Identifying future restocking options for Blue Swimmer Crabs (*Portunus armatus*)

Greg I. Jenkins¹, Robert Michael¹, James R. Tweedley²

¹ Australian Centre for Applied Aquaculture Research, South Metropolitan TAFE, Fremantle, Western Australia.
² School of Veterinary and Life Science, Murdoch University, Perth, Western Australia.

June 2017

**Recipient:** Australian Centre for Applied Aquaculture Research

**Grantor:** The Government of Western Australia Department of Fisheries (as a delegate of the Minister of Fisheries)
Copyright Recreational Fishing Initiative Fund, South Metropolitan TAFE and Murdoch University

This work is copyright. Except as permitted under the Copyright Act 1968 (Cth), no part of this publication may be reproduced by any process, electronic or otherwise, without the specific written permission of the copyright owners. Information may not be stored electronically in any form whatsoever without such permission.

Disclaimer
The authors do not warrant that the information in this document is free from errors or omissions. The authors do not accept any form of liability, be it contractual, tortious, or otherwise, for the contents of this document or for any consequences arising from its use or any reliance placed upon it. The information, opinions and advice contained in this document may not relate, or be relevant, to a reader’s particular circumstances. Opinions expressed by the authors are the individual opinions expressed by those persons and are not necessarily those of the publisher, research provider or those associated with the Recreational Fishing Initiative Fund.
# Table of Contents

Acknowledgments .............................................................................................................................................. 4  
Non-technical summary of research findings ................................................................................................. 5  
Section 1: Background information and project aims ..................................................................................... 7  
Section 2: Culture and release of Blue Swimmer Crabs ................................................................................. 9  
  Specific aim ................................................................................................................................................ 9  
  Obtain relevant project approvals ................................................................................................................ 9  
  Broodstock collected ................................................................................................................................. 10  
  Culture of crabs ....................................................................................................................................... 12  
  Completion of hatchery work and release of crabs if successful ............................................................... 16  
Section 3: Literature review ........................................................................................................................... 17  
  Rationale ................................................................................................................................................. 17  
  Results ..................................................................................................................................................... 18  
References .................................................................................................................................................... 19  
Appendix 1. Details of the Blue Swimmer Crab release in November 2015 ................................................. 21  
Appendix 2. Health clearance of hatchery-reared Blue Swimmer Crabs .................................................... 22  
Appendix 3. Literature review title and contents pages .............................................................................. 24  
Appendix 4. Portunid Crab Bibliography .................................................................................................... 28  
Appendix 5. Theodore Campbell Honours abstract .................................................................................... 29
Acknowledgments

This project was made possible by the Recreational Fishing Initiatives Fund and supported by Recfishwest and the WA Department of Fisheries. Additional financial and logistical support was provided by the Australian Centre for Applied Aquaculture Research (ACAAR) and Murdoch University. Gratitude is expressed to Dr Danielle Johnston and her team at the WA Department of Fisheries for catching broodstock crabs and for providing advice on the project.
Non-technical summary of research findings

This project had two main aims, *i.e.* (i) attempt to culture and release Blue Swimmer Crabs (*Portunus armatus*) and (ii) produce an extensive literature review detailing existing knowledge on the biology/ecology of portunids, techniques for successfully rearing these species in aquaculture and review the successes and lessons learned from Portunid release programs around the world. Berried female *P. armatus* collected from the Peel-Harvey Estuary in October and November spawned in the hatchery each producing between 300,000 and 900,000 zoea. One of the two culture runs were successful, producing 175,000 megalopa from 340,000 zoea at a survival rate of 52%. Survival decreased dramatically following metamorphosis from megalopa to crablet (2.4%; *i.e.* 1.2% of the zoea). This was due to the morphological development of claws and the highly aggressive and cannibalistic nature of the crabs. Once the individuals were transferred to a tank with habitat to hide in, mortality decreased with 18% of the 500 crabs stocked surviving for 53 days before being euthanised. Of the 4,200 crablets produced, 3,700 were released, following clearance from the WA Department of Fisheries into the Peel-Harvey Estuary.

The literature review demonstrated that, in general, portunids are highly fecund, fast growing, short-lived species, with high natural mortalities and are opportunistic predators. These species are also subjected to high fishing pressure with an overall mean exploitation rate of 0.57% ± 0.15 (maximum *Portunus trituberculatus* at 0.82%), indicating that, on average, more crabs are captured by fisheries each year than die of natural causes. All release programs for portunids were initiated in response to declines in stocks caused by overfishing, disease, habitat degradation and climate change. In each case, successful hatchery techniques were developed to enable small-scale production, however, only in the case of *P. trituberculatus* was production increased to a commercial scale (~27-35 million juveniles per year). Hatchery-reared individuals are released at the crablet stage as stocking megalopae has not been effective. However, there is a trade-off between the economic cost of production and size-at-release and thus survival in the wild. This is poorly understood and likely requires detailed biological studies and bio-economic analysis to answer definitely.
Cannibalism is a major reason for the increased cost of producing larger numbers of bigger crabs. Techniques, such as habitat enrichment and grading, can reduce intra-specific predation and should be investigated further. This would increase the cost-effectiveness of any future release program for *P. armatus* (and other portunids).

In summary, juvenile *P. armatus* were able to be cultured for the first time in Western Australia from berried broodstock. Given this success, potential exists for a future restocking program for *P. armatus* in Western Australia although further research and development is needed to increase survival through to the crablet stage.
Section 1: Background information and project aims

Portunid crabs are heavily targeted by commercial, recreational and artisanal fishers around the world and also grown in culture, with the exploitation and aquaculture production of these species increasing seven fold between the 1970s and 2000s (Keenen 2004). The greatest wild capture landings occur in the Indo-West Pacific (FOA 2016) and these species are the focus of major recreational fisheries in countries such as Australia and the United States of America (Sumner et al. 2000, Miller 2001, Ryan et al. 2015). While, in countries such as Indonesia, Malaysia and Thailand, production has risen rapidly (Keenen 2004), catches in some fisheries in the USA and Australia have declined (Miller et al. 2005, Johnston et al. 2011b).

The Blue Swimmer Crab *Portunus armatus* is distributed and fished recreationally and commercially throughout Australian coastal waters and estuaries (Poore 2004, Johnston et al. 2014b). In Western Australia, this species is targeted by commercial fishers in (i) Shark Bay, Exmouth Gulf and Nickol Bay in the north of the state, (ii) the Peel-Harvey and Swan-Canning estuaries, Cockburn and Warnbro sounds, Comet Bay and in coastal waters between Mandurah and Bunbury on the lower west coast of Australia and (iii) in Princess Royal and Oyster harbours, Wilson and Irwin inlets on the south coast of the state (Johnston et al. 2016). Crabbing for *P. armatus* is the most popular recreational fishery in Western Australia, with an estimated 900,000 individuals caught by boat-based recreational fishers in 2013/14, and thus far greater than the next most caught species School Whiting (350,000 individuals; Ryan et al. 2015).

Recreational fishing pressure is concentrated in estuarine and coastal waters, particularly those located near population centres, such as the Peel-Harvey Estuary (Sumner et al. 2000). Recreational take from canals and boat and shore-based fishing in this system in 2007/08 was estimated at between 110–180 t (Johnston et al. 2014a), which is greater than the 50-100 t caught by commercial trap fishers in the same estuary (Johnston et al. 2016). The nearby Swan-Canning Estuary also supports a *P. armatus* fishery, although annual catches across both the recreational and commercial sectors is < 50 t (Johnston et al. 2016).
While the stocks of *P. armatus* in the Peel-Harvey Estuary are classified as sustainable (Johnston et al. 2016) and the commercial and recreational sectors of the fishery have received Marine Stewardship Council certification (Johnston et al. 2015), abundances of *P. armatus* have declined markedly in the nearby marine embayment of Cockburn Sound. This embayment was fished commercially and recreationally until abundances declined and the fishery was closed in 2006, before reopening in 2009 and subsequently closing again in 2014 (de Lestang et al. 2010, Johnston et al. 2011a, 2011b, 2016). The population collapse that lead to the closure of this fishery in 2006 is thought to be due to high fishing pressure on pre-spawning females in winter (reducing the spawning stock) and cooler than average water temperatures between 2002 and 2005, leading to poor recruitment (de Lestang et al. 2010, Johnston et al. 2011b). Although the fishery was re-opened to fishing under strict management controls for the 2009/10 season (Johnston et al. 2011a), it was subsequently closed in April 2014 due to low stock levels and remains closed to this day (Johnston et al. 2016).

Given the popularity of *P. armatus* as a recreational-targeted species, their commercial importance and the declines that have occurred in some fisheries around the world, the first aim of this project was to attempt to culture *P. armatus* in Western Australia with a view to developing a suite of hatchery methods that could be employed in a release program (restocking or stock enhancement) if required in the future. As portunids have been aquacultured in other regions of the world, on both an experimental (restocking) and commercial (stock enhancement) scale, the second aim was to produce a literature review detailing existing knowledge on the biology and ecology of *P. armatus*, techniques for successfully rearing this and other similar species in aquaculture and the results of any release programs.
Section 2: Culture and release of Blue Swimmer Crabs

Specific aim

The overall aim of this component of the project was to attempt to culture Blue Swimmer Crabs (*Portunus armatus*) in Western Australia, using novel techniques developed by Jenkins et al. (2017) as part of the Western School Prawn restocking project (Tweedley et al. 2017). While the aquaculture and release of portunid crabs (*e.g.* *Portunus trituberculatus* in Japan and *Callinectes sapidus* in the Chesapeake Bay, USA) has been undertaken previously (see Section 2), *P. armatus* has not been cultured in Western Australia and with only limited success in South Australia. In the event that the culture attempt was successful, the resultant hatchery-reared individuals would be released into the area where the broodstock were collected.

The following sections describe the activities and their results carried out under milestones detailed in the “Description of completion of the project” that related to the culture of *P. armatus*.

Obtain relevant project approvals

An ‘Application for Exemption’ to collect berried *P. armatus* from nearshore marine and estuarine waters in the West Coast Bioregion for research purposes was made to the WA Department of Fisheries (DoF) in August 2015. This application was approved and incorporated into the Australia Centre for Applied Aquaculture Research (ACAAR) general broodstock exemption, which is valid until 31st December 2018.

An application to release hatchery-reared *P. armatus* was submitted to the Director General of the WA Department of Fisheries in September 2015 and granted, subject to the cultured crabs being approved by the Fish Health Section and the details of the release being submitted to the department prior to any release.
**Broodstock collected**

Although ACAAR had the broodstock exemption for the collection of berried *P. armatus*, Dr Danielle Johnston from the DoF offered to provide information on the location of berried females recorded during her team’s regular sampling program. Members of that team captured four early stage berried females (Fig. 1) from the Peel-Harvey Estuary on the 5th October 2015 and Mr Robert Michael of ACAAR picked them up from the field site. On the 4th November 2015 the DoF crab team collected and transported four more berried female crabs to the ACAAR facility in Fremantle. Individuals were caught from waters with a temperature of 19 °C and were transferred into hatchery holding tanks, where the water temperature was slowly increased to 25 °C, over several hours.

It took approximately 7 days at 25°C for the eggs on the berried female crabs to change from yellow to grey-black colour (Fig. 2). At this point females were transferred from holding tanks into individual 300 L spawning tanks (Fig. 3). Spawning occurred at night, with each tank containing between ~ 300,000 –800,000 zoea the following morning (Table 1).

---

**Fig 1.** Early stage berried female *P. armatus* on arrival to the hatchery.  **Fig 2.** Late stage berried female *P. armatus* being transferred to a spawning tank.
Table 1. Relationship between carapace length and the number of zoea hatched.

<table>
<thead>
<tr>
<th>Crab #</th>
<th>Carapace length (mm)</th>
<th>Number of zoea hatched</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>110</td>
<td>296,000</td>
</tr>
<tr>
<td>2</td>
<td>115</td>
<td>352,000</td>
</tr>
<tr>
<td>3</td>
<td>140</td>
<td>896,000</td>
</tr>
<tr>
<td>4</td>
<td>145</td>
<td>826,000</td>
</tr>
</tbody>
</table>

Zoea were harvested from the 250 µm collectors (Fig. 4), counted and then stocked into 3,000 L larval tanks at various stocking densities.

Fig. 3. 300 L spawning tanks and 250 µm zoea collectors.
Fig. 4. Submerged flow through zoea collector.
Culture of crabs

Two crab culture runs were attempted during the austral summer of 2015/16. Two of the first batch of females released their eggs, and ~ 867,000 first stage Zoea were stocked into two culture tanks at a density of 100 L⁻¹ and 200 L⁻¹, respectively. This culture run was unsuccessful likely due to a bacterial issue and was terminated after 14 days. The second run, however, was much more successful. Two crabs contributed to the spawning and ~336,000 zoea were stocked into one culture tank at 120 L⁻¹. Several small changes were made to the culture protocol, which helped to achieve a 52% survival rate through the culture phase resulting in ~175,000 megalopa being produced. These included:

- Stocking density 100-150 L⁻¹
- Reduce algal and artemia feeds
- Last fed algae on day 10
- Maximum water temperature of 26 °C
- Passive transfer to clean tank at day 12

Survival into the next developmental stage (crablet) was very low (1.85%) and only 4,200 individuals were harvested. It is well documented in the scientific literature that crablets are highly aggressive and cannibalistic (Marshall et al. 2005, Møller et al. 2008, Romano and Zeng 2017). It is therefore recommended that, for any future restocking efforts with Blue Swimmer Crabs, individuals are be released or transferred into a habitat with suitable substrate to hide in while they are still in the megalopa stage to better ensure their chances of survival.

The resultant 4,200 crablets were stained at 22 Days Post Hatch (DPH) with 10 ppm Alizarin Complexone (ALC) for 1 hr. Of these 3,700 were released into the Peel-Harvey Estuary (see details below) and the remaining 500 were stocked into a 1,000 L tank filled with substrate to allow them to hide. After 53 days in this tank (i.e. 71 DPH) the tank was drained and 89 individuals were collected (18% of initial crablets stocked). These were measured, photographed and frozen for future assessment of the gastric mill to determine the success of ALC staining.

It took approximately 12 days at 25 °C for crabs to reach megalopa stage and a further five days to moult into the first crab instar (crablet 1).
The photographs below outline the larval development through the main life stages.

Day 2: Zoea 1. Eyes sessile, abdomen 5 segments.

Day 4: Zoea 2. Eyes stalked, abdomen 5 segments.

Day 7: Zoea 3. Eyes stalked, abdomen 6 segments, pleopod buds forming along lower ventral side of abdomen.

Day 10: Zoea 4. Eyes stalked, abdomen 6 segments, pleopod buds well developed.


Day 16: late stage megalopa. Abdomen beginning to curve beneath cephalothorax.

Day 19: crablet 1. Abdomen completely curved beneath cephalothorax.

Day 22: crablet 1. Terminal segments of the fifth pair or periopods are fully developed and now function as swimmers.

A total of 500 crablets were stained with ALC at 22 DPH and transferred to a 1,000 L tank filled with Bio-block and fishing net (Fig 5). Crablets remained in this tank for 53 days and were fed a mix of commercial prawn feed, fish pellets and fresh minced fish. Upon harvesting, there was a very large size distribution, suggesting cannibalism was occurring. Sizes ranged from 8 to 40 mm carapace length (Figs 6, 7).
Fig. 5. Crablet tank with artificial habitat (Bio-block and fishing net).

Fig. 6. Size distribution at 73 days post hatch.

Fig. 7. Larger size classes at 73 days post hatch (see black box on Fig. 6).
Completion of hatchery work and release of crabs if successful

Following the completion of the hatchery program, 3,700 crablets were released into the Peel-Harvey Estuary at from the shore at Creey’s Wetlands (southern end of Chatsworth Drive), east of Boundary Island (Fig. 8). Further details of the release are provided in Appendix 1 and the Fish Health Clearance in Appendix 2.

Fig. 8. Map and satellite images of the broad release location and release site (red marker). Images provided by Google Maps.
Section 3: Literature review

Rationale

The stocks of portunids in a number of fisheries around the world are declining, including Chesapeake Bay, where the income generated from the *Callinectes sapidus* fishery has been reduced by 70% from US$ 900,000 to 300,000 in only 15 years (Zohar et al. 2008). As many of these declines are linked to overfishing, stocks are below their carrying capacity and thus aquaculture-based enhancement or release programs (Taylor et al. 2017) are seen as a potential option to increase stocks (Hines et al. 2008, Johnston et al. 2011b). In recent years, aquaculture technology has been developed for a number of portunids and these individuals have been used in a number of restocking and stock enhancement programs, some of which release up to 35 million crablets per year (Keenen 2004). However, not all of these programs have been successful and, although some have made it to the experimental stage, they were not always progressed to the commercial scale. Thus, before attempting to develop the technology to culture portunids, such as the Blue Swimmer Crab *Portunus armatus*, in Western Australia, there is value in critically evaluating the successes and failures of previous aquaculture efforts and/or release programs. In addition, Keenen (2004) recognised the lack of information on the basic biology of portunids, particularly those of interest to aquaculture. Thus the aims of this literature review were to:

- Summarise the components of portunid biology and ecology that are relevant to the successful aquaculture of members of this species.
- Identify previously successful aquaculture/restocking efforts for portunids and similar species in other parts of the world.
- Detail any aquaculture methods and techniques, which may have application in Western Australia.
Results

Due to the size of this review, it has been provided as a separate document. Copies of the title and contents pages, however, can be found in Appendix 3.

A bibliography containing the citations and abstracts of 1,320 references listed in the Scopus database as of June 2017 that contain the words ‘portunid’, ‘portunidae’ and/or ‘portunus’ has also been provided as a separate document (see Appendix 4). This later document is essentially a ‘print-out’ from the Scopus database, but provides a repository of relevant papers that can be searched for key words.
References


Miller, T. J. 2001. The precautionary approach to managing the blue crab in Chesapeake Bay: establishing limits and targets. University of Maryland Center for Environmental Science.


Appendix 1. Details of the Blue Swimmer Crab release in November 2015

**Project:** Identifying future restocking options for Blue Swimmer Crabs *Portunus armatus*

**Blue Swimmer Crablet Release 2015**

**Release No 1:** Friday 27th November

Species: *Portunus armatus*

Broodstock: Peel Harvey Estuary

Crab age: Day 22 Crablets

Delivery: Sealed oxygenated plastic bags within foam boxes.

No. of Sites: 1

Location: Creey’s Wetlands east of Boundary Island, Peel Harvey Estuary.

Shore based release at the southern end of Chatsworth Drive, Mandurah

Time: 6.00 pm

Coordinates: 32°33’50.60” S 115°41’46.21” E

Number: 3,700

Moon phase: Full moon, Rise 7.24 pm, set 5.22 am

Tidal state: High Tide at 9.42 pm

Wind SW Moderate and dropping to gentle by 8 pm

Fish Health Clearance attached.
Appendix 2. Health clearance of hatchery-reared Blue Swimmer Crabs

Form 130
HEALTH CERTIFICATE
LIVE CRUSTACEANS

I. Identification

<table>
<thead>
<tr>
<th>Cultured stocks</th>
<th>Wild stocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>☑</td>
<td></td>
</tr>
</tbody>
</table>

Latin name: Portunus pelagicus
Common name: Blue crab

*NOTE: Mark all the relevant items with a cross in the appropriate space.*

<table>
<thead>
<tr>
<th>Fertilised eggs</th>
<th>Post-larvae</th>
<th>Juveniles</th>
<th>Broodstock</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

II. Origin of consignment & Place of harvest

Company: Challenger TAFE
Address: 1 Fleet Street
Suburb: Fremantle
State: WA
Postcode: 6160

Total weight or number: 100,000

III. Destination

Country and zone: WA
Establishment: PEEL ESTUARY
Address: 
Method of transport: ROAD

<table>
<thead>
<tr>
<th>Broodstock</th>
<th>Growout</th>
<th>Competition/exhibition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ornamental</th>
<th>Restocking</th>
<th>Other (specify)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>☑</td>
<td></td>
</tr>
</tbody>
</table>


V Declaration

I, the undersigned, certifying official certifies that the live post larvae in the present consignment satisfy the following requirements:

THERE ARE NO SIGNIFICANT HEALTH ABNORMALITIES OR LESIONS IN THE ISO ANIMAL EXAMINED BY HISTOLOGY ON THIS DAY OF EXAMINATION.

Certifying Official: DO. JO BANNISTER
Name and address: AQUATIC PATHOLOGY
Date: 25/11/15
Official Position: AQUATIC PATHOLOGY INTERN

IMPORTANT NOTE: This certificate must be completed no more than seven days prior to shipment and is valid for 14 days from date of issue.
Appendix 3. Literature review title and contents pages

Due to size restrictions, this document has been provided as a separate attachment.

Biology and Aquaculture of Portunid Crabs

James R. Tweedley, Theodore I. Campbell, Neil R. Loneragan & Danielle Johnston

1Centre for Fish and Fisheries Research, School of Veterinary and Life Sciences, Murdoch University
2Department of Fisheries, Western Australia

June 2017
Table of Contents

Summary ......................................................................................................................... 4
Table of Contents .......................................................................................................... 5
References ..................................................................................................................... 100

Section 1. Life History characteristics of three genera of portunid crabs, Calappa, Portunus and Sinallama......................................................... 9

1.2. Overview of portunids .......................................................................................... 9

1.2.2. Biology ............................................................................................................. 12

1.2.2.1. Life cycle ................................................................................................... 11

1.2.2.2. Description of life cycle stages ................................................................ 13

1.2.2.3. Seasonal abundance ..................................................................................... 15

1.2.2.4. Habitat utilization ....................................................................................... 16

1.2.3. Reproduction .................................................................................................... 17

1.2.3.1. Mating ........................................................................................................ 18

1.2.3.2. Sex at maturity ............................................................................................ 19

1.2.3.3. Mate selection, courtship and mating behaviour ....................................... 23

1.2.4. Growth, mortality and the history ratio .......................................................... 23

1.2.4.1. Growth ...................................................................................................... 24

1.2.4.2. Mortality .................................................................................................... 28

1.2.4.3. Beverton-Holt life history ratios ................................................................ 31

1.2.5. Diet ................................................................................................................. 34

1.2.5.1. Dietary composition .................................................................................... 34

1.2.5.2. Factors influencing dietary composition ...................................................... 35

1.3. Behaviour ........................................................................................................... 40

1.3.1. Mating behaviour .......................................................................................... 40

1.3.2. Breeding ........................................................................................................ 41

1.3.3. Submating and saprophagy ............................................................................ 48

1.3.3.1. Migration for reproduction ...................................................................... 49

1.4. Maturity ............................................................................................................. 42

1.4.1. Mating season ................................................................................................ 47

1.5. Influence of environmental conditions ............................................................. 49

1.5.1. Influence of water temperature and salinity ............................................... 49

1.5.2. Influence of environmental conditions on fisheries recruitment and production ............................................................... 50

2.5. Conclusion ......................................................................................................... 52

Section 2. Portunid fisheries and aquaculture-based enhancement ..................................... 55

2.1. Fisheries ........................................................................................................... 55

2.1.1. Overview of portunid fisheries ..................................................................... 56

2.1.2. Influence of fishing pressure on crab stocks ............................................... 57

2.1.3. Management strategies .................................................................................. 59

2.2. Aquaculture-based enhancement ..................................................................... 62

2.2.1. Rational for release programs ....................................................................... 62

2.2.2. Release programs for portunids ................................................................. 63

2.2.2.1. Puntunius brevicorne in Japan ................................................................. 64

2.2.2.2. Puntunius pagopus in Thailand .................................................................. 68

2.2.3. Sicyda spp. in the Philippines ...................................................................... 68

2.2.4. Sicyda panamericana in Japan .................................................................... 71

2.2.5. Callinectes sapidus in the Chesapeake Bay, USA ....................................... 71

2.2.6. Release programs for other bivalve species .............................................. 76

2.3. Conclusions ....................................................................................................... 81

2.3.1. Validation of release programs ................................................................... 81

2.3.2. Commemorative between release programs for brachyuran and lessons learned .............................................................. 82

Section 3. Aquaculture of portunids ............................................................................... 86

3.1. Overview of portunid aquaculture ................................................................... 86

3.1.1. Breeding collection and conditioning ......................................................... 88

3.1.2. Egg incubation and hatching ....................................................................... 91

3.1.3.ansen culture ................................................................................................. 93

3.1.4. Water quality ............................................................................................... 92

3.1.4.1. Food ......................................................................................................... 96

3.1.4.2. Hardness environment ............................................................................. 97

3.1.4.3. Consolidation ............................................................................................ 100

3.1.4.4. Nursery ................................................................................................... 101

3.1.4.5. Breeding ................................................................................................ 104

3.1.4.6. Conclusions ............................................................................................. 106

References .................................................................................................................. 108
Abstract

This review summarises (i) the biology and behaviour of portunid crabs, focusing on the commercially and recreationally important species within the genera *Callinectes*, *Portunus* and *Scylla*, (ii) identifies previously successful aquaculture/restocking efforts for portunids and (iii) detail any successful aquaculture methods/techniques for these species.

Portunids are highly fecund, fast growing, short-lived species, with high natural mortalities and whose populations are characterised by an abundance of immature individuals and fewer older, mature individuals. The dietary composition of these crabs, which are opportunistic, is influenced significantly by ontogeny, moult stage, habitat and season. Bivalves, gastropods, crustaceans and teleosts are the major prey categories consumed, with larger crabs consuming more mobile prey. Portunid crabs are more active during night than day, when many species bury. They have developed intricate mating and moulting behaviours that are influenced by water temperature and salinity. The females of many species undertake migrations associated with reproduction and the release of hatching eggs.

Portunid fisheries occur globally, with the greatest capture rates occurring in the Indo-West Pacific. Global catches of portunid crabs are still increasing despite the relative stability in the catch rates of world finfish fisheries. High fishing pressure on many established portunid fisheries, exacerbated by environmentally driven fluctuations in recruitment, has led to several localised depletions. The management of portunid fisheries varies greatly between and within countries, but all employ input (*i.e.* licences, spatial and temporal closures) and/or output controls (size, sex and catch limits). Aquaculture-based enhancement has been suggested as a possible means is increasing stocks in depleted fisheries.

A number of restocking and stock enhancement programs have been implemented around the world, including USA, Japan and South East Asia. These were all initiated in response to declines in stocks and, in each case, successful hatchery techniques were developed to enable small-scale production to occur. Releases were found to be most successful when the hatchery-reared individuals were released as crablets and not megalopae. Noting that far smaller numbers of individuals were produced due to cannibalism. Typically, release
programs for brachyuran crabs appear to have been successful, albeit too different extents. For the most part, the evaluations of the effectiveness of these releases have been carried out at the pilot scale with only the culture of *P. trituberculatus* scaled up (~27-35 million juveniles per year). Species with fast growth rates, limited home ranges and a large economic value are likely to be the most appropriate species to culture and release. Any future release program for a portunid is likely to require extensive research and development, particularly to scale up production, and thus the biggest gains in this field to-date have come from increased knowledge rather than increased stocks.

In terms of aquaculture, broodstock are typically collected from the wild using commercial fishers and to increase the success of the hatch, conditions in the culture environment should be similar to those in the waters the broodstock were collected from. If inseminated but not berried broodstock are collected, crabs require access to sandy substrate to spawn. Maintaining appropriate water quality is paramount and *P. pelagicus* larvae require relatively warm (25-30 °C) water at near-marine salinities (30-35 ppt) that is well oxygenated and of a slightly basic pH (8). The larvae require different feed throughout the transition from zoea to megalopa. Typically, zoea are fed a range of microalgae strains (which also enrich live feeds and provide a greenwater culture) and rotifers, with *Artemia* being provided once the larvae reach the later zoeal stages. At the crablet stage, diet in the hatchery comprises commercial shrimp/prawn feeds. Stocking density is important, with faster growth and greater survival occurring at lower densities. Cannibalism in portunids starts at the megalopa stages and lower stocking densities and the provision of greater substrate complexity reduce juvenile cannibalism. Portunid species have been shown to actively select more complex habitats, such as seagrass, macroalgae, pebbles and crushed shells over finer sand substrates and artificial habitats, such a nets, have also been successful in increasing survival.
Appendix 4. Portunid Crab Bibliography

Due to size restrictions, this document has been provided as a separate attachment.

Portunid Crab Bibliography

References listed in the Scopus database as of June 2017 that contain the words ‘portunid’, ‘portunidae’ and/or ‘portunus’

[Image of a crab]

© John Lewis / naturevisions.co.uk

Taken from http://www.arkive.org/pacific-blue-swimming-crab/portunus-pelagicus/image-GBS102.html
Appendix 5. Theodore Campbell Honours abstract

Dietary composition of the Blue Swimmer Crab, *Portunus armatus*, and life history characteristics of related species

Abstract

Coastal and estuarine systems worldwide suffer from a range of anthropogenic influences and high fishing pressure. Portunid crabs are abundant in such systems globally and the magnitude of degradation and variations in environmental conditions can influence the dynamics of the fisheries they support. This Thesis investigated two major components relating to portunid crabs: (i) a review and summary of the literature on portunid biology and behaviour and an assessment of how they vary among species and regions (Chapter 2); and (ii) a study of the dietary composition of Blue Swimmer Crabs *Portunus armatus* and how it varies among two estuaries and a coastal embayment and seasons in temperate southwestern Australia (Chapter 3). Portunids are highly fecund, fast growing, short-lived species, with high natural mortalities and are opportunistic predators. These characteristics vary among species, but also between different populations. The dynamics of portunid fisheries are therefore reliant not only on the biology of the fished species but also on the local environmental conditions, through their influence on portunid biology. These factors need to be taken into consideration by fishery managers. The diet of *P. armatus* is dominated by shelled molluscs, polychaetes and small crustaceans. Dietary composition varied significantly between the Peel-Harvey and Swan-Canning estuaries and three sites (habitats) within Cockburn and this variation was greater in magnitude than the seasonal variation. The diet of crabs in the Peel-Harvey Estuary was distinct from that of crabs in the Swan-Canning Estuary and Cockburn Sound because of greater consumptions of the bivalves *Arthritica semen* and *Spisula trigonella* and fragments of their shells. Differences in the dietary composition follow closely the known variation between the benthic macroinvertebrates assemblages, *i.e.* the prey availability, between systems and sites. Seasonal variation was greater in the estuaries than Cockburn Sound and is likely caused by greater seasonal changes in the prey availability driven by much greater seasonal fluctuations in salinity in estuaries than in nearby coastal marine waters. Qualitative assessment shows the diet of *P. armatus* in the Peel-Harvey has
changed since 1994/5 and reflects changes in the prey availability driven by anthropogenic modifications to the system. The results from this Thesis provide information on the role of *P. armatus* in the benthic food webs of these systems and is valuable for the continued Marine Stewardship Council certification of the *P. armatus* fishery in the Peel-Harvey Estuary and identifying potential functional groups for use in ecosystem models of these three systems.