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Synopsis of the biology and exploitation of the blue swimmer crab, *Portunus pelagicus* Linnaeus, in Western Australia

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The Fisheries Research Division of Fisheries Western Australia is based at the Western Australian Marine Research Laboratories, P.O. Box 20, North Beach (Perth), Western Australia, 6020. The Marine Research Laboratories serve as the centre for fisheries research in the State of Western Australia.

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Abstract

This report summarises the existing studies which have provided information on the biology, population characteristics and exploitation of the blue swimmer crab, Portunus pelagicus*, in Western Australia. Gaps in the existing knowledge are also highlighted to assist in targeting new research initiatives.* Portunus pelagicus *matures at about one year and in temperate regions females mate only once a year. This is because mature crabs moult only once a year. It appears from studies to date that Western Australian crabs are one genetic population. This is being further investigated. Migration of the blue swimmer crab occurs between estuaries and the ocean in south-western Western Australia. In general, female crabs (which have settled into estuaries/nurseries during the late summer/autumn period the year before) move from estuaries to oceanic waters to spawn in summer. First-stage zoeae feed on the surface in the morning and this behaviour facilitates offshore movement with prevailing easterly winds in the mornings. Later zoeal stages feed on the surface in the afternoon and evening. This allows them to be transported back inshore with south-westerly sea breezes. The females move back into the estuaries for a time after spawning and may again move out during the winter due to reduced salinities in the estuaries. Male crabs which have settled (from summer spawning in the ocean) in estuaries feed and grow during late summer and autumn and move out of the estuaries when salinities decline. Males do not appear to return to the estuary.*

The biological knowledge to date has been generally limited to small regions of the coastline, particularly estuaries, and may not be representative of all regions now exploited or under consideration for future exploitation. Additional information is required on a broader spatial scale incorporating seasonal variation in size, distribution, abundance and sex ratios.

In Western Australia, 150 licence holders participate in fishing for the blue swimmer crab. The commercial catches of blue swimmer crabs have risen from around 200 tonnes in 1987/88 to 740 tonnes, valued at around $2.2 million, in 1997/98. The recreational sector contributes to a significant level of catch of crabs in some regions of Western Australia including the Leschenault and Peel-Harvey estuaries and Cockburn Sound.

Research programs on crab biology, habitat requirements, movement and growth, stock structure, fishery dynamics and recreational catch and effort are under way in order to address the paucity of biological knowledge and detailed fisheries information (commercial and recreational) on the species in Western Australia.

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1.0 Introduction

The blue swimmer crab (*Portunus pelagicus*) supports substantial commercial fisheries and is an important component of many recreational fisheries in Australia and other parts of the world. In Australia, the commercial catches of blue swimmer crabs have been growing rapidly and recent annual catches were of the order of 1800 tonnes (Kumar 1998). With further development of crab fisheries, this figure is likely to increase substantially in the next five years.

Traditionally in Western Australia (WA), the blue swimmer (locally called the blue manna) crab has been targeted by recreational fishers. A recreational survey conducted by the Australian Bureau of Statistics in July 1987 indicated that 77,000 people participated in crab fishing in the previous 12 months. The expansion of the commercial fishery for blue swimmer crabs has been rapid in WA and the parallel expansion of residential development along the coastline has most likely contributed to increased recreational effort on the crab stocks. Resource allocation issues are likely to be prominent as a result. These factors have led to the requirement to obtain more detailed information on the biology and exploitation of *P. pelagicus* in WA.

While a number of studies on the biology of *P. pelagicus* have been undertaken in both south-west WA and nationally, research on the blue swimmer crab fisheries within Australia to date has been limited. This is principally due to the relatively low size and value of commercial crab fisheries compared to fisheries for species such as prawns, rock lobster and abalone. However, as a result of increased interest and exploitation and the likelihood of further development of blue crab fisheries within Australia, it has been recognised that a national approach to research is required (Kumar 1997, 1998).

In WA, most of the research has been carried out in estuaries (Meagher 1970, 1971, Potter *et al.* 1983, 1998, Potter and de Lestang, in press), with only one study in the marine embayment of Cockburn Sound (Penn 1977) and one dietary study (Edgar 1990) at Cliff Head.

This synopsis summarises the current biological knowledge of the blue swimmer crab in Australia and overseas, describes the commercial catch trends in WA, and is designed to provide a compilation of information which will be extended by the current research projects being undertaken throughout Australia. These projects include:

- genetic (microsatellite) determination of stock structure of the blue swimmer crab in Australia;
- the collection of biological data required for management of the blue swimmer crab fishery on the central and lower west coasts of Australia;
- estimation of recreational catch of blue swimmer crabs in WA and Moreton Bay, Queensland;
- the collection of fisheries data required for management of the blue swimmer crab fishery on the central and lower west coasts of Australia; and
- fisheries biology and spatial modelling in South Australia.

The synopsis also identifies the geographical, biological and fishery knowledge gaps within Australia to assist in targeting new research initiatives.

2.0 Biology

2.1 Taxonomy

Affinities

Phylum: Crustacea
Class: Malacostraca
Subclass: Eumalacostraca
Order: Decapoda
Family: Portunidae

Nomenclature

Current valid name

Portunus pelagicus (Linnaeus, 1766).

Synonyms

Cancer pelagicus: Linnaeus (1766), *Neptunus pelagicus*: De Haan (1833), Milne-Edwards (1861), Miers (1866), *Lupea pelagica*: Milne-Edwards (1834), Barnard (1950).

Taxonomic history

The use of the name *Portunus* has been confused by its being applied to two quite different genera. This was resolved by the International Commission on Zoological Nomenclature (1956). Therefore, the genus commonly know as *Neptunus* De Haan 1833, became *Portunus* Weber 1795. The genus commonly know as *Portunus* Fabricius 1798 and occasionally as *Liocarcinus* Stimpson 1870, became *Macropipus* Prestandrea 1833.

Common names

Blue swimmer crab, blue manna crab, sand crab, blue crab.

2.2 Description

Blue swimmer crabs are swimming crabs and have their last pair of legs modified as swimming paddles (Figure 1). Their carapace (shell) is rough in texture (Kailola *et al.* 1993). The carapace is broad and flattened, with nine teeth on each side, the last teeth very pronounced as 'horns'. The clawed legs are long, elongated and ridged. Their colouration is generally mottled blue on males and mottled brown on females, but the intensity and pattern of the colouration is variable.

2.3 Distribution and life history

2.3.1 Distribution

The blue swimmer crab *P. pelagicus* is found in nearshore marine and estuarine waters throughout the Indo-West Pacific (Stephenson 1962, Kailola *et al.* 1993). Within Australia, *P. pelagicus* has been recorded in all States except Tasmania (Stephenson and Campbell 1959). In WA, the blue swimmer crab is mainly found from Cape Naturaliste in south-western WA north along the whole coastline to the Northern Territory.

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

2.3.2 Population structure

Only one study has been undertaken in Australia to determine the population structure of blue swimmer crabs. Bryars and Adams (1999) analysed the allozyme variation of *P. pelagicus* from eight sites around Australia and found that the South Australian specimens were geographically isolated and genetically distinct from all other regions of Australia. Within South Australia, populations of *P. pelagicus* from Spencer Gulf, Gulf St Vincent and west coast regions also represent separate stocks (Bryars and Adams 1999).

The current research project on the genetic (microsatellite) determination of stock structure of the blue swimmer crab in Australia, undertaken by Murdoch University (WA), will provide additional information on population separation within Australia.

2.3.3 Life history

The time for a complete reproductive cycle varies according to annual temperature variations (Meagher 1971, Pillay and Nair 1976, Potter *et al.* 1983, 1998). Spawning takes place all year in tropical and subtropical waters (Campbell and Fielder 1986, Potter *et al.* 1987). Reproduction in temperate regions is restricted to the warmer months. In these regions, blue swimmer crabs form breeding pairs (Smith 1982) and mating takes place during the late summer (January to March) moult of the female (Penn 1977, Smith 1982, Potter *et al.* 1983) once they have spawned using sperm from the previous year's mating. The male courting response is triggered by a pheromone released by the female (Meagher 1971). The courtship behaviour of *P. pelagicus* is described by Fielder and Eales (1972). Mature males moult some weeks before the maturing females, and each male carries a female clasped beneath him for 4-10 days before she moults. Mating occurs immediately after the female has moulted and when the shell is still soft. Males can mate with a number of females during the season. Most of the large mature females mate only once a year, because they moult only once a year, but receive enough sperm to fertilise millions of eggs. Juvenile females often reach maturity in the middle of summer at about a year old. Some of these will mate and spawn during that summer.

In temperate areas, after mating, the sperm is retained by the female in spermatheca over the winter period (Smith 1982) until the temperatures rise again in spring (November to January) and ovule maturation is completed (Penn 1977). The exact timing can vary between locations and between years according to annual temperature variations. Mating, egg production and egg extrusion do not appear to have any relationship (Sumpton *et al.* 1994) as the fertilisation occurs externally. Van Engel (1958) found that sperm in the spermathecum of female *Callinectes sapidus* could remain viable for at least 12 months. Therefore rhythmic egg production based on annual climatic/environmental cues determines the timing of egg production and spawning.

When the female is ready to deposit her eggs she settles into the sand with her abdomen extended. The eggs are extruded and attached to hairs on the female's abdomen. Some sperm from the sperm capsule are released and fertilisation takes place externally. The eggs are incubated under the abdominal flap by the female. They are bright orange when first spawned and change progressively to dark grey as they develop and use up the yolk. Small grey remnants of the egg mass may remain for a short period after the developing eggs have been released into the water (Potter *et al.* 1983). The speed of development depends on water temperature. At 25°C it takes eight days for the eggs to become fully developed and ready for release and at 20°C it takes 18 days (Smith 1982).

Generally, most ovigerous crabs (those carrying eggs) are caught during the period November to January (Penn 1977, Smith 1982). Larval sampling in Gulf St Vincent, South Australia indicated that the main hatching period of *P. pelagicus* extends from November to March (Bryars 1997). A few females with eggs can be found throughout the year if temperatures are in the range 15-25°C. Some recent studies in Leschenault Estuary and Koombana Bay (Potter & de Lestang, in press) indicated that the numbers of egg-bearing females were highest in Koombana Bay between October and January and highest in the Leschenault Estuary in December and January. Many more ovigerous females were found in Koombana Bay compared to the estuary and the authors consider most spawning takes place in the bay, not the estuary. Their data suggest spawning peaks in early January in Koombana Bay, and that the spawning period is similar to that identified by Penn (1977) in Cockburn Sound. The difference in timing of the peaks in egg-bearing females between Koombana Bay and Leschenault Estuary they attribute to the size of the crabs. In the bay, the crabs are larger and are at a size (50% mature at 97 mm carapace width) and stage of maturing at which they are capable of ovulating as soon as environmental conditions provide the appropriate trigger. In contrast, those in the estuary are usually smaller (and younger) and so they take longer to become mature.

Potter *et al.* (1998) looked at the effect of the Dawesville Channel on the Peel-Harvey Estuary and found that, whereas prior to the construction of the channel the highest numbers of egg-bearing females in the estuary occurred in January and February, now they occur in November and December. Because of this the females emigrate from the estuary (to release their eggs) earlier than previously.

Adults generally spawn in oceanic waters, either in the entrance channels of estuaries or in adjacent coastal waters. Female crabs spawn up to two million eggs per batch, larger crabs producing more eggs than smaller crabs. Generally, females leave inshore estuarine areas and move offshore to spawn. 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). However, some females may release their eggs just inside the estuary mouth, usually in marine water areas, and the larvae are carried out of the estuary on outgoing tides (personal observation in Swan River). Gaughan and Potter (1994) found larvae of *P. pelagicus* in the lower Swan Estuary between the months of September and April, with a peak in January and February.

Twenty-four hours before spawning, there is a marked change in activity, the female remaining on the substrate even during daylight hours and continually moving around. The eggs are released sometime between midnight and dawn, and the female remains inactive for some hours after spawning has been completed. During this time, she cleans the remnants of the egg capsules from the pleopodal setae and within four hours of spawning, all trace of the old egg cases has been removed. The female behaviour of emerging from the sand and wandering around in the afternoon before spawning is the beginning of the process which keys the hatching time of the eggs to the period when behavioural feeding activity of the zoea will enable them to feed successfully.

The eggs and larvae of blue swimmer crabs are planktonic. The eggs hatch after about 15 days at 24°C. The larval phase consists of five stages. During the larval phase, the crabs may drift as far as 80 km out to sea before returning to settle in shallow inshore waters (Williams 1982). Bryars (1997) predicted the larval duration of *P. pelagicus* in South Australia to be 26-45 days under average environmental (temperature) conditions. The released larvae therefore spend up to six weeks in coastal waters being mixed and distributed by the prevailing currents before settling inshore and immigrating into estuaries in the spring and summer. This transport is facilitated by changes in the diurnal behaviour of larvae (Meagher 1971). Meagher (1971) suggests that the transition in distribution from an offshore, semi-planktonic habitat to the onshore, benthic habitat occurs in juveniles somewhere between 0.4 cm and 1.0 cm carapace width (CW).

Rapid growth occurs in the estuaries and protected bays over summer. Juveniles and adults emigrate out into the ocean during winter to avoid the freshwater flow (Potter *et al.* 1983) and many then migrate back into the estuaries before the summer.

Latitudinal differences in life history patterns are being elucidated in current biological studies undertaken in Cockburn Sound (32° S) and Shark Bay (24-26° S), WA by Murdoch University.

2.4 Bionomics

2.4.1 Feeding

A number of studies have been conducted, providing a good understanding of the feeding biology of blue swimmer crabs. Blue swimmer crabs are opportunistic, bottom-feeding carnivores and scavengers. They are most active in foraging and feeding at sunset (Grove-Jones 1987, Smith and Sumpton 1987, Wassenberg and Hill 1987). They have a wide-ranging foraging strategy (Edgar 1990). Their diet chiefly consists of a variety of sessile and slow-moving invertebrates, including bivalve molluscs, crustaceans, polychaete worms and brittle stars (Patel *et al.* 1979, Williams 1982, Edgar 1990). Diet is largely dependent upon local availability of prey species, the main foods for intertidal stages being small hermit crabs and gastropods, while subtidal *P. pelagicus* feed mainly on bivalves and ophiuroids (Williams 1982). Williams (1982) found that diet composition changed little with size of crab although within broad taxonomic groups, prey species change with size of crab. However, Edgar (1990) found size-related changes in the diets of crabs. These changes were influenced by the different habitats of small and larger crabs. Seagrasses and algae may be eaten occasionally. In some localities, fish and squid discarded from prawn trawlers may be important sources of food (Wassenberg and Hill 1987, 1990a).

In the Leschenault Estuary, *P. pelagicus* feeds on a wide range of benthic invertebrates, such as amphipods, polychaetes and bivalve molluscs, and on teleosts (Potter and de Lestang, in press). These authors found that the diets of small (CW ≤ 75 mm) and larger (CW ≥ 75 mm) crabs differed. The contribution made to the diet by amphipods declined from 41.6% in small crabs to 13.3% in large crabs, whereas polychaetes and teleosts rose from 13.1% and 2.2% to 27% and 10.3% respectively with an increase in body size. This difference is presumably related to the influence of an increase in the size of the chela and muscle mass on the type of prey that is most susceptible to predation (Freier *et al.* 1996), and to the greater ability of larger crabs to ingest larger prey such as polychaetes.

For juvenile *P. pelagicus* diet did not vary seasonally in intertidal areas (Williams 1982) in Moreton Bay, Queensland.

Crabs cease feeding prior to and during moulting. Immediately after moulting, the gastric mill is filled with calcareous fragments. As the crab shell hardens, feeding on organic material commences, being greatest during the early intermoult periods and reduced in later intermoult.

2.4.2 Movement

Movement of *P. pelagicus* in and out of estuaries into the open ocean occurs for spawning and as a reaction to lowered salinities (Meagher 1971, Potter *et al.* 1983, 1998, Potter and de Lestang, in press). Due to their strong swimming ability, *P. pelagicus* are capable of moving substantial distances, with one recorded as travelling 20 km in one day in Moreton Bay, Queensland (Sumpton and Smith 1991). However, tagging studies in Moreton Bay showed fairly small-scale movement of crab populations. Of the recaptures, 79% were caught less than 2 km from their release points, and only 4% were recaptured more than 10 km from their release point (Potter *et al.* 1991). Similarly, recaptures within 4 km of release sites have occurred for *Scylla serrata* (Hyland *et al.* 1984) and *C. sapidus* (Mayo and Dudley 1970). Tagging studies in WA are required to determine the movement patterns of crabs in and out of estuaries, and whether longshore movement occurs from one embayment to another. A tagging program recently commenced in Cockburn Sound, WA is providing information on suitable tagging methodology, movement and growth in this region. An extension of this program is planned for areas near Cockburn Sound, including the Peel-Harvey Estuary, Comet Bay and the Swan River, to determine movement patterns between regions. Additional information on movement and growth patterns for other areas in south-western and central WA would be beneficial.

Due to their relatively long planktonic larval life, crab larvae may be transported long distances. The potential for larval dispersal is in part dependent on water temperature which determines the length of larval life. Bryars (1997) found in laboratory studies that *P. pelagicus* larvae in South Australia have a larval life of 20.7 days at 20°C and 39.1 days at 25°C. He predicted that the length of total larval duration at 17°C was 62.2 days. This represents a considerable time in the plankton and a high potential for dispersal. In laboratory studies, Meagher (1970) found that first-stage zoeae feed at the surface in the morning and in WA would therefore be carried offshore by the prevailing summer easterly winds (morning offshore land breeze). They do not appear to feed during the afternoon and evening and are assumed to sink in the subsurface waters and are therefore not returned shoreward by the prevailing onshore south-westerly afternoon sea breeze.

Their entry back into estuarine embayments is the result of a combination of factors. These include winds, currents, salinity and crab behaviour. Larval transport using locally existing current systems to reach settling areas was observed in the brachyuran species *Callianassa californiensis* (Johnson and Gonor 1982). The larval distribution within the water column may facilitate inshore transport. Zoeae of *P. pelagicus* were found to occur in highest numbers at the surface during daytime sampling in the Ragay Gulf, Philippines (Ingles and Braum 1989). Clancy and Epifanio (1989) and Dittel and Epifanio (1982) also found high abundance of crab zoeae in the upper 5 m of the water column in Delaware Bay, USA. Zoeae presence in surface waters during summer afternoons in WA would result in net inshore movement due to the influence of onshore south-westerly sea breezes. Meagher (1971) and Bryars (1997) found megalopae in surface waters, whereas no significant difference was observed in abundance between surface and bottom samples for megalopae by Ingles and Braum (1989). Older megalopae may tend to stay at the bottom in preparation for their metamorphosis to benthic life (Ingles and Braum 1989).

2.4.3 Mortality and survival

High mortality is observed in larval *P. pelagicus.* Ingles and Braum (1989) estimated 98% mortality from hatching to the megalopal stage for *P. pelagicus* in the Philippines and Bryars (1997) estimated > 99% mortality from hatching to the fourth zoeal stage in South Australia.

Large gaps exist in the knowledge and quantification of natural and fishing mortality in blue swimmer crabs in Australia. No stock assessments have been conducted to date. Currently WA, Queensland and South Australia are improving fisheries data collection. In WA, regular catch monitoring is taking place in key regions, with information on daily catch and effort provided by fishers to supplement monthly catch and effort data.

A few studies have been conducted in Queensland and in Torres Strait on the survival of crabs discarded from prawn trawlers, and the survival of damaged crabs was assessed by tagging in Moreton Bay, Queensland (Potter *et al.* 1991). Undamaged crabs at release had twice the recapture rate of damaged crabs.

A study of discard mortality from prawn trawlers in Queensland indicated that 14% of blue swimmer crabs died within eight hours from the effects of trawling, despite having a high injury rate (51% of animals caught in the trawl had been injured). Wassenberg and Hill (1993) found that the greatest mortality occurred within the first three days after capture. There was little mortality after four days, with 84% survival overall. Larger individuals caught and discarded by commercial trawlers tend to have lower mortality than smaller individuals (Wassenberg and Hill 1987). Exposure to air was investigated, with 100% survival of crabs for 12 hours after exposure to air for 10 minutes (Wassenberg and Hill 1990b).

2.4.4 Parasites

The rhizocephalan *Sacculina granifera* has a marked effect on gonad development and growth of *P. pelagicus*. *Sacculina* infection may cause degeneration of the gonads in both male and female crabs and a modification of the secondary sexual characteristics in the male crab resulting in the acquisition of female characteristics (Day 1935). The parasite is present internally for some time before evaginating as an externa on the undersurface of the abdomen of the crab where it is easily discernible.

In Moreton Bay, Queensland Shields and Woods (1993) found that crabs were frequently castrated by the parasite but, in some cases, castration was incomplete. Hence the reproductive potential of the infected host is not necessarily zero. Infected hosts were also capable of mating and, in a few cases, produced egg clutches. Infection rates were seasonal for both sexes and higher in the adult female population, with more than 20% of adult females carrying externae during some summer months (Sumpton *et al*. 1994). In WA, *S. granifera* occurs on crabs, is more prevalent in warmer months (Potter *et al.* 1987), and is common in the north.

2.4.5 Predation

Predators of the blue swimmer crab in WA have not been identified. The smooth stingray, *Dasyatis brevicaudata*, southern fiddler, *Trygonorhina fasciata guanerius*, and gummy shark, *Mustelus antarcticus* are known predators of adult crabs in South Australia (Smith, unpublished).

Crabs are most vulnerable to predation immediately after moulting.

2.5 Growth and longevity

2.5.1 Growth

Crabs are encased in a hard external shell and must shed this (moult) in order to grow. Blue swimmer crabs usually moult one or more times within each of their several distinct life stages. Just prior to moulting, the underlying skin secretes substances that sever the connections between the skin and the old shell. A thin layer of new shell is excreted just below the old shell, which begins to split. Once the old shell is discarded, the crab takes up water to stretch the new shell. It is thought that crabs reabsorb calcium from their old shells and store the calcium in their blood and/or organs. The crab also absorbs calcium from the sea water and these calcium sources are used for the primary recalcification of the shell. Crabs then ingest large amounts of calcareous material, such as shell fragments, to complete calcification (S. de Lestang, pers. comm.). Substances are then secreted by the skin that oxidise and harden the shell. The crab is very vulnerable during moulting and usually stays buried (Davis 1988).

In young crabs, the animal's weight at each moult can increase by 75-80% and its carapace width (from tips of spines) by 20% (Meagher 1968), with moult frequency being temperature-dependent. At 24^{o}C, juvenile crabs of around 30-40 mm CW can moult every three weeks and grow 7-10 mm at each moult. Juveniles of 50-60 mm CW moult every four weeks but grow 10-13 mm at each moult (Meagher 1971). At 20^{o}C, the time between moults is extended by about a week (Meagher 1971). On the south-west coast of India, *P. pelagicus* of 32.5 mm CW grew 70-80 mm in seven months (Sukumaran and Neelakantan 1997), and under laboratory conditions a juvenile *P. pelagicus* of 15 mm CW attained a size of 23 mm CW in three weeks (Prasad and Tampi 1953). Under laboratory conditions, crabs of 11-25 mm CW attained a size of 140-145 mm CW at the twelfth moult after a period of 14 months (Hamsa 1982). Pubertal females moult to maturity throughout summer, however after puberty, moulting in females changes from being simply temperature-dependent to being annual. Adult crabs moult only once a year. Overall, growth rate slows during the winter due to a decrease in water temperature.

In South Australia, *P. pelagicus* reaches a size of 150 mm CW (base of spines) in about 18 months (Smith 1982). In the Peel-Harvey Estuary, WA a size of 127 mm CW (tips of spines) is reached in about one year (Potter and de Lestang, in press), while in south-west India, a size of 132.5 mm CW is reached by females in one year (Sukumaran and Neelakantan 1997).

P. pelagicus is capable of limb regeneration. Hamsa (1982) found during laboratory experiments that after the removal of a limb or a cheliped, regeneration occurred by the development of a rudimentary appendage from the basis after about four to seven days. This was followed by a complete regeneration to normal size at the next moult.

2.5.2 Longevity

One of the characteristics fundamental to stock assessment is longevity. Longevity of blue swimmer crabs in WA needs to be determined. Current tagging studies may provide some information. For the blue swimmer crab in Queensland, the maximum recorded age is estimated at three years (Smith and Sumpton 1987). Longevity of *P. pelagicus* determined for south-western India is 2.5 years (approximately 152 mm CW) using length frequency analysis (Sukumaran and Neelakantan 1997). The longevity of the blue crab *C. sapidus* was thought to be three years, based on crabs held in captivity (Van Engel 1958). More recent tagging studies have indicated that longevity of *C. sapidus* is greater, with an estimated life span of eight years (Rugolo *et al.* 1998).

2.6 Reproduction

2.6.1 Seasonal variation

In tropical regions *P. pelagicus* breeds throughout the year (Batoy *et al.* 1987), whereas in temperate regions reproduction is restricted to the warmer months (Meagher 1971, Smith 1982). In temperate regions, female crabs suspend ovary development during winter but do not regress ovary development already completed the previous autumn. Females actively feed and develop ovules until the temperature becomes limiting in late autumn. The maturation of the ovary is then suspended throughout winter until temperatures rise again in spring and ovule maturation is completed.

2.6.2 Size at maturity

Blue swimmer crabs mature at about one year of age (Smith 1982). The size at which maturity occurs can vary with latitude or location (Campbell and Fielder 1986, Sukumaran and Neelakantan 1996a) and within individuals at any location. The smallest female *P. pelagicus* that was observed to have undergone a pubertal moult in the Peel-Harvey Estuary was 89 mm CW (Potter *et al.* 1998), while in the Leschenault Estuary the smallest was 94 mm CW (Potter and de Lestang, in press). In the Peel-Harvey Estuary, 50% of female crabs first become mature at 98 mm CW (Potter *et al.* 1998), and in the Leschenault Estuary at 97 mm CW. The corresponding size for a male crab was 84 mm CW in the Peel-Harvey Estuary (Potter *et al.* 1998) and 88 mm CW in the Leschenault Estuary (Potter and de Lestang, in press). In India, males may undergo a pubertal moult at a CW ranging between 85 and 90 mm, and females at 80-90 mm CW (Sukumaran and Neelakantan 1996a).

2.6.3 Fecundity

The number of eggs produced by females varies with the size of the individual as well as between individuals of a similar size. Generally, larger females produce more eggs than smaller females. Yatsuzuka (1962) measured 900,000 to 1,600,000 eggs per batch. Ingles and Braum (1989) determined the relationship between weight (W) and fecundity (F) for *P. pelagicus* in the Philippines to be $F = 972.75\ W^{1.23}$. A female has the potential to produce three batches of eggs between moults and therefore it is possible to produce as many as 3,600,000 eggs in six weeks (Meagher 1971).

2.6.4 Larval development

Larval development of *P. pelagicus* in the laboratory is described by Yatsuzuka (1962), Kurata and Midoridawa (1975) and Bryars (1997). *P. pelagicus* hatches as a prezoea and has five larval instars (four zoea and one megalopa). The megalopal stage has the longest duration of all five larval stages, occupying around 30% of the total larval duration. The extended duration of the megalopal stage may be useful in terms of the amount of time available for reaching and/or selecting suitable settlement sites (Bryars 1997). Mean larval duration under laboratory conditions from zoea stage one to crab stage one was 21 days at 25°C and 39.5 days at 20°C (Bryars 1997). Survival of larvae to the first crab stage was directly related to temperature (Bryars 1997). *P. pelagicus* has approximately 16 juvenile instars (Yatsuzuka 1962, Meagher 1971). At the fourth instar, juveniles are morphologically distinct as males and females. Juvenile growth is markedly affected by environmental conditions of food and temperature.

3.0 Stock assessment and exploitation

3.1 Population characteristics

3.1.1 Sex ratio

There may be differences in habitat preferences for male and female crabs. Mature *P. pelagicus* display sexual segregation at times (Thomson 1951, Weng 1992) and females are more abundant in shallow areas, particularly on the tops of sandbanks (Potter *et al.* 1986). Females are known to require a sandy substrate for successful egg extrusion and attachment to the pleopods (Campbell 1984), and migration of mature females on to sandbanks for egg extrusion may be partly responsible for the variation of sex ratios in Moreton Bay just prior to the spawning season (Sumpton *et al.* 1994). Males prefer deeper gutters and lower slopes of sandbanks.

Seasonal changes in sex ratio can be attributed to behavioural changes in males and females (Potter *et al.* 1993) and to the effects of fishing. In the Peel-Harvey Estuary, Potter *et al.* (1993) found that the sex ratio was close to parity for recruits into the estuary. Males usually dominate the catch at the start of the season, probably because they moult first. The proportion of females taken increases steadily as the season progresses, and because more males have been caught earlier in the season, by autumn females begin to dominate the catch (Davis 1988).

In the Leschenault Estuary and Koombana Bay, the sex ratio of crabs < 90 mm CW caught by trawl was close to parity, whereas crabs > 90 mm CW had a female:male ratio of 1:1.8 in Leschenault Estuary and 1:0.5 in Koombana Bay. Pot catches in the Leschenault Estuary showed a higher proportion of males, with a sex ratio of 1:3.8, while those in Koombana Bay were in the ratio 1:1.7. Crab pots appeared to have a greater tendency to catch male than female crabs (Potter and de Lestang, in press).

Meagher (1971), using set nets, captured more males than females in the Bunbury region during summer and autumn.

3.1.2 Size and age composition

In the Peel-Harvey Estuary, growth between apparent year-class modes was 0+ ≈ 55 mm CW in March 1980 to 1+ ≈ 125 mm CW in March 1981 (Potter *et al.* 1983). At present there are no data available for marine embayments or for tropical regions in WA. Monthly sampling currently being conducted by Murdoch University in Cockburn Sound, and bimonthly sampling in Shark Bay, will provide additional information on temporal and spatial size frequency distributions.

3.1.3 Carapace width–weight relationships

Differences are observed between the weight–carapace width relationships for male and female *P. pelagicus* (Potter *et al*. 1983). At the same size (CW), males are heavier than females. The relationship between body weight (g) and carapace width measured between the tip of the lateral spines (CW) for crabs in the Peel-Harvey Estuary is:

Males: $\log W = \log 2.56 \times 10^{-5} + 3.260 \log CW$
Females: $\log W = \log 5.97 \times 10^{-5} + 3.056 \log CW$

Currently, differences between male and female carapace width–weight relationships are being investigated for Shark Bay.

3.1.4 Spine to spine, base of spine size relationship

Differences were observed between males and females for the relationship of the carapace width measured from the base of the large lateral spines (CW_1) and from the tip of these spines (CW) (Potter *et al.* 1983). The relationships were:

Males: $(CW_1) = -5.2513 + 0.8840\, CW$
Females: $(CW_1) = -2.6865 + 0.8480\, CW$

3.2 Factors affecting distribution

Both temperature and salinity are important factors influencing the distribution, activity and movement of the blue swimmer crab. In the south-west, in summer they are caught easily as they are active, but in winter they are present but inactive (Meagher 1971). During laboratory experiments, Meagher (1971) found that crabs remained buried at temperatures below 13°C, while males were more active than females between 13°C and 21°C. Although they are inactive in temperatures less than 14°C, their mobility or speed of movement is not impaired if artificially aroused at temperatures greater than 9°C (Meagher 1971). Movement of crabs may take place in winter from shallower (cooler) waters to deeper waters.

There is a decline in numbers of crabs in south-west estuaries during winter (Potter and de Lestang, in press) when salinities and water temperatures decline to their lowest levels (below 25‰ and 10°C). The subsequent marked decline in crab numbers in an estuary is accompanied by a rise in densities of crabs in nearshore, shallow waters (Potter and de Lestang, in press). In the laboratory, Smith and Sumpton (1989) have shown that crab activity declines when water temperatures fall below 20°C. Lower catches during winter may be as a result of decreased catchability caused by crabs remaining inactive and buried in the substrate (Sumpton *et al.* 1989).

P. pelagicus regulates in water hyposaline to sea water and conforms in hypersaline water. It can withstand a wide range of salinities (11-53‰) for extended periods (Meagher 1971). Salinity is important in determining whether crabs remain in nurseries over winter (Potter and de Lestang, in press). Under laboratory conditions, Neverauskas and Butler (1982) found the Upper Incipient Lethal Temperature (UIL) for *P. pelagicus* from Torrens Island, South Australia to be 39.5°C. *P. pelagicus* has been shown to be highly tolerant of large fluctuations in oxygen availability as observed in estuaries (Meagher 1971). It may at times be anaerobic in its respiration and can withstand oxygen deprivation at both high (19°C) and lower (13°C) temperatures (Meagher 1971).

Potter and de Lestang (in press) found that densities of crabs are greatest in south-west estuaries when salinities and water temperatures are high, and low when salinity and water temperature decline to 25‰ and 10°C. Potter *et al.* (1983) found in the Peel-Harvey Estuary that the blue swimmer crab has a preference for salinities of 30-40‰. Salinity can influence whether crabs remain in estuaries or not. In the Peel-Harvey Estuary they found that crabs were no longer caught in winter when rainfall reduces the salinity to less than 10‰. In the Leschenault Estuary they found that the larger crabs moved out first and were more sensitive than smaller crabs to a decline in salinity.

Dense blooms of the blue-green alga *Nodularia spumigena* have affected crab populations in the Peel-Harvey Estuary, WA in the 1970s and 1980s (Potter *et al.* 1983). In the Peel-Harvey Estuary, the construction of the Dawesville Channel in early 1990 has influenced the patterns of immigration and emigration, the abundance and to some degree the reproductive biology of the blue swimmer crab in this region (Potter *et al.*1998). The blue swimmer crab is now found in greater numbers and for longer periods in the estuary. This can be attributed to the following factors:

- There is a direct connection between the sea and the estuary, so that the juvenile crabs have a far shorter distance to travel from the ocean into the estuary.
- A greater tidal water flow occurs into the estuary, providing a more effective means of transporting fauna into this part of the system.
- Salinities in the estuary remain higher for longer periods, providing an environment conducive to the retention of crabs for a longer period.

Increased tidal movement throughout the Peel-Harvey Estuary now allows:

- recruitment from the ocean of juvenile crabs over a longer period;
- earlier emigration than previously from the estuary of female crabs once they become ovigerous; and
- faster growth rates resulting in an earlier attainment of sexual maturity.

Little is known of the movements of crabs within the large marine embayments in WA, such as Geographe Bay and Shark Bay, which contain large populations of blue swimmer crabs. Tagging studies in Cockburn Sound and proposed tagging studies in the Peel-Harvey Estuary, Comet Bay and the Swan River will assist in elucidation of movement patterns in these regions.

3.3 History of fishing in Western Australia

3.3.1 Commercial and recreational fishing

The blue swimmer crab fishery in WA is predominantly an open access fishery for both commercial and recreational participants (Campbell and Broderick 1997, Campbell 1997). The overall number of commercial participants is limited to the 1600 fishing boat licences issued throughout WA. In 1997/98, 170 vessels recorded landings of blue swimmer crabs. Except for two components of the blue swimmer crab fishery, commercial management arrangements have been developed in a reactive and ad hoc manner or not at all.

Various methods are used by the commercial sector to target crabs. Predominantly they use crab pots, set (gill) nets and drop nets. The Cockburn Sound Crab Managed Fishery, which contributes almost half of the total crab catch in the State, has fully converted to using crab pots from set (gill) nets. Alternative methods used in some areas are haul nets, beam tide trawling and wading. Crabs are also a bycatch component of the commercial prawn and scallop trawl activities in the Shark Bay Prawn, Shark Bay Scallop and the Exmouth Gulf Prawn Managed Fisheries.

Historically, commercial fishers availed themselves of blue swimmer crab to fill a resource gap when alternative species were not available. However, since 1991/92 the commercial catch has been increasing substantially, from 215 tonnes in that season to 740 tonnes in 1997/98, principally due to the use of pots and improved technology. Increasing market prices and new market opportunities have also been driving commercial interests. Anecdotal evidence of good recreational catches in recent years (1996/97) may indicate good recruitment.

There are six key commercial fishing areas for blue swimmers in waters between Exmouth Gulf in the north-west and Albany in the south (Figure 2). Two are managed crab fisheries, both adjacent to the Perth metropolitan region. These are the Cockburn Sound Crab Managed Fishery and the Warnbro Sound Crab Managed Fishery. Other main areas are Exmouth, Shark Bay, Geographe Bay, the south-west estuaries (Swan-Canning, Peel-Harvey and Leschenault) and Mandurah (ocean fishing). A small amount of commercial fishing for crabs takes place in the south coast estuaries (Campbell 1997).

Since late 1997, a public and commercial consultative process has been undertaken to develop recommendations for the future management of blue swimmer crab fishing in WA (Campbell 1997, 1998).

Currently, recreational fishers may take crabs by hand, drop nets or wire scoop nets. Recreational fishers are restricted to a bag limit of 24 crabs per fisher and a boat limit of 48 crabs per boat per day, using no more than 10 drop nets per boat or per person from shore. A minimum size limit of 127 mm carapace width (point to point) applies (Campbell 1997) to both commercial and recreational fishers. Two exceptions are, in Geographe Bay commercial fishers have a size limit of 128 mm CW and in Cockburn Sound Crab Managed Fishery the commercial size limit is 130 mm.

It is estimated that more than 76,000 people fish for blue swimmer crabs each summer (Davis 1988). The Peel-Harvey Estuary and Leschenault Estuary are popular recreational crabbing areas in the south-west of WA. The crabs are most abundant from January to May. A survey on the recreational take in the Leschenault Estuary conducted during 1998 produced a result of 37.8 tonnes for boat-based fishers and 7.9 tonnes for shore-based fishers (Malseed *et al.* 2000). This compares to approximately 4 tonnes for the commercial sector in this area during the same period.

A survey of boat-based recreational fishing was conducted between Augusta and Kalbarri, on the west coast of WA, during 1996/97. Estimated boat-based recreational catches of blue swimmer crabs for Geographe Bay were 17.5 tonnes and for Cockburn Sound 18.8 tonnes, while the catch for Perth South (which includes Warnbro Sound, Shoalwater Bay, Cockburn Sound to Fremantle and west of Garden Island) was estimated to be 34.7 tonnes (Sumner and Williamson, in prep.).

Fisheries WA is presently completing surveys of recreational fishing in the Peel-Harvey Estuary and Swan River to estimate the total recreational catch and fishing effort for blue swimmer crabs in these areas to add to the existing survey data. Recreational surveys should be conducted at least every five years to monitor trends in the level of catch, effort and size composition (where possible) in different regions.

3.3.2 Distribution of commercial crab catch

Most of the commercial crab catch is taken from Cockburn Sound (Figure 3). The other areas with substantial crab catches are Shark Bay, the Peel-Harvey Estuary and Exmouth. Over the last ten years, commercial catches of *P. pelagicus* have shown a significant increase.

3.3.3 Distribution of catch by gear types

Pots are the main gear type now used by commercial fishers in WA (Figure 4), having recently replaced gill nets. An analysis of the effect of the conversion from set (gill) nets to pots on catch and effort in the Peel-Harvey and Cockburn Sound fisheries was recently completed (Melville-Smith *et al.* 1999). Crabs caught as bycatch from prawn and scallop trawl activities constitute a significant component of annual catches.

3.3.4 Yearly trends in catch per unit effort values

The yearly trends in catch per unit effort for the Cockburn Sound region show little variation (April 1993 to June 1998) since pots were introduced into the fishery. However, increased effort during this period has resulted in a major increase in total catch in this region (Figure 5).

3.3.5 Stock assessment

Most studies in Australia have involved descriptions of crab biology, habitat requirements and variability in distribution. Limited descriptions of the catch and effort and fishing trends are available (Grove-Jones 1987, Baker and Kumar 1994, Kumar *et al.* 1998), but no stock assessments have been attempted for *P. pelagicus* within Australia, and only recently was an assessment made for *P. pelagicus* along the south-west coast of India (Sukumaran and Neelakantan 1996). It is believed that stocks of *P. pelagicus* in WA are fairly resilient due to the life history strategies of the species, which include fast growth, high fecundity, high interannual variability in abundance, early reproductive maturity and relatively short life span. The stock is also protected by management controls which include gear limitations (number of pots or total length of net), a minimum size limit that is above the mean size at sexual maturity for both males and females, full protection of berried females and bag, boat and gear limits for recreational fishers.

In WA, several research programs were instigated in 1998 that will address key biological parameters and fishery dynamics information required for stock assessments in the future.

3.3.6 Potential for exploitation

An Inshore Crab Review of the blue swimmer crab fishery and its future development was completed in 1999 and outlines the potential areas for further development and exploitation of *P. pelagicus* in WA waters. As a result of this, a Fisheries Development Policy has been developed which seeks expressions of interest from people keen to develop new fisheries including blue swimmer crab fisheries.

4.0 Current blue crab research in Australia and Western Australia

4.1 National collaborative research programs

In 1997 a national meeting was held (Kumar 1997) to determine national and local research requirements for the sustainable development and utilisation of blue swimmer crab stocks. As a consequence of this meeting, research funding was provided by the Fisheries Research and Development Corporation (FRDC) for a national, collaborative approach to research on the blue crab stocks. The research projects currently in progress and potential benefits are summarised in Kumar (1998).

4.2 Current WA research projects

The recent rapid increase in the catches of commercial fishers and the high participation in the fishery by recreational fishers, particularly in the south-west, make it imperative that sustainable catch levels are identified and factors affecting recruitment are described.

There is a need to establish the habitat requirements of the blue swimmer crab in the different environments in which it occurs in WA. Other research issues relate to the effectiveness of the different fishing methods and attributing a uniform measure of fishing effort across the various fishing sectors. Determining fishing pressure in various parts of the fishery will also require a knowledge of the spatial movements of crabs, particularly migration between estuaries and the open sea. Reliable estimates of the relative levels of recreational catches are required to assess exploitation of blue crabs and enable an assessment of resource-sharing issues. An understanding of growth, survival and annual recruitment is also required for proper assessments of blue swimmer crab stocks.

Four research projects are currently under way to provide this vital information on the biology and commercial and recreational exploitation of blue crab stocks in WA.

(a) Genetic (microsatellite) determination of stock structure of the blue swimmer crab in Australia (FRDC 98/118)

There is a need to identify whether different stocks of blue swimmer crabs exist within WA. A study is currently under way (FRDC 98/118) to provide detailed information on the population genetic structure of *P. pelagicus* over virtually its entire range in Australia. The two-year study by Murdoch University commenced in July 1998 and the project is due to be completed in June 2000.

(b) The collection of biological data required for management of the blue swimmer crab fishery in the central and lower west coasts of Australia (FRDC 97/137)

- Determination of habitat requirements and the way in which these change with body size and state of maturity.
- Determination of the reproductive biology of the blue swimmer crab in Cockburn Sound and Shark Bay.
- Determination of growth and movement patterns.

The three-year study by Murdoch University commenced in January 1998 and the project is due to be completed in December 2000.

(c) **Estimation of recreational catch of blue swimmer crabs (FRDC 98/119)**

- Analysis of crab catches in existing recreational survey data collected during the course of earlier finfish surveys (Ayvazian *et al.* 1997 (FRDC 93/79), Sumner and Williamson 1999 and Malseed *et al.* 2000).
- Peel-Harvey and Swan River recreational survey (current).

The 18-month study by Fisheries WA commenced in July 1998 and the project is due to be completed in December 1999.

(d) **The collection of fisheries data required for management of the blue swimmer crab fishery in the central and lower west coasts of Australia (FRDC 98/121)**

- Establishment of a voluntary research logbook to provide detailed daily catch and effort information for all regions of the blue crab fishery
- Establishment of a commercial catch monitoring system to provide regular monthly or seasonal size composition and abundance information from major commercial fishing regions. Measurement of environmental variables will be made on each sampling trip by researchers.
- Estimation of discard mortality rates using different commercial and recreational fishing methods.
- Establishment of the effect of pot selectivity/efficiency on the size composition, sex ratio and moult stage of the catch in Cockburn Sound.
- Estimation of conversion factors for relating the effort for pots to that of the set nets used historically.

The three-year study by Fisheries WA commenced in July 1998 and the project is due to be completed in June 2001.

The data collected on growth, reproduction and mortality of the blue swimmer crab will be utilised to perform yield-per-recruit and egg-per-recruit analyses, and information from all four projects will be used to develop a generic spatial model of a blue crab fishery. This will allow managers and resource users to investigate likely outcomes of various management regimes.

5.0 References

Australian Bureau of Statistics (1987). Recreational Fishing, Western Australia, July 1987. Catalogue No. 7602.5, 19 pp.

Ayvazian, S., Lenanton, R., Wise, B., Steckis, R. and Nowara, G. (1997). Western Australian salmon and Australian herring creel survey. FRDC Final Report, Project 93/79, 93 pp.

Baker, J.L. and Kumar, M. (1994). Review of the blue crab (*Portunus pelagicus*) fishery in South Australia. *SARDI Research Report Series*, **9**: 1-59.

Batoy, C.B., Sarmago, J.F. and Pilapil, B.C. (1987). Breeding season, sexual maturity and fecundity of the blue crab, *Portunus pelagicus* (L.) in selected coastal waters in Leyte and vicinity, Philippines. *Annals of Tropical Research*, **9**: 157-177.

Bryars, S.R. (1997). Larval dispersal of the blue swimmer crab *Portunus pelagicus* Linnaeus (Crustacea: Decapoda: Portunidae) in South Australia. Flinders University, Australia. Unpublished PhD thesis, 256 pp.

Bryars, S.R. and Adams, M. (1999). An allozyme study of the blue swimmer crab *Portunus pelagicus* (Crustacea: Portunidae), in Australia: stock delineation in southern Australia and evidence for a cryptic species in northern waters. *Marine and Freshwater Research*, **50**: 15-26.

Campbell, C. (1997). Issues affecting Western Australia's inshore crab fishery. Fisheries WA. *Fisheries Management Paper,* **108**, 53 pp.

Campbell, C. (1998). Summary of submissions to Fisheries Management Paper No. 108 - issues affecting Western Australia's inshore crab fishery. Fisheries WA. *Fisheries Management Paper,* **112**, 41 pp.

Campbell, C. and Broderick, C. (1997). Case study of issues affecting Western Australia's inshore crab fishery. In: Proceedings of the First National Workshop on Blue Swimmer Crab *Portunus pelagicus* (ed. Kumar, M.)*, SARDI Research Report Series*, **16**: 31-39.

Campbell, G.R. (1984). A comparative study of adult sexual behaviour and larval ecology of three commercially important portunid crabs from the Moreton Bay region of Queensland, Australia. University of Queensland, Australia. Unpublished PhD thesis, 253 pp.

Campbell, G.R. and Fielder, D.R. (1986). Size at sexual maturity and occurrence of ovigerous females in three species of commercially exploited portunid crabs in SE Queensland. *Proceedings of the Royal Society of Queensland*, **97**: 79-87.

Clancy, M. and Epifanio, C.E. (1989). Distribution of crab larvae in relation to tidal fronts in Delaware Bay, USA. *Marine Ecology Progress Series,* **57**: 77-82.

Davis, G. (1988). The biology of the Blue Manna Crab (*P. pelagicus*) in estuaries of south-western Western Australia. Waterways Commission. Waterways Information No. 1, 6 pp.

Day, J.H. (1935). The life history of *Sacculina. Quarterly Journal of Microbial Science,* **77**: 549-583.

Dittel, A. and Epifanio, C.E. (1982). Seasonal abundance and vertical distribution of crab larvae in Delaware Bay. *Estuaries,* **5**: 197-202.

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.R. and Eales, A.J. (1972). Observations on courtship, mating and sexual maturity in *P. pelagicus* (L., 1766) (Crustacea, Portunidae). *Journal of Natural History,* **6**: 273-277.

Fisheries Department, WA (1990). The blue manna crab. Fishing WA No. 7, 4 pp.

Freier, J., Paz Sampedro, M. and Gonzáles-Gurriáran, E. (1996). Influence of morphometry and biomechanics on diet selection in three portunid crabs. *Marine Ecology Progress Series,* **137**: 111-121.

Gaughan, D.J. and Potter, I.C. (1994). Relative abundance and seasonal changes in the macrozooplankton of the lower Swan Estuary in south-western Australia. *Records of the Western Australian Museum,* **16(4)**: 461-474.

Grove-Jones, R. (1987). Catch and effort in the South Australian blue crab (*Portunus pelagicus*) fishery. South Australian Department of Fisheries, discussion paper, September 1987, 45 pp.

Hamsa, K.M.S. (1982). Observations on moulting of crab *Portunus pelagicus* Linnaeus reared in the laboratory. *Journal of the Marine Biological Association of India,* **24**: 69-71.

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

Ingles, J.A. and Braum, E. (1989). Reproduction and larval ecology of the blue swimming crab *Portunus pelagicus* in Ragay Gulf, Philippines. *Internationale Revue der gesamten Hydrobiologie,* **74**: 471-490.

Johnson, G.E. and Gonor, J.J. (1982). The tidal exchange of *Callianassa californiensis* (Crustacea: Decapoda) larvae between the ocean and the Salmon River Estuary. *Estuarine Coastal Shelf Science*, **14**: 501-516.

Kailola, P.J., Williams, M.J., Stewart, P.C., Reichelt, R.E., McNee, A. and Grieve, C. (1993). Australian Fisheries Resources. Bureau of Resource Sciences, Department of Primary Industries and Energy, and the Fisheries Research and Development Corporation, Canberra, Australia.

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

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

Kumar, M., Ferguson, G. and Boxall, V. (1998). Blue Crabs. *South Australian Fisheries Assessment Series,* **97/14**, 25 pp.

Kurata, H. and Midorikawa, T. (1975). The larval stage of the swimming crabs, *P. pelagicus* and *P. sanguinolentus,* reared in the laboratory. *Bulletin Nansei Regional Fisheries Research Laboratory*, **8**: 29-38.

Laurenson, L.J.B., Unsworth, P., Penn, J.W. and Lenanton, R.C.J. (1993). The impact of trawling for saucer scallops and western king prawns on the benthic communities in coastal waters off south-western Australia. Fisheries Department of Western Australia. *Fisheries Research Report*, **100**: 1-93.

Linnaeus, C. (1766.) Systema naturae per regna tria naturae, secudum classes, ordines, genera, species cum characteribus, differentiis, locis, 10th ed., 1042 pp.

Malseed, B.E., Sumner, N.R. and Williamson, P.C. (2000). A 12-month survey of recreational fishing in the Leschenault Estuary of Western Australia during 1998. Fisheries WA. *Fisheries Research Report*, **120**, 22 p.

Mayo, H.J. and Dudley, D.L. (1970). Movements of tagged blue crabs in North Carolina waters. *Commercial Fisheries Review,* **32**: 29-35.

Meagher, T.D. (1968). Unpublished report to the Fisheries Department of Western Australia.

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

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

Melville-Smith, R., Cliff, M. and Anderton, S.M. (1999). Catch, effort and the conversion from gill nets to traps in the Peel-Harvey and Cockburn Sound blue swimmer crab *(Portunus pelagicus)* fisheries. Fisheries WA. *Fisheries Research Report,* **113**: 24 pp.

Neverauskas, V.P. and Butler, A.J. (1982). Tolerance of blue crab, *Portunus pelagicus* (L.), to high temperatures. *Transactions of the Royal Society of South Australia,* **106**: 215-216.

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.

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

Pillay, K.K. and Nair, J.B. (1976). Observations on the breeding biology of some crabs from the southwest of India. *Journal of Marine Biological Association of India,* **15**: 754-770.

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

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

Potter, I..C. and de Lestang, S. (in press). 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.*

Potter, M., Sumpton, W. and Smith, G. (1987). Queensland sand crab study highlights a need for changes in management. *Australian Fisheries,* **46(6)**: 22-26.

Potter, M.A., Sumpton, W.D. and Smith, G.S. (1991). Movement, fishing sector impact and factors affecting the recapture rate of tagged sand crabs, *Portunus pelagicus* (L.) in Moreton Bay, Queensland. *Australian Journal of Marine and Freshwater Research,* **42**: 751-760.

Prasad, R.R. and Tampi, P.R.S. (1953). A contribution to the biology of the blue swimming crab *Neptunus pelagicus* (L) with a note on the zoea of *Thalamitta crenata. Journal Bombay Natural History Society,* **51**: 674-689.

Rugolo, L.J., Knotts, K.S., Lange, A.M. and Crecco, V.A. (1998). Stock assessment of Chesapeake Bay blue crab (*Callinectes sapidus* Rathbun). *Journal of Shellfish Research,* **17**: 493-517.

Shields, J.D. and Wood, F.E.I. (1993). Impact of parasites on the reproduction and fecundity of the blue sand crab *P. pelagicus* from Moreton Bay, Australia. *Marine Ecology Progress Series,* **92**: 159-170.

Smith, G.S. and Sumpton, W.D. (1987). Sand crabs a valuable fishery in southeast Queensland. *Queensland Fisherman,* **5**: 13-15.

Smith, G.S. and Sumpton, W.D. (1989). Behaviour of the commercial sand crab *Portunus pelagicus* (L.) at trap entrances. *Asian Fisheries Science,* **3**: 101-113.

Smith, H. (1982). Blue crabs in South Australia - their status, potential and biology. *SAFIC,* **6(5)**: 6-9.

Stephenson, W. (1962). Evolution and ecology of portunid crabs, with special reference to Australian species. In: The evolution of living organisms (ed. Leeper, G.W.), Melbourne University Press, Melbourne, pp 311-327.

Stephenson, W. and Campbell, B. (1959). The Australian portunids (Crustacea: Portunidae). III. The genus *Portunus. Australian Journal of Marine and Freshwater Research,* **10**: 84-124.

Sukumaran, K.K. and Neelakantan, B. (1996a). Relative growth and sexual maturity in the marine crabs, *Portunus (Portunus) sanguinolentus* (Herbst) and *Portunus (Portunus) pelagicus* (Linnaeus) along the south-west coast of India. *Indian Journal of Fisheries,* **43**: 215-223.

Sukumaran, K.K. and Neelakantan, B. (1996b). Mortality and stock assessment of two marine portunid crabs, *Portunus (Portunus) sanguinolentus* (Herbst) and *Portunus (Portunus) pelagicus* (Linnaeus) along the south-west coast of India. *Indian Journal of Fisheries,* **43**: 225-240.

Sukumaran, K.K. and Neelakantan, B.(1997). Age and growth in two marine portunid crabs, *Portunus (Portunus) sanguinolentus* (Herbst) and *Portunus (Portunus) pelagicus* (Linnaeus) along the south-west coast of India. *Indian Journal of Fisheries,* **44**: 111-131.

Sumner, N.R. and Williamson, P. (1999). A 12-month survey of coastal recreational boat fishing between Augusta and Kalbarri on the west coast of Western Australia during 1996-97. *Fisheries Research Report,* **117**: 52 pp.

Sumner, N.R. and Williamson, P. (in prep). An assessment of the impact of marine recreational boat-based fishing on the lower west coast of Western Australia. Fisheries WA. *Fisheries Research Report.*

Sumpton, W.D. and Smith, G.S. (1991). The facts about sand crabs. *The Queensland Fisherman,* June 1991: 29-31.

Sumpton, W.D., Potter, M.A. and Smith, G.S. (1989). The commercial pot and trawl fisheries for sand crabs *(Portunus pelagicus)* in Moreton Bay, Queensland. *Proceedings of the Royal Society of Queensland,* **100**: 89-100.

Sumpton, W.D., Potter, M.A. and Smith, G.S. (1994). Reproduction and growth of the commercial sand crab, *Portunus pelagicus* (L.) in Moreton Bay, Queensland. *Asian Fisheries Science,* **7**: 103-113.

Thomson, J.M. (1951). Catch composition of the sand crab fishery in Moreton Bay. *Australian Journal of Marine and Freshwater Research,* **2**: 237-244.

Van Engel, W.A. (1958). The blue crab and its fishery in Chesapeake Bay. Part I. Reproduction, early development, growth and migration. *Commercial Fishing Review* **20**: 6-17.

Wassenberg, T.J. and Hill, B.J. (1987). Feeding by the sand crab *P. pelagicus* on material discarded from prawn trawlers in Moreton Bay, Australia. *Marine Biology,* **95:** 387-393.

Wassenberg, T.J. and Hill, B.J. (1989). The effect of trawling and subsequent handling on the survival rates of the by-catch of prawn trawlers in Moreton Bay, Australia. *Fisheries Research,* **7**: 99-110.

Wassenberg, T.J. and Hill, B.J. (1990a). Partitioning of material discarded from prawn trawlers in Moreton Bay. *Australian Journal of Marine and Freshwater Research,* **41**: 27-36.

Wassenberg, T.J. and Hill, B.J. (1990b). Fate of discards from prawn trawlers in Torres Strait. *Australian Journal of Marine and Freshwater Research,* **41**: 53-64.

Wassenberg, T.J. and Hill, B.J. (1993). Selection of the appropriate duration of experiments to measure the survival of animals discarded from trawlers. *Fisheries Research,* **17**: 343-352.

Weng, H.T. (1992). The sand crab (*Portunus pelagicus)* (Linnaeus)) populations of two different environments in Queensland. *Fisheries Research,* **13**: 407-422.

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.

Yatsuzuka, K. (1962). Studies on the artificial rearing of the larval Brachyura, especially of the larval blue-crab *Neptunus pelagicus*. Reports of the USA Marine Biological Station No. 9, 4 pp.

6.0 Figures

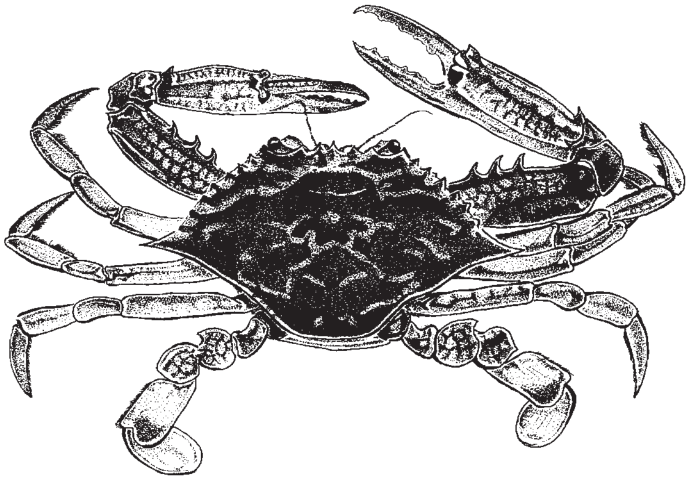

Figure 1 Drawing of the blue swimmer crab *Portunus pelagicus* Linnaeus.

Figure 2 Map of south Western Australia showing key locations in the distribution and fishery for blue swimmer crab.

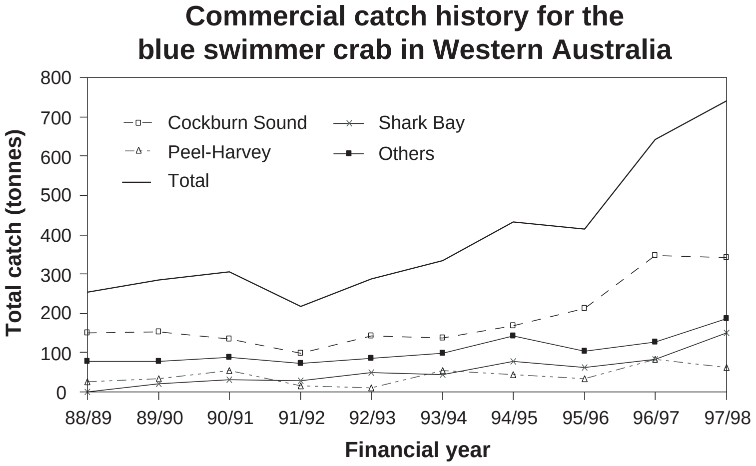

Figure 3 Commercial catch history for the blue swimmer crab (*Portunus pelagicus)* in Western Australia between 1988/89 and 1997/98 by region.

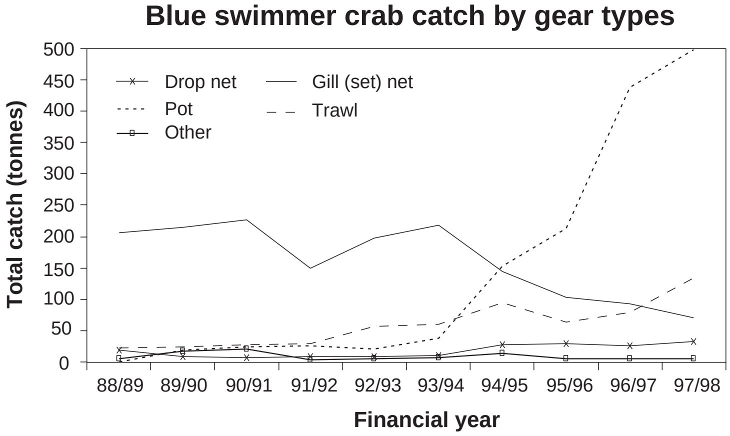

Figure 4 Blue swimmer crab catch by gear types in Western Australia between 1988/89 and 1997/98.

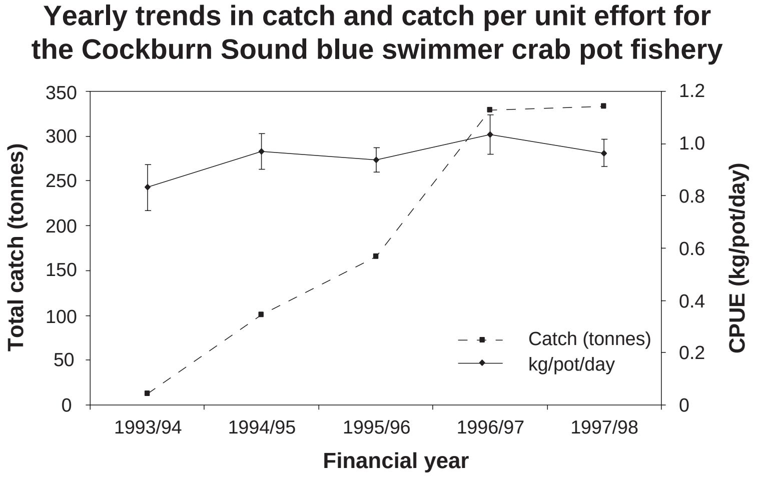

Figure 5 Total catch and catch per unit effort (kg/pot/day) in the Cockburn Sound pot fishery between 1993/94 and 1997/98. **Note**: Pot catches in 1993/94 only depicted for January to June.