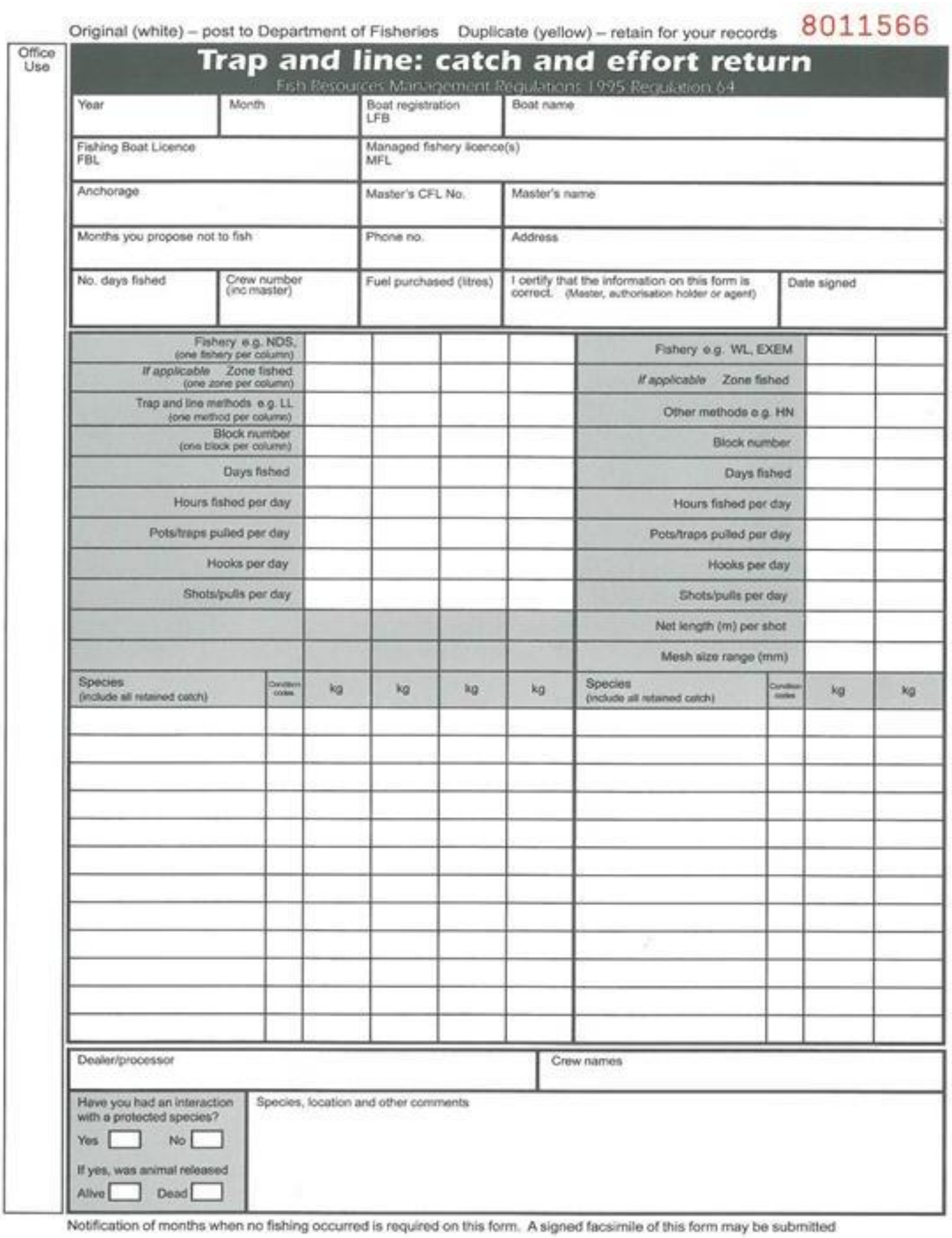
8.2 Monitoring

8.2.1 Commercial Catch and Effort

Under the Fisheries Resource Management Act (FRMA) 1994, 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 of Primary Industry and Regional Development (DPIRD) (Figure 8.1). The returns record monthly catch totals for each retained species, estimates of daily effort and spatial information in 60 × 60 nm blocks.

The CAES blocks specific to the Pilbara Crab Managed Fishery (PCMF) are presented in Figure 8.2; the EGDCF (blocks number 2014 and 2114) in Figure 8.3; and the KCMF in Figure 8.4.

These data are collected and collated by DPIRD and contained in the CAES database. CAES data has been collected for the PCMF since its inception in 2001, in EGDCF between 2003 and 2009 and from 2016 onwards, and from 1994 onwards in the KCMF. Note, that for the KCMF catch and effort totals include data from all commercial licences and Aboriginal Bodies Corporate Exemption (ABCE) holders.



Original (white) – post to Department of Fisheries Duplicate (yellow) – retain for your records 8011566

Office Use

Trap and line: catch and effort return

Fish Resources Management Regulations 1995 Regulation 64

Year | Month | Boat registration LFB | Boat name

Fishing Boat Licence FBL | Managed fishery licence(s) MFL

Anchorage | Master's CFL No. | Master's name

Months you propose not to fish | Phone no. | Address

No. days fished | Crew number (inc master) | Fuel purchased (litres) | I certify that the information on this form is correct. (Master, authorisation holder or agent) | Date signed

Fishery e.g. NDS, (one fishery per column)					Fishery e.g. WL, EXEM		
If applicable Zone fished (one zone per column)					If applicable Zone fished		
Trap and line methods e.g. LL (one method per column)					Other methods e.g. HN		
Block number (one block per column)					Block number		
Days fished					Days fished		
Hours fished per day					Hours fished per day		
Pots/traps pulled per day					Pots/traps pulled per day		
Hooks per day					Hooks per day		
Shots/pulls per day					Shots/pulls per day		
					Net length (m) per shot		
					Mesh size range (mm)		

Species (include all retained catch)	Condition codes	kg	kg	kg	kg	Species (include all retained catch)	Condition codes	kg	kg

Dealer/processor | Crew names

Have you had an interaction with a protected species? Yes ☐ No ☐

If yes, was animal released Alive ☐ Dead ☐

Species, location and other comments

Notification of months when no fishing occurred is required on this form. A signed facsimile of this form may be submitted

Figure 8.1. Monthly Catch and Effort Return log sheet completed by crab trap fishers in WA.

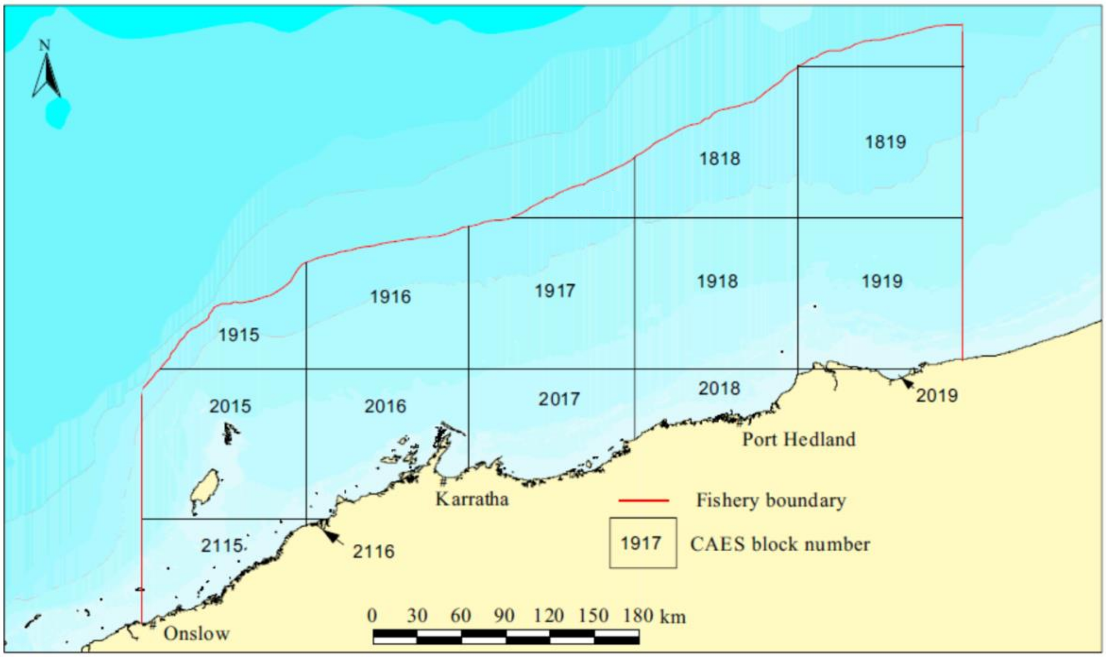


Figure 8.2. Map displaying the 60 x 60 nm CAES fishing blocks reported by trap fishers operating in the Pilbara Crab Fishery in statutory monthly catch and effort returns. (Onslow:– blocks 2015, 2115, 2116; Nickol Bay region: – blocks 2016, 2017; Port Hedland: – blocks 1918, 1919, 2018, 2019).

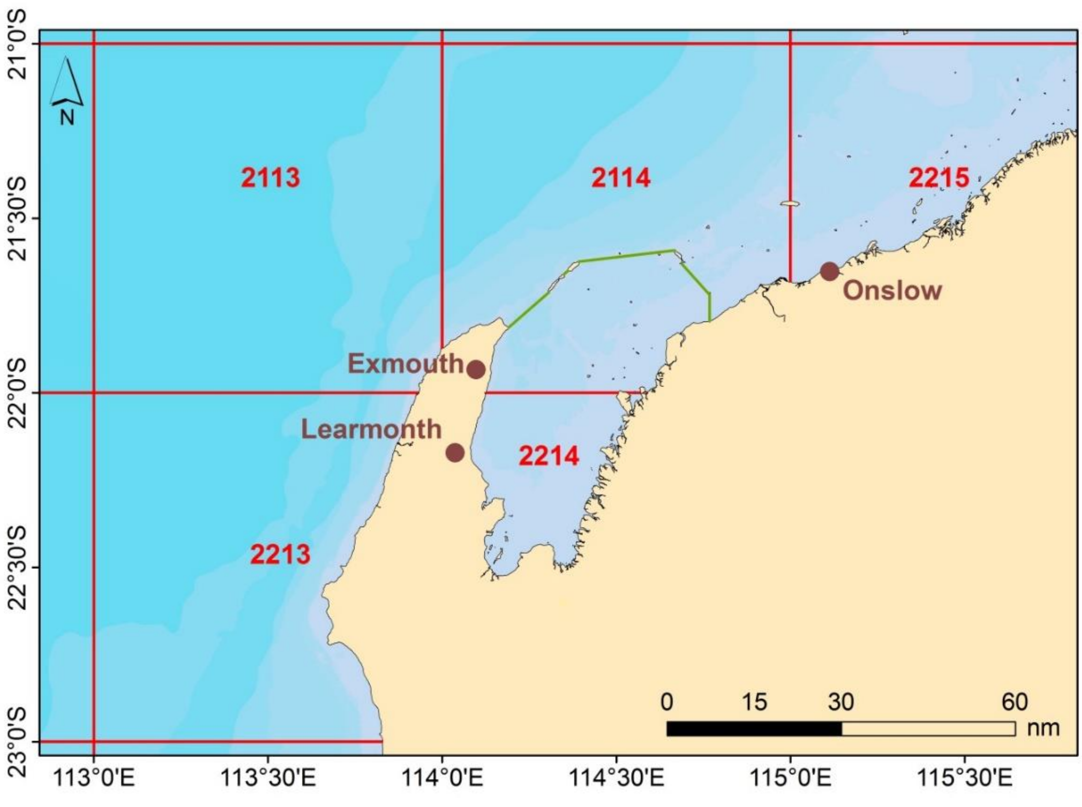


Figure 8.3. Map displaying the 60 x 60 nm CAES fishing blocks reported by trap fishers operating in the Exmouth Gulf Developing Crab Fishery (2114, 2214) in statutory monthly catch and effort returns. — Fishery boundary.

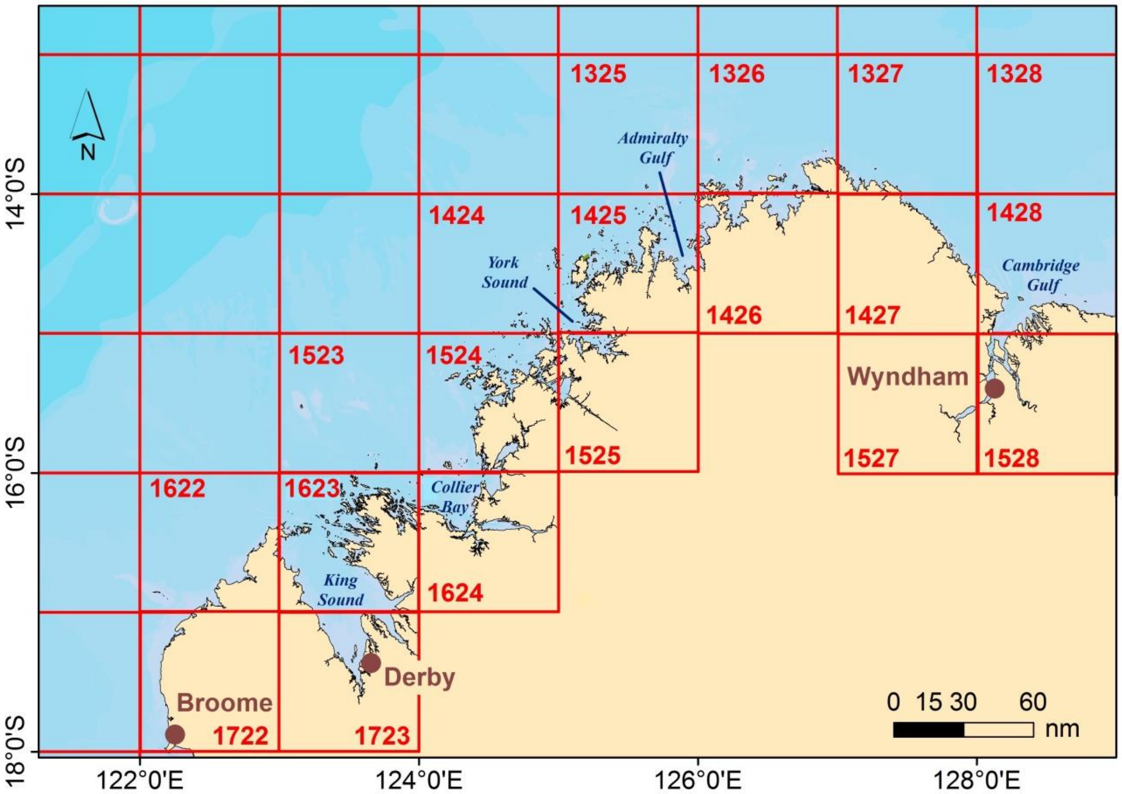


Figure 8.4. Map displaying the CAES fishing blocks reported by trap fishers operating in the Kimberley Crab Managed Fishery in statutory monthly catch and effort returns, and the specific blocks used for commercial catch and effort analysis by area in this report: Cambridge Gulf (1428, 1528); Camden Sound (1524); Admiralty Gulf (1425, 1426); Collier Bay (1624); York Sound (1525); King Sound (1623, 1723); Camp Inlet/Carnot Springs (1622).

8.2.2 Recreational/Charter Catch and Effort

Blue swimmer crab

Surveys estimating recreational catch and effort of blue swimmer crabs along the Pilbara coastline and in Exmouth Gulf have been conducted sporadically by DPIRD.

An ongoing biennial state-wide survey was implemented in 2011 to collect information on private (non-charter), boat-based recreational fishing 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 fishing catch, effort, location and other demographic information every two years. The initial survey was conducted between March 2011 and February 2012, and repeated between May 2013 and April 2014, and September 2015 and August 2016.

The Phone Surveys represented the main component of the integrated surveys. Fishing information was collected on an 'event' basis, where separate events were recorded for changes in location, habitat, target species and/or fishing method. Fishing activity in the boat ramp surveys was recorded on a 'trip' or day basis. Where possible, data elements were standardised between surveys, in terms of question wording and responses (see Ryan *et al.*, 2013). 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 Survey 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. Average weight was calculated from data collected using electronic scales recording measurement of whole weight.

There is no reported catch and effort data for blue swimmer crabs by charter boat fishers in either the North Coast or GB.

Mud crab

A state-wide survey was implemented in 2011 to collect information on private (non-charter), boat-based recreational fishing in WA (Ryan *et al.*, 2013; 2015; 2017; 2019). Refer to blue swimmer crab above for details of survey methodology.

Charter boat clients occasionally fish for mud crabs in the Pilbara and Kimberley regions of WA. Charter operators are required to record the retained catch and effort from their charter operations on a DPIRD daily trip return sheet for each day fished (Figure 8.5).

Tour Operator Return Book - **Daily Trip Return Sheet** **TO**

Trip date (DD/MM/YYYY):	Licence №. e.g. FT… RFT… :	No fishing this month*	Enter months of nil fishing: (MM/YY): to (MM/YY):

Master of the boat		Boat name	

Trip details	Total No. of clients		Start point		Finish point	
Was this day part of a trip in which you stayed overnight?	Yes ☐ No ☐					

Fishing session		Session 1	Session 2	Session 3
Start time (hh:mm)		__ __:__ __ (24 hrs)	__ __:__ __ (24 hrs)	__ __:__ __ (24 hrs)
Finish time (hh:mm)		__ __:__ __ (24 hrs)	__ __:__ __ (24 hrs)	__ __:__ __ (24 hrs)
GPS co-ordinates** (DDD° MM')		__ __ ° __ __ ' S __ __ __ ° __ __ ' E	__ __ ° __ __ ' S __ __ __ ° __ __ ' E	__ __ ° __ __ ' S __ __ __ ° __ __ ' E
OR Block location**				
Depth (metres)				
Fishing Effort	No. fishing lines/pots			
	No. of divers			
	No. snorkeling			
		Nil Fish Caught *(Please tick)* ☐	Nil Fish Caught *(Please tick)* ☐	Nil Fish Caught *(Please tick)* ☐

	Species/Common name (Record all species)	**Session #** **1, 2** or **3**	**Activity** Fishing, Diving or Snorkeling (**F, D, S**)	**Total kept**	**Total released**	**Length of kept (mm)** *(Do not enter a range)*	**Protected species** Alive or Dead (**A** or **D**)
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							

Protected species interaction	Yes ☐ No ☐		
Comments (include protected species interactions)			
I certify that the information on this form is correct.	Signature	Date	/ /
	Print name	Contact number	

* Notification of months when no fishing occurred is required on this form.

** Only need to report either the GPS Latitude and Longitude coordinates or block location.

HPRM 8674/15

Office use only	Date:	Licence №.:	Nil fishing: to

Figure 8.5. Daily trip return log sheet for charter vessels operating in the North Coast Bioregion of Western Australia.

8.2.3 Customary Catch

There is no reported customary catch and effort data for blue swimmer crabs in either the North Coast or GB. Although some traditional fishing for mud crabs is likely to occur in the Kimberley Region as a source of sustenance for local communities, there is no data currently reported to DPIRD for this traditional fishing.

8.2.4 Illegal, Unreported or Unregulated Catch

There is no information on illegal catch of blue swimmer crabs or mud crabs in either the North Coast or GB.

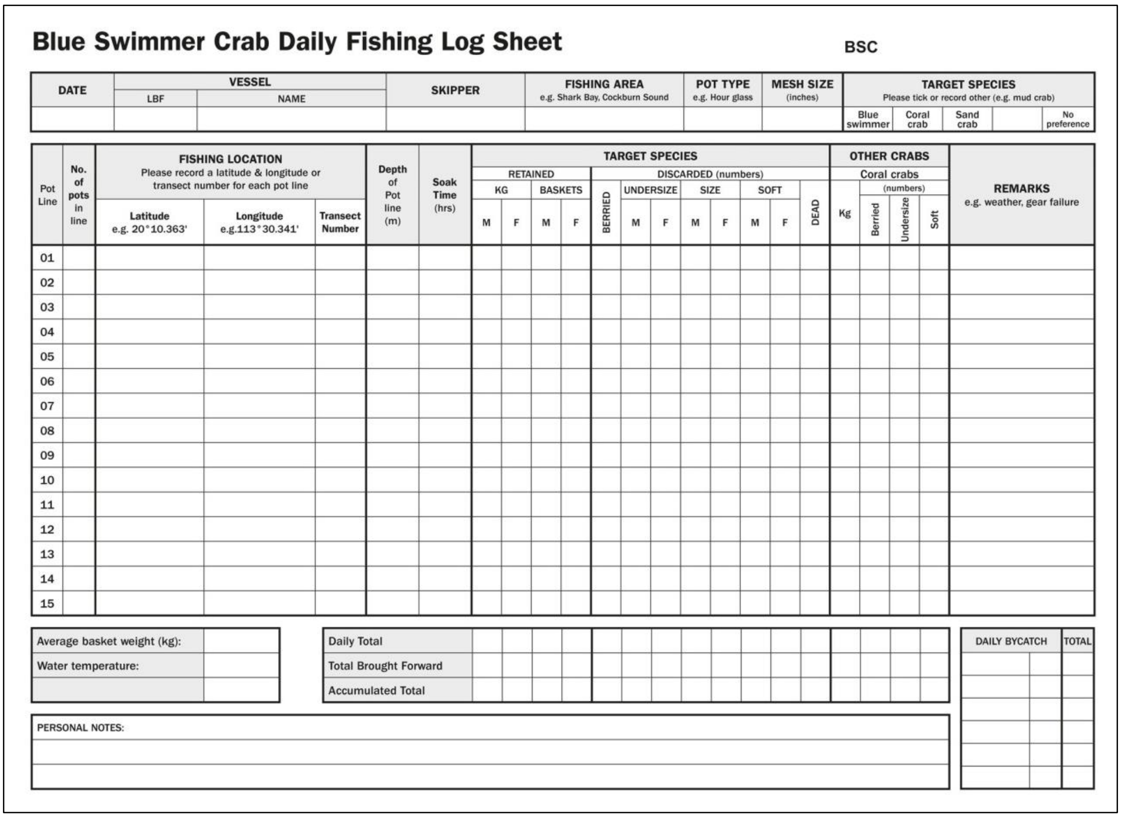
8.2.5 Fishery-Dependent Monitoring

8.2.5.1 Daily Research logbooks

Daily Research trap logbooks were introduced in 2001 in the KCMF, in 2002 in the PCMF, and in 2003 in the EGDCF, to gain comprehensive (finer resolution) daily catch and effort data from commercial trap fishers (Figure 8.6, Figure 8.7, Table 8.3). For each line of crab traps set, fishers were required to record a latitude and longitude or block reference, the number of traps in the line, depth, trap soak-time and a total catch estimate in either kilograms or baskets of crab. If reporting in baskets, the fisher was to include an average basket weight to allow for the conversion of the basket estimate to a catch in kilograms for that line.

Logbook data is validated by comparing research log books with statutory monthly catch and effort (CAES) returns, and spatially presenting fishing locations when transect grid numbers or latitude and longitude details are recorded by fishers. However, daily research logbook compliance has been sporadic in all three fisheries so daily logbook returns do not necessarily represent the total numbers of days fished when compared to fishing effort declared in CAES returns. This is particularly the case with the KCMF, where remote fishing operations, difficulty in contacting fishers, and miscommunication due to high turnover of skippers, has resulted in CAES and log sheets often being many months behind.

While efforts are being made to improve research logbook compliance by the commercial fishers in the KCMF, the data submitted to date is not considered reliable and therefore has not been included in this report.



Blue Swimmer Crab Daily Fishing Log Sheet

BSC

DATE	VESSEL: LBF	VESSEL: NAME	SKIPPER	FISHING AREA e.g. Shark Bay, Cockburn Sound	POT TYPE e.g. Hour glass	MESH SIZE (inches)	TARGET SPECIES Please tick or record other (e.g. mud crab)
							Blue swimmer / Coral crab / Sand crab / / No preference

Pot Line | No. of pots in line | FISHING LOCATION Please record a latitude & longitude or transect number for each pot line: Latitude e.g. 20°10.363' / Longitude e.g.113°30.341' / Transect Number | Depth of Pot line (m) | Soak Time (hrs) | TARGET SPECIES: RETAINED (KG M F; BASKETS M F); DISCARDED (numbers) (BERRIED; UNDERSIZE M F; SIZE M F; SOFT M F; DEAD) | OTHER CRABS: Coral crabs Kg; (numbers) Berried, Undersize, Soft | REMARKS e.g. weather, gear failure

01 02 03 04 05 06 07 08 09 10 11 12 13 14 15

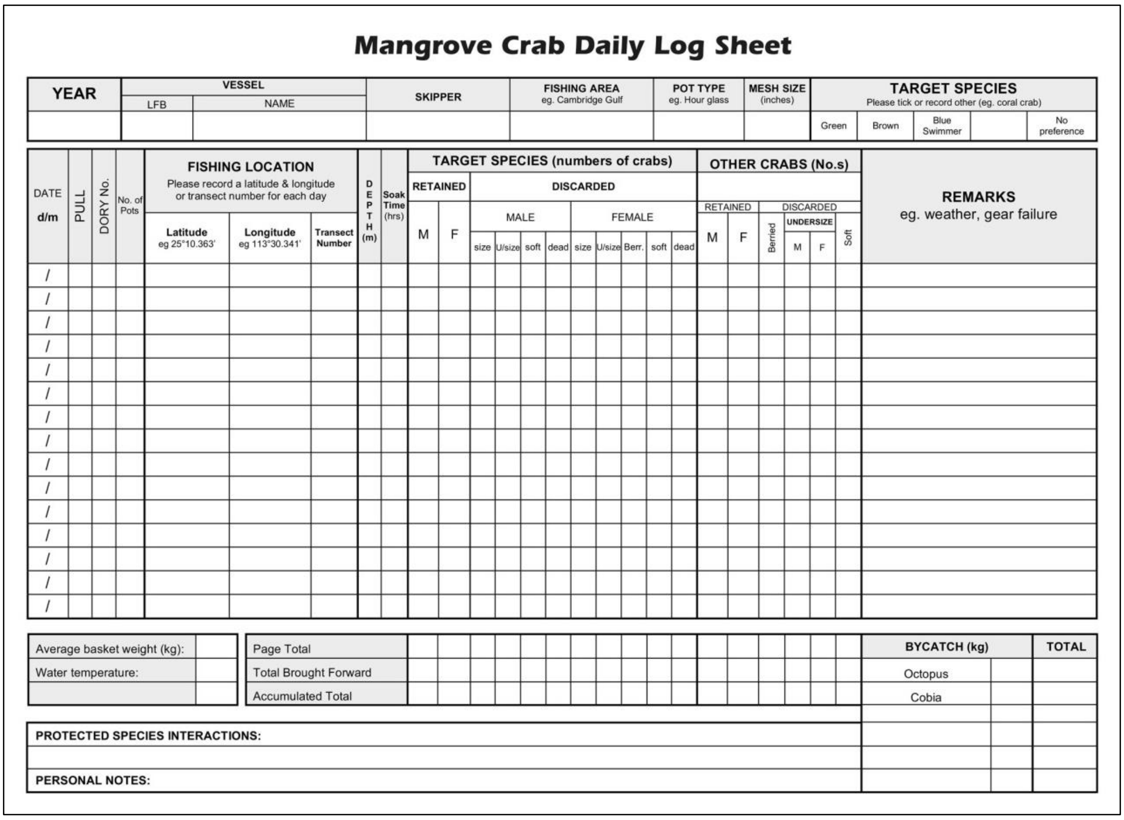
Average basket weight (kg):
Water temperature:

Daily Total
Total Brought Forward
Accumulated Total

DAILY BYCATCH | TOTAL

PERSONAL NOTES:

Figure 8.6. Blue Swimmer Crab Daily Research log sheet completed by crab trap fishers in the PCMF and EGDCF.



Mangrove Crab Daily Log Sheet

YEAR	VESSEL: LFB	VESSEL: NAME	SKIPPER	FISHING AREA eg. Cambridge Gulf	POT TYPE eg. Hour glass	MESH SIZE (inches)	TARGET SPECIES Please tick or record other (eg. coral crab)
							Green / Brown / Blue Swimmer / / No preference

DATE d/m | PULL | DORY No. | No. of Pots | FISHING LOCATION Please record a latitude & longitude or transect number for each day: Latitude eg 25°10.363' / Longitude eg 113°30.341' / Transect Number | DEPTH (m) | Soak Time (hrs) | TARGET SPECIES (numbers of crabs): RETAINED M F; DISCARDED MALE (size, U/size, soft, dead), FEMALE (size, U/size, Berr., soft, dead) | OTHER CRABS (No.s): RETAINED M F; DISCARDED Berried, UNDERSIZE M F, Soft | REMARKS eg. weather, gear failure

Average basket weight (kg):
Water temperature:

Page Total
Total Brought Forward
Accumulated Total

BYCATCH (kg) | TOTAL
Octopus
Cobia

PROTECTED SPECIES INTERACTIONS:

PERSONAL NOTES:

Figure 8.7. Daily Research Logbook sheet completed by mud crab trap fishers.

Table 8.3 Comparison of records of fishing submitted in statutory monthly catch and effort (CAES) returns with records of fishing submitted in Daily Research logsheets for Exemption 1 operating in the Pilbara Crab Fishery.

Fishing Area	Year	MONTH JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Port Hedland	2001											30 0	
	2002					30 0	28 0	30 0					
Nickol Bay	2001										30 0		
	2002											0 7	
	2003			25 0	27 0	23 0	1 0	7 0	23 0	23 0			
	2004							20 21	27 30	18 18			
	2005			11 0		9 5	25 25	26 15	26 0	10 0	20 0		
	2006					24 23	23 23	27 27	28 27	28 14	26 0		
	2007				6 0	26 0	23 0	7 0					
	2008			10 0	16 0	23 17	23 23	27 15	26 0	20 0			
	2009			9 9	24 24	20 20	25 11	26 0	25 0	21 0			
	2010					11 11	26 26	25 25	25 26	21 5			
	2011						11 11	26 26	20 20				
	2012										14 14	13 0	
	2013							11 11	28 29	17 20	1 0	4 3	0 4
	2014				17 16	21 19	21 22	22 24	20 10				
	2015			11 11	18 19	29 29	28 26	26 0	26 24	4 4		6 6	11 11
	2016			14 14	24 24	29 29	25 25	29 29	13 13			5 5	

Explanation of numbering and shading:

25 days fished in month submitted in CAES returns	Months with CAES returns but no logsheets
25 days fished in month recorded in Logbook returns	Months with both CAES and Logbook returns
	Months with Logbook returns but no CAES returns

8.2.5.2 Commercial Monitoring

Monitoring of commercial crab trap catches in the PCMF was conducted on an annual basis from 2002 to 2006, and again in 2008 (Figure 8.8). Commercial fishers were accompanied by research staff during daily crabbing operations on 2 – 4 consecutive days each year, and the day's catch and effort recorded. Carapace width (the distance between the tips of the two lateral spines of the carapace measured to the nearest millimetre), sex, moult stage, female breeding condition (absence/presence of externally visible eggs), the number of pots in the line, soak time (number of hours the traps have been in the water since they were last serviced) and a latitude, longitude and depth for each trap line were recorded. These data provide an indication of annual variation of the size structure and sex ratio observed for the trap fishery.

Commercial monitoring surveys in the fishery were discontinued after 2008 due to the substantial cost of undertaking sampling on the Pilbara coast, and narrow temporal and spatial stratification of the data collected during the commercial monitoring surveys. Due to the sporadic nature of the commercial monitoring and the cessation of the program after 2008 indicators based on these data were not developed.

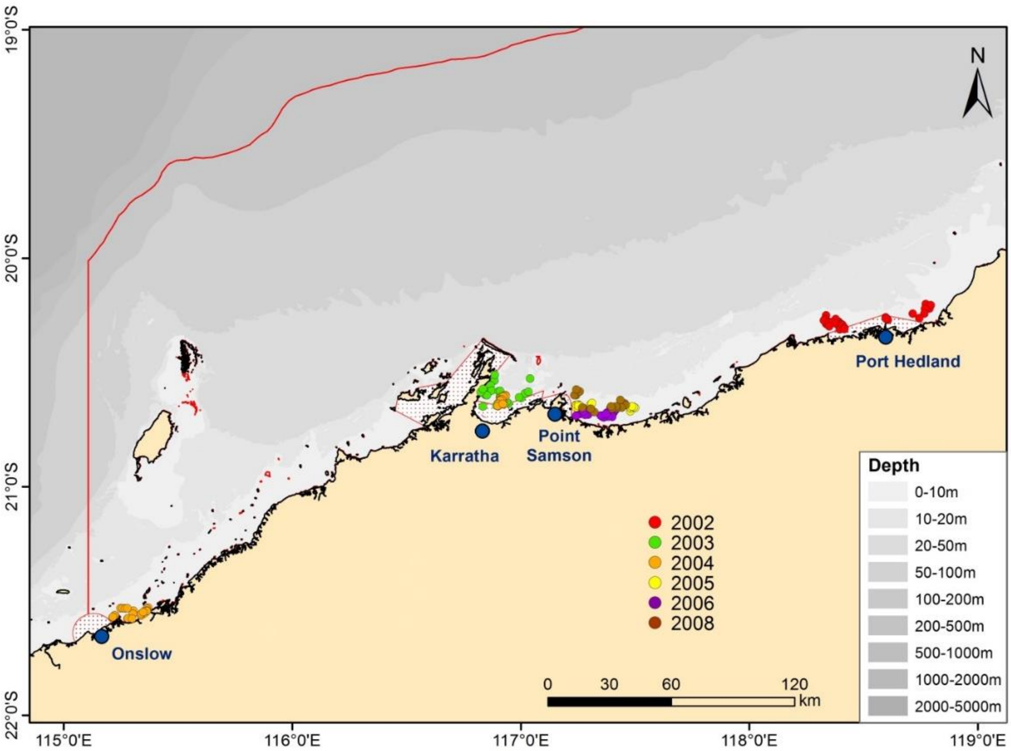


Figure 8.8. Locations by year of traplines sampled during catch monitoring surveys in the Pilbara Crab Fishery between 2002 and 2008. No sampling occurred during 2007 (▬ Fishery boundary; ░ Fishery closures).

No commercial monitoring has been undertaken in either the EGDCF or KCMF.

8.2.6 Fishery-Independent Monitoring

No targeted fishery-independent monitoring has been undertaken in either of the PCMF, EGDCF or KCMF. However, fishery-independent data on mud crabs was collected opportunistically during a marine park survey in the Kimberley region aboard the Fisheries Research vessel *RV Naturaliste* in October 2015. Locations surveyed included Camden Sound, Mud Bay, Doubtful Bay, Walcott Inlet, Secure Bay, Leadline Creek and Horizontal Falls. The biological data collected during this pilot survey formed the basis for the first fishery independent data set. A total of 164 crabs were collected and an outline of the data obtained is summarised below.

Various attributes were collected (e.g. species identification, spatial distribution, size, weight, sex, berried status, reproductive data, female size at maturity, morphometrics), however, due to the relatively small sample size these data have not been used in stock assessment.

8.2.7 Environmental Monitoring

Databases with environmental variables (e.g. water temperature, rainfall, wind and sea level) are continuously updated and extended as new data becomes available from collections by the Department, internet sources and from other agencies (see Caputi *et al.*, 2015). The environmental variables from these databases have been used in analyses of correlations with biological parameters of species and allow for the examination of long-term trends.

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

The Pilbara Crab Managed Fishery (PCMF), Exmouth Gulf Developing Crab Fishery (EGDCF) and Kimberly Crab Managed Fishery (KCMF) are small, low-value fisheries that are conservatively fished. Consequently, an appropriate low-cost stock assessment tool has been employed to evaluate the status of the blue swimmer and mud crab stocks targeted by these fisheries.

Pilbara Crab Fishery

A Level 2 assessment (see *Status Reports of the Fisheries and Aquatic Resources of Western Australia*) was undertaken for the Pilbara crab stock, involving analyses of catch and effort data from statutory CAES returns to calculate annual standardised catch rates to compare with historical levels. Commercial trap catch rate has been used successfully as an indicator of abundance in other blue swimmer crab fisheries in WA. The proposed harvest strategy provides formal reference points for these indices based on a period (2005–2015) of stable catch rates. Commercial trap catch rates for the Nickol Bay region are used, as this area provides the longest time series to judge the performance of the fishery. Additionally, daily logbook data is used for spatial analysis in the PCMF.

Exmouth Gulf Developing Crab Fishery

A Level 2 assessment was undertaken for the Exmouth crab stock, involving analyses of catch and effort data from statutory CAES returns to calculate annual nominal catch rates to compare with historical levels. At present, there is insufficient data to accurately assess the status of stocks as the trap fishery has only resumed in 2016.

Kimberley Crab Managed Fishery

A Level 2 assessment was undertaken for the KCMF crab stock, involving analyses of catch and effort data from statutory CAES returns to calculate annual standardised catch rates to compare with historical levels. Commercial catch rates are calculated using the total trap catch and effort recorded in all CAES blocks within the Kimberley region and compared with historical levels. The proposed harvest strategy provides formal reference points (target, threshold and limit) for these indices based on a reference period (2005–2016) to assess the current stock status.

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. Assessment summaries (see weight-of-evidence risk assessment presented in Section 9.4) are signed off by the relevant Senior Principal Research Scientists and the Director of Aquatic Science and Assessment before being provided to the fishery managers to inform decision-making. Assessments and annual catch information are also presented by the Department and discussed with commercial licence holders at Annual Management Meetings (AMMs).

The PCMF and KCMF underwent pre-assessments against the Marine Stewardship Council (MSC) standard for sustainable fishing (V1.3) in 2013–14 using a bioregional approach to evaluate all commercial fisheries in WA (Bellchambers *et al.,* 2016).

The Pre-Assessment Team identified a precautionary management approach as the main strengths of both the PCMF and KCMF, specifically:

a) The issuance of a small number of Exemptions to access the fishery;

b) The use of a restrictive pot limit;

c) The application of a minimum carapace width that ensures the crab species targeted by each fishery has an opportunity to spawn at least once before attaining legal size.

The use of closed areas and the availability of some data on bycatch in the PCMF were also recognised.

However, it noted the main weaknesses of both fisheries as:

a) The lack of any information on stock biomass;

b) The absence of formal harvest control rules (although some have been proposed, but not introduced);

c) The lack of independent verification of the catch profile (i.e. daily research logbooks), including coral crabs and three spot sand crabs which are thought to be retained but are not recorded in landings;

d) Potential interactions with endangered, threatened and protected (ETP) species.

The difficulty distinguishing between the two different target mud crab species was also recognised as a weakness in the KCMF, which had resulted in the reporting of commercial mud crab catches as *Scylla* spp. rather than the individual species in fisher's commercial catch and effort returns.

Subsequent to these pre-assessments, effort has been put into improving daily research logbook compliance by the commercial fisher in the PCMF, and the commercial fishers and Aboriginal licence holders in the KCMF, with particular reference to reporting both retained and released catch of coral and three spot sand crabs, bycatch species, and potential interactions with ETP species. Furthermore, a draft harvest strategy and control rules have been implemented for each fishery (refer to Section 7.2).

As the EGDCF was only re-opened in 2016, the fishery did not undergo pre-assessment against the MSC standard for sustainable fishing.

9.3 Analyses and Assessments

9.3.1 Data Used in Assessment

CAES / Logbook Recreational fishing survey data Environmental data Fishery-dependent data

9.3.2 Catch and Effort Trends

9.3.2.1 Commercial Catch and Effort

Pilbara Crab Managed Fishery

Annual trap catches of blue swimmer crab from the Pilbara Developing Crab Fishery (PDCF)/PCMF between 2001 and 2019 have ranged from 5.5 to 73.2 t (Figure 9.1). The 2019 catch was 19.3 t from 11,600 traplifts at a nominal catch rate of 1.67 kg/traplift. This represents a decrease in total catch from 2018 to 2019 by approximately one third (10.9 t lower catch during 2019), but an increase in CPUE by 0.67 kg/traplift.

Since the inception of dedicated trap fishing in 2001, total annual catch has largely fluctuated in line with fishing effort ($R = 0.77$, $P < 0.001$; Figure 9.2). However, there is no correlation between annual catch rate and fishing effort, which could potentially indicate the fishery is yet to be fully exploited ($P > 0.05$; Figure 9.3). Harsh climatic conditions over the summer months, means that fishing effort tends to be concentrated between March and September

(Figure 9.4). In 2019, fishing only occurred during three months of the year from June to August, with peak catch and effort in July, although peak CPUE occurred in August (Figure 9.5).

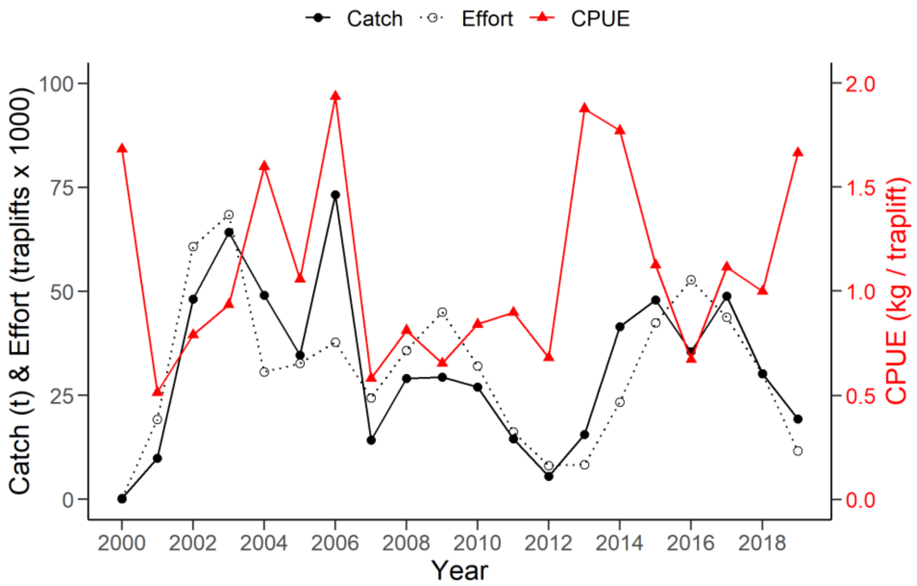


Figure 9.1. Annual commercial catch (tonnes), fishing effort (traplifts x 1000) and CPUE (kg/traplift) of blue swimmer crab in the Pilbara Crab Fishery between 2000 and 2019.

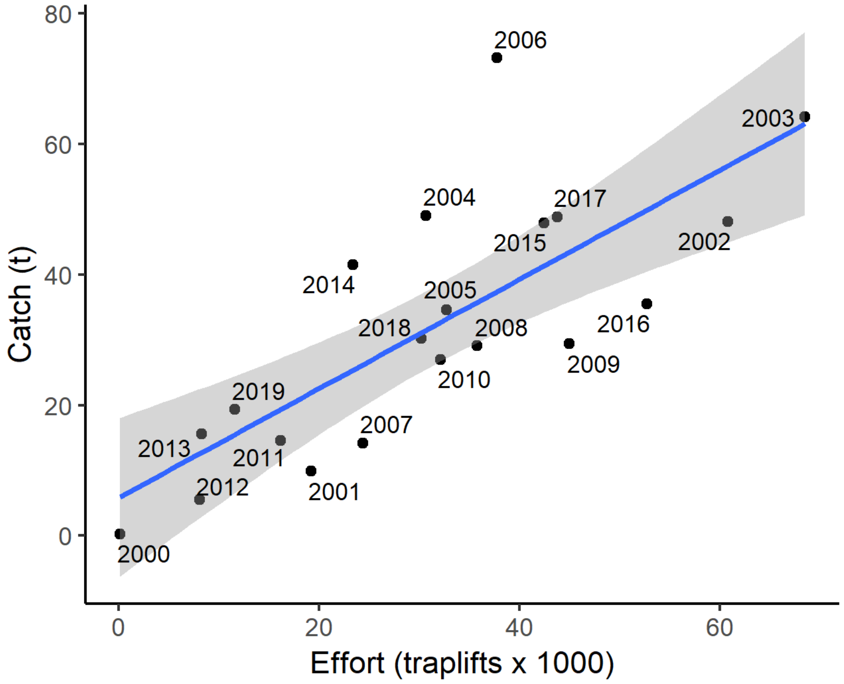


Figure 9.2. Plot of nominal effort (traplifts x 1000) versus total annual catch (tonnes) by year from 2001–19 for commercial trap fishers operating in the Pilbara Crab Fishery. The blue line shows the linear correlation and shading represents the confidence interval of the relationship (Pearson's R correlation = 0.77, P < 0.001).

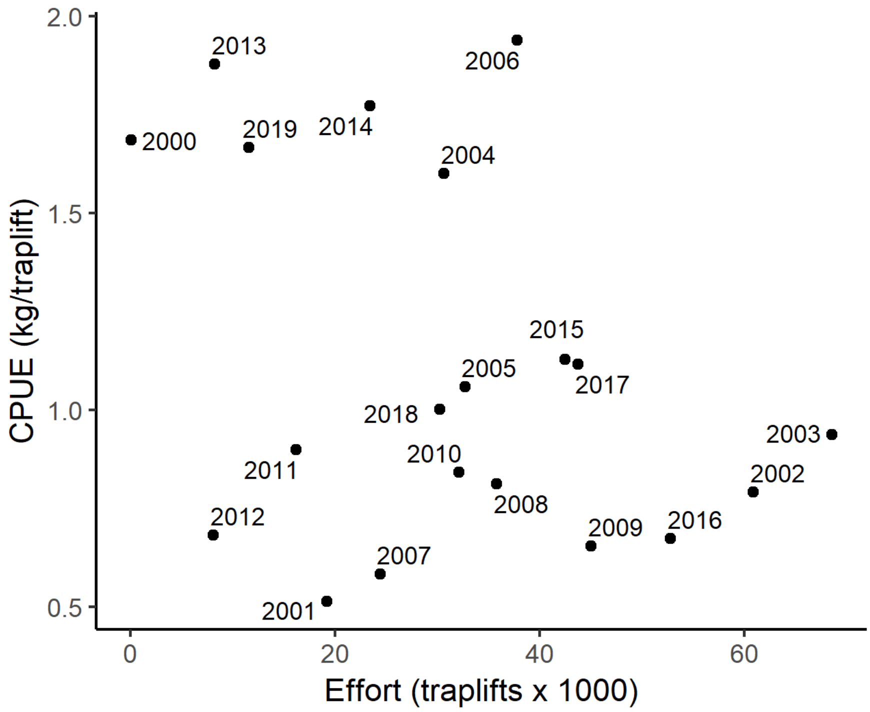


Figure 9.3. Plot of nominal effort (traplifts x 1000) versus annual catch per unit effort (kg/traplift) by year from 2001–19 for commercial trap fishers operating in the Pilbara Crab Fishery. Pearson's R correlation = -0.35, P = 0.14.

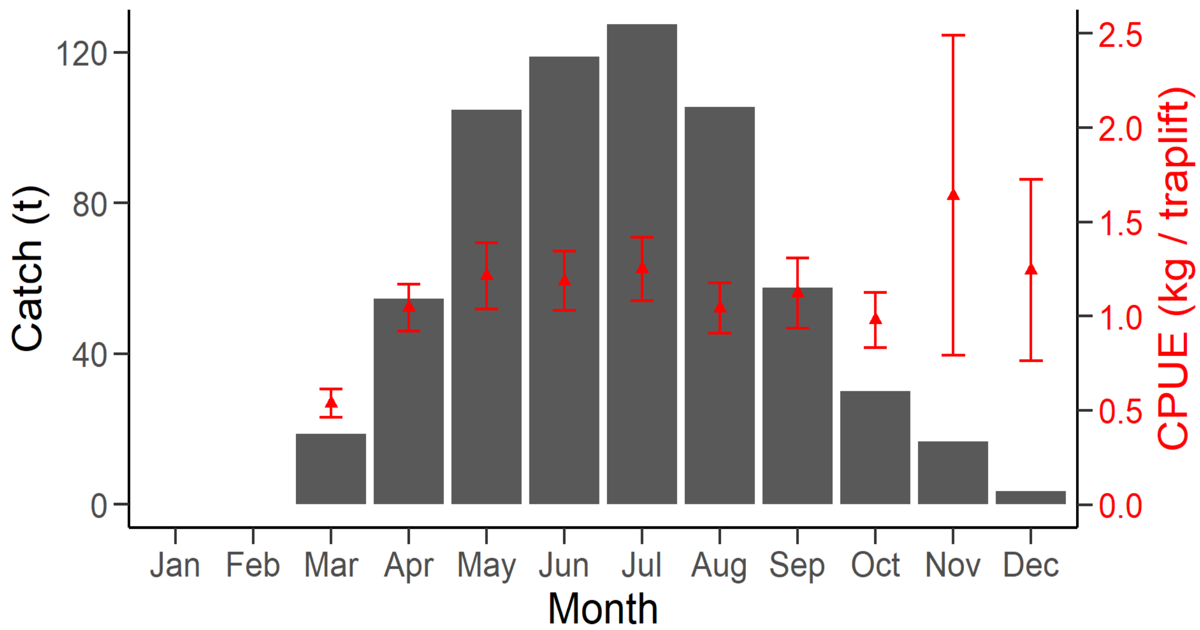


Figure 9.4. Monthly total commercial trap catch (tonnes) and mean CPUE (kg/traplift) for the Pilbara Crab Fishery across all years from 2000 to 2019.

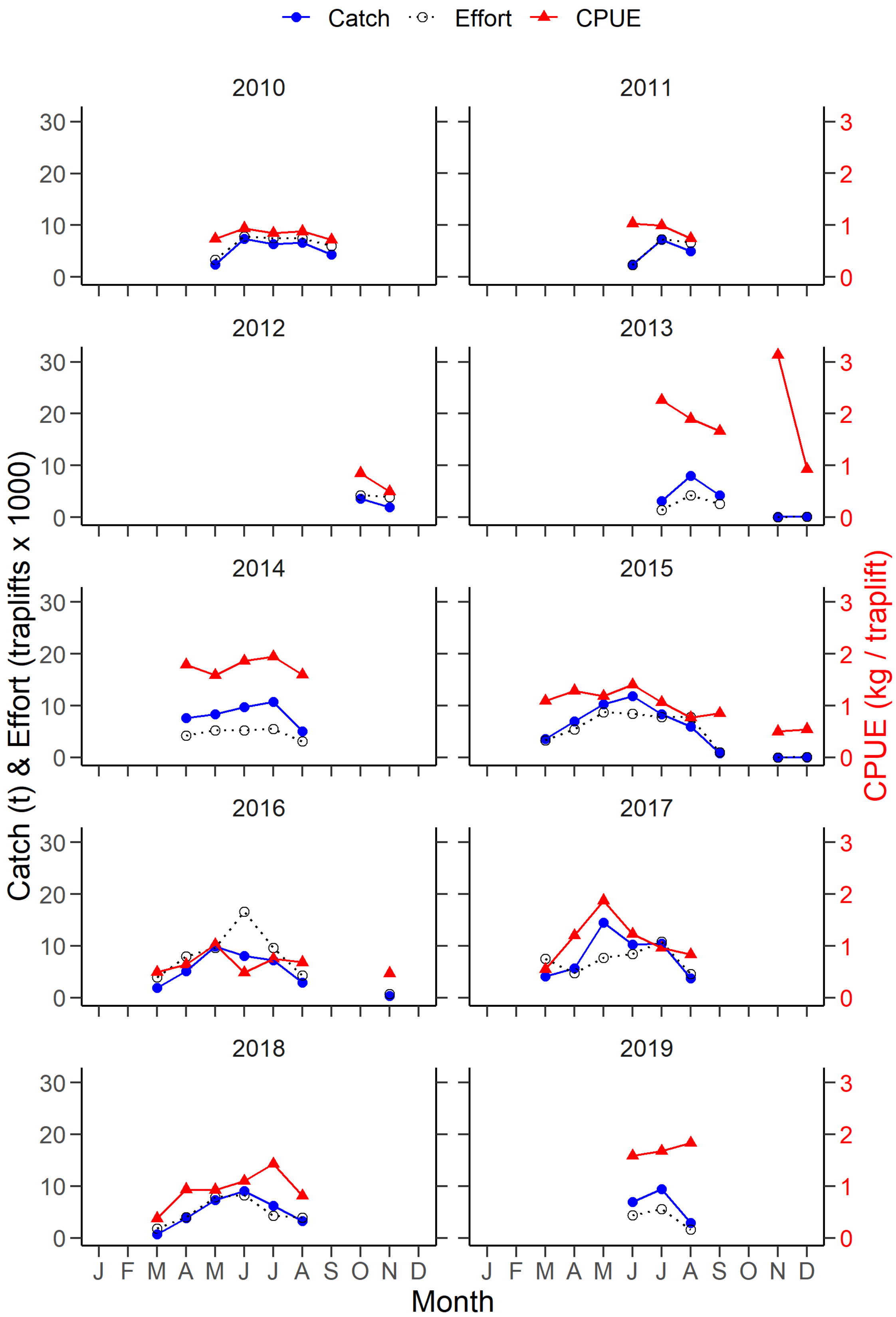


Figure 9.5. Monthly commercial trap catch (tonnes), effort (traplifts x 1000) and catch per unit effort (kg/traplift) each year for the Pilbara Crab Fishery from 2010 to 2019. A season closure was introduced between 15th August and 15th November in 2016.

Exmouth Gulf Developing Crab Fishery

Limited fishing was undertaken by either Exemption issued to dedicated trap fishers during the first 6 years (2003-08) of the EGDCF. A combined total catch of 28 t was taken over the five year period from 2004 to 2008, with annual catches ranging over 0-10 t and annual effort over 0-14,800 traplifts (Figure 9.6). Consequently, the two Exemptions were not renewed upon their expiry in 2009.

Following a subsequent submission to the Department of Fisheries (DoF), a new Exemption to fish commercially for blue swimmer, three spot sand and coral crabs using purpose-designed traps in Exmouth Gulf was issued in June 2016. A small amount of exploratory fishing was conducted during 2016, with 316 kg of blue swimmer crab landed from 852 traplifts (Figure 9.6). No trap fishing catch has been reported from 2017 to 2019.

Due to the climatic conditions over the summer months, most of the exploratory fishing for blue swimmer crabs in the EGDCF to date has been conducted during the winter/spring period from June to October (Figure 9.7). In 2016, fishing occurred between June and September, with a peak catch and effort in July.

Since the inception of the EGDCF, the annual catch of blue swimmer crabs from dedicated trap fishers has tended to fluctuate in line with fishing effort (Figure 9.8).

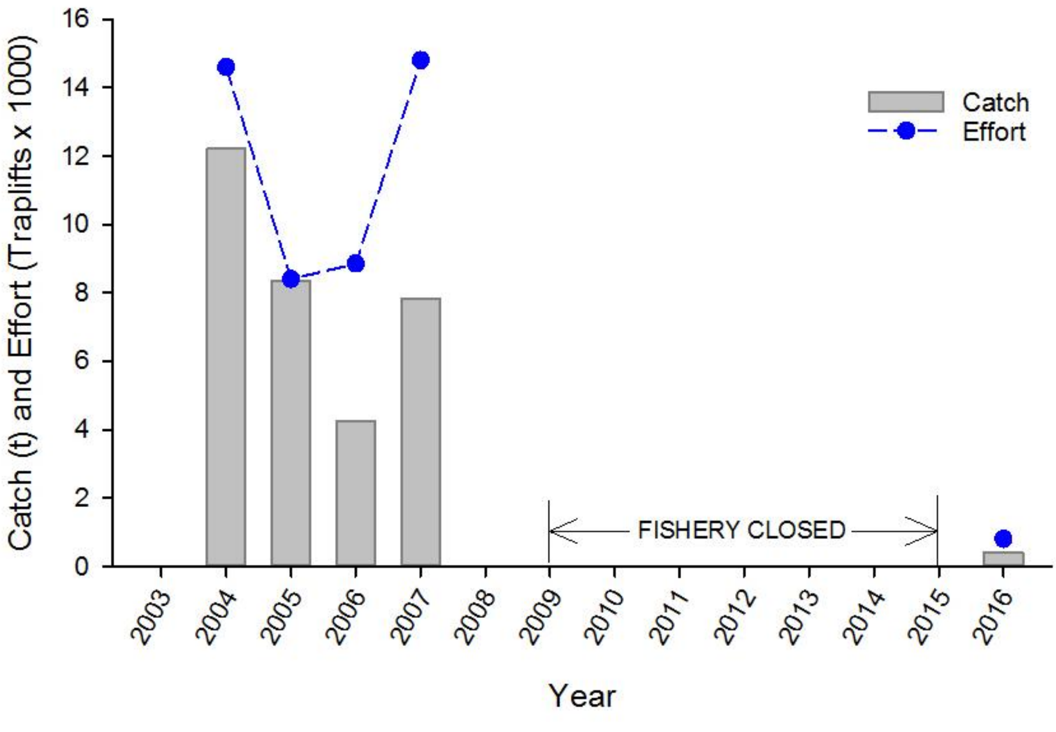


Figure 9.6 Annual commercial blue swimmer crab catch (tonnes) and effort (traplifts x 1000) for trap fishers in the Exmouth Gulf Developing Crab Fishery between 2003-16. No fishing has occurred since 2016.

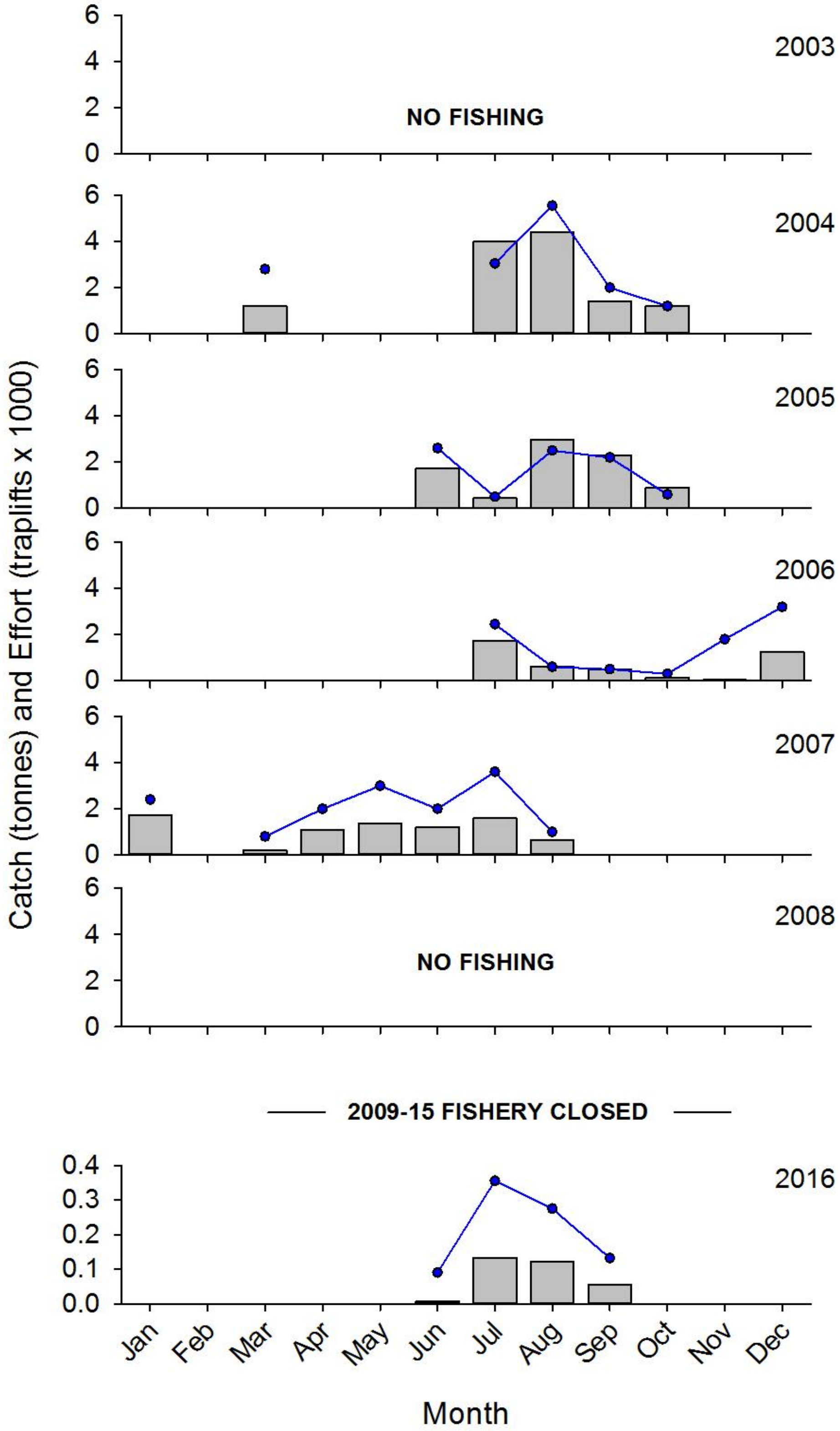


Figure 9.7. Monthly commercial trap catch (tonnes) and effort (traplifts x 1000) by year for trap fishers in the Exmouth Gulf Developing Crab Fishery from 2003 to 2016. Note, the fishery was closed between 2009 and 2015 and no fishing has occurred since 2016.

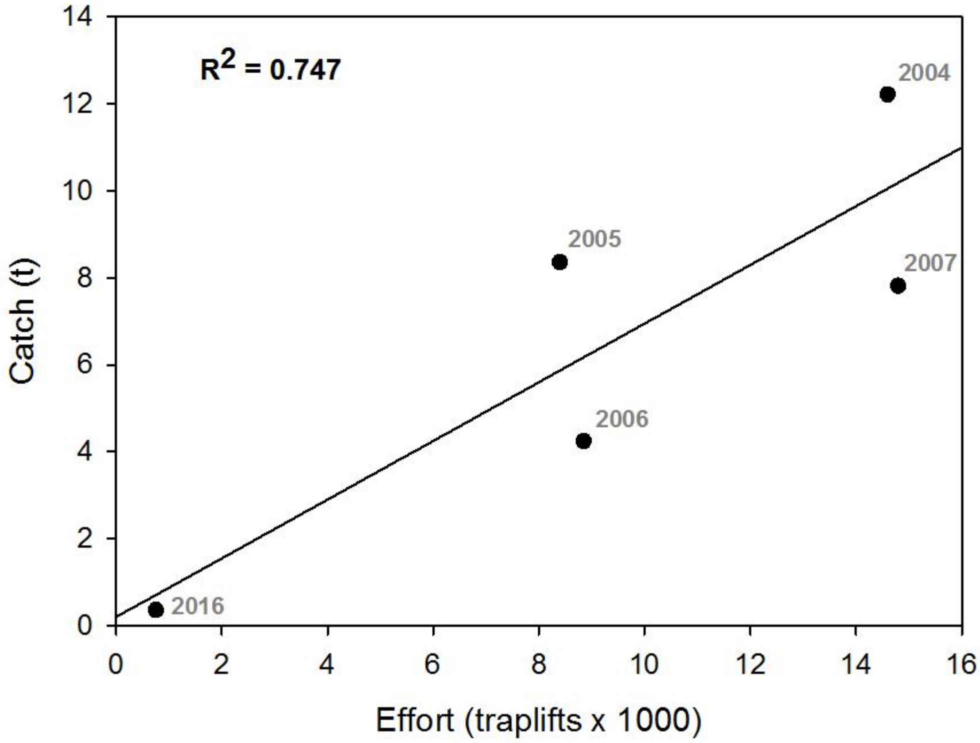


Figure 9.8. Plot of nominal effort (traplifts x 1000) versus total annual catch (tonnes) by year for commercial trap fishers operating in the Exmouth Gulf Developing Crab Fishery derived from trap fisher's statutory monthly catch and effort returns.

Kimberley Crab Managed Fishery

Annual catch and effort ranges in the Kimberly Developing Crab Managed Fishery (KDMCF) from 2013 to 2017 were 0.1–15.3 t and 1,644–27,020 traplifts, respectively (Figure 9.9). Total catches during 2018 and 2019, *i.e.* the first two years of operation as the KCMF, were 3.2 and 7.4 t, respectively, from 4,894 and 19,882 traplifts (CPUE of 0.66 and 0.37 kg/ traplift). The 2019 catch total was reported to contain 1.15 t of brown mud crabs (*S. olivacea*) and 6.27 t of green mud crabs (*S. serrata*), with 17 kg unreported.

Peak catch and effort in the KCMF generally occurs over winter months from May to October (Figure 9.10; Figure 9.11). In 2015, unusually high catch occurred during all months of the year, which was primarily due to one fisher exerting very high effort. The monthly distribution of catch and effort during 2019 was similar to the long-term trend, with most catch taken between May and September.

Since 2015 fishers in the KDMCF/KCMF have been permitted to retain blue swimmer crabs, although only minor catches have been reported with 289 kg landed in 2015 and 56 kg landed in 2019.

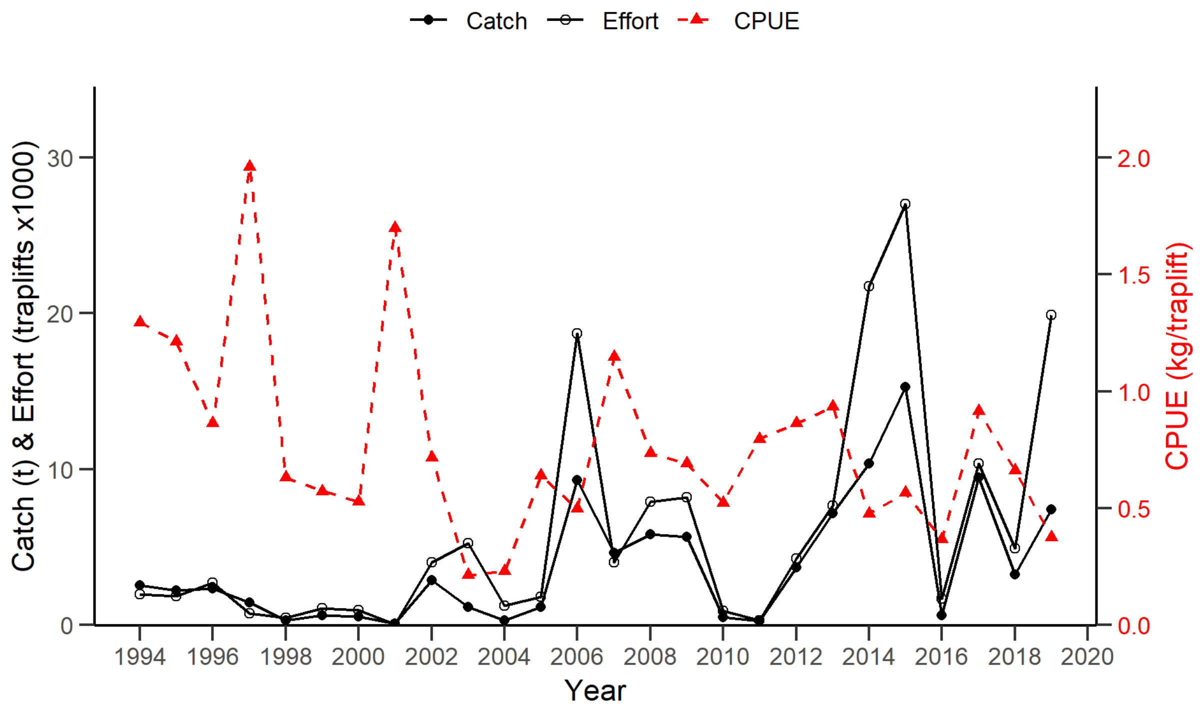


Figure 9.9 Annual total commercial catch (tonnes), effort (traplifts x 1000) and nominal CPUE (kg/traplift) of mud crab (Scylla spp.) from the Kimberley Developing Mud crab Fishery/Kimberly Managed Crab Fishery between 1994 and 2019.

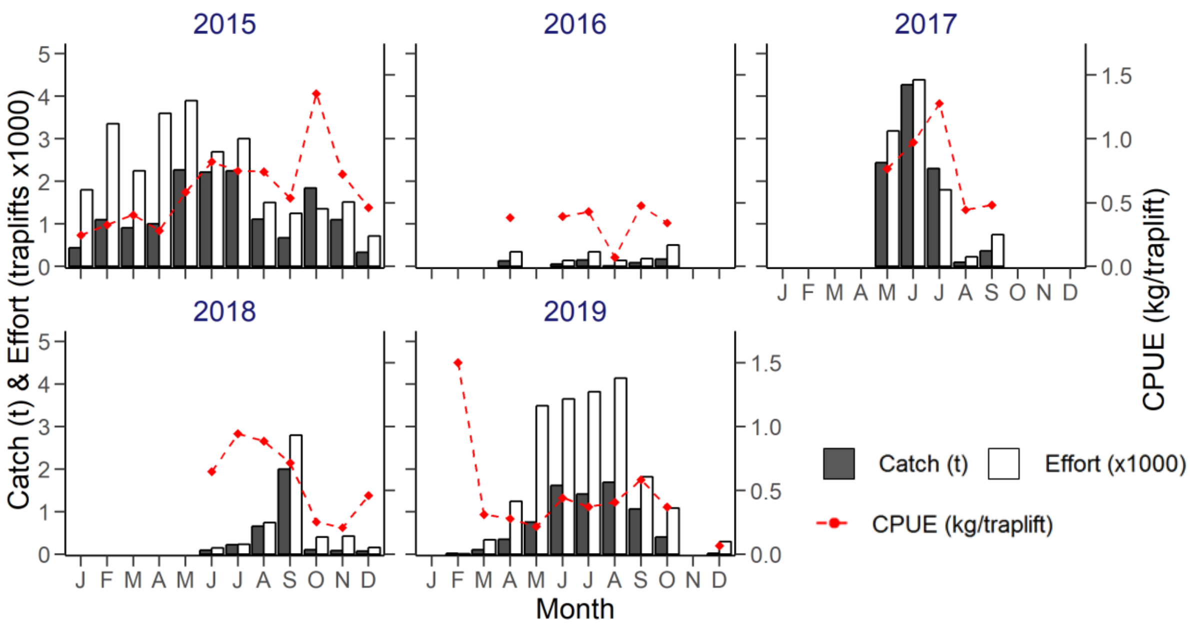


Figure 9.10 Monthly total commercial catch (tonnes), effort (traplifts x 1000) and nominal CPUE (kg/traplift) of mud crab (Scylla spp.) from the Kimberley Developing Mud crab Fishery/Kimberly Managed Crab Fishery between 2015 and 2019.

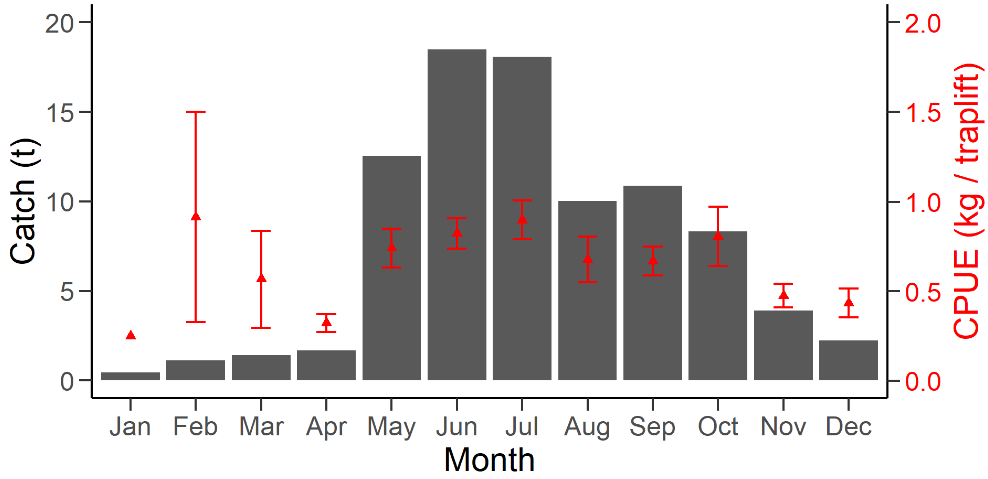


Figure 9.11. Monthly total commercial trap catch (tonnes) and mean CPUE (kg/traplift) of mud crab (Scylla spp.) for the Kimberly Managed Crab Fishery across all years from 2000 to 2019.

9.3.2.2 Recreational/Charter Catch and Effort

Blue swimmer crab

The 2017/18 Department of Primary Industry and Regional Development (DPIRD) survey (i-Survey) of recreational fishing in WA provided a boat-based catch estimate of 1.5 t (95% CI 1–2 t) of retained blue swimmer crabs for the North Coast Bioregion (NCB; approximately 2.6% of the state's recreational catch), and 5 t (95% CI 1–10 t) for the Gascoyne Bioregion (GB; 9% of the state catch) (Ryan *et al.*, 2019). The North Coast recreational blue swimmer crab estimate was slightly lower than earlier estimates from 2015/16, 2013/14 and 2011/12 of 2, 4 and 3 t, respectively. Conversely, the Gascoyne Coast estimate was slightly higher than earlier totals of 1, 2 and 4 t during those surveys (Ryan *et al.*, 2019). The majority of the blue swimmer crab recreational catch from the GB is likely to come from Shark Bay.

There has not been any catch and effort data for blue swimmer crabs reported by charter boat fishers in the North Coast or GB.

Mud crab

The 2017/18 DPIRD survey (i-Survey) of recreational fishing in WA provided a boat-based harvest estimate of 2.5 t (95% CI 2-3 t) of mud crabs for the NCB (Ryan *et al.*, 2019). This was estimated to comprise of 1.34 t of green mud crab and 1.17 t of brown mud crab. Collectively, this accounted for approximately 92% of the State's recreational mud crab catch. As with commercial catches, most recreational mud crab catch was taken during autumn and winter (Ryan *et al.*, 2019). The North Coast recreational mud crab catch during 2017/18 had not changed from an earlier 2015/16 estimate (i.e. 2.5 t), but was less than during 2013/14 and 2011/12 (6.5 and 7 t, respectively).

Seventeen charter vessels reported fishing for mud crabs in the Kimberley region during 2016, over a combined 118 fishing trips. A total of 1,179 mud crabs were retained by the vessels for the year, with a further 945 mud crabs released (Table 9.1).

Table 9.1. Annual catch (numbers of crabs) of mud crabs and effort (numbers of fishing trips) by charter operators in the North Coast Bioregion between 2006 and 2016 inclusive.

Year	Numbers of crabs		Vessels	Fishing Trips
	Retained	Released		
2006	725	236	19	124
2007	1,115	394	20	184
2008	1,130	566	18	176
2009	614	284	16	111
2010	762	355	15	121
2011	1,179	817	20	146
2012	1,097	790	17	173
2013	1,070	716	20	166
2014	1,396	1,270	25	201
2015	1,232	1,087	21	134
2016	1,179	945	17	118

9.3.2.3 Conclusion

Pilbara Crab Fishery	Annual blue swimmer crab catches in the PCMF following inception grew rapidly in line with increases in fisher knowledge, gear development and fishing effort from 10 t from 19,200 traplifts in 2001 to 64 t from 68,500 traplifts in 2003. Subsequent annual catches have varied considerably (between 6-73 t), largely in response to effort (8,100–45,000 traplifts). The 2019 catch was 19.3 t from 11,600 traplifts at a nominal catch rate of 1.67 kg/traplift. A creel survey conducted along the Pilbara coast between December 1999 and November 2000 estimated the recreational blue swimmer crab catch for this period to be 22 t, with most (19 t) taken from Nickol Bay. State-wide surveys estimated the total weight of blue swimmer crab retained in the North Coast Bioregion for private (non-charter), boat-based recreational fishing to be 1.5 t during 2017/18 (one year period, September to August). Commercial CPUE has been relatively constant over time, and was substantially higher in 2019 than earlier years. Given the vast area of the Pilbara region, the relatively low total catch and effort for blue swimmer crabs, and no evidence of declining catch rates, the level of fishing is considered acceptable.

Exmouth Gulf Developing Crab Fishery	Limited fishing was undertaken during the first 6 years (2003–08) of the EGDCF. A combined total blue swimmer crab catch of 28 t was taken over the five-year period from 2004 to 2008, with annual catches ranging over 0-10 t and annual effort over 0 -14,800 traplifts. The fishery was closed during 2009-15. A small amount of exploratory fishing was conducted in 2016, with 316 kg of blue swimmer crab landed from 852 traplifts. State-wide surveys estimated the total weight of blue swimmer crab retained in the Gascoyne Bioregion for private (non-charter), boat-based recreational fishing to be 5 t during 2017/18 (September to August), the majority of which is likely to have been taken from Shark Bay. Based on the low levels of commercial and recreational catch in recent years, the level of stock depletion for blue swimmer crabs in the EGDCF is considered acceptable.
Kimberley Crab Fishery	Annual catch and effort ranges of mud crabs in the KDMCF from 2013 to 2018 were 0.1–15.3 t and 1,644–27,020 traplifts, respectively. The total catch in 2019 was 7.4 t from 19,882 traplifts (CPUE of 0.37 kg/ traplift). The 2017/18 DPIRD iSurvey of recreational fishing in WA provided a boat-based harvest estimate of 2.5 t (95% CI 2–3 t) of mud crabs for the North Coast Bioregion. This accounted for approximately 92% of the State's recreational mud crab catch. Negligible blue swimmer crab catch has been taken from the Kimberly region during recent years. Based on the low levels of commercial and recreational catch in recent years and the vast area of the Kimberly region, the level of stock depletion for mud and blue swimmer crabs is considered acceptable.

9.3.3 Catch Distribution Trends

Spatially, commercial catch and effort data for the PCMF, EGDCF and KCMF has been reported by 60 × 60 nm blocks in statutory CAES returns that report total monthly catch and effort. Reporting of catch returns has occurred for 10 nm transects or latitude and longitude co-ordinates for each trap line fished in daily research logbooks, however this information is sporadic.

Pilbara Crab Fishery

Although reasonable commercial catches (~ 1 kg/traplift) of blue swimmer crabs have been identified in nearshore waters along the length of the Pilbara coastline, the logistics of getting the catch to market from such isolated locations has rendered most of the area commercially unviable for crab fishing. Following an initial period of exploration in waters around the coastal towns of Port Hedland and Onslow, commercial crab fishing has centred on Nickol Bay and the surrounding area (Figure 9.12, Figure 9.13). As a consequence, only a small proportion of the available fishery (<10%) is currently being exploited (Figure 9.14). In the latter part of 2016 and in 2017 there has been some exploratory fishing to the north-east of Nickol Bay (Figure 9.13).

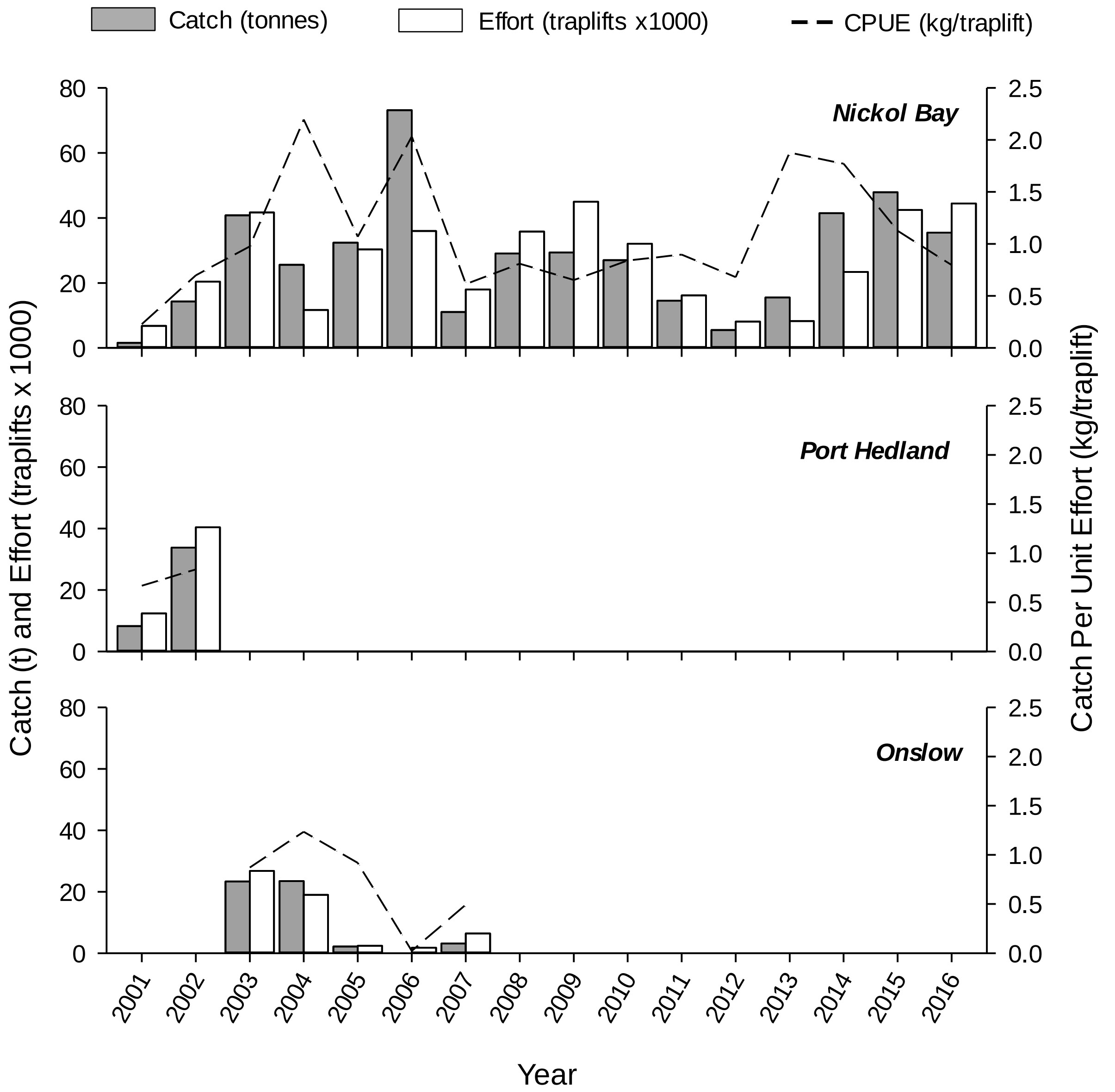


Figure 9.12. Annual commercial catch (tonnes), effort (traplifts x 1000) and catch per unit effort (kg/traplift) for the Pilbara Crab Fishery between 2001 and 2016 by area (defined by CAES blocks: Nickol Bay region – 2016, 2017; Port Hedland – 1918, 1919, 2018, 2019; Onslow – 2015, 2115, 2116).

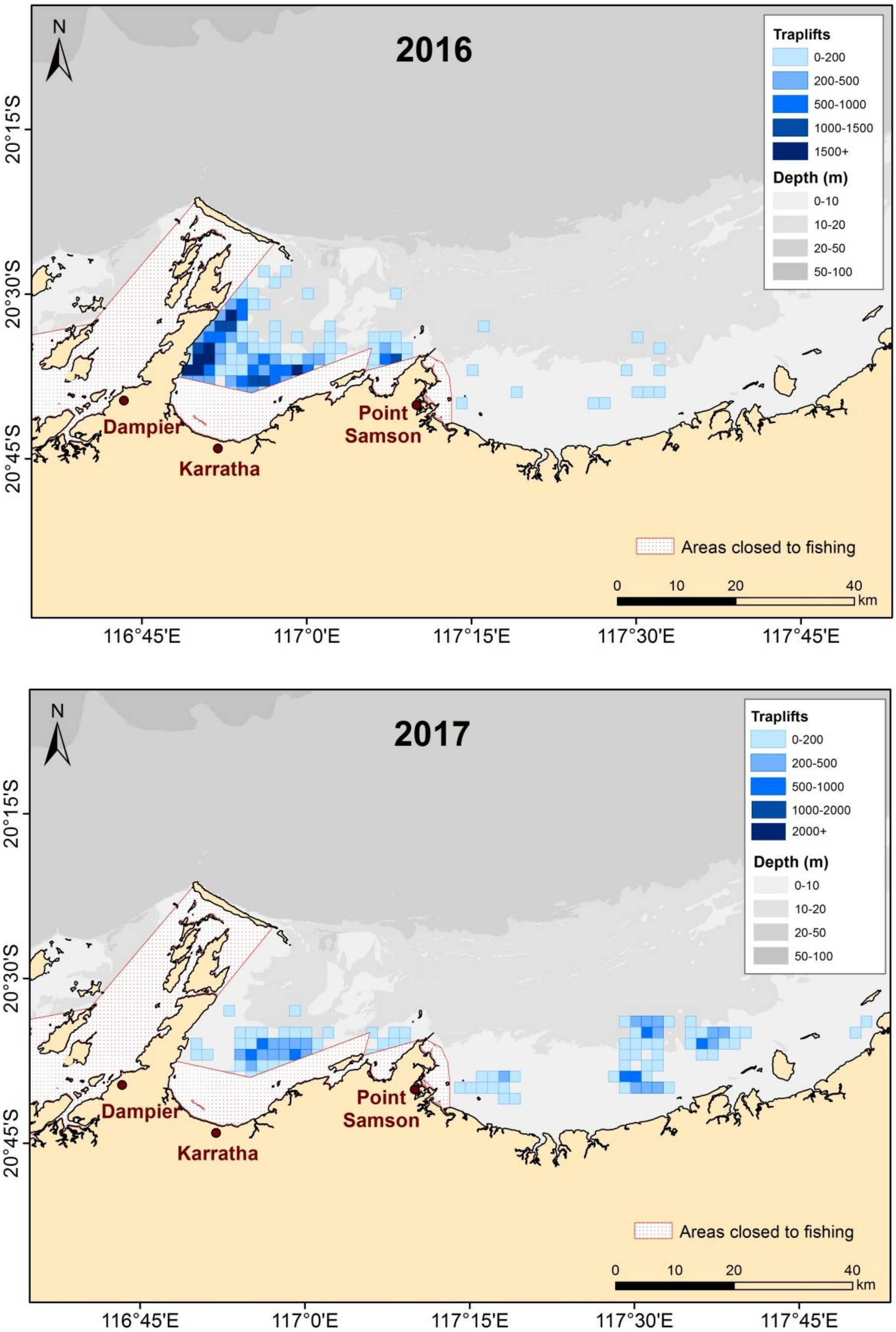


Figure 9.13. Spatial distribution of commercial blue swimmer crab effort (traplifts) from Research Logbook data in the Pilbara Crab Fishery during 2016 (upper map) and 2017 (lower map), focusing on the Nickol Bay Region where the majority of fishing has occurred.

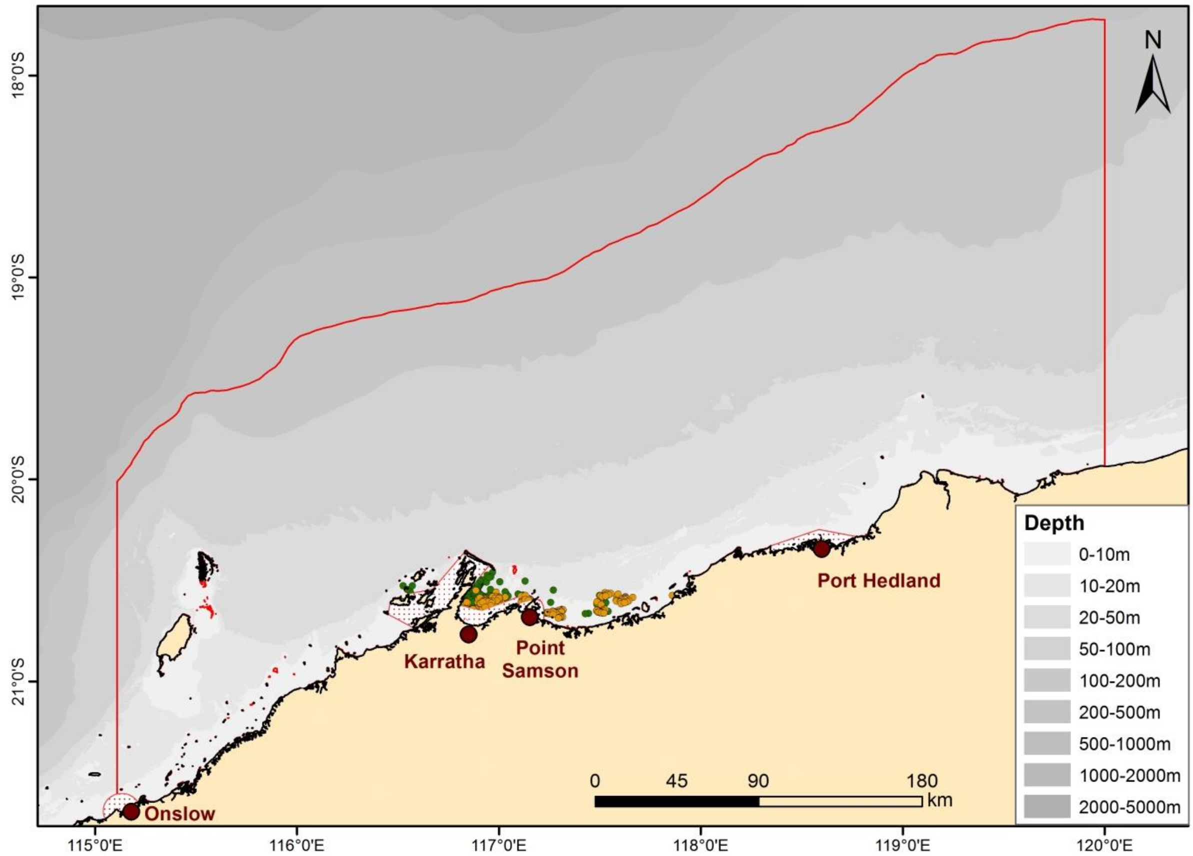


Figure 9.14. Spatial distribution of commercial blue swimmer crab effort from Research Logbook data in the Pilbara Crab Fishery during 2016 (●) and 2017 (●). (▬ Fishery boundary; ░ Fishery closures).

Exmouth Gulf Developing Crab Fishery

Fishing in the EGDCF between 2003 and 2008 was typically exploratory in nature, with comparatively equal amounts of effort expended in the northern (CAES block 2114) and southern (CAES block 2214) areas of Exmouth Gulf (Figure 9.15).

A commercial crab trap fisher with endorsements for Shark Bay and Cockburn Sound leased one EGDCF Exemption and one PCMF Exemption between 2005 and 2007 and undertook sporadic exploratory fishing along the eastern side of Exmouth Gulf before following the Pilbara coastline towards Karratha (Figure 9.16, Figure 9.17). Although exploratory in nature, this was some of the most consistent effort expended in Exmouth Gulf and the south western area of the PCMF.

The small amount of exploratory fishing undertaken by the current Exemption holder in the EGDCF during 2016 has focused on the southern area (CAES block 2214) of Exmouth Gulf (Figure 9.15, Figure 9.18).

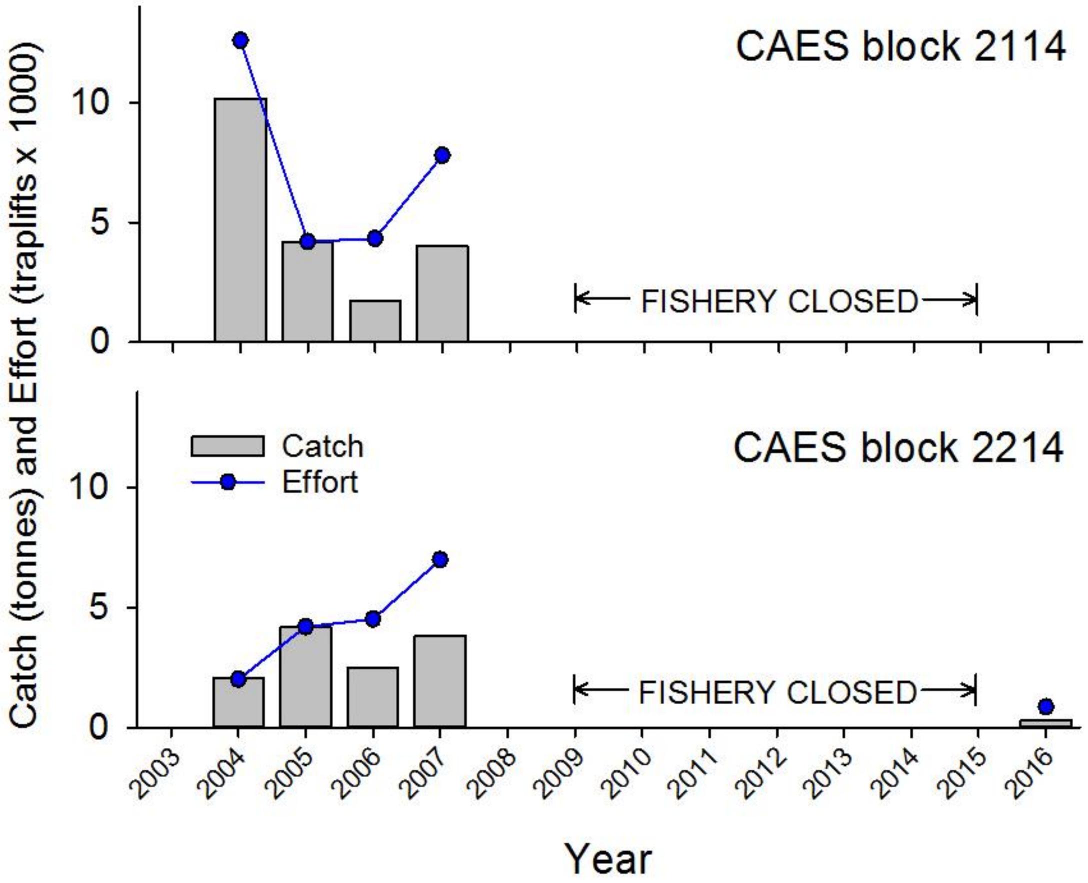


Figure 9.15. Annual commercial blue swimmer crab catch (tonnes) and effort (traplifts x 1000) by CAES block for trap fishers in the Exmouth Gulf Developing Crab Fishery between 2003-08 and when the fishery reopened in 2016. Fishery was closed in 2009 due to a lack of effort by the exemption holder and re-opened in 2016 with a new exemption holder with existing infrastructure in this area. Fishing has not occurred since 2016.

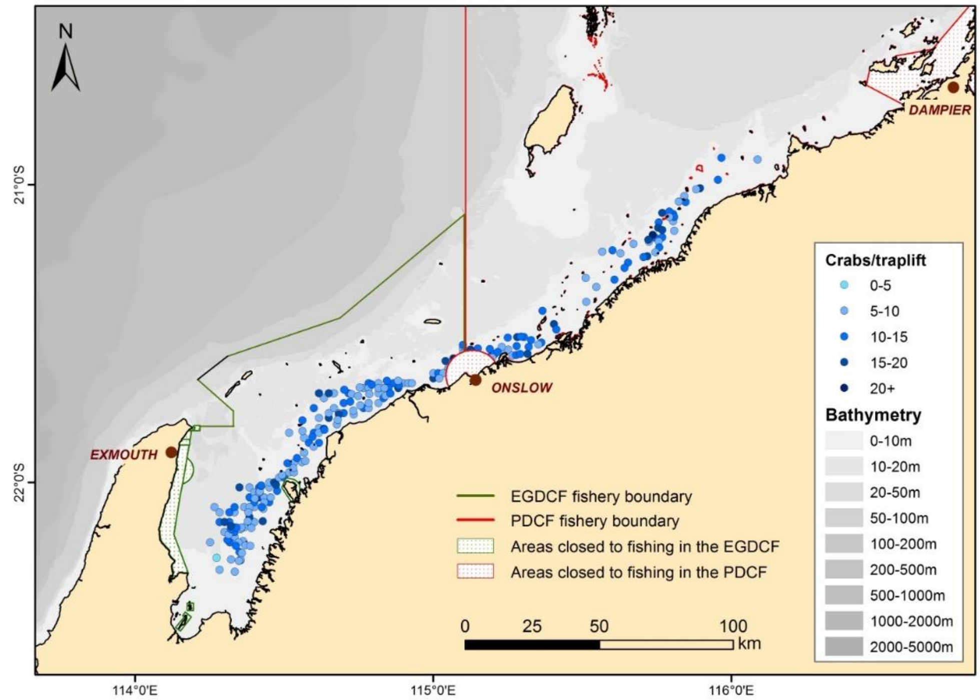


Figure 9.16. Nominal catch rates (kg/traplift) by trapline of blue swimmer crabs from catch and effort data reported in the Daily Research Logbook submitted by a commercial fisher leasing Exemptions in the Exmouth Gulf (EGDCF) and Pilbara (PCMF) Developing Crab Fisheries during sporadic fishing between 2005 and 2007.

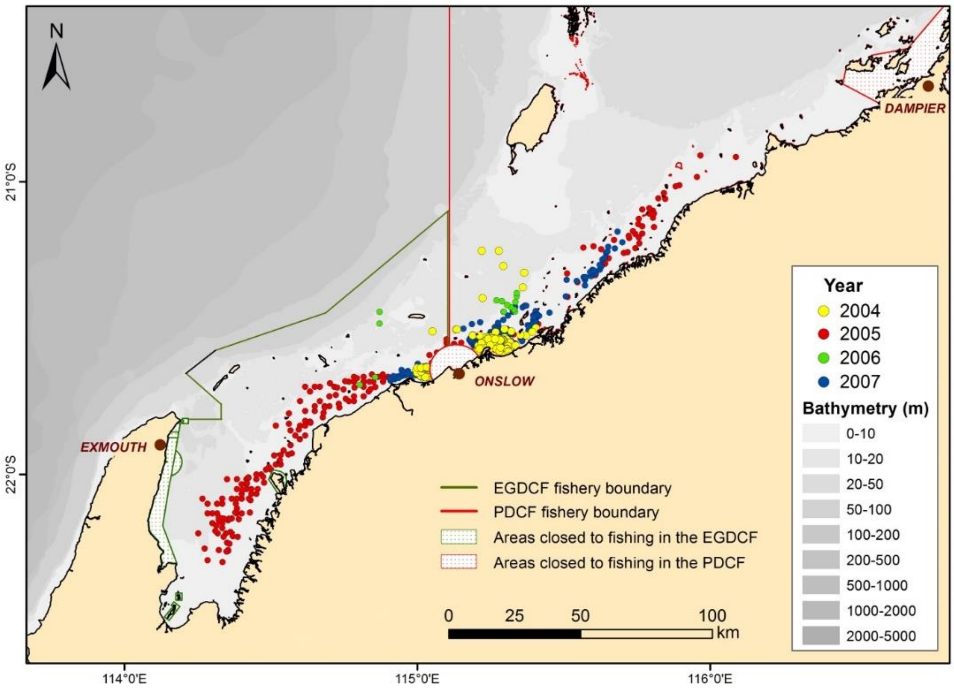


Figure 9.17. Spatial distribution of commercial blue swimmer crab traplines reported in the Daily Research Logbook submitted by commercial fishers in the Exmouth Gulf (EGDCF) and Pilbara (PCMF) Developing Crab Fisheries during sporadic experimental fishing trips between 2004 and 2007.

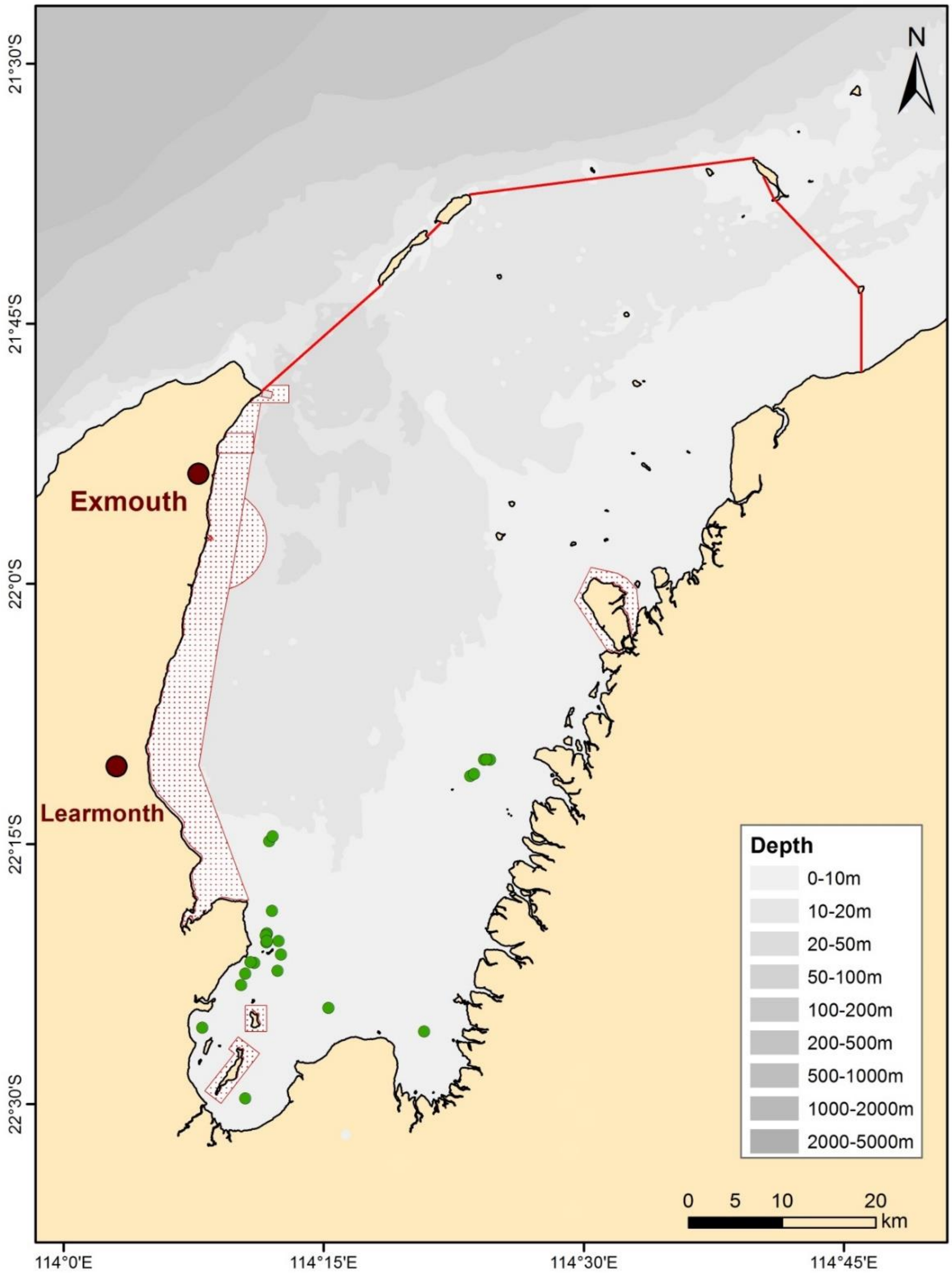


Figure 9.18. Spatial distribution of commercial blue swimmer crab traplines (●) from Research Logbook data in the Exmouth Gulf Developing Crab Fishery during 2016. (▬ Fishery boundary; ░ Fishery closures).

Kimberley Crab Managed Fishery

From 1994 to 2000, the majority of commercial mud crab catches were taken from King Sound and Collier Bay whereas from 2000 to 2009 the contribution of catches from York Sound substantially increased (Figure 9.19; Figure 9.20). However, from 2010 to 2019 the vast majority of catch has been taken from Cambridge Gulf, with notable contributions also taken from Admiralty Gulf and King Sound in one or more years (Figure 9.19; Figure 9.20). As CPUE has not substantially increased in Cambridge Gulf over time, higher catches are a considered result of increased fishing effort (Figure 9.21). Sporadic fishing has been recorded in Camden Sound, Camp Inlet, Carnot Springs and the Broome Area, with low catches generally reported. The contribution of green *vs* brown mud crabs to catches also varied between fishing areas, with almost entirely brown mud crabs reported from Admiralty Gulf, King Sound and York Sound, while mostly green mud crabs were caught in other areas (Figure 9.22).

In 2019, 6.88 t was landed from Cambridge Gulf, with minor catch from York Sound (0.44 t), King Sound (0.02 t) and the Broome area (0.08 t). Annual nominal CPUE during 2019 was highest in the Broome area (2.3 kg/traplift) and lowest in Cambridge Gulf (0.36 kg/traplift; Figure 9.21).

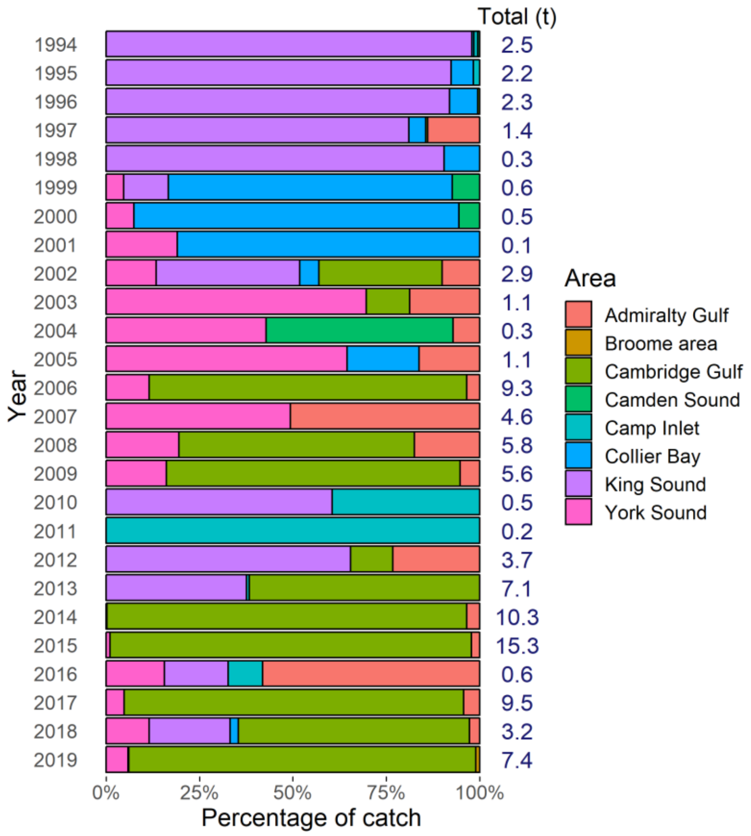


Figure 9.19. Percentage of annual mud crab (Scylla spp.) catch by fishing area between 1994 and 2019. Areas defined by CAES blocks — Cambridge Gulf: 1428, 1528; Camden Sound: 1524; Admiralty Gulf: 1425, 1426; Collier Bay: 1624; York Sound: 1525; King Sound: 1623, 1723; Camp Inlet: 1622.; Broome area: 1722, 1822.

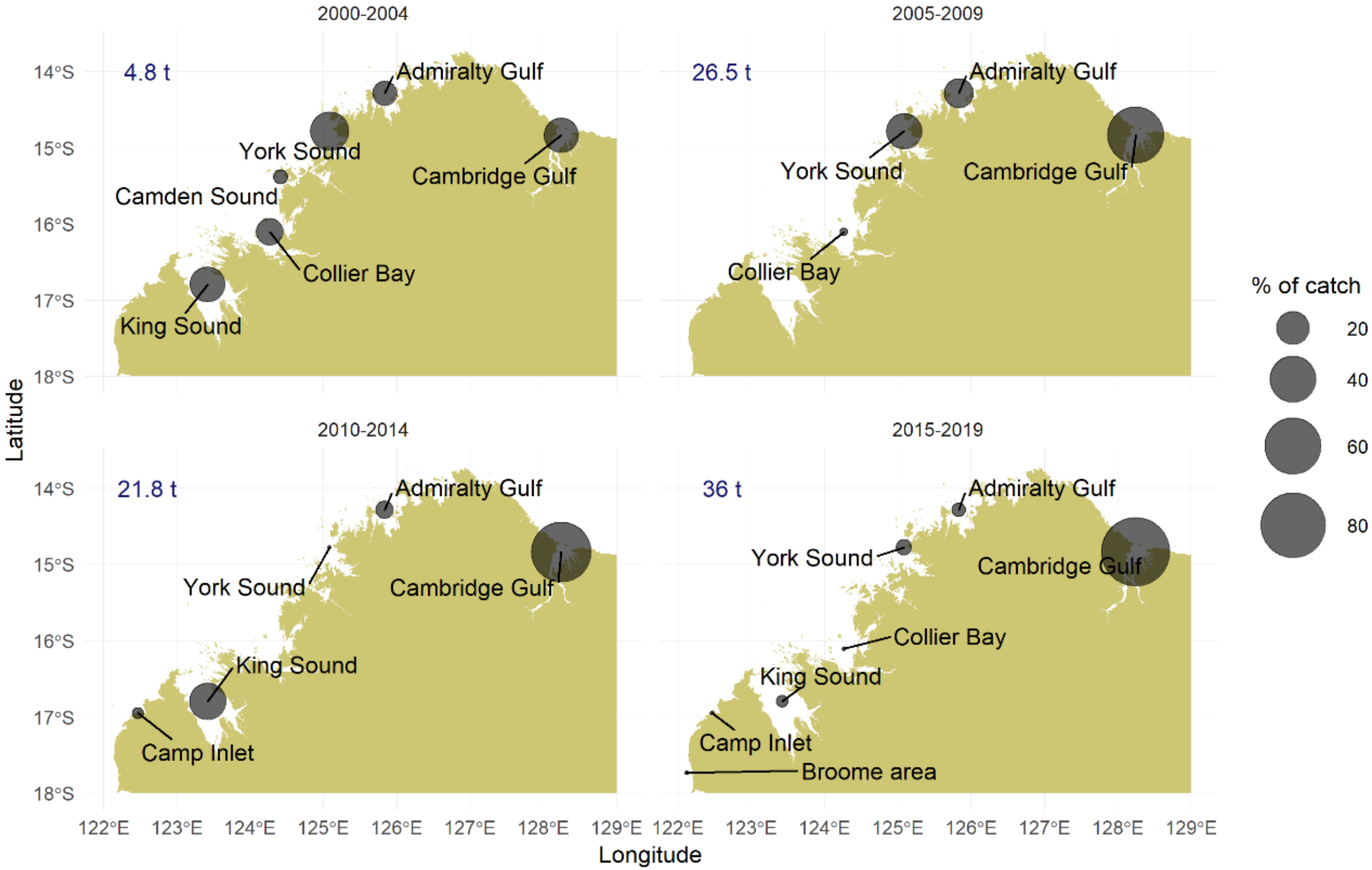


Figure 9.20. Percentage of mud crab (Scylla spp.) catch by fishing area during 2000-04, 2005-09, 2010-14 and 2014-19. The total catch in tonnes (across all areas) is also given for each period (blue text). Areas denoted by CAES blocks as detailed in Figure 9.19.

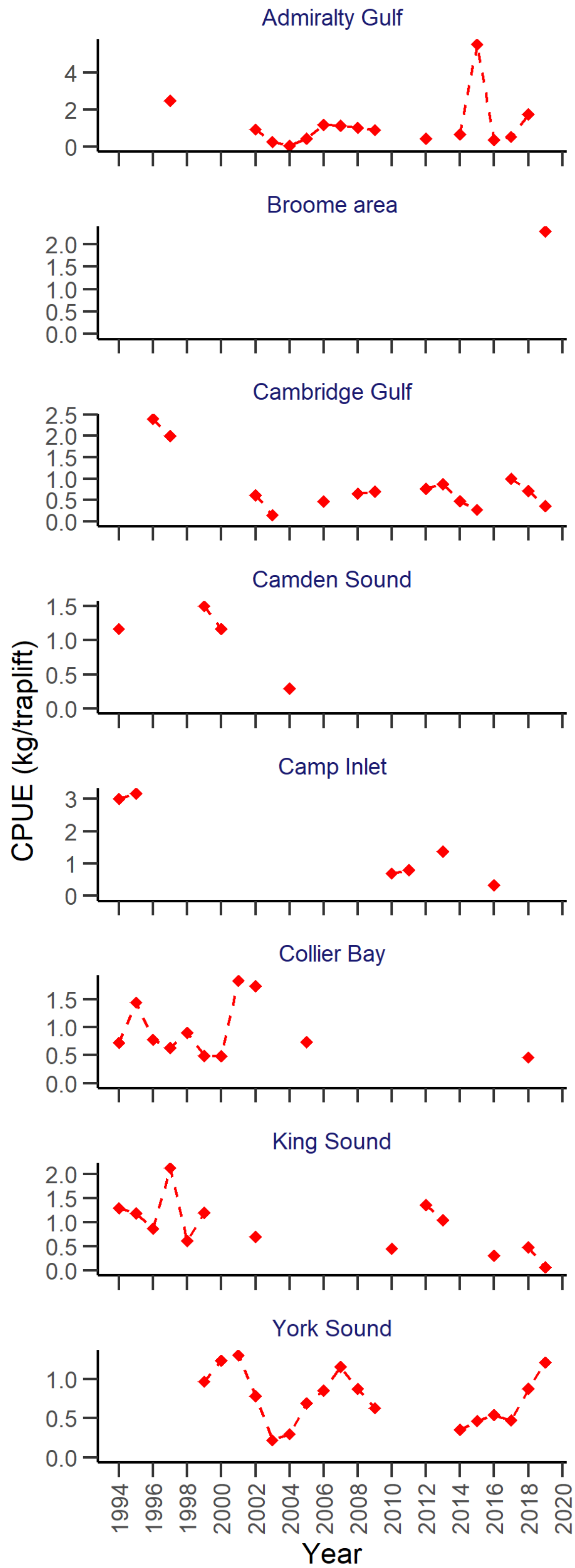


Figure 9.21. Nominal annual CPUE of mud crab (Scylla spp.) by fishing area from 1994 to 2019. Areas denoted by CAES blocks as detailed in Figure 9.19.

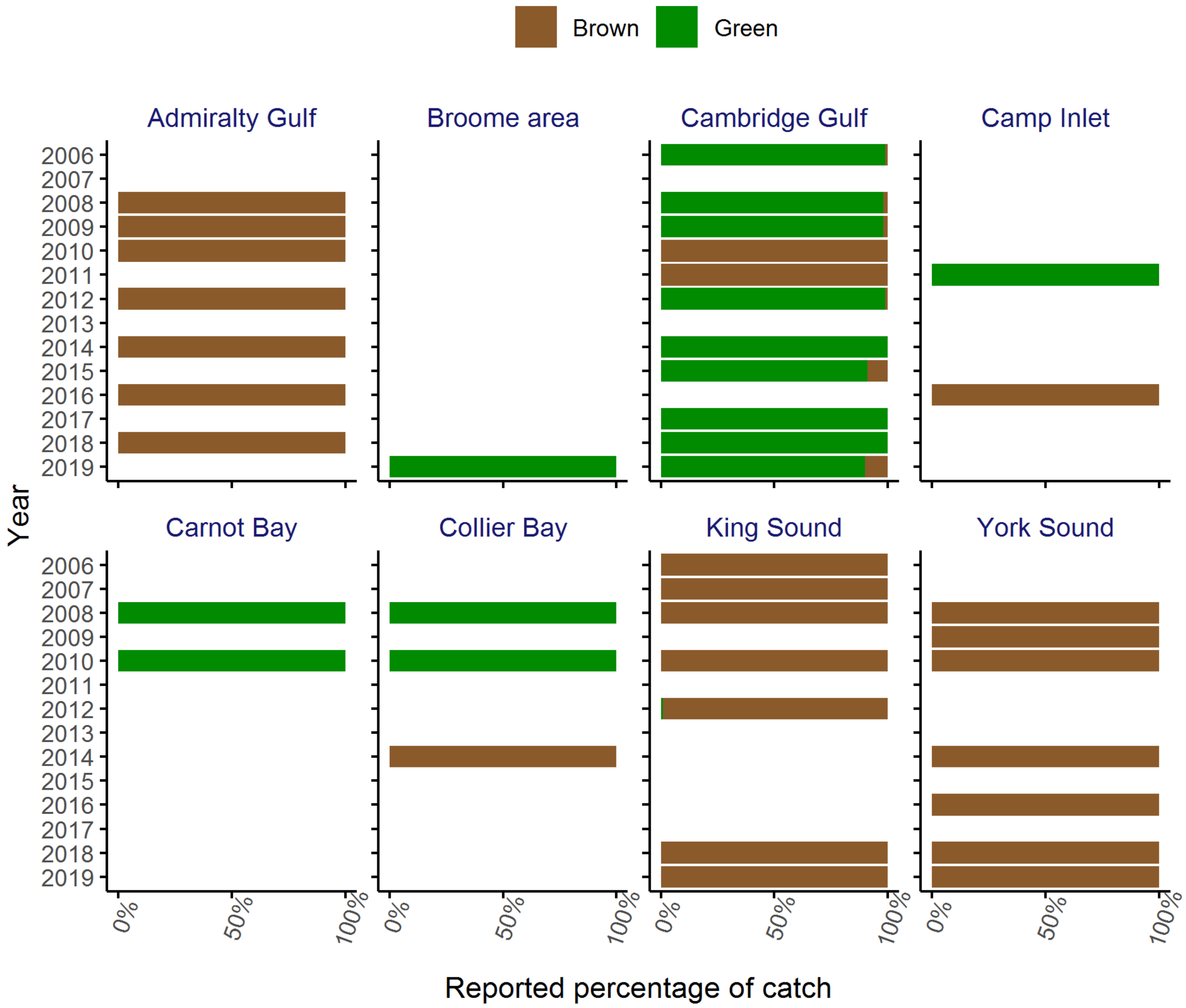


Figure 9.22 The reported annual proportion of brown mud crab (Scylla olivacea) and green mud crab (S. serrata) in each fishery area of the Kimberley Developing Mud crab Fishery/Kimberly Managed Crab Fishery between 2006 and 2019. Years when no catch were reported or the species composition is unknown are left blank.

Spatial catch information from charter or recreational surveys is reported on a Bioregional basis and not by fishery. Both specify numbers retained and released and effort in number of days within the NCB, with recreational mud crab numbers converted to weight (kg) using length weight conversions (Refer to Section 9.3.2.2).

9.3.3.1 Conclusion

Pilbara Crab Fishery	Although reasonable commercial catches (~ 1 kg/traplift) of blue swimmer crabs have been identified in near shore waters along the length of the Pilbara coastline, the logistics of getting the catch to market from such isolated locations has rendered most of the area commercially unviable for crab fishing. Following an initial period of exploration in waters around the coastal towns of Port Hedland and Onslow, commercial crab fishing has centred on Nickol Bay and the surrounding area since 2007. As a consequence, only a small proportion of the available fishery (<10%) is currently being exploited and the level of fishing is considered acceptable.
Exmouth Gulf Developing Crab Fishery	The limited fishing that has taken place in the EGDCF between 2003 and 2008 has been typically exploratory in nature, with comparatively equal amounts of effort expended in the northern and southern areas of Exmouth Gulf. In 2016 exploratory fishing has occurred in the southern area only. No dedicated crab (trap) fishing has occurred since 2016 and only minor trawl by-product has been taken.
Kimberley Crab Fishery	In recent years (2010–2019) the largest commercial catch of mud crab has been from Cambridge Gulf with some catch also retained in Admiralty Gulf, York Sound and King Sound. Given the wide distribution of mud crabs throughout the KCMF and the minimal portion of the fishery that has been exploited to date, the level of fishing is considered acceptable.

9.3.4 Fishery-Dependent Data Analyses

Pilbara Crab Fishery

The proposed harvest strategy for the Pilbara crab stock involves analyses of commercial catch and effort data from statutory CAES returns, with standardised catch rates (kg/traplift) providing an index of abundance to assess fishery performance. Monthly commercial catch rates for the Nickol Bay region are calculated using the total trap catch and effort recorded in CAES blocks 2016 and 2017, as this area provides the longest time series to judge the performance of the fishery. These monthly catch rates are standardised to an annual catch rate using a generalised linear model (GLM).

During the reference period of 2005 to 2015 annual standardised catch rates ranged from 0.46 to 1.89 kg/traplift, being lowest during 2007 and highest in 2013 (Figure 9.23). From 2016 catch rates have steadily increased from 0.62 to 1.5 kg/traplift. Total catch of 19.3 t during 2019 had declined by approximately one third from 2018 (30.2 t), reflecting a decreasing in fishing effort (Figure 9.1).

The 2019 standardised catch rate and total annual catch for Nickol Bay were within their target and tolerance ranges of the harvest strategy, indicating there should be adequate egg production such that recruitment is not impaired under typical environmental conditions and the breeding stock is considered adequate.

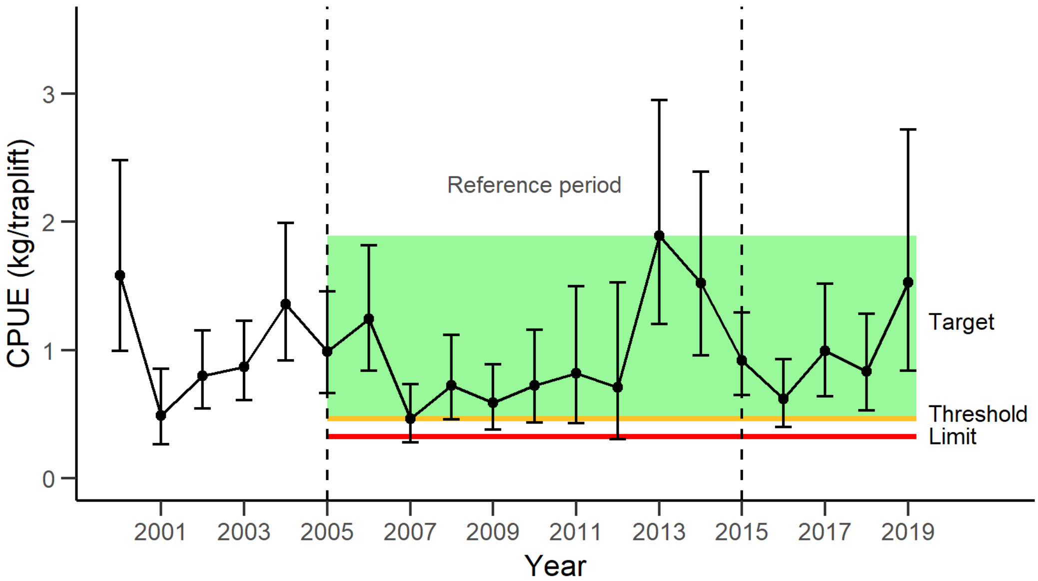


Figure 9.23. The primary performance indicator, annual standardised commercial catch rate (kg/traplift) of blue swimmer crabs for the Pilbara Crab Fishery relative to the associated reference points (target, threshold and limit) for the proposed harvest strategy. The reference period is from 2005 to 2015; where the fishery was operating under relative stability following an initial exploratory period (2000-04).

Exmouth Gulf Developing Crab Fishery

Annual commercial blue swimmer crab trap catch rates in the EGDCF from 2003-08, and when the fishery reopened in 2016, ranged between 0.5–1.0 kg/traplift (Figure 9.24). These annual catch rates are low compared with historical catch rates in other WA commercial blue swimmer crab fisheries. However, the limited amount of fishing that has been undertaken over this period makes it difficult to determine if these catch rates are reflective of lower stock abundance than other areas, or more the exploratory and developmental nature of fishing effort in this fishery to date.

With minimal fishing to date, a harvest strategy has not been developed yet for this fishery due to lack of data. However, given the very low level of blue swimmer crab catch and effort in Exmouth Gulf in 2016, there should be adequate egg production such that recruitment is not impaired under typical environmental conditions and the stock is being fished at sustainable levels.

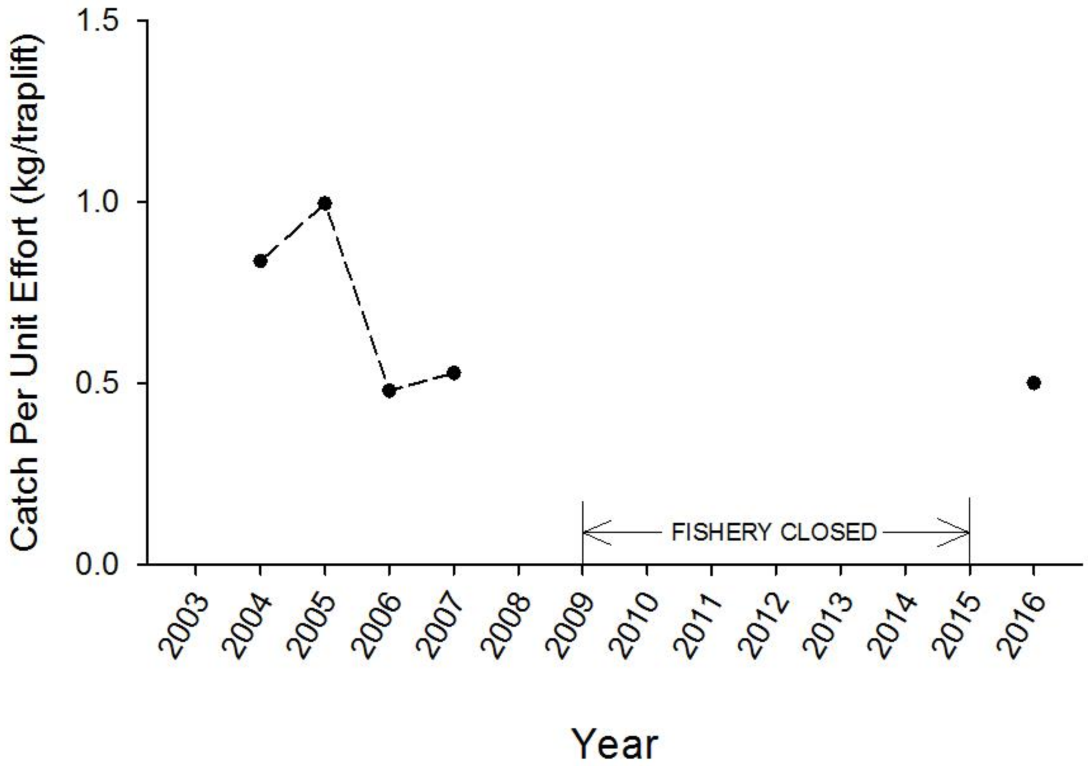


Figure 9.24. Annual nominal commercial trap catch rate (kg/traplift) of Portunus armatus for the Exmouth Gulf Developing Crab Fishery since 2003. Fishing has not occurred since 2016.

Kimberley Crab Managed Fishery

From 1994 to 2005, commercial fishing for mud crabs in the Kimberley region was authorised through permissive conditions on Fishing Boat Licences. Annual catch rates varied notably during this period, ranging between 0.2–1.3 kg/traplift (Figure 9.25). The fluctuation in catch rate was due either to the unviability of the fishery, the limitations of permissive conditions, or operators concentrating their efforts on other commercial fisheries.

Exemptions granting access to the KCMF replaced the permissive conditions in 2006 (Figure 9.25). Standardised catch rates during the harvest strategy reference period of 2006–2015 ranged from 0.44 to 0.91 kg/traplift. Catch rates during 2016 (0.26 kg/traplift) fell below the harvest strategy lower limit, however, catch rates increased during 2017 and 2018 (0.61 and 0.5 kg/traplift, respectively) and were within the target range. The 2019 catch rate was 0.33 kg/traplift, which fell below the threshold of the harvest strategy, but above the limit. These fluctuations in catch rate appear to be primarily driven by changes in effort and operator. The 2019 total annual catch of 7.4 t was within the catch tolerance range.

Catch and effort has been limited to such a low level in recent years that based on the relatively small impact of commercial operations, the wide distribution of the species throughout the region, and the minimum legal size set well above size at maturity, the risk to sustainability has been considered to be negligible. Consequently, there should be adequate egg production such that recruitment is not impaired under typical environmental conditions and the stock is classified as **sustainable.** Nevertheless, considering the proximity of the 2019 catch rate to the limit reference level, catch, effort and catch rate is being monitored closely in this fishery during the 2020 season.

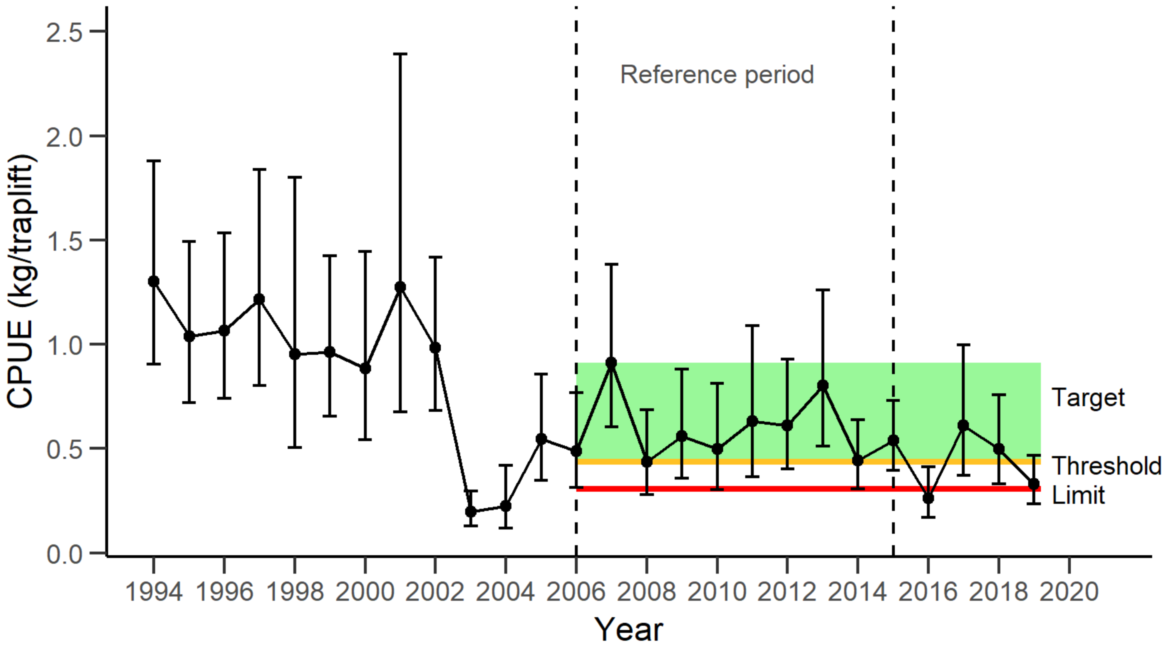


Figure 9.25. The primary performance indicator, annual standardised commercial catch rate (kg/traplift) for the Kimberley Crab Managed Fishery relative to the associated reference points (target, threshold and limit) for the proposed harvest strategy. The reference period is from 2006 to 2015; where the fishery was operating under relative stability following initial exploratory fishing (2000–05).

9.3.4.1 Conclusion

Pilbara Crab Fishery	The total annual commercial blue swimmer crab catch for Nickol Bay during 2019 was 19.3 t at a standardised catch rate of 1.5 kg/traplift. The 2019 standardised catch rate and total annual catch for Nickol Bay were within their target and tolerance ranges of the harvest strategy, indicating there should be adequate egg production such that recruitment is not impaired under typical environmental conditions and the breeding stock is considered Adequate.
Exmouth Gulf Developing Crab Trap Fishery	Annual commercial blue swimmer crab trap catch rates in the EGDCF from 2003-08, and when the fishery reopened in 2016, ranged between 0.5 – 1.0 kg/traplift. These annual catch rates are low compared with historical catch rates in other Western Australian commercial blue swimmer crab fisheries. However, the limited amount of fishing that has been undertaken over this period makes it difficult to determine if these catch rates are reflective of lower stock abundance than other areas, or more the exploratory and developmental nature of fishing effort in this fishery to date. With minimal fishing to date, a harvest strategy has not been developed yet for this fishery due to lack of data. Given the very low level of blue swimmer crab catch and effort in Exmouth Gulf there is likely to be negligible impact on stocks.
Kimberley Crab Fishery	Catch rates during 2016 (0.26 kg/traplift) fell below the harvest strategy lower limit, however, catch rates increased during 2017 and 2018 (0.61 and 0.5 kg/traplift, respectively) and were within the target range. The 2019 catch rate was 0.33 kg/traplift, which fell below the threshold of the harvest strategy, but above the limit. These fluctuations in catch rate appear to be primarily driven by changes in effort and operator. The 2019 total annual catch of 7.4 t was within the catch tolerance range. Catch and effort has been limited to such a low level in recent years that based on the relatively small impact of commercial operations and the wide distribution of the species throughout the region, the risk to sustainability has been considered to be negligible. Nevertheless, considering the proximity of the 2019 catch rate to the limit reference level, catch, effort and catch rate is being monitored closely in this fishery during the 2020 season.

9.3.5 Trends in Age / Size Structures

Pilbara Crab Fishery

Commercial monitoring analysis

The size structure and sex ratios of crabs sampled during monitoring surveys aboard commercial crab trap vessels in the PCMF varied considerably, both between years and between areas (Figure 9.26). In the Nickol Bay area, samples in August 2003 and September 2006 were dominated by female crabs, with substantial numbers of berried females also represented in the 2006 sample. However, samples measured in July 2004 were dominated by male crabs, while samples in October 2005 and August 2008 contained equal numbers of male and female crabs. Commercial catches sampled in the Port Hedland region during July 2002, and a sample measured in the Onslow region in 2004, both contained predominantly male crabs (Figure 9.26). There have been no surveys since 2008 so current data is not available.

Despite the variation in sex ratio and abundance identified in samples from commercial monitoring surveys between different areas and years, the carapace width of crabs was relatively consistent between all survey samples, the majority of which ranged between 140 and 180 mm CW (Figure 9.26). The size of crabs was consistent with samples of commercial catches measured in Shark Bay, and noticeably larger than the carapace width of commercial samples from most crab fisheries in southwest WA. This is quite likely due to the increased water temperature in the northern waters of the Pilbara, which supports faster growth rates in Portunid species. It may also be related to the relatively lower fishing pressure in the Pilbara fishery allowing a greater proportion of crabs to enter their third year of growth.

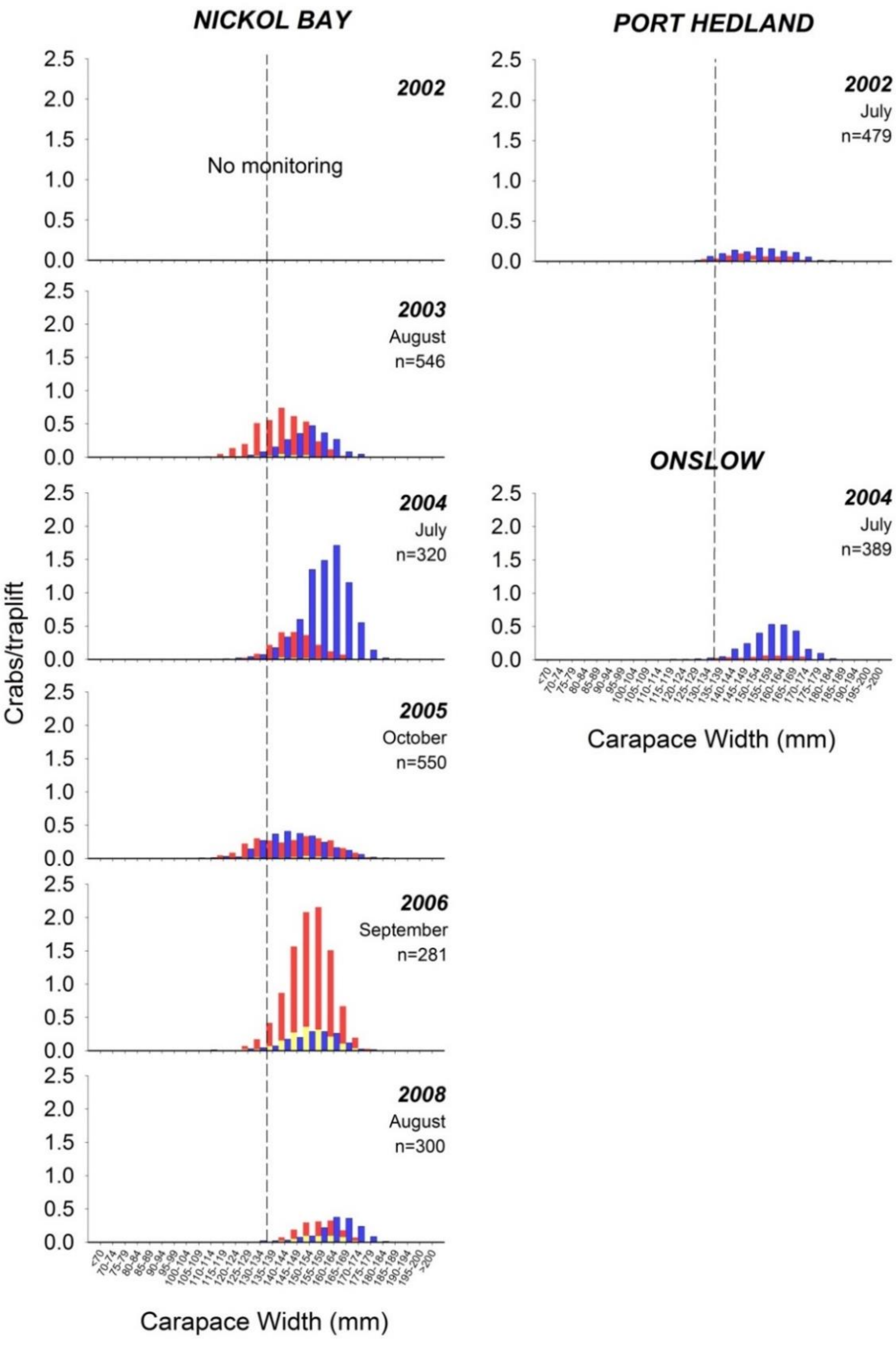


Figure 9.26. Annual length frequency distributions of male (■), female (■), and ovigerous female (■) blue swimmer crabs sampled during catch monitoring surveys aboard commercial crab trap vessels in Nickol Bay (left hand graphs) between 2003 and 2008, and surveys in Port Hedland in July 2002 and Onslow in July 2004 (right hand graphs). No survey was conducted in Nickol Bay during 2007. No surveys have been conducted since 2008. Minimum commercial size limit 135 mm CW (denoted by dashed vertical lines).

Logbook analysis

Analysis of data provided by the commercial trap fisher in the PCMF indicates that male crabs dominate the commercial catch in the autumn months of March to May, accounting for 97-100% of the retained catch (Figure 9.27). Female crabs begin to appear in traps during autumn, and comprise over half the retained catch by late winter and throughout the spring months. While records are incomplete, the majority of berried female crabs reported in daily research logbooks were captured in the late autumn/spring months between June and October (Figure 9.28). Consequently, an annual seasonal closure (15th August to 15th November) was introduced for the PCMF in 2016 to provide additional protection for pre-mated spawned and berried females. Catch rates of undersize crabs in the commercial trap catch in the PCMF have generally been slightly higher during the winter months (Figure 9.29). However, the three and a half inch mesh used on the traps that selects against the retention of undersize crabs, the seasonality of fishing, and incomplete logbook records means that it is difficult to have confidence in these trends representing the actual seasonal abundance of undersize crabs in this fishery.

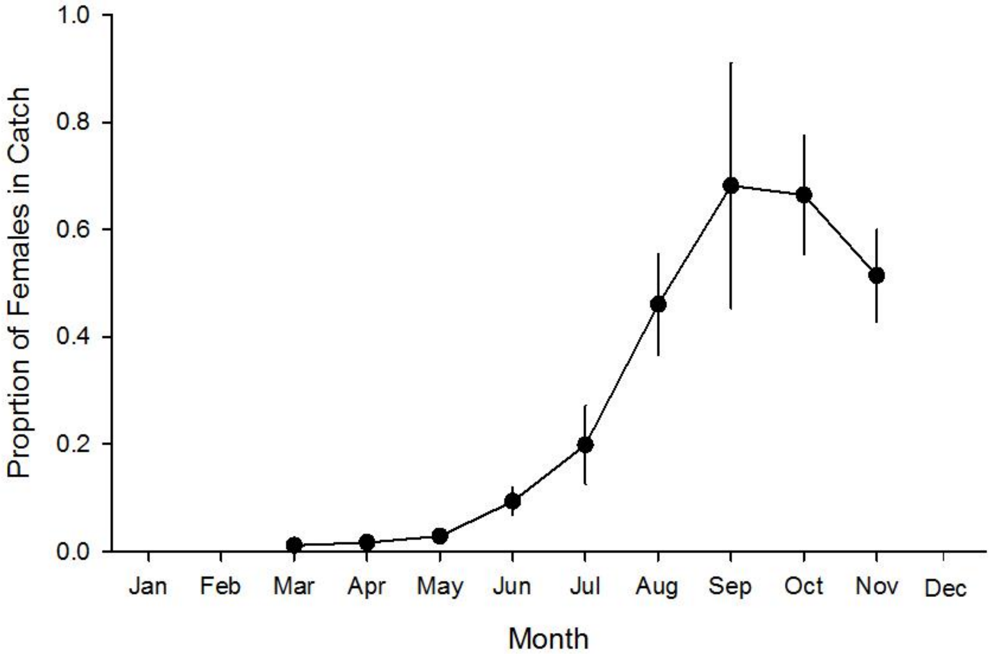


Figure 9.27. Mean proportions (± SE) of female blue swimmer crabs in the retained commercial catch as reported in daily research logbooks for the PCMF by month from 2011–16. Data not available in Dec, Jan, Feb due to lack of fishing in these months.

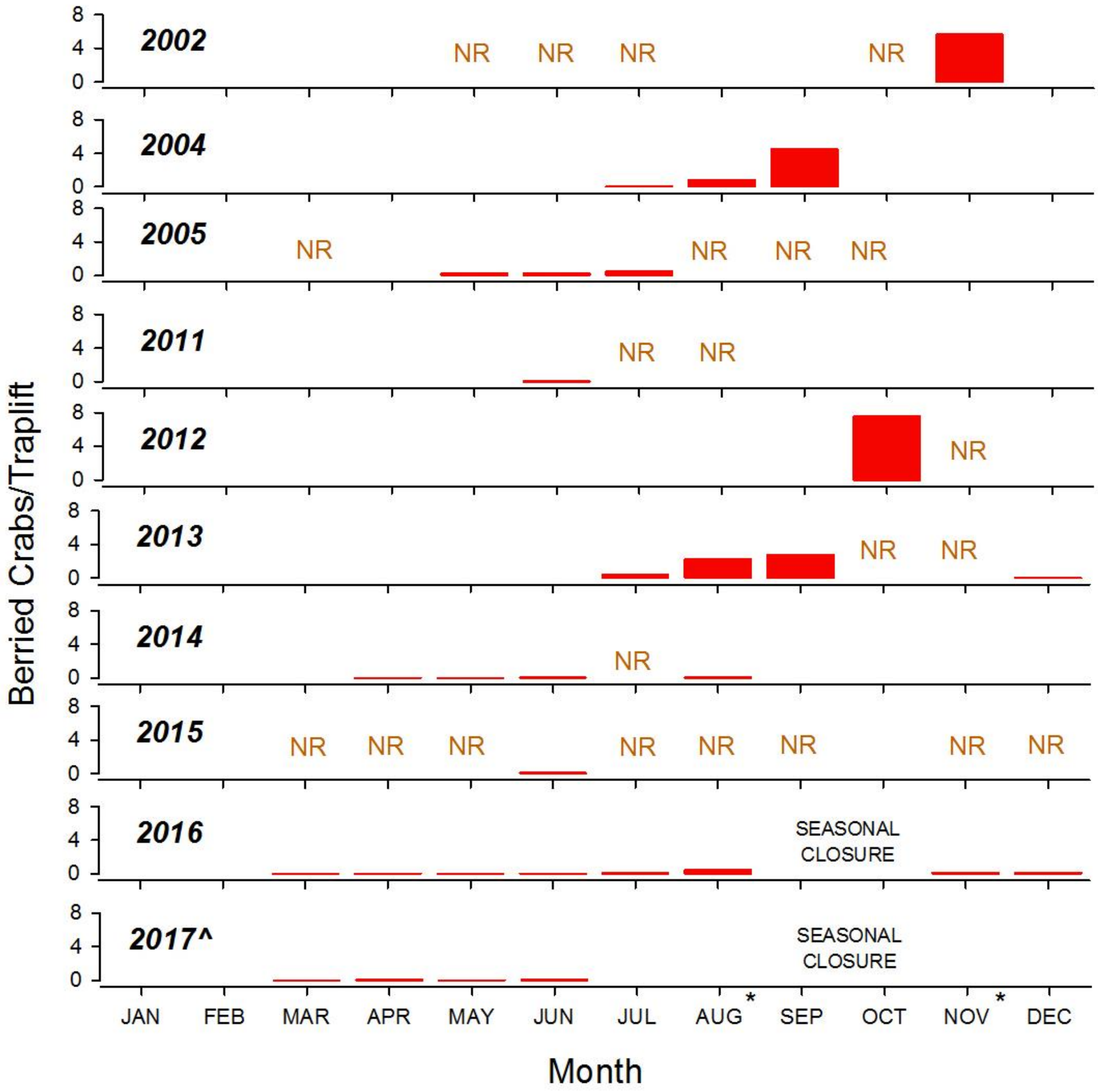


Figure 9.28. Catch rates (numbers of crabs/traplift) of berried female blue swimmer crabs (■) by month as reported in daily research logbooks from the PCMF during 2001-16. Please note the variation in scale between years. No data was recorded in 2001, 2003 or from 2006-10. NR: Fishing occurred but no information was recorded in the daily research logbook. * A seasonal closure was introduced in 2016 between August 15 and November 15 inclusive. ^ 2017 data provisional to June 2017.

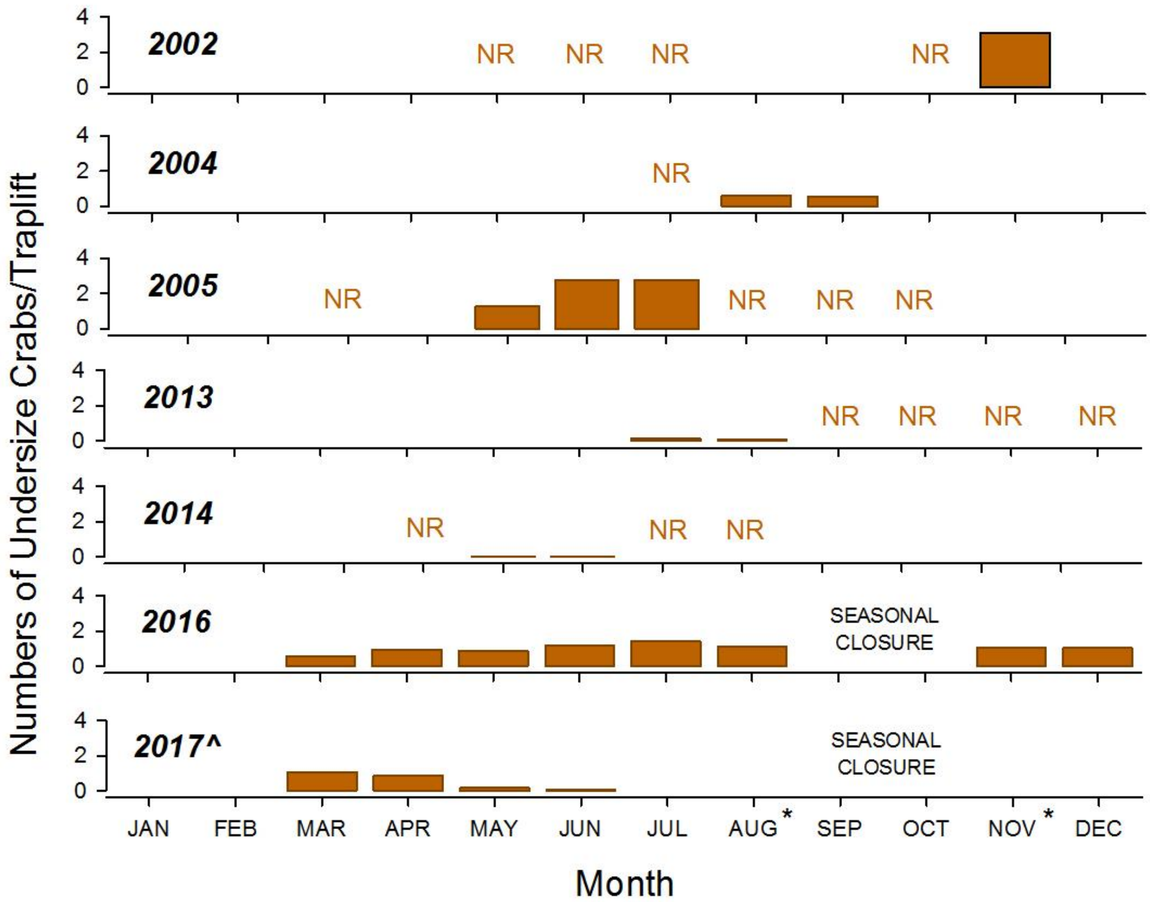


Figure 9.29. Catch rates (numbers of crabs/traplift) for undersize (< 127 mm CW) blue swimmer crabs (■) by month as reported in daily research logbooks from the PCMF between 2001-16. Please note the variation in scale between years. No data was recorded in 2001, 2003 or from 2006-11 and 2015. NR: Fishing occurred in this month but no information on undersize was recorded in the daily research logbook. * A seasonal closure was introduced in 2016 between August 15 and November 15 inclusive. ^ 2017 data provisional to June 2017.

Exmouth Gulf Developing Crab Fishery

No age/size structure analysis has been undertaken in the EGDCF to date.

Kimberley Crab Managed Fishery

No age/size structure analysis has been undertaken in the KCMF to date.

9.3.5.1 Conclusion

Pilbara Crab Fishery	The carapace width of the majority of crabs caught in the PCMF (sampled once a year on commercial vessels between 2003 and 2008) ranged between 140 and 180 mm which is consistent with commercial crab catches in Shark Bay, but noticeably larger than in most crab fisheries in southwest WA. Sporadic logbook data suggests males dominate the catch between March and May and females dominate by late winter and throughout spring months. While records are incomplete, the majority of berried females were captured between June and November. Consequently, an annual seasonal closure (15th August to 15th November) was introduced in 2016 to provide additional protection for pre-mated spawned and berried females. The crab size composition data indicates that substantial quantities of mature crabs remain in the catch and fishing mortality is relatively low.
Exmouth Gulf Developing Crab Trap Fishery	No age/size structure analysis has been undertaken in the EGDCF to date.
KCMF	No age/size structure analysis has been undertaken in the KCMF to date.

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 in north-west WA.

9.3.6.1 Productivity

The crab stocks evaluated for the PSA analysis included blue swimmer crab *P. armatus* in the Pilbara Crab Managed Fishery and Exmouth Gulf Developing Crab Fishery and mud crabs *Scylla* spp. in the Kimberley Crab Managed Fishery. Key factors influencing the score for productivity for both species are short longevity (and thus also low age at maturity), high fecundity, broadcast spawning strategy, and mid-trophic level (Table 9.2). The total productivity score for both species averaged 1.50 (Table 9.2).

Table 9.2. PSA productivity scores for blue swimmer crab Portunus armatus and mud crabs Scylla spp. in all fisheries targeting the resource in the North Coast Bioregion.

Productivity attribute	Portunus armatus	Scylla spp.
Average maximum age	**1**	**1**
Average age at maturity	**1**	**1**
Reproductive strategy	**1**	**1**
Fecundity	**1**	**1**
Trophic level	**2**	**2**
Density dependence	**3**	**3**
Total productivity (average)	**1.50**	**1.50**

9.3.6.2 Susceptibility

Blue swimmer crab – Pilbara Crab Fishery

The crab stock scored 1.28 for susceptibility and the Onslow Prawn Trawl and Nickol Bay Prawn Trawl, scored 1.65 for susceptibility (Table 9.3). Key factors influencing the score for trap susceptibility include low availability (areal overlap), high encounterability (vertical overlap) and medium selectivity and post-release mortality and high selectivity and post-release mortality for the trawl fisheries. The overall weighted PSA score was 2.04 with an MSC PSA-derived score of 94 (= low risk).

Blue swimmer crab – Exmouth Gulf Developing Crab Fishery

The crab stock scored 1.28 and the Exmouth Gulf Prawn Trawl Fishery, scored 1.65 for susceptibility (Table 9.3). Key factors influencing the score for trap susceptibility include low availability (areal overlap), high encounterability (vertical overlap) and medium selectivity and post-release mortality and high selectivity and post-release mortality for the trawl fisheries. The overall weighted PSA score was 2.21, with an MSC PSA-derived score of 91 (= low risk).

Table 9.3. PSA susceptibility scores for each fishery / sector that impact on blue swimmer crab *Portunus armatus* and mud crab *Scylla spp.* in North and Gascoyne Coast Bioregions.

Susceptibility attribute	PCMF trap	Pilbara trawl	EGDCF	Exmouth trawl	KCMF	Recreational
Areal overlap	1	1	1	1	1	1
Vertical overlap	3	3	3	3	3	3
Selectivity	2	3	2	3	2	2
Post-capture mortality	2	3	2	3	2	2
Total susceptibility (multiplicative)	1.28	1.65	1.28	1.65	1.28	1.28

Kimberley Crab Managed Fishery

The mud crab stock in the Kimberley Region scored 1.28 for susceptibility (Table 9.3). Key factors influencing the score for susceptibility include low availability (areal overlap), high encounterability (vertical overlap) and medium selectivity and post-release mortality. A potential risk recognised by the analysis is depensatory stock dynamics. The overall weighted PSA score was 1.97, giving an overall MSC PSA-derived score of 95 (= low risk).

9.3.6.3 Conclusion

Based on the productivity and susceptibility scores, the overall weighted (by fishery / sector catches) PSA score of the inshore crab Resource for North Coast blue swimmer crab was 2.04, Kimberley mud crabs was 1.97 and the Exmouth Gulf blue swimmer crab was 2.21.

North Coast Bioregion Blue Swimmer Crab (Pilbara trap and trawl)	The blue swimmer crab stock scored 1.50 for productivity and 1.28 for trap susceptibility and 1.65 for trawl susceptibility. Key factors influencing the score for productivity are short longevity (and thus also low age at maturity), high fecundity, broadcast spawning strategy, and mid-trophic level. Those for susceptibility include low availability, high encounterability and medium selectivity and post-release mortality for the trap fishery and high selectivity and post-release mortality for the prawn trawl fisheries. A potential risk recognised by the analysis is *depensatory* stock dynamics. The overall PSA score was 2.04 and MSC PSA-derived score was 94 (= low risk).

Exmouth Gulf	The blue swimmer crab stock in the Exmouth Gulf, scored 1.50 for productivity and 1.28 for susceptibility. Key factors influencing the score for productivity are short longevity (and thus also low age at maturity), high fecundity, broadcast spawning strategy, and mid-trophic level. Those for susceptibility include low availability, high encounterability and medium selectivity and post-release mortality. A potential risk recognised by the analysis is *depensatory* stock dynamics. The overall PSA score was 2.21 and MSC PSA-derived score was 91 (= low risk).
Kimberley Crab Managed Fishery	The mud crab stock in the North Coast Bioregion, scored 1.50 for productivity and 1.28 for susceptibility. Key factors influencing the score for productivity are short longevity (and thus also low age at maturity), high fecundity, broadcast spawning strategy, and mid-trophic level. Those for susceptibility include low availability, high encounterability and medium selectivity and post-release mortality. A potential risk recognised by the analysis is depensatory stock dynamics. The overall PSA score was 1.97 and MSC PSA-derived score was 95 (= low risk).

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 blue swimmer crab and mud crab resource of the North and Gascoyne Coast Bioregions, 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 Pilbara Crab Managed Fishery

Category	Lines of evidence (Consequence / Status)
Catch and effort	Annual blue swimmer crab catches in the PCMF following inception grew rapidly in line with increases in fisher knowledge, gear development and fishing effort from 10 t from 19,200 traplifts in 2001 to 64 t from 68,500 traplifts in 2003. Subsequent annual catches have varied considerably (between 6-73 t), largely in response to effort (8,100–45,000 traplifts). The 2019 catch was 19.3 t from 11,600 traplifts at a nominal catch rate of 1.67 kg/traplift. A creel survey conducted along the Pilbara coast between December 1999 and November 2000 estimated the recreational blue swimmer crab catch for this period to be 22 t, with most (19 t) taken from Nickol Bay. State-wide surveys estimated the total weight of blue swimmer crab retained in the North Coast Bioregion for private (non-charter), boat-based recreational fishing to be 1.5 t during 2017/18 (one year period, September to August). Commercial CPUE has been relatively constant over time, and was substantially higher in 2019 than earlier years. Given the vast area of the Pilbara region, the relatively low total catch and effort for blue swimmer crabs, and no evidence of declining catch rates, the level of fishing is considered acceptable.

Catch distribution	Although reasonable commercial catches (~ 1 kg/traplift) of blue swimmer crabs have been identified in near shore waters along the length of the Pilbara coastline, the logistics of getting the catch to market from such isolated locations has rendered most of the area commercially unviable for crab fishing. Following an initial period of exploration in waters around the coastal towns of Port Hedland and Onslow, commercial crab fishing has centred on Nickol Bay and the surrounding area since 2007. As a consequence, only a small proportion of the available fishery (<10%) is currently being exploited and the level of fishing is considered acceptable.
Commercial catch rates	The total annual commercial blue swimmer crab catch for Nickol Bay during 2019 was 19.3 t at a standardised catch rate of 1.5 kg/traplift. The 2019 standardised catch rate and total annual catch for Nickol Bay were within their target and tolerance ranges of the harvest strategy, indicating there should be adequate egg production such that recruitment is not impaired under typical environmental conditions and the breeding stock is considered Adequate.
Size composition	The carapace width of the majority of crabs caught in the PCMF (sampled once a year on commercial vessels between 2003 and 2008) ranged between 140 and 180 mm which is consistent with commercial crab catches in Shark Bay, but noticeably larger than in most crab fisheries in southwest WA. Sporadic logbook data suggests males dominate the catch between March and May and females dominate by late winter and throughout spring months. While records are incomplete, the majority of berried females were captured between June and November. Consequently, an annual seasonal closure (15th August to 15th November) was introduced in 2016 to provide additional protection for pre-mated spawned and berried females. The crab size composition data indicates that substantial quantities of mature crabs remain in the catch and fishing mortality is relatively low.
Productivity susceptibility analysis	The Pilbara blue swimmer crab stock scored 1.50 for productivity and 1.28 for trap susceptibility and 1.65 for trawl susceptibility. Key factors influencing the score for productivity are short longevity (and thus also low age at maturity), high fecundity, broadcast spawning strategy, and mid-trophic level. Those for susceptibility include low availability, high encounterability and medium selectivity and post-release mortality for the trap fishery and high selectivity and post-release mortality for the prawn trawl fisheries. A potential risk recognised by the analysis is *depensatory* stock dynamics. The overall PSA score was 2.04 and MSC PSA-derived score was 94 (= low risk).

Consequence (Stock Depletion) Level	Likelihood				Risk Score
	L1 Remote (<5%)	L2 Unlikely (5- <20%)	L3 Possible (20- <50%)	L4 Likely (≥50%)	
C1 Minimal		X			2
C2 Moderate				X	8
C3 High		X			6
C4 Major	NA				NA

C1 (Minor Depletion): Unlikely (L2) – substantial catches have occurred throughout the history of this fishery and catch rate in the lower half of the target range;

C2 (Moderate Depletion): Likely (L4) is based on catch rate being just above threshold level and catch within catch tolerance range;

C3 (High Depletion): Unlikely (L2) catch rate lower confidence limit fell slightly below harvest strategy threshold in 2016;

C4 (Major Depletion): Not plausible (NA) catch rate (including confidence limits) well above harvest strategy limit.

In summary, the current risk to the stock of blue swimmer crabs in Pilbara Crab Fishery is scored as **Medium which reflects an acceptable level of depletion/exploitation**. No management changes are required.

9.4.1.2 Exmouth Gulf Developing Crab Fishery

Category	Lines of evidence (Consequence / Status)
Catch and effort	Limited fishing was undertaken during the first 6 years (2003–08) of the EGDCF. A combined total blue swimmer crab catch of 28 t was taken over the five-year period from 2004 to 2008, with annual catches ranging over 0-10 t and annual effort over 0 -14,800 traplifts. The fishery was closed during 2009-15. A small amount of exploratory fishing was conducted in 2016, with 316 kg of blue swimmer crab landed from 852 traplifts. State-wide surveys estimated the total weight of blue swimmer crab retained in the Gascoyne Bioregion for private (non-charter), boat-based recreational fishing to be 5 t during 2017/18 (September to August), the majority of which is likely to have been taken from Shark Bay. Based on the low levels of commercial and recreational catch in recent years, the level of stock depletion for blue swimmer crabs in the EGDCF is considered acceptable.
Catch distribution	The limited fishing that has taken place in the EGDCF between 2003 and 2008 has been typically exploratory in nature, with comparatively equal amounts of effort expended in the northern and southern areas of Exmouth Gulf. In 2016 exploratory fishing has occurred in the southern area only. No dedicated crab (trap) fishing has occurred since 2016 and only minor trawl by-product has been taken.
Commercial catch rates	Annual commercial blue swimmer crab trap catch rates in the EGDCF from 2003-08, and when the fishery reopened in 2016, ranged between 0.5 – 1.0 kg/traplift. These annual catch rates are low compared with historical catch rates in other Western Australian commercial blue swimmer crab fisheries. However, the limited amount of fishing that has been undertaken over this period makes it difficult to determine if these catch rates are reflective of lower stock abundance than other areas, or more the exploratory and developmental nature of fishing effort in this fishery to date. With minimal fishing to date, a harvest strategy has not been developed yet for this fishery due to lack of data. Given the very low level of blue swimmer crab catch and effort in Exmouth Gulf there is likely to be negligible impact on stocks.
Size composition	No age/size structure analysis has been undertaken in the EGDCF to date.
Productivity susceptibility analysis	The blue swimmer crab stock in the Exmouth Gulf, scored 1.50 for productivity and 1.28 for susceptibility. Key factors influencing the score for productivity are short longevity (and thus also low age at maturity), high fecundity, broadcast spawning strategy, and mid-trophic level. Those for susceptibility include low availability, high encounterability and medium selectivity and post-release mortality. A potential risk recognised by the analysis is *depensatory* stock dynamics. The overall PSA score was 2.21 and MSC PSA-derived score was 91 (= low risk).

Consequence (Stock Depletion) Level	Likelihood				Risk Score
	L1 Remote (<5%)	L2 Unlikely (5- <20%)	L3 Possible (20- <50%)	L4 Likely (≥50%)	
C1 Minimal			X		3
C2 Moderate		X			4
C3 High	X				3
C4 Major	NA				NA

C1 (Minor Depletion): Possible (L3) – commercial catch has remained extremely low in the past decade reflecting very low effort.

C2 (Moderate Depletion): Unlikely (L2) – although targeted crab trap catch is very low, trawl fisheries also exploit the resource, but at very low catch levels.

C3 (High Depletion): Remote (L1) – historical catches by trawlers have been much higher than in recent years and depending on market demands and crab abundances it is remotely possible that catch may substantially increase.

C4 (Major Depletion): Not plausible (NA) given the extremely low catch and effort on blue swimmer crabs in recent years.

In summary, the current risk to the stock of blue swimmer crabs in Exmouth Gulf is scored as **Medium, which reflects an acceptable level of depletion/exploitation**. No management changes are required.

9.4.1.3 Kimberley Crab Managed Fishery

Category	Lines of evidence (Consequence / Status)
Catch and effort	Annual catch and effort ranges of mud crabs in the KDMCF from 2013 to 2018 were 0.1–15.3 t and 1,644–27,020 traplifts, respectively. The total catch in 2019 was 7.4 t from 19,882 traplifts (CPUE of 0.37 kg/ traplift). The 2017/18 DPIRD iSurvey of recreational fishing in WA provided a boat-based harvest estimate of 2.5 t (95% CI 2–3 t) of mud crabs for the North Coast Bioregion. This accounted for approximately 92% of the State's recreational mud crab catch. Negligible blue swimmer crab catch has been taken from the Kimberly region during recent years. Based on the low levels of commercial and recreational catch in recent years and the vast area of the Kimberly region, the level of stock depletion for mud and blue swimmer crabs is considered acceptable.
Catch distribution	In recent years (2010–2019) the largest commercial catch of mud crab has been from Cambridge Gulf with some catch also retained in Admiralty Gulf, York Sound and King Sound. Given the wide distribution of mud crabs throughout the KCMF and the minimal portion of the fishery that has been exploited to date, the level of fishing is considered acceptable.
Commercial catch rates	Catch rates during 2016 (0.26 kg/traplift) fell below the harvest strategy lower limit, however, catch rates increased during 2017 and 2018 (0.61 and 0.5 kg/traplift, respectively) and were within the target range. The 2019 catch rate was 0.33 kg/traplift, which fell below the threshold of the harvest strategy, but above the limit. These fluctuations in catch rate appear to be primarily driven by changes in effort and operator. The 2019 total annual catch of 7.4 t was within the catch tolerance range. Catch and effort has been limited to such a low level in recent years that based on the relatively small impact of commercial operations and the wide distribution of the species throughout the region, the risk to sustainability has been considered to be negligible. Nevertheless, considering the proximity of the 2019 catch rate to the limit reference level, catch, effort and catch rate is being monitored closely in this fishery during the 2020 season.
Size composition	No age/size structure analysis has been undertaken in the KCMF to date.
Productivity susceptibility analysis	The mud crab stock in the North Coast Bioregion, scored 1.50 for productivity and 1.28 for susceptibility. Key factors influencing the score for productivity are short longevity (and thus also low age at maturity), high fecundity, broadcast spawning strategy, and mid-trophic level. Those for susceptibility include low availability, high encounterability and medium selectivity and post-release mortality. A potential risk recognised by the analysis is depensatory stock dynamics. The overall PSA score was 1.97 and MSC PSA-derived score was 95 (= low risk).

Consequence (Stock Depletion) Level	Likelihood				Risk Score
	L1 Remote (<5%)	L2 Unlikely (5- <20%)	L3 Possible (20- <50%)	L4 Likely (≥50%)	
C1 Minimal		X			2
C2 Moderate			X		6
C3 High	X				3
C4 Major	NA				NA

C1 (Minor Depletion): Unlikely (L2) – catch rate has breached harvest strategy threshold in 2016 and 2019, however, total catch is very low and within total catch tolerance range.

C2 (Moderate Depletion): Possible (L3) – catch rate has generally been with harvest target range and catch tolerance range during recent years. Catches are taken over an expansive spatial area that is highly variable over time, suggesting minimal depletion of localised populations.

C3 (High Depletion): Remote (L1) – historical catches for the Kimberley region have been very low, however, there is a high amount of latent effort in the fishery, that when fully utilised, may substantially increase fishing mortality.

C4 (Major Depletion): Not plausible (NA) – given the extremely low historical catch and effort and vast spatial area of the fishery, it is not plausible that fishing mortality will cause major stock depletion within the assessment period.

In summary, the current risk to the stock of mud crabs in Kimberley Crab Managed Fishery is scored as **Low (4) which reflects an acceptable level of depletion/exploitation**. No management changes are required.

9.4.2 Current Risk Status

9.4.2.1 Pilbara Crab Managed Fishery

Based on the information available, the current risk level for blue swimmer crabs in the Pilbara region are estimated to be MEDIUM (C2 × L4). The Medium Risk (see Appendix 2) reflects acceptable level of fishing mortality and adequate levels of spawning biomass. All the lines of evidence are consistent with a moderate level of risk, hence the overall Weight of Evidence assessment indicates the status of the blue swimmer crab stock is adequate and that current management settings are maintaining risk at acceptable levels.

This score assumes the total catch will be maintained at near current levels which could require the development and implementation of a suitable set of management arrangements for all sectors to ensure this is maintained and that the stock status is monitored at regular intervals into the future.

9.4.2.2 Exmouth Gulf Developing Crab Fishery

Based on the information available, the current risk level for blue swimmer crabs in the Exmouth Gulf regions is estimated to be MEDIUM (C2 × L2). The Medium Risk (see Appendix 2) reflects acceptable level of fishing mortality and adequate level of spawning biomass. However, the resource can be targeted by both trap and trawl sectors and there is a possibility that catch may increase in the future. 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 blue swimmer crab stock is adequate and that current management settings are maintaining risk at acceptable levels.

9.4.2.3 Kimberley Crab Managed Fishery

Based on the information available, the current risk level for mud crabs in the Kimberley region is estimated to be MEDIUM (C2 × L3). The Medium Risk (see Appendix 2) reflects acceptable level of fishing mortality and adequate level of spawning biomass. Due to high latent effort and catch rates breaching threshold levels in recent years (primarily due to low effort and changing operators), the catch and effort will be monitored closely in the future. The lines of evidence are consistent with a medium level of risk, hence the overall Weight of Evidence assessment indicates the status of the mud crab stock is adequate and that current management settings are maintaining risk at acceptable levels.

This score assumes the total catch will be maintained at near current levels which could require the development and implementation of a suitable set of management arrangements for all sectors to ensure this is maintained and that the stock status is monitored at regular intervals into the future.

9.4.3 Future Monitoring

There is minimal fishery-dependent data available for the PCMF, EGDCF and KCMF due their remoteness and subsequent costs associated with sampling these relatively small fisheries. It would be highly beneficial to initiate fishery independent surveys (as occurs in many other crab fisheries in WA) to compliment fishery depend data and generate greater confidence around the sustainability of these stocks.

Due to the current lack of information on fishery dynamics in the PCMF, EGDCF and KCMF, a conservative management regime is required. Future monitoring will need to be assessed in relation to the value of each crab resource (i.e. size and social value of each individual fishery).

10. References

Afzaal, Z., Kalhoro M.A., Buzdar, M.A., Nadeem, A., Saeed, F., Haroon, A. and Ahmed, I., 2016. Stock Assessment of Blue Swimming Crab *Portunus pelagicus* (Linnaeus, 1758) from Pakistani Waters (Northern, Arabian Sea). *Pakistan Journal of Zoology,* **48:** 1531-1541.

Aguilar, R., Johnson, E.G., Hines, A.H., Kramer, M.A. and Goodison, M. R., 2008. Importance of blue crab life history for stock enhancement and spatial management of the fishery in Chesapeake Bay. *Reviews in Fisheries Science,* **16**: 117-124.

Alberts-Hubatsch, H., Lee, S.Y., Meynecke, J.O., Diele, K., Nordhaus, I., and Wolff, M., 2016. Life-history, movement, and habitat use of *Scylla serrata* (Decapoda, Portunidae): current knowledge and future challenges. *Hydrobiologia,* **763**: 5-21.

Andersen, L.E., Norton, J.H. and Levy, N.H., 2000. A new shell disease in the mud crab *Scylla serrata* from Port Curtis, Queensland (Australia). *Diseases of aquatic organisms*, **43(3)**: 233-239.

Beauchamp, J.J. and Olson, J.S., 1973. Corrections for bias in regression estimates after logarithmic transformation. *Ecology*, **54(6)**: 1403-1407.

Bellchambers, L.M., Gaughan, D.J., Wise, B.S., Jackson, G. and Fletcher, W.J., 2016. Adopting Marine Stewardship Council certification of Western Australian fisheries at a jurisdictional level: the benefits and challenges. *Fisheries Research,* **183**: 609-616.

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

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

Bellchambers, L., Sumner, N. and Melville-Smith, R., 2005. Development of stock allocation and assessment techniques in Western Australian blue swimmer crab fisheries. FRDC Project No. 2001/068. pp 33-71.

Beverton, R.J.H. and Holt, S.J., 1957. On the dynamics of exploited fish populations. Fisheries Investigations Series II. *Marine Fisheries, Great Britain Ministry of Agriculture, Fisheries and Food*, **19**.

Bryars, S., 1997. Larval Dispersal of the Blue Swimmer Crab, *Portunus Pelagicus* (Linnaeus) (Crustacea: Decapoda: Portunidae), in South Australia. *Thesis*, Flinders University of South Australia. 250 pp.

Bryars, S. and Havenhand, J., 2006. Effects of constant and varying temperatures on the development of blue swimmer crab (*Portunus pelagicus*) larvae: laboratory observations and field predictions for temperate coastal waters. *Journal of Experimental Marine Biology and Ecology*, **329(2):** 218-229.

Brown, I.W., 1993. Mangrove crabs. In, *Nearshore marine resources of the South Pacific: Information for fisheries management and development. Forum Fisheries Agency, Honiara, Solomon Islands,* pp 611-642.

Campbell, T., 2017. Dietary composition of the Blue Swimmer Crab, *Portunus armatus*, and life history characteristics of related species. *Honours Thesis*, Murdoch University, Western Australia.

Caputi, N., Brown, R.S. and Phillips, B.F., 1995. Predicting catches of the western rock lobster (*Panulirus cygnus*) based on indices of puerulus and juvenile abundance. In, *ICES Marine Science Symposia*, **199**: 287-293. Copenhagen, Denmark: International Council for the Exploration of the Sea, 1991.

Caputi, N., Feng, M., Pearce, A., Benthuysen, J., Denham, A., Hetzel, Y., Matear, R., Jackson, G., Molony, B., Joll, L. and Chandrapavan, A., 2015. Management implications of climate change effect on fisheries in Western Australia. Part 1. Environmental change and risk assessment. Department of Fisheries, Western Australia.

Caputi, N., Jackson, G. and Pearce, A., 2014. The marine heat wave off Western Australia during the summer of 2010/11 – 2 years on. Fisheries Research Report No. 250. Department of Fisheries, Western Australia. 40 pp.

Chandrapavan, A., Caputi, N. and Kangas, M. I., 2019. The Decline and Recovery of a Crab Population from an Extreme Marine Heatwave and a Changing Climate. *Frontiers in Marine Science*, **6**: 510.

Chandrapavan, A., Kangas, M.I., Johnston, D., Caputi, N., Hesp, A., Denham, A. and Sporer, E., 2017. Improving confidence in the management of the blue swimmer crab (*Portunus armatus*) in Shark Bay. Part 1. Rebuilding of the Shark Bay Crab Fishery. FRDC Project No. 2012/15. Fisheries Research Report No. 283. Department of Fisheries, Western Australia.

Chaplin, J.A., and Sezmis, E., 2008. A genetic assessment of the relationships among the assemblages of the blue swimmer crab, *Portunus pelagicus*, in Cockburn Sound, the Swan River Estuary, and Warnbro Sound. Final report prepared for the Department of Fisheries, Western Australia. Centre for Fish and Fisheries Research, Murdoch University, Perth.

Chaplin, J., Yap, E.S., Sezmis, E. and Potter, I. C., 2001. Genetic (microsatellite) determination of the stock structure of the blue swimmer crab in Australia. FRDC Project 98/118. Final Report to the Fisheries Research and Development Corporation. Murdoch University, Perth. 84 pp.

Davis, J.A., Churchill, G.J., Hecht, T. and Sorgeloos, P., 2004. Spawning characteristics of the South African mudcrab *Scylla serrata* (Forskål) in captivity. *Journal of the World Aquaculture Society*, **35(2)**: 121-133.

De Lestang, S., 2002. Biology of the blue swimmer crab, *Portunus pelagicus* (Linnaeus). *PhD. Thesis*, Murdoch University, Perth.

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

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

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

Delathiere, S., 1990. Biologie et exploitation du crabe de paletuviers. *Scylla serrata*.

Department of Fisheries — DoF., 2011. Resource Assessment Framework (RAF) for finfish resources in Western Australia. Fisheries Occasional Publication No. 85. Department of Fisheries, Western Australia.

Department of Fisheries — DoF., 2015. Harvest Strategy Policy and Operational Guidelines for the Aquatic Resources of Western Australia. Fisheries Management Paper No. 271. Department of Fisheries, Western Australia.

Department of Primary Industries and Regional Development — DPIRD., 2018. Draft Management Plan for the Pilbara Crab Managed Fishery. Fisheries Management Paper No. 290. Department of Primary Industries and Regional Development, Western Australia. 19 pp.

Department of Primary Industries and Regional Development — DPIRD., 2020. Portunidae crab resource of the Pilbara-Kimberley region. Harvest Strategy 2020–2025. Fisheries Management Paper No. XXX. Department of Primary Industries and Regional Development, Western Australia. *In Press.*

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

Fielder, D.F. and Heasman, M.P., 1978. *The mud crab*. Queensland Museum.

Fisher, J.L., 2007. Seasonal timing and duration of brachyuran larvae in a high-latitude fjord. *Marine Ecology Progress Series*, **323**, 213–222.

Fisher, M.R., 1999. Effect of temperature and salinity on size at maturity of female blue crabs. *Transactions of the American Fisheries Society*, **128**: 499–506.

Fletcher, W.J., 2002. Policy for the implementation of ecologically sustainable development for fisheries and aquaculture within Western Australia. Fisheries Management Paper No. 157. Department of Fisheries, Western Australia.

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

Fletcher, W.J. and Santoro, K. (eds.)., 2015. Status reports of the fisheries and aquatic resources of Western Australia 2014/15: State of the fisheries. Department of Fisheries, Western Australia.

Fletcher, W.J. and Santoro, K. (eds.)., 2016. Status reports of the fisheries and aquatic resources of Western Australia 2015/16: State of the fisheries. Department of Fisheries, Western Australia.

Fletcher, W.J., Shaw, J., Metcalf, S.J. and Gaughan, D.J., 2010. An Ecosystem Based Fisheries Management framework: the efficient, regional-level planning tool for management agencies. *Marine Policy*, **34**: 1226-1238.

Fletcher, W.J., Wise, B.S., Joll, L.M., Hall, N.G., Fisher, E.A., Harry, A.V., Fairclough, D.V., Gaughan, D.J., Travaille, K., Molony, B.W. and Kangas, M., 2016. Refinements to harvest strategies to enable effective implementation of Ecosystem Based Fisheries Management for the multi-sector, multi-species fisheries of Western Australia. *Fisheries Research*, **183**: 594-608.

Fratini, S. and Vannini, M., 2002. Genetic differentiation in the mud crab *Scylla serrata* (Decapoda: Portunidae) within the Indian Ocean. *Journal of Experimental Marine Biology and Ecology*, **272(1)**: 103-116.

Gopurenko, D., Hughes, J. M., and Bellchambers, L., 2003. Colonisation of the south-west Australian coastline by mud crabs: evidence for a recent range expansion or human-induced translocation? *Marine and Freshwater Research*, **54**: 833–840.

Gopurenko, D., Hughes, J.M. and Keenan, C.P., 1999. Mitochondrial DNA evidence for rapid colonisation of the Indo–West Pacific by the mudcrab *Scylla serrata*. *Marine Biology*, **134(2)**: 227-233.

Grubert, M., Johnson, D., Johnston, D. and Leslie, M., 2016. Mud crabs *Scylla spp*., *Scylla olivacea*, *Scylla serrata*. In, Stewardson, C., Andrews, J., Ashby, C., Haddon, M., Hartmann, K., Hone, P., Horvat, P., Mayfield, S., Roelofs, A., Sainsbury, K., Saunders, T., Stewart, J., Stobutzki, I. and Wise, B. (Eds.). Status of Australian Fish Stocks 2016, Fisheries Research Development Corporation, Canberra.

Grubert, M.A. and Lee, H.S., 2013. Improving Gear Selectivity in Australian Mud Crab Fisheries. Northern Territory Government, Australia. Fishery Report No. 112.

Grubert, M.A., Phelan, M.J. and Bird, M.H., 2012. Use of a Durometer to Differentiate Between Soft-and Hard-Shelled Mud Crabs (*Scylla serrata*). *Journal of aquatic food product technology*, **21(1)**: 3-13.

Harris, D., Johnston, D., Baker, J. and Foster, M., 2017. Adopting a Citizen Science approach to develop cost-efficient methods that will deliver annual information for managing small-scale recreational fisheries: The Southwest Recreational Crabbing Project. Fisheries Research Report No. 281, Department of Fisheries, Western Australia. 121 pp.

Harris, D., Johnston, D., Sporer, E., Kangas, M., Felipe, N. and Caputi, N., 2012. Biology and management of a multi-sector blue swimmer crab fishery in a subtropical embayment - Shark Bay, Western Australia. *Marine and Freshwater Research*, **63**: 1165-1179.

Harris, D., Johnston, D., Sporer, E., Kangas, M., Felipe, N. and Caputi, N., 2014. Status of the Blue Swimmer Crab Fishery in Shark Bay, Western Australia. Fisheries Research Report No. 233. Department of Fisheries, Western Australia. 84 pp.

He, L., Zhang, A., Zhu, C., Weese, D. and Qiao, Z., 2011. Phylogeography of the mud crab (*Scylla serrata*) in the Indo-West Pacific reappraised from mitochondrial molecular and oceanographic clues: transoceanic dispersal and coastal sequential colonization. *Marine Ecology*, **32(1)**: 52-64.

Heasman, M.P., 1980. Aspects of the general biology and fishery of the mud crab *Scylla serrata* (Forskal) in Moreton Bay, Queensland. *Doctoral dissertation*, University of Queensland.

Heasman, M.P., Fielder, D.R. and Shepherd, R.K., 1985. Mating and spawning in the mudcrab, *Scylla serrata* (Forskaål) (Decapoda: Portunidae), in Moreton Bay, Queensland. *Marine and Freshwater Research*, **36(6):** 773-783.

Henry, G.W. and Lyle, J.M., 2003. The National Recreational and Indigenous Fishing Survey. Final Report to the Fisheries Research & Development Corporation and the Fisheries Action Program. Project No. 1999/158. 188 pp.

Hewitt, D.A. and Hoenig. J.M., 2005. Comparison of two approaches for estimating natural mortality based on longevity. *Fishery Bulletin*, **103:** 433-437.

Hill, B.J., 1975. Abundance, breeding and growth of the crab *Scylla serrata* in two South African estuaries. *Marine Biology*, **32(2)**: 119-126.

Hill, B.J., 1976. Natural food, foregut clearance-rate and activity of the crab *Scylla serrata*. *Marine biology*, **34(2)**: 109-116.

Hill, B.J., 1979. Aspects of the feeding strategy of the predatory crab *Scylla serrata*. *Marine Biology*, **55(3)**: 209-214.

Hill, B.J., 1994. Offshore spawning by the portunid crab *Scylla serrata* (Crustacea: Decapoda). *Marine Biology*, **120(3)**: 379-384.

Hill, B.J., Williams, M.J. and Dutton, P., 1982. Distribution of juvenile, subadult and adult *Scylla serrata* (Crustacea: Portunidae) on tidal flats in Australia. *Marine Biology*, **69(1):** 117-120.

Hobday, A.J., Smith, A.D.M., Stobutzki, I.C., Bulman, C., Daley, R., Dambacher, J.M.,Deng, R.A., Dowdney, J., Fuller, M., Furlani, D., Griffiths, S.P., Johnson, D., Kenyon, R., Knuckey, I.A., Ling, S.D., Pitcher, R., Sainsbury, K.J., Sporcic, M., Smith, T., Turnbull, C., Walker, T.I., Wayte, S.E., Webb, H., Williams, A., Wise, B.S. and Zhou, S., 2011. Ecological risk assessment for the effects of fishing. *Fisheries Research*, **108**: 372-384.

Hoenig, J.M., 1983. Empirical use of longevity data to estimate mortality rates. *Fishery Bulletin*, **82**: 898–903.

Hyland, S.J., Hill, B.J. and Lee, C.P., 1984. Movement within and between different habitats by the portunid crab *Scylla serrata*. *Marine Biology*, **80(1)**: 57-61.

Ikhwanuddin, M., Azmie, G., Juariah, H.M., Zakaria, M.Z., and Ambak, M.A., 2011. Biological information and population features of mud crab, genus *Scylla* from mangrove areas of Sarawak, Malaysia. *Fisheries Research*, **108:** 299-306.

Jayamanne, S.C. and Jinadasa, J., 1991. Food and feeding habits of the mud crab, *Scylla serrata* (Forskal) inhabiting the Negombo Lagoon in the West Coast of Sri Lanka.

Jeffries, W.B., Voris, H.K. and Poovachiranon, S., 1992. Age of the mangrove crab *Scylla serrata* at colonization by stalked barnacles of the genus *Octolasmis*. *The Biological Bulletin*, **182(2)**: 188-194.

Johnston, D. *et al.*, (in preparation). Is there evidence of temporal and spatial variation in reproductive biology of temperate and sub-tropical blue swimmer crabs (*Portunus armatus*) in Western Australia? *Marine Biology*.

Johnston, D., Chandrapavan, A., Wise, B. and Caputi, N., 2014. Assessment of blue swimmer crab recruitment and breeding stock levels in the Peel-Harvey Estuary and status of the Mandurah to Bunbury developing crab fishery. Fisheries Research Report No. 258. Department of Fisheries, Western Australia. 142 pp.

Johnston, D., Evans, R., Foster, M., Oliver, R., and Blay, N., 2015, North Coast Crab Fishery Status Report, in Fletcher, W.J. and Santoro, K. (eds), Status reports of the fisheries and aquatic resources of Western Australia 2014/15: the state of the fisheries. Department of Fisheries, Western Australia. 62–70 pp.

Johnston, D., Garland, A., Beckmann, C. and Johnson, D., 2016. Blue swimmer crab *Portunus armatus*. In: Stewardson, C., Andrews, J., Ashby, C., Haddon, M., Hartmann, K., Hone, P., Horvat, P., Mayfield, S., Roelofs, A., Sainsbury, K., Saubders, T., Stewart, J., Stobutzki, I. and Wise, B. (Eds.) Status of Australian Fish Stocks 2016, Fisheries Research Development Corporation, Canberra.

Johnston, D., Harris, D., Caputi, N., de Lestang, S. and Thomson, A., 2011b. Status of the Cockburn Sound Crab Fishery. Fisheries Research Report No. 219. Department of Fisheries, Western Australia. 104 pp.

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

Johnston, D., Harris, D., Fissioli, J., Walshe, K., 2012. West Coast Blue Swimmer Crab Fishery Status Report. In: Fletcher, W.J. and Santoro, K. (eds) Status Report of the Fisheries and Aquatic Resources of Western Australia 2011/12: the state of the fisheries. Department of Fisheries, Western Australia. 68-75 pp.

Johnston, D., Smith, K., Brown, J., Travaille, K., Crowe, F., Oliver, R. and Fisher, E., 2015b. Western Australian Marine Stewardship Council Report Series No. 3: West Coast Estuarine Managed Fishery (Area 2: Peel-Harvey Estuary) & Peel-Harvey Estuary Blue Swimmer Crab Recreational Fishery. Department of Fisheries, Western Australia. 284 pp.

Johnston, D., Yeoh, D. and Harris, D., 2020. Environmental drivers of commercial blue swimmer crab (*Portunus armatus*) catch rates in Western Australian fisheries. *Fisheries Research. In Press*.

Jirapunpipat, K., 2008. Population structure and size at maturity of the orange mud crab *Scylla olivacea* in Klong Ngao mangrove swamp, Ranong Province, Thailand. *Kasetsart Journal of Natural Science*, **42**: 31-40.

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

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

Kangas, M.I., Chandrapavan, A., Hetzel, Y.L. and Sporer, E.C., 2012. Minimising gear conflict and resource sharing issues in the Shark Bay trawl fisheries and promotion of scallop recruitment. Fisheries Research Report No 229. Department of Fisheries, Western Australia. 136 pp.

Keenan, C.P., Davie, P.J.F. and Mann, D.L., 1998. A revision of the genus *Scylla* de Haan, 1833 (Crustacea: Decapoda: Brachyura: Portunidae). *The Raffles Bulletin of Zoology*, **46**: 217–245.

Knuckey, I.A., 1996. Maturity in male mud crabs, *Scylla serrata*, and the use of mating scars as a functional indicator. *Journal of Crustacean Biology*, **16**: 487–495.

Knuckey, I.A., 1999. Mud crab (*Scylla serrata*) population dynamics in the Northern Territory, Australia and their relationship to the commercial fishery. *PhD Thesis*, Nothern Territory University, Darwin.

Kvingedal, R., Owens, L. and Jerry, D.R., 2006. A new parasite that infects eggs of the mud crab, *Scylla serrata*, in Australia. *Journal of Invertebrate Pathology*, **93(1)**: 54-59.

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

Lloris, D., 2001. FAO/SIDS species identification sheet: *Scylla serrata*. FAO, Rome

Marine Stewardship Council - MSC., 2014. MSC Guidance for the Fisheries Certification Requirements, V2.0, 1st October 2014.

Meagher, T.D., 1971. Ecology of the crab *Portunus pelagicus* (Crustacea: Portunidae) in south western Australia. *PhD Thesis*, University of Western Australia, Perth.

Meynecke, J.O., Grubert, M., Arthur, J.M., Boston, R., and Lee, S.Y., 2012a. The influence of the La Niña-El Niño cycle on giant mud crab (*Scylla serrata*) catches in Northern Australia. Estuarine. *Coastal and Shelf Science*, **100**: 93–101.

Meynecke, J.O., Grubert, MA and Gillson, J., 2012b. Giant mud crab (*Scylla serrata*) catches and climate drivers in Australia—a large scale comparison. *Marine and Freshwater Research*, **63**: 84–94.

Millamena, O.M. and Quinitio, E., 2000. The effects of diets on reproductive performance of eyestalk ablated and intact mud crab *Scylla serrata*. *Aquaculture*, **181(1-2)**: 81-90.

Norriss, J.V. and Crisafulli, B., 2010. Longevity in Australian snapper *Pagrus auratus* (Sparidae). *Journal of the Royal Society of Western Australia*, **93**: 129-132.

Patel, N.M., Chhaya, N.D. and Bhaskaran, M., 1979. Stomach contents of *Portunus pelagicus* (Linn.) from AD net catches. *Indian Journal of Marine Science*, **8**: 48-49.

Pauly, D., 1980. A selection of simple methods for the assessment of tropical fish stock. *FAO Fisheries Circular*, **729**: 54.

Pavasovic, M., Richardson, N.A., Anderson, A.J., Mann, D. and Mather, P.B., 2004. Effect of pH, temperature and diet on digestive enzyme profiles in the mud crab, *Scylla serrata*. *Aquaculture*, **242(1-4)**: 641-654.

Pearce, A., Lenanton, R., Jackson, G., Moore, J., Feng, M. and Gaughan, D., 2011. The “marine heat wave” off Western Australia during the summer of 2010/11. Fisheries Research Report No. 222. Department of Fisheries, Western Australia.

Pearce, A., Buchan, S., Chiffings, T., D’Adamo, N., Fandry, C., Fearns, P., Mills, D., Phillips, R. and Simpson, C., 2003. A Review of the Oceanography of the Dampier Archipelago, Western Australia. The Marine Flora and Fauna of Dampier, Western Australia. Western Australian Museum, Perth. 13–50 pp.

Perrine, D., 1978. The mangrove crab (*Scylla serrata*) on Ponape. *Marine Resources Division, Ponape, East Caroline Islands, Trust Territory of the Pacific Islands*. 66 pp.

Pinder, A., Halse, S., Shiel, R. and McRae, J., 2010. An Arid Zone Awash with Diversity: Patterns in the Distribution of Aquatic Invertebrates in the Pilbara Region of Western Australia.

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

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

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

Potter, I.C., de Lestang, S. and Young, G.C., 1998. Influence of the Dawesville Channel on the recruitment, distribution and emigration of crustaceans and fish in the Peel-Harvey Estuary. FRDC Final Report on Project No. 95/042. 61 pp.

Potter, I.C., de Lestang, S. and Melville-Smith, R., 2001. The collection of biological data required for management of the blue swimmer crab fishery in the central and lower coasts of Western Australia. Final report to Fisheries Research and Development Corporation Project No. 97/137. March 2001. Centre for Fish and Fisheries Research, Murdoch University, Western Australia.

Prasad, P.N. and Neelakantan, B., 1990. Size at maturity in the male crab *Scylla serrata* as determined by chela allometry and gonad condition. *Fishery Technology*.

Quinn II, T.J. and Deriso, R.B., 1999. Quantitative fish dynamics, 542 p. Oxford University Press, New York, NY.

Rikhter, V.A. and Efanov, V.N., 1976. On one of the experimental determination of the selection of natural mortality of fish populations. *ICNAF Research Document*, *76*.

Robertson, W.D., 1996. Abundace, population structure and size at maturity of *Scylla serrata* (Forskal) (Decapoda: Portunidae) in Eastern Cape estuaries, South Africa. *South African Journal of Zoology*, **31(4)**: 177-185.

Robertson, W.D. and Kruger, A., 1994. Size at maturity, mating and spawning in the portunid crab *Scylla serrata* (Forskål) in Natal, South Africa. *Estuarine, Coastal and Shelf Science*, **39(2)**: 185-200.

Rosenkranz, G.E., Tyler, A.V. and Kruse, G.H., 2001. Effects of water temperature and wind on year-class success of Tanner crabs in Bristol Bay, Alaska. *Fisheries Oceanography*, **10(1)**: 1-12.

Ryan, K.L., Wise, B.S., Hall, N.G., Pollock, K.H., Sulin, E.H. and Gaughan, D.J., 2013. An integrated system to survey boat-based recreational fishing in Western Australia 2011/12. Fisheries Research Report No. 249. Department of Fisheries, Western Australia.

Ryan, K.L., Hall, N.G., Lai, E.K., Smallwood, C.B., Taylor, S.M. and Wise, B.S., 2015. Statewide survey of boat-based recreational fishing in Western Australia 2013/14. Fisheries Research Report No. 268. Department of Fisheries, Western Australia.

Ryan, K.L., Hall, N.G., Lai, E.K., Smallwood, C.B., Taylor, S.M. and Wise, B.S., 2017. Boat-based recreational fishing in Western Australia 2015/16. Fisheries Report No. 287, Department of Fisheries, Western Australia.

Ryan, K.L., Hall, N.G., Lai, E.K., Smallwood, C.B., Tate, A., Taylor, S.M. and Wise, B.S., 2019. Statewide survey of boat-based recreational fishing in Western Australia 2017/18. Fisheries Research Report No. 297, Department of Primary Industries and Regional Development, Western Australia. 195 pp.

Safaie, M., Kiabi, B., Pazooki, J. and Shokri, M.R., 2013. Growth parameters and mortality rates of the blue swimming crab, Portunus segnis (Forskal, 1775) in coastal waters of Persian Gulf and Gulf of Oman, Iran. *Indian Journal of Fisheries*, **60(1)**: 9-13.

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

Smith, H., 1982. Blue crabs in South Australia-their status, potential and biology. *South Australian Fishing Industry Council*, **6**: 6-9.

Smith, K., 2006. Review of fishery resources and status of key fishery stocks in the Swan-Canning Estuary. Fisheries Research Report No. 156. 84 pp.

Smith, K., Brown, J., Lewis, P., Dowling, C., Howard, A., Lenanton, R. and Molony, B., 2013. Status of nearshore finfish stocks in south-western Western Australia Part 1: Australian herring. Fisheries Research Report No. 246. 194 pp.

Somers, I.F., 1988. On a seasonally oscillating growth function. *Fishbyte,* **6**: 8–11

Sumner, N.R. and Malseed, B.E., 2004. Quantification of changes in recreational catch and effort on blue swimmer crabs in Cockburn Sound and Geographe Bay. Fisheries Research Report No. 147. FRDC Project No. 2001/067. Department of Fisheries, Western Australia.

Sumner, N.R., Williamson, P.C. and Malseed, B.E., 2002. A 12-month survey of recreational fishing in the Gascoyne bioregion of Western Australia during 1998-99. Fisheries Research Report No. 139. Department of Fisheries, Western Australia. 60 pp.

Thomas, M., 1987. Age and growth of three estuarine portunid crabs *Scylla serrata*, *Scylla serrata serrata* and *Thalamita crenata*. *Journal of the Marine Biological Association, India*, **29**: 154-157.

Tongdee, N., 2001. Size distribution, sex ratio and size at maturity of mud crab (*Scylla spp*.) in Ranong Province, Thailand. *Asian Fisheries Science*, **14(2)**: 113-120.

Uphoff, J.M., 1998. Stability of the blue crab stock in Maryland. *Journal of Crustacean Biology,* **17:** 519–528.

Veale, L., Tweedley, J.R., Clarke, K.R., Hallet C.S. and Potter, I.C., 2014. Characteristics of the ichthyofauna of a temperate microtidal estuary with a reverse salinity gradient, including inter-decadal comparisons. *Journal of Fish Biology*, **85(5)**: 1320-1354.

Viswanathan, C., Pravinkumar, M., Suresh, T.V., Elumalai, V. and Raffi, S.M., 2016. Carapace width-weight relationship, age, growth and longevity of the mud crab *Scylla olivacea* (Herbst, 1796) in the Pichavaram mangroves, south-east India. *Journal of the Marine Biological Association of the United Kingdom*, **96**: 1379-1386.

Warner G.F., 1977. The Biology of Crabs. Caledonian Road, London. Paul Elek Ltd.

Webley, J.A., Connolly, R.M. and Young, R.A., 2009. Habitat selectivity of megalopae and juvenile mud crabs (*Scylla serrata*): implications for recruitment mechanism. *Marine Biology*, **156(5)**: 891-899.

Welch, D.J., Saunders, T., Robins, J., Harry, A., Johnson, J., Maynard, J., Saunders, R., Pecl, G., Sawynok, B. and Tobin, A., 2014. Implications of climate change on fisheries resources of northern Australia, Part 1: Vulnerability assessment and adaptation options. Fisheries Research and Development Corporation and James Cook University, Australian Capital Territory.

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

Williamson, P.C., Sumner, N.R. and Malseed, B.E., 2006. A 12-month survey of recreational fishing in the Pilbara region of Western Australia during 1999-2000. Fisheries Research Report No. 153. Department of Fisheries, Western Australia. 61 pp.

Zainal, K.A.Y., 2017. Relative growth and heterochely in the blue swimmer crab *Portunus pelagicus* (Linnaeus 1758) from the Kingdom of Bahrain. *Arabian Journal of Science and Engineering*, **42(1)**: 75-84.

Zairion, W.Y. and Fahrudin, A., 2015. Sexual Maturity, Reproductive Pattern and Spawning Female Population of the Blue Swimming Crab, *Portunus pelagicus* (Brachyura: Portunidae) in East Lampung Coastal Waters, Indonesia. *Indian Journal of Science and Technology*, **8(7)**: 596-607.

Appendix 1

Justification for Harvest Strategy Reference Levels

The performance indicators used to evaluate the stock status of *P. armatus* and *Scylla* spp. in the PCMF and KCMF are 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 and mud crab Scylla spp. in the Pilbara Crab Managed Fishery (PCMF) and Kimberley Crab Managed Fishery (KCMF).

	Reference Levels		
Performance Indicator	**Target**	**Threshold (B_{MSY})**	**Limit**
Commercial catch rate *P. armatus* (PCMF) [kg/traplift]	0.5–1.9	0.5	0.3
Commercial catch rate *Scylla* spp. (KCMF) [kg/traplift]	0.4–0.9	0.4	0.3

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