Golden Fish: Evaluating and optimising the biological, social and economic returns of small-scale fisheries

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Acknowledgement of Country

We acknowledge the Traditional Custodians of Australia and their continuing connection to land and sea, waters, environment and community. We pay our respects to the Traditional Custodians of the lands we live and work on, their culture, and their Elders past and present.

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Abbreviations

CoM	City of Mandurah
CS	Consumer Surplus
DBCA	Department of Biodiversity, Conservation and Attractions
DPIRD	Department of Primary Industries and Regional Development
DWER	Department of Water and Environmental Regulation
EBFM	Ecosystem-based Fisheries Management
ERGNs	Exponential Random Graph Models
FRDC	Fisheries Research and Development Corporation
LEK	Local Ecological Knowledge
MLFA	Mandurah Licenced Fishermen's Association
MOFSC	Mandurah Offshore Fishing and Sailing Club
MSC	Marine Stewardship Council
MSL	Minimum Size Limit
NB	Negative Binomial Model
NGO	Non-Governmental Organization
PDC	Peel Development Commission
PHBSC	Peel-Harvey Blue Swimmer Crab Fishery
PHCC	Peel-Harvey Catchment Council
RFW	Recfishwest
SBS	Shifting Baseline Syndrome
SCS	Scientific Certification Systems
SES	Social-Ecological Systems
SNA	Social Network Analysis
SSF	Small-Scale Fisheries
SSPWA	Southern Seafood Producers of Western Australia
TCM	Travel Cost Method
TL	Total Length
TPB	Theory of Planned Behaviour
WAFIC	Western Australian Fishing Industry Council
WAM	Western Angler Magazine

Executive Summary

This project investigates recreational and commercial fisher motivations for using a fishery and the beliefs, attitudes and perceived benefits of aquaculture-based enhancement programs and other management options. It also determines the total economic value for recreational fishing for Blue Swimmer Crabs (*Portunus armatus*) and Black Bream (*Acanthopagrus butcheri*) in a range of estuaries in south-western Australia and investigates the benefits of release programs in contributing to the optimisation of biological, social and economic objectives for those fisheries. Finally, it provides training for the next generation of fisheries and social scientists and fishery economists and project members engaged in community engagement and education.

Work was focused on two iconic small-scale estuarine fisheries in south-western Australia, i.e. those for Blue Swimmer Crabs and Black Bream. A two-phase approach to elicit common recreational fisher beliefs using semi-structured interviews (phase 1) and then sample a broader pool of respondents using closed-question online surveys (phase 2). Analyses demonstrated that motivations for recreational fishing were markedly different for the two fisheries, even when operating in the same system. Aquaculture-based enhancement was universally supported by the recreational sector as a fishery management approach as they believed it would enhance stocks and catches, and, although it may cause negative impacts, they were considered unlikely. Commercial fishers were less supportive of this management intervention. Enhancement of stocks was estimated to increase the economic value of recreational fishing through increased visitation. Biological modelling highlights that stocking could provide substantial benefits to the biomass of the target stocks, particularly Black Bream, but the parameters of any future stocking the need to carefully considered to ensure maximum benefits and the mitigation of density-dependent effects on wild stocks. Advice on the numbers and size-at-release for Blue Swimmer Crabs in the Peel-Harvey and Black Bream in the Blackwood River Estuary are provided to optimise the biological, social and economic dimensions of these fisheries.

Background

Fish and crustacean stocks in estuaries are under pressure from a range of sources. Fisheries managers can use a suite of tools to maintain sustainability. Often these can be restrictive, e.g. decreasing effort or access, however, aquaculture based-enhancement can boost stocks without restricting fishers, although a combination of both approaches has been advocated by scientists. Work in other parts of the world shows that aquaculture-based enhancement is popular with recreational fishers, but the impacts of such programs are rarely investigated. Historically, emphasis has been placed on determining and utilising biological dimensions, e.g. abundance and stock structure, to manage stocks. However, there is growing recognition of the need to also understand the social and economic factors influencing fisher behaviour and management decision making. There is thus a need to consider the three dimensions – biological, social and economic – together in order to understand the role aquaculture-based enhancement could have in sustaining and enhancing fisheries.

Objectives

The objectives of the project were to:

1. Determine the motivations for using a fishery and the beliefs, attitudes and perceived benefits of release programs and other management options for the Blue Swimmer Crab and Black Bream fisheries.

2. Determine the total economic value of the recreational fishing of each selected fishery.

3. Investigate the benefits of release programs in contributing to the optimisation of biological, social and economic objectives for those fisheries.

4. Provide training for the next generation of fisheries and social scientists and fishery economists (Honours, PhD students and early career researchers) and community engagement and education.

Methodology

Objective 1: To obtain the views of recreational fishers two sequential data collection methods, (Phase 1) face-to-face semi-structured interviews and (Phase 2) an online questionnaire were completed. The semi-structured interviews consisted of a series of open-ended questions to gather qualitative data that informed a subsequent closed-question online survey, which generated quantitative data. Semi-structured interviews were also conducted of all commercial fishers operating in the estuaries of interest (i.e. this was a complete census of commercial fishers). Multiple sets of surveys were used for different components of this objective and answer response-curves and snowball sampling employed to determine when sufficient samples had been obtained.

Objective 2: Data on economic expenditure were obtained from an online questionnaire, that was pre-tested on recreational fishers at a range of estuaries throughout south-western Australia. The economic value of each species in each fishery was calculated using respondent's information on direct expenditure and the Travel Cost Method for opportunity costs for time they spend travelling and fishing and for estimating the consumer surplus (i.e. the difference between the maximum amount that a person is willing to pay for a good or service and the amount they actually pay).

Objective 3: Simulation models were constructed using published data and collaboration (Blue Swimmer Crabs) and using existing data from a previous stocking project for Black Bream (FRDC 2000/180), to estimate how changes in parameters would impact the biological success of any stocking program.

Objective 4: Supervision and mentoring were provided to one Honours and two PhD students and two early-career researchers. Members of the project team were encouraged to present their work at scientific and community events (e.g. Mandurah Crab Fest), catchment council presentations and fishing competitions. Further dissemination of results was achieved using websites, social media and face-to-face meetings with recreational and commercial fishers and peak-bodies.

Results

- Recreational Blue Swimmer Crab fishers were strongly food-motivated, with the overwhelming majority fishing for food and were primarily motivated to '*catch big crabs*' and '*catch enough crabs to eat*'. Thus, most consume all their catch.

- In contrast, Black Bream fishers fished for the sport/challenge, with the strongest motivation being to catch a large bream (trophy fishery). Food was a minor motivation and most fishers practiced catch and releasing fishing.

- Recreational fishers for both species felt their fisheries were poorly managed. Of the suggested management measures, those that were already employed such as minimum size limits and education programs, were the most acceptable together with stocking. The least preferred management options were those that restricted recreational fishing or introducing a maximum size limit for crabs.

- Recreational fishers believed stock enhancement could have strong positive outcomes for the abundances of their target species and increase their subsequent catches. While they also recognised that this management strategy could lead to some negative outcomes, such as increasing fishing pressure and environmental issues, they considered them unlikely to occur.

- Commercial crab fishers generally did not support stocking as it was not considered needed. However, some commercial bream fishers in the Blackwood River Estuary supported stocking because of the demonstrated very beneficial effects of stocking in 2002 (FRDC 2000/180).

- For the crab fishery, differences in the perceived changes in the average size of crabs and fishing effort, reported concerns and supported solutions were detected between recreational and commercial fishers. However, some common views were expressed including concerns over recreational fisher compliance and increased fishing and environmental pressures. While both sectors believed that reducing fishing and increasing compliance would benefit stocks, the mechanisms for achieving this differed between commercial and recreational fishers.

- A social network was constructed to investigate the flow of information between stakeholders in the Blue Swimmer Crab fishery in the Peel-Harvey Estuary. Several individuals were identified as key for sharing information and different modes of communication were used by different stakeholders. Communication modes differed between government departments and those used by recreational fishers.

- On a per fisher annual basis, incorporating direct expenditure on fishing-related items, the opportunity cost and consumer surplus recreational Blue Swimmer Crab fishing was estimated at \$334, \$189 and \$58 in the Swan-Canning, Peel-Harvey and Leschenault estuaries.

- Using identical methods, the economic value of recreational Black Bream fishing (per fisher annually) as estimated as \$3,200 in the Swan-Canning and \$205 in the Walpole-Nornalup. This reflects large differences in the number of trips respondents took to each system.

- The per fisher economic value of Black Bream was significantly larger than that for Blue Swimmer Crabs, due to the greater cost of fishing gear (including bait/lures) and opportunity costs resulting from longer travel and fishing times.

- The cost-effectiveness of stocking for Blue Swimmer Crabs in the Peel-Harvey is highly dependent on stocking density and the natural density of crabs in the estuary. For example, when numbers of the natural population the estuary are high, density-dependent effects are strong and stocking is likely to lead to a decrease in the biomass of the catch. Thus, no stocking is recommended at this time.

- In the absence of natural recruitment of Black Bream in the Blackwood, which is episodic, stocking would be required on a regular basis (every five years) to maintain catches. Size-at-release was not found to be influential on the biomass in the population, but the numbers of released fish was. Releases of 150,000 juveniles of 20 mm are recommended for future stocking events. This is the same number but 20 mm smaller than the Black Bream that were released in 2002 (FRDC 2000/180).

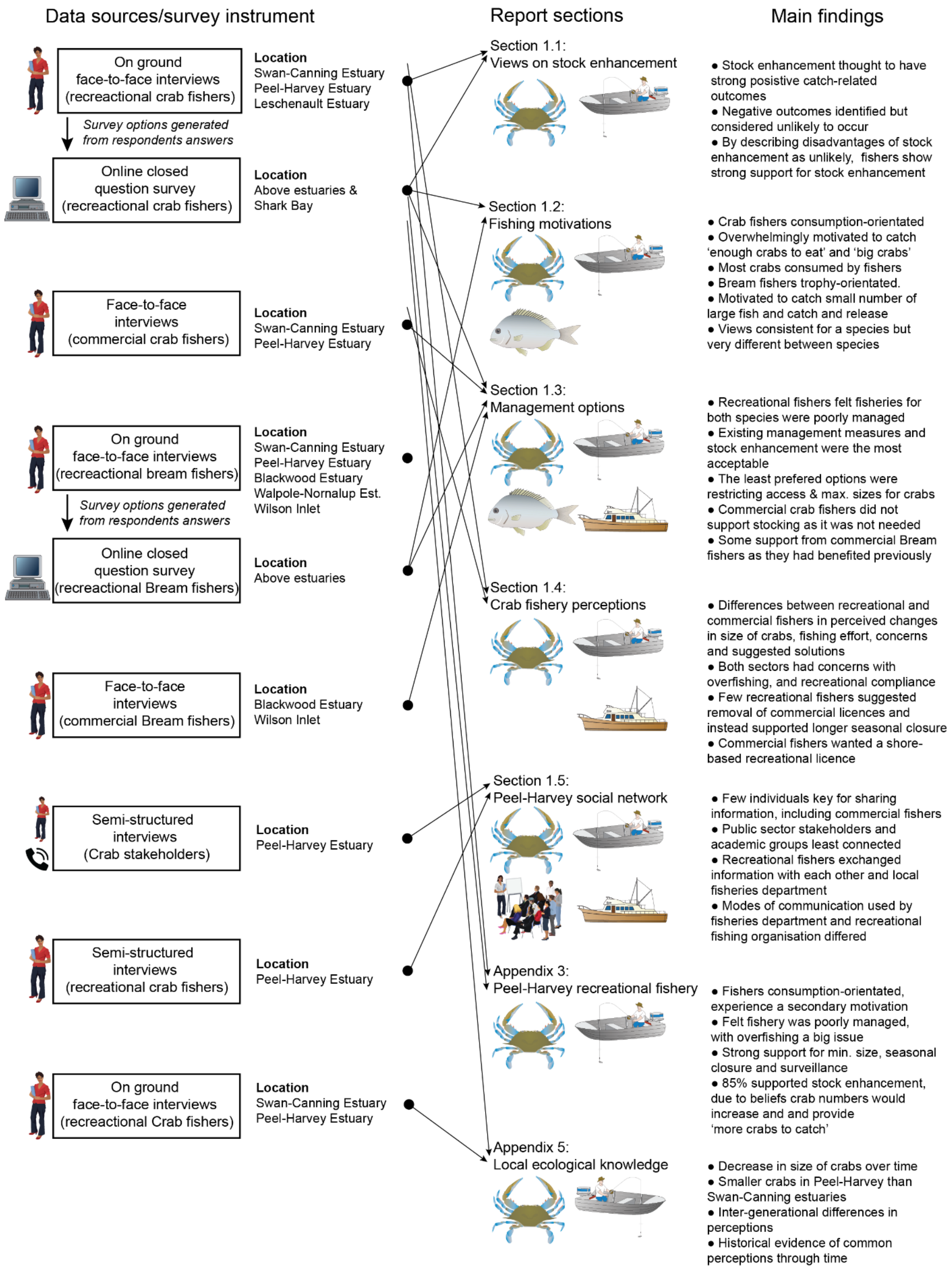
- In response to a hypothetical aquaculture-based enhancement project which resulted in recreational catches increased by 50%, fishers suggested that their frequency of fishing would increase. For both Blue Swimmer Crabs and Black Bream this would substantially increase their direct expenditure on fishing and the aggregate consumer surplus, although not infinitely due to scarcity constraints of fisher's income and time.

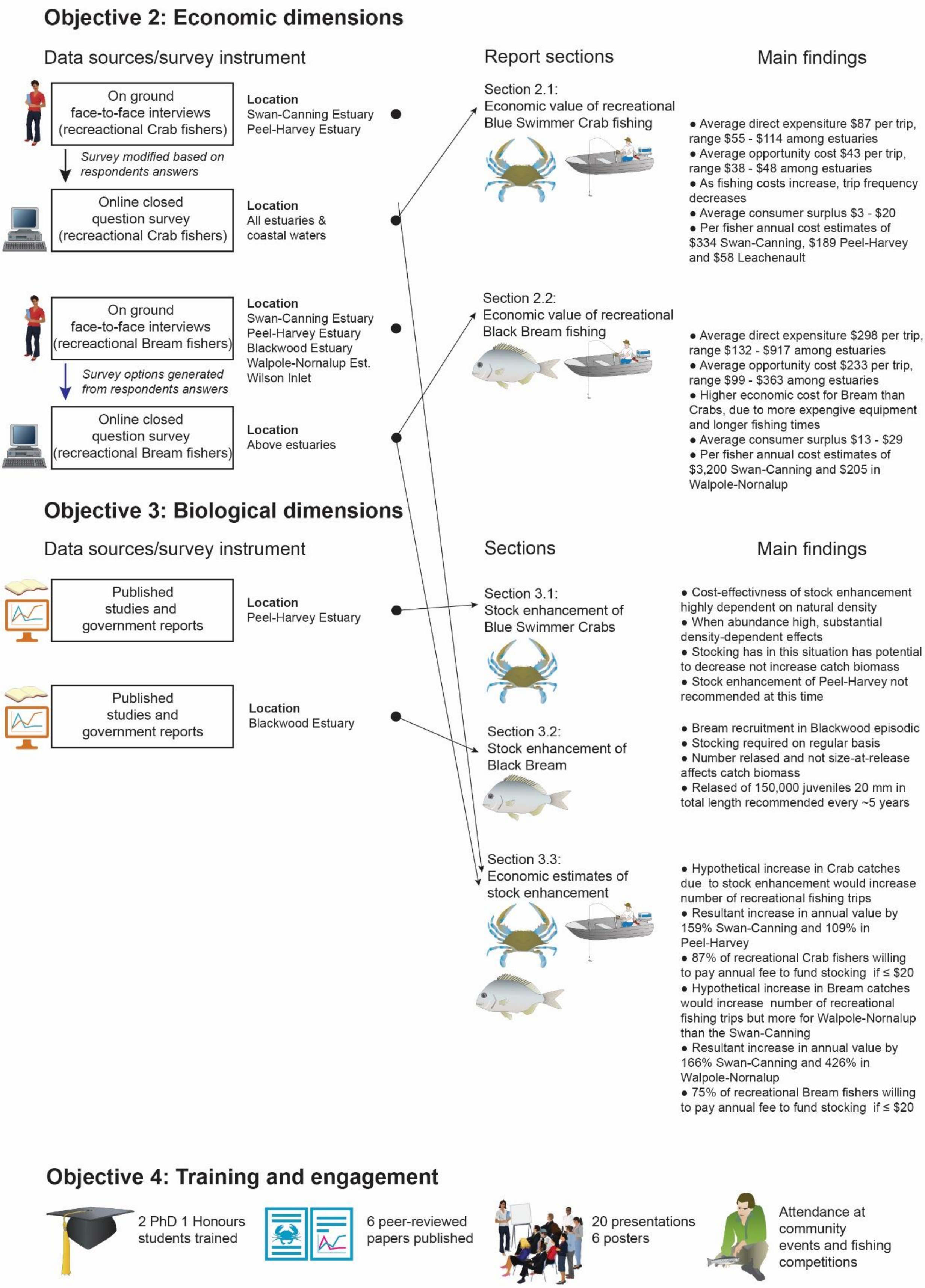
- Two-thirds of recreational Blue Swimmer Crab and half of Black Bream fishers would be willing to pay an annual license fee of to support aquaculture-based enhancement, with a maximum value of ≤ \$20.

- To-date, one Honours and one PhD student have graduated, with a second PhD student due to submit in mid-2022. Members of the project team produced 5 papers in international journals, 1 conference paper, 2 theses (1 PhD and 1 Honours) and 21 oral and 6 poster presentations at conferences. The project team also participated in community presentations and events such as the Mandurah Crab Fest, presentations held by Peel Bright Minds and the Peel-Harvey Catchment Council and fishing competitions.

Graphical summary

Objective 1: Social dimensions





Objective 2: Economic dimensions
Data sources/survey instrument
Report sections
Main findings
On ground face-to-face interviews (recreactional Crab fishers)
Location
Swan-Canning Estuary
Peel-Harvey Estuary
Survey modified based on respondents answers
Online closed question survey (recreactional Crab fishers)
Location
All estuaries & coastal waters
On ground face-to-face interviews (recreactional Bream fishers)
Location
Swan-Canning Estuary
Peel-Harvey Estuary
Blackwood Estuary
Walpole-Nornalup Est.
Wilson Inlet
Survey options generated from respondents answers
Online closed question survey (recreactional Bream fishers)
Location
Above estuaries
Section 2.1:
Economic value of recreational Blue Swimmer Crab fishing
● Average direct expensiture $87 per trip, range $55 - $114 among estuaries
● Average opportunity cost $43 per trip, range $38 - $48 among estuaries
● As fishing costs increase, trip frequency decreases
● Average consumer surplus $3 - $20
● Per fisher annual cost estimates of $334 Swan-Canning, $189 Peel-Harvey and $58 Leachenault
Section 2.2:
Economic value of recreational Black Bream fishing
● Average direct expensiture $298 per trip, range $132 - $917 among estuaries
● Average opportunity cost $233 per trip, range $99 - $363 among estuaries
● Higher economic cost for Bream than Crabs, due to more expengive equipment and longer fishing times
● Average consumer surplus $13 - $29
● Per fisher annual cost estimates of $3,200 Swan-Canning and $205 in Walpole-Nornalup
Objective 3: Biological dimensions
Data sources/survey instrument
Sections
Main findings
Published studies and government reports
Location
Peel-Harvey Estuary
Published studies and government reports
Location
Blackwood Estuary
Section 3.1:
Stock enhancement of Blue Swimmer Crabs
● Cost-effectivness of stock enhancement highly dependent on natural density
● When abundance high, substantial density-dependent effects
● Stocking has in this situation has potential to decrease not increase catch biomass
● Stock enhancement of Peel-Harvey not recommended at this time
Section 3.2:
Stock enhancement of Black Bream
● Bream recruitment in Blackwood episodic
● Stocking required on regular basis
● Number relased and not size-at-release affects catch biomass
● Relased of 150,000 juveniles 20 mm in total length recommended every ~5 years
Section 3.3:
Economic estimates of stock enhancement
● Hypothetical increase in Crab catches due to stock enhancement would increase number of recreational fishing trips
● Resultant increase in annual value by 159% Swan-Canning and 109% in Peel-Harvey
● 87% of recreational Crab fishers willing to pay annual fee to fund stocking if ≤ $20
● Hypothetical increase in Bream catches would increase number of recreational fishing trips but more for Walpole-Nornalup than the Swan-Canning
● Resultant increase in annual value by 166% Swan-Canning and 426% in Walpole-Nornalup
● 75% of recreational Bream fishers willing to pay annual fee to fund stocking if ≤ $20
Objective 4: Training and engagement
2 PhD 1 Honours students trained
6 peer-reviewed papers published
20 presentations
6 posters
Attendance at community events and fishing competitions

Implications and recommendations

- Recreational fishers elicited strong and consistent motivations for fishing and view on management. As non-compliance is an issue in some fisheries and that management of these fishers is reliant, in part, on encouraging voluntary compliance there is value in engaging with both recreational and commercial fishers in a co-management approach.
- Aquaculture-based enhancement is strongly supported by members of the recreational sector and is estimated to increase economic value of the fisheries providing it provides increased catches.
- Results from the simulation studies clearly show that careful consideration is needed about the parameters of any future stocking, particularly for crabs. To maximize biological, social and economic outcomes, good information is required on the density of wild-stock and impacts of the size and number at release. Under the scenarios tested, excess releases are cost inefficient and could decrease the overall biomass in the population through density-dependent effects.
- While stocks of Blue Swimmer Crabs in the Peel-Harvey and Swan-Canning estuaries are sustainable, the information derived in this project would be vital in informing any stocking in the nearby embayment of Cockburn Sound, where the stock has collapsed and has not recovered despite the continuous closure of the commercial fishery since 2011. Thus, stocking in Cockburn Sound is not likely to have any adverse density-dependent effects on the natural population. If stocking was implemented in Cockburn Sound, in addition to the biological surveys undertaken by the Department of Primary Industries and Regional Development, social and economic surveys of recreational fishers would be an invaluable component of evaluating how fishers respond to stocking, e.g. to determine whether the number of fishers increases and so does the per person expenditure and fishing frequency.
- Due to the cannibalistic nature of crabs, any large-scale stocking program with the capacity to release millions of crablets would require an investment in grow-out facilities not currently available. Inland saline aquaculture could provide a cost-effective option for producing aquaculture reared crablets, as a trial has demonstrated previously for Black Bream.
- Stocks of Black Bream in the Blackwood River Estuary could be supplemented using existing aquaculture capacity in Western Australia to provide the 150,000 juveniles needed to achieve this.

Keywords

Aquaculture-based enhancement; stock enhancement; human dimensions; Blue Swimmer Crab; *Portunus armatus*; Black Bream; *Acanthopagrus butcheri.*

Introduction

Background

This project investigates recreational and commercial fisher's motivations for using a fishery and the beliefs, attitudes and perceived benefits of release programs (e.g. stock enhancement) and other management options (Section 1). It also determines the total economic value of the recreational Blue Swimmer Crab and Black Bream fishing in a range of estuaries in south-western Australia (Section 2); investigates the benefits of release programs in contributing to the optimisation of biological, social and economic objectives for those fisheries (Section 3); and provides training for the next generation of fisheries and social scientists and fishery economists and community engagement and education (Section 4). The Introduction section provides background to the emergence of release programs as a potential management option and the status of the two small-scale fisheries in south-western Australia chosen for investigation, i.e. Blue Swimmer Crabs (*Portunus armatus*) and Black Bream (*Acanthopagrus butcheri*). It covers the historical trends in these fisheries, their management arrangements and the trial release programs that have been implemented.

Fishery management and aquaculture-based enhancement

To ensure that a fishery will remain sustainable, authorities need to manage a wide range of pressures (Elliott et al., 2022). In terms of controlling fishing effort, this can be achieved through an array of restrictions, which can occur as input controls; e.g. limited entry, gear restrictions, minimum and maximum size limits and time quota, output controls; e.g. total allowable catches, bag limits and prohibited species and access controls; e.g. closed areas, closed seasons and marine protected areas (McPhee, 2008). While such restrictions are targeted, either directly or indirectly, at controlling harvest level, fishing effort and by-catch (Hatcher et al., 2000), success is generally determined by compliance to the regulations (Gutiérrez, Hilborn and Defeo, 2011), which is perceived by their level of legitimacy (Britton, 2014) and the level of communication between members of the community (Hatcher et al., 2000). Therefore, management programs with restrictions can have strong consequences on the livelihood of fishers and people in many regions of the world have been adversely affected by fishing limitations, poor planning and a lack of consultation (Britton, 2014).

Aquaculture-based enhancement is an alternative (and at times complementary) approach that can be employed in fisheries management. Rather than limiting fishers to what or how much they are permitted to take, enhancement can allow fishing to continue by releasing individuals into the system to replace those removed by fishing activities (Taylor et al., 2017; Lorenzen et al., 2021). This generally involves the release of hatchery-reared (aquacultured) juveniles into a system and comprises (1) *stock enhancement*, i.e. releases to improve an already sustainable population, (2) *restocking*, i.e. releases to increase severely depleted stocks and (3) *sea ranching*, i.e. releases into a put, grow, and take system (Bell et al., 2008; Taylor et al., 2017). Sea ranching is now often conducted together with the use of artificial reefs (Greenwell et al., 2019; Wu et al., 2019; Ramm et al., 2021). While each of the three approaches can increase fishery yields, restocking differs in comparison as the primary aim is to restore a severely depleted spawning biomass to a point that can once again provide regular yields at a sustainable level (Lorenzen et al., 2013; Crisp et al., 2018). Effective restocking requires rigorous assessment, targeted research and clear objectives tailored for the species (Zohar et al., 2008; Lorenzen, Leber and Blankenship, 2010). Additionally, this needs to be coupled with an appropriate management system that integrates the release of the cultured juveniles with sufficient control of fishing effort and habitat creation, protection or restoration (Caddy and Defeo, 2003; Bell et al., 2006; 2008). This mixed management approach has proven effective in many fisheries, such as the Sea Cucumber *Holothuria scabra* fishery in New Caledonia, which incorporated no-take zones together with restocking (Purcell and Kirby, 2006).

Sustainable resource exploitation requires decisions and an understanding of what, where, when, and how to initiate management interventions. To successfully achieve this, there needs to be an understanding of the Triple Bottom Line (sensu Elkington, 1994). This is a business concept that posits companies should commit to measuring their social and environmental impact in addition to their financial performance, instead of solely focusing on generating profit, or the standard "bottom line. The Triple Bottom Line strives to achieve an outcome where conservation goals, economic return and equity in social outcomes are maximised, while the overall costs are simultaneously minimised and is increasing being applied to fisheries (Halpern et al., 2013; Anderson et al., 2015; Asche et al., 2018; Garlock et al., 2022). In a fisheries context, biological/environmental aspects could include the biology of the species, e.g. body size, growth rate, age at sexual maturity, fecundity, lifecycle, stock size and habitat requirements. Economic aspects include, total harvesting income, fishery-related employment, and whether the fishery is effectively generating market benefits and reaching maximum economic yield (Pascoe et al., 2014b). Finally, the social dimension requires investigation, e.g. whether and how the fishery is supporting people and how management will influence human outcomes.

Commercial and recreational fisheries in Western Australia

Despite having one of the largest fishing zones in the world at 8.94 million km^2 most Australian commercial fisheries are comprised of small family businesses, with, in 1993, 50% of fishing vessels being <6 m (Tull, 1993; McPhee, 2008). Thus, the majority of the commercial fisheries are not represented by large trawlers or purse seiners that operate in international waters. Currently, in Western Australia, commercial fishing contributes annually ~$AUD 400 million to the state's economy and employs about 10,000 people in fishing activities and associated industries, including the catch, process, export and sale of the fish products (Gaughan and Santoro, 2021). The commercial fishing industry is the third most important industry in the state of Western Australia, including the catch, process, export and sale of the fish products (DPIRD, 2019).

Recreational fishing, i.e. that which does not constitute the individual's primary means of meeting basic nutritional needs, and includes fish caught and not generally sold or otherwise traded on markets (FAO, 2012b), is an integral part of Australian culture. Across the industrialised world, an estimated 10.5% of the population fish recreationally (Arlinghaus, Tillner and Bork, 2015), however, as of 2003, this was 16.8% of the Australian population, i.e. ~3.4 million people (Henry and Lyle, 2003; Young, Foale and Bellwood, 2016). Moreover, participation in the state of Western Australia is greater than the national average at approximately 30% of the population. Although this percentage has declined slightly since the late 1990s (DPIRD, 2019), the state's recent rapidly increasing population, has resulted in the estimated number of recreational fishers more than doubling from 315,000 in 1989/90 to 711,000 25 years later (Ryan et al., 2015). Although studies on the economic value of recreational fisheries are rare (Rolfe and Prayaga, 2007; Prayaga, Rolfe and Stoeckl, 2010; Pascoe et al., 2014b), one such recent study estimated that the aggregate annual expenditure of recreational fishing in Western Australia was $1.8 billion, with $1.2 billion spent on fishing trips (excluding food) and $389 million and $160 million on boats and fishing gear, respectively (McLeod and Lindner, 2018a).

Blue Swimmer Crab

Biological characteristics

The Blue Swimmer Crab (*Portunus armatus;* Linnaeus 1758; A. Milne Edwards 1861) is a member of the family Portunidae and part of the *Portunus pelagicus* species complex that also contains *Portunus segnis* and *Portunus reticulatus* (Lai, P.K.L and Davie, 2010). Blue Swimmer Crabs occur in estuarine and inshore coastal environments (< 50 m deep) throughout the Indo-West Pacific. In Australia this species is present along the entire Western Australian coast, around the north of Australia to the south coast of New South Wales, and also in the warmer waters of the South Australian gulfs (Johnston et al., 2020a). Individuals, in the absence of fishing pressure, are expected to reach 2-3 years old and reach a maximum size of 220 mm carapace width (Marks et al., 2020). However, it is estimated most crabs on the lower-west coast of Australia will die through natural or fishing mortality before they reach ~18-20 months old (Potter, de Lestang and Melville Smith, 2001; de Lestang, Hall and Potter, 2003c). Regardless of their size male crabs are slightly heavier than females reaching maximum weights of ~600 and 570 g, respectively (Johnston and Yeoh, 2020). At the minimum legal size, the average female crab weighs 161.5 g compared to 183.1 g for a male.

Reproductive biology of Blue Swimmer Crabs is strongly influenced by water temperature and therefore causes significant variations in the timing of reproduction, size at maturity and fecundity (de Lestang, Hall and Potter, 2003b; Johnston and Yeoh, 2021; Nolan et al., 2022). In this region, spawning occurs in nearshore marine waters between September and January with the resultant eggs spending ~15 days in the plankton before hatching and undergoing four zoeal and one megalopal stage before metamorphosing into crablets after three to six weeks depending on water temperature (Meagher, 1971; Bryars, 1997). At approximately 10 months they reach a size of ~95 mm CW (late spring) and as growth continues over summer, they reach a legal size of ~130 mm CW by early autumn (~March at 15 months of age; de Lestang, Hall and Potter, 2003c). Most juvenile crabs migrate back to estuaries at the end of the austral spring and throughout summer (November to March), with adult males re-entering estuaries between November and January and adult females between January and March (Johnston et al., 2014; 2020a). Thus, Blue Swimmer Crabs are regarded as a marine estuarine-opportunist species (Potter et al., 2015a; 2015b).

Blue Swimmer Crabs are opportunistic predators and ingest large volumes of bivalves (both live organisms and dead shell), polychaetes, amphipods, small decapods, and smaller volumes of teleosts, echinoderms and plant material, i.e. seagrass, algae (Campbell et al., 2021). A comparison of their diets in 1995-97 and 2017 in the Peel-Harvey Estuary, suggested that crabs currently consume smaller volumes of high-calorie prey, i.e. polychaetes, small bivalves and teleosts, and instead ingest greater proportions of calcareous material than previously (de Lestang, Platell and Potter, 2000; Campbell et al., 2021). This marked shift in dietary composition parallels changes in the availability of benthic macroinvertebrate prey in the Peel-Harvey Estuary (Wildsmith et al., 2009; Tweedley et al., 2014b).

Commercial fishery

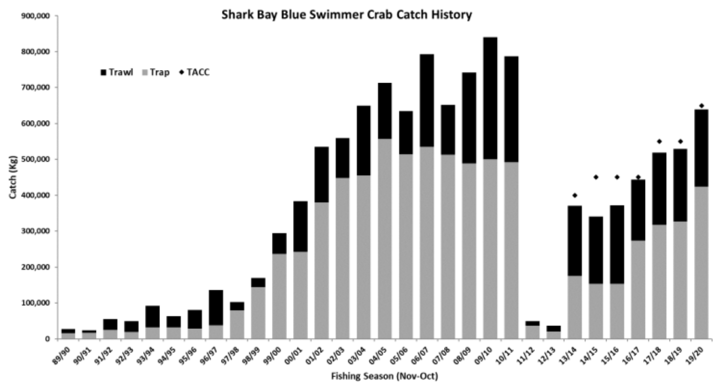
Blue Swimmer Crabs are caught in ten fisheries across four Australian states, i.e. Western Australia, South Australia, New South Wales and Queensland with stocks regarded as *sustainable* in all except Cockburn Sound, Western Australia (depleted; Johnston et al., 2022). Total commercial catches across Australia between 2010 and 2019 ranged from around 800 to 1,850 t, with the over 75% in most years obtained from fisheries in Shark Bay and North-eastern Australia. Commercial Blue Swimmer Crab fisheries have been valued at ~ AUD $8 million in South Australia (Beckmann, Noell and Hooper, 2020), and ~$4 million in both Queensland (BDO-EconSearch, 2020) and Western Australia (Gaughan and Santoro, 2021). Within Western Australia fishing occurs in all four bioregions; (i) North Coast (i.e. the Kimberley Crab Managed Fishery, Pilbara Crab Managed Fishery and Exmouth Gulf Developing Crab Fishery (Johnston et al., 2020b)), (ii) Gascoyne Coast, i.e. Shark Bay Managed Fishery (Harris et al., 2014)), (iii) West Coast, i.e. Cockburn Sound Crab Managed Fishery, Warnbro Sound Crab Managed Fishery, West Coast Estuarine Managed Fishery, which contains three areas (Swan-Canning Estuary Crab Fishery [Area 1], Peel-Harvey Crab Fishery [Area 2]; Mandurah to Bunbury Developing Crab Fishery [Area 1 Comet Bay and Area 2 - Mandurah-Bunbury] and Hardy Inlet [Area 3]) (Johnston, Harris and Yeoh, 2020; 2020a) and (iv) South Coast i.e. South Coast Estuarine Managed Fishery.

Blue Swimmer Crabs in Shark Bay are caught directly in a trap fishery and as by-catch in prawn trawl and scallop fisheries, with 639 t caught in 2019/20 (98% of the total allowable catch). This was the highest landed catch since the resumption of fishing in 2013 (Figure I1a), following an 18 month closure to allow stocks to recover following a marine heatwave (Chandrapavan, Caputi and Kangas, 2019). The trap sector's total catch was 424 t (65%), followed by 215 t from the prawn trawl sector (33%) with only 70 kg being obtained from scallop trawling (Newman et al., 2021). Catches of Blue Swimmer Crabs in the North Coast Bioregion totalled 22.1 t in 2019 and only 0.6 t in 2020, with the majority taken from the Pilbara (Newman et al., 2021). In the South Coast Bioregion catches of 7.3, 19 and 10.5 t were caught in 2018, 2019 and 2020, respectively, with most caught from traps in the marine embayment of Princess Royal Harbour and in the nearby estuary (Oyster Harbour) and as by-catch in gill nets in Wilson Inlet, respectively (Newman et al., 2021). As this species is at the poleward limit of its range, the high variability in catches along this region are thought to be due to the strength of the warm, southward flowing Leeuwin Current. This theory is supported by the fact that the two peaks in abundance of this species in the last 20 years coincided with 1999 and 2011-2013 marine heatwaves (Newman et al., 2021).

Both the commercial and recreational sectors of the Western Australia Peel Harvey Estuarine Fishery (which also includes the commercial catch of Sea Mullet, *Mugil cephalus*) obtained certification for sustainability by the Marine Stewardship Council in 2016 (Johnston et al., 2015; Morison et al., 2016). This was the first fishery in the world where both sectors were jointly accessed and certified. The key strengths of the fishery were that most of the gears used are selective and small scale, so any interactions with habitat and ecosystem are limited (Johnston et al., 2015). In the 2020/21 State of the Fishery Report for Western Australia, stocks of Blue Swimmer Crabs in the Pilbara, Shark Bay, Peel-Harvey and south coast were all classified as *sustainable-adequate*, but the stock in Cockburn Sound was *environmentally limited* (Newman et al., 2021).

The commercial Blue Swimmer Crab fishery in Cockburn Sound started in the late 1970s. Annual landings were ~ 30 – 50 tonnes for the first five years and peaked in the late 1990s at ~ 300 tonnes (de Lestang et al., 2010; Johnston et al., 2011). Catches began to decline in the early 2000s and, apart from a small increase from 2001/2 to 2002/3 and continued to drop until 2006 when the fishery was closed due to low stock abundance (Johnston et al., 2011). The collapse of this fishery is thought to largely be due to lower water temperatures prior to the breeding season, reducing the length of the breeding season, and the number of batches of eggs that females were able to produce and, as a consequence, greatly reducing the population fecundity (Johnston et al., 2011). The mean water temperature in August and September was between ~0.6 and ~ 1.8°C lower than average for four years (from 2002 to 2005), although within the range of normal fluctuations (de Lestang et al., 2010). The drop in reproductive potential and subsequent recruitment, due to the reduced number of batches each female was able to produce, combined with continued fishing pressure on mated pre-spawning females during winter over those four years, led the population to collapse and to the closure of the fishery in 2014 (de Lestang et al., 2010; Johnston et al., 2011). Stock enhancement was suggested by Johnston et al. (2011) as potential management measure to increase stocks if they did not fully recover following revised management measures.

(a)



(b)

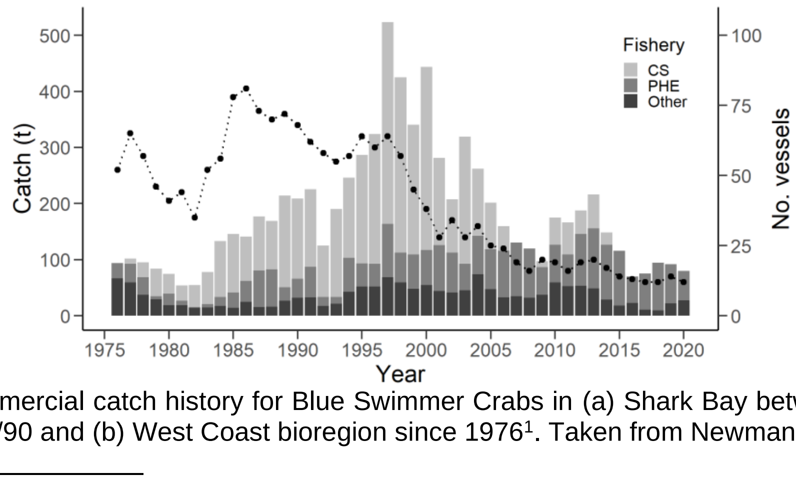


Figure I1. (a) Commercial catch history for Blue Swimmer Crabs in (a) Shark Bay between trap and trawl sectors since 1989/90 and (b) West Coast bioregion since 1976[1]. Taken from Newman et al. (2021).

[1] On (a) *The catch for 2012/13 was generated from the experimental commercial fishing trial. A TACC of 400 tonnes was set for 2013/14, 450 t between 2014/15 and 2016/17, 550 t for 2017/18 and 2018/19, and 650 t for 2019/20. On (b) the number of licensed fishing vessels retaining Blue Swimmer Crabs each year is also shown (●). CS — Cockburn Sound, PHE — Peel-Harvey Estuary. Other fisheries, i.e. Swan-Canning Estuary, Warnbro Sound, Mandurah to Bunbury (Area 1 and 2), Geographe Bay, Leschenault Estuary and Hardy Inlet. The Cockburn Sound Crab Managed fishery was closed from December 2006 – December 2009 and has been closed since April 2014.

Commercial fishing for Blue Swimmer Crabs in Western Australia is managed mainly by regulating the numbers of fishing vessels and traps, but size restrictions for retention (i.e. minimum size limit = 127 mm carapace width), fishing season and daily time limits also apply. A review of the Blue Swimmer Crab resources in south-western Australia was initiated in 2018 to improve the level of protection to the breeding stock, in particular mated pre-spawn females (DPIRD, 2018). For the commercial fishery from Perth to Minnimup Beach (~ 200 km south from Perth) this resulted in (i) an annual 3-month closure (1 September through 30 November) and (ii) a process to buy back commercial fishing licences in the Cockburn Sound, Warnbro Sound and Mandurah to Bunbury Crab Fisheries prior to their permanent closure (Newman et al., 2021). At the same time, the State Government funded a voluntary fisheries adjustment scheme to buy back some of the 11 existing commercial licences operating on the estuary. Four commercial licences were removed from the Peel-Harvey Estuary in 2020 (Newman et al., 2021). Given the small number of commercial fishers they feel marginalization by the numerically dominant recreational sector (Obregón et al., 2022b).

Commercial Blue Swimmer Crab catch in the West Coast Bioregion in 2020, most of which came from the Peel-Harvey, had an estimated gross value of production of approximately $0.65 million, a decrease on the $0.74 million reported in 2019 (Newman et al., 2021). This is mainly due to a reduction in catch from 91.9 t in 2019 to 80.8 t in 2020. The average price (kg^{-1}) of whole Blue Swimmer Crabs in 2019/20 as reported by land-based processers was $8.10 (Newman et al., 2021).

Recreational fishery

Blue Swimmer Crabs are an iconic species for Western Australia, with information on catches being reported in local newspapers for over 100 years (Obregón et al., 2022a) and the hosting of annual crab festival (https://www.crabfest.com.au/) on the banks of the Peel-Harvey Estuary. Crabs are mainly targeted in estuaries and coastal embayments from the Swan-Canning Estuary southwards to Geographe Bay, with the Peel-Harvey Estuary being the largest recreational fishery in the region (Johnston et al., 2020a). This species is among the most popular for recreational fishers in Australia with an annual harvest of 3.9 million individuals (Henry and Lyle, 2003). In Western Australia an estimated 900,000 crabs were caught by recreational boat fishers alone in 2013/14 and 670,000 in 2017/18, ranking 1st and 2nd in terms of number of catches among all species, respectively (Ryan et al., 2015; 2019). In 2017-18, total boat-based recreational catch was estimated to be 61.1 t, of which 54.1 t (88.5%) was taken from the West Coast Bioregion, with minor contributions of 5.36 t from the Gascoyne, 1.57 t from the North Coast and 0.078 t from the South Coast (Ryan et al., 2019). Note that, importantly, this does not include the recreational catch from shore-based fishers, which are significant in the shallow-waters of the Peel-Harvey, Swan-Canning and Leschenault estuaries (Malseed and Sumner, 2001a, b).

Recreational crab fishers may be boat-based or shore-based (wading through shallows, snorkelling/diving, deploying gear from jetties), and utilise a range of simple and cheap equipment, such as baited drop nets, scoop nets, wire hooks or simply their hands (DPIRD, 2022). Note that crab rakes, which are commonly used in places such as South Australia are not legal in Western Australia. Crabbing is permitted from various locations, such as boats (albeit with a recreational fishing from a boat licence; currently AU$40), jetties, private houses along the rivers and canals, among others (Johnston et al., 2015). Although current surveys to estimate recreational catch only use boat-based fishers (Ryan et al., 2015), historical surveys in the Swan-Canning and Peel-Harvey Estuary in 1998/99 provide an indication of the relative catches, albeit they were conducted during daylight hours (07:00 to 19:00) and some fishing activities are conducted outside of these, i.e. crepuscular and nocturnal fishing (Taylor et al., 2018). The total recreational catch in the Peel-Harvey was estimated at 289 t (range = 269-309) totalling 1,360,000 Blue Swimmer Crabs. Of these the boat-based catch comprised 832,000 crabs or 61% of the catch, with the remainder coming from the shore-based catch of 528,000 crabs (Malseed and Sumner, 2001a). Catches in the deeper Swan-Canning Estuary were far smaller at 7.3 t comprising 20,875 crabs, with the 97% (20,176) obtained from boat-based catches and only 699 caught from the shore (Malseed and Sumner, 2001b).

Recreational Blue Swimmer Crab catches are regulated via a minimum size limit of 127 carapace width (CW), which is substantially above the size at 50% maturity (~93 mm CW in the Peel-Harvey; Johnston and Yeoh, 2021), a daily personal bag (10 crabs), boat limit (up to 20 crabs depending on the number of licensed fishers), a ban on keeping berried females and a temporal closure over the peak spawning period (Johnston et al., 2020a). As part of the 2018 review on crab management a number of changes to the recreational fishing regulations were implemented. This were (i) an annual 3-month closure (1 September through 30 November) across all crab fisheries in south-western Australia (except for Geographe Bay; note this restriction previously only applied to the Peel-Harvey Estuary); (ii) a reduction in the bag limit from 10 to 5 crabs in the Swan-Canning Estuary to and (iii) a maximum of 5 female crabs (as part of the 10 crab bag limit) in Geographe Bay (Newman et al., 2021). Note that prior to 2007 the daily bag limit was 20 crabs per person (Johnston et al., 2020a). Compliance is monitored via both sea and land-based inspections, with the majority of checks being carried out on land at boat ramps. The Peel-Harvey Blue Swimmer Crab recreational fishery has the highest-recorded levels of non-compliance of any fishery for any species in Western Australia, particularly for retention of undersize crabs during night-time periods, with 20% of all reported enforcement issues along the Western Australian coast being from this estuary (Johnston et al., 2015; DPIRD, 2018).

Aquaculture-based enhancement

The aquaculture and release of several crab species including other portunids has been undertaken at various scales ranging from experiments to the commercial production (see review by Tweedley et al., 2017a). For example, Hatchery techniques for *Portunus trituberculatus* and *Portunus pelagicus* were developed in Japan in the 1960s and now annual releases of 27-35 million and 1-2 million juveniles, respectively, occur for these species (Hamasaki et al., 2011). Following the success of a restocking program for Western School Prawns (*Metapenaeus dalli*), which included the development of novel hatchery-techniques (Jenkins, Tweedley and Trayler, 2016; Tweedley et al., 2019b), and the re-closure of the Cockburn Sound Blue Swimmer Crab fishery and hypothesis that stock enhancement may relieve the recruitment bottleneck, an attempt to culture this species in Western Australia was undertaken (Jenkins, Michael and Tweedley, 2017). In this project, berried females were 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), 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 into the Peel-Harvey Estuary (Jenkins, Michael and Tweedley, 2017).

Following this success, a second project was initiated to determine whether the cost of larval rearing could be reduced by not using live microalgae as a food source (Jenkins et al., 2018). A new suite of hatchery methods was developed utilising an algal paste (Reed Shellfish diet) together with rotifers and *Artemia.* Survival of crabs remained relatively high (37%) right up until the last day of megalopae, thought to be a bacterial outbreak. This, however, did suggest that these more cost-effective hatchery methods could be used and that the major bottleneck was now cannibalism. Currently no further trails have been established in Western Australia, but some associated research has been undertaken in New South Wales (e.g. Junk et al., 2021).

Black Bream

Biological characteristics

The Black Bream, *Acanthopagrus butcheri,* (Munro 1949) is a member of the Sparidae endemic to southern Australia, where they reside in estuarine waters from the Shark Bay in Western Australia southwards through to Ulladulla in New South Wales and also occur in Tasmania and on Flinders and Kangaroo islands. Individual fish can reach 530 mm TL, weigh up to 3.45 kg and live for up to 31 years (Smallwood, Hesp and Beckley, 2013). Black Bream are opportunistic in their feeding, targeting abundant benthic invertebrates such as molluscs and polychaetes, although individuals will consume algae when their preferred prey are unavailable

(Sarre, Platell and Potter, 2000; Poh et al., 2018; Potter et al., 2022). Although Black Bream are relatively tolerant of a wide range of salinities including hypersaline conditions, they typically occur in the middle and upper reaches of estuaries where salinities are brackish (Hoeksema and Potter, 2006). Individuals are highly mobile, with a study in the Vasse-Wonnerup finding that fish moved on average 2.73 ± 0.06 km.day^{-1}, with a maximum of distance of 45 km within a 24 hour period (Beatty et al., 2018).

Despite having the ability to leave the estuary and, at times, being swept out during periods of particularly high freshwater discharge (Lenanton et al., 1999; Burridge and Versace, 2006) individuals typically remain in the estuary and spawn in the upper reaches during the spring and early summer (Sarre and Potter, 2000; Nicholson et al., 2008; Williams et al., 2012). This spatial pattern of distribution, together with analysis of their reproductive biology, indicates that individuals complete their life cycle within their natal estuary (Sarre and Potter, 1999, 2000). Thus, they belong to the solely estuarine guild (sensu Potter et al., 2015a; Whitfield et al., 2022). Such a conclusion is consistent with the fact that the genetic compositions of Black Bream across a range of estuaries in south-western Australia are significantly different (Chaplin et al., 1998). Furthermore, tagging studies in the Swan-Camming Estuary (Norriss et al., 2002), Gippsland Lakes and the Coorong found limited or no evidence of coastal migration or emigration between estuaries (Butcher and Ling, 1962; Hall, 1984; Norriss et al., 2002). Due to this affinity to their natal estuary, if a population becomes depleted, it cannot be naturally replenished from outside sources. This may be a major issue for some populations, particularly in stocks that have episodic recruitment or experience fish kills (Potter et al., 2015b; Cottingham et al., 2022). Fish kills containing large numbers of Black Bream (up to 1.3 million individuals) have been recorded in the Culham and Beaufort Inlets on the south coast of Western Australia caused by extreme hypersalinity (Hoeksema, Chuwen and Potter, 2006; Tweedley et al., 2019a; Krispyn et al., 2021) and also in the Vasse-Wonnerup on the lower-west coast of the state due, at least in part, to hypoxia (Tweedley et al., 2014a; Cottingham et al., 2022). In addition to the above lethal effects, environmental degradation and declining rainfall in the region (Hallett et al., 2018; Warwick, Tweedley and Potter, 2018), have resulted in increases in the extent of hypoxia in the deeper waters of some estuaries, forcing the bream to move towards the more oxygenated and shallow waters, thus causing a density-dependent effect on the growth (Cottingham et al., 2014; 2018b).

Commercial fishery

Black Bream are caught in nine fisheries across five Australian states, including Western Australia, South Australia, Victoria, New South Wales and Tasmania with each stock regarded as sustainable except in the Gippsland Lakes (depleting) and Coorong (depleted; Victorian Fisheries Authority et al., 2022). Total commercial catches across Australia between 2010 and 2019 ranged from around 115 to 180 t, with over 75% of the catch in most years obtained from the Gippsland Lakes and south coast of Western Australia. Within Western Australia Black Bream are targeted in the West Coast Estuarine Managed Fishery, which includes the Swan-Canning Estuary, Peel-Harvey Estuary, Vasse-Wonnerup Estuary, Toby Inlet and Blackwood River Estuary (also known as Hardy Inlet), and the South Coast Estuarine Managed Fishery, comprising 13 estuaries from Broke Inlet in the west through to Stoke Inlet ~500 km to the east (State of Western Australia, 2005). These two fisheries employ gillnets and haul nets to target a range of species including Black Bream, Cobbler (*Cnidoglanis macrocephalus*), Sea mullet (*Mugil cephalus*) and Australian Herring (*Arripis georgianus*). When using gill nets, fishers can set up to 6 nets constructed from mesh > 76 mm, with a combined length of no more than 1,500 m (State of Western Australia, 2005).

Catches of Black Bream along the west coast ranged from 0.36 t in 2012 to 3.52 t in 2017 (Victorian Fisheries Authority et al., 2022), with the majority caught in the Blackwood River Estuary with a minor contribution from the Vasse-Wonnerup (Cottingham et al., 2019). Between 31.59 and 75.31 t of Black Bream have been caught in the south coast fishery between 2010 and 2019 (Victorian Fisheries Authority et al., 2022), with a catch of 70 t obtained in 2020 (Newman et al., 2021). Catches within individual estuaries vary markedly among years, but in recent years ~60% of fish have been taken from Wilson Inlet and Beaufort Inlet (Figure I2). Catches from Beaufort inlet, had been relatively high over the last 20 years declined from 17 t in 2019 to zero in 2020 (Newman et al., 2021). Extreme hypersalinity caused by prolonged closure of the bar at the mouth of the estuary and limited riverine input led to a substantial fish kill of Black Bream in February and the subsequent absence of this species from the estuary during the rest of 2020 (Krispyn et al., 2021). Despite this and similar events in the past (Hoeksema, Chuwen and Potter, 2006) stock status is determined at the bioregion level and are currently assessed as *adequate* (Newman et al., 2021). This decision is made on the basis of a catch vs maximum sustainable yield analysis, which estimates the current biomass to be greater than 50% of the unfished biomass. The average price (kg^{-1}) of whole Black Bream in 2019/20 as reported by land-based processers was $5.45, which is greater than for other commonly-caught species, i.e. $2.54 for Sea Mullet, $2.96 for Australian Herring and $3.56 for Cobbler (Newman et al., 2021).

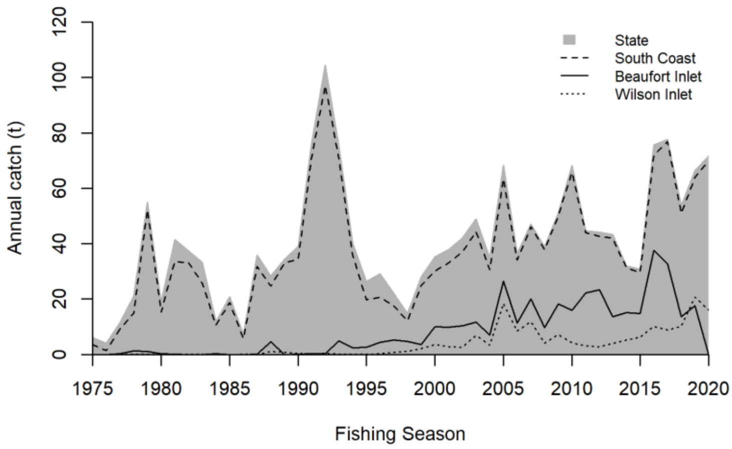


Figure I2. Annual commercial catches of Black Bream in the State, South Coast Bioregion, and two major estuaries, Wilson Inlet and Beaufort Inlet, 1975 to 2020. Taken from Newman et al. (2021).

Recreational fishery

Black Bream are among the most iconic fish present in estuaries across southern Australia. In Western Australia, these fish are caught by shore and boat-based rod and line fishers using bait and soft plastic lures in estuaries on both the west and south coasts of the state (Ryan et al., 2015). Creel surveys suggest that in some estuaries, such as the Swan-Canning and Walpole-Nornalup, Black Bream are the most targeted fish species. Moreover, in those systems that become disconnected from the ocean e.g. Stokes Inlet and Beaufort Inlet, Black Bream have been found to represent > 96% of all fish retained by recreational fishers (Smith, 2006; Smallwood, Hesp and Beckley, 2013). Fishing for Black Bream occurs throughout the year, but higher catches from boat-based fishers are recorded in summer (36%) and autumn (32%) compared to winter (18%) and spring (14%; Ryan et al., 2015). An estimated 62% of fish retained by recreational fishers are taken from estuaries on the south coast with the remaining 38% from systems on the lower-west coast (Ryan et al., 2015). The boat-based recreational harvest of Black Bream on the south coast of Western Australia in 2017/18 was estimated to be between 1.6 and 3 t (Newman et al., 2021). The current shore-based recreational catch is unknown but believed to comprise a significant share of the catch of this species. There are a range of competitions for Black Bream fishers including the WA Bream Classic organised by the WA Tournament Anglers. This tournament involves four rounds of both boat and kayak fishing, with the eight events occurring in five estuaries, i.e. Moore River, Oyster Harbour, Blackwood River Estuary, Peel-Harvey Estuary and the Swan-Canning Estuary.

In terms of regulations, a minimum size limit for Black Bream of 200 mm TL was first introduced in 1913, which was subsequently increased to 240 and eventually 250 mm in 1937 and 1975, respectively (Smallwood, Hesp and Beckley, 2013). The first bag limit (30 fish) was instigated in 1986, before being reduced to 20 in 1991. These were maintained statewide until 2000 when a lower bag limit (8 fish) for fishers in the Swan-Canning Estuary was established. The current bag limit of 6 fish was set in 2013 for all estuaries in the state. However, in the Swan-Canning Estuary only two of those fish can exceed 400 mm TL (DPIRD, 2022).

Aquaculture-based enhancement

Successful aquaculture techniques have been developed for Black Bream (Jenkins, 1995; Jenkins, Frankish and Partridge, 1999) and cultured individuals have been used to stock a range of natural and man-made waterbodies in Western Australia. The first stocking attempt involved inducing broodstock collected from the Swan-Canning Estuary to spawn. The results offspring were held in captivity for 14 months and 767 fish of ~150 mm TL and 60-100 g in body weight were T-bar tagged and released into the upper reaches of this estuary in March 1995 (Dibden et al., 2000). By October 1997 recreational fishers had recaptured 12.6% of the hatchery-reared fish. A larger release (30,000 individuals) of smaller-sized fish (< 70 mm TL) tagged using the fluorochrome dye, oxytetracycline was undertaken but the success of the stocking was not able to be determined due to the lack of an associated monitoring program (Dibden et al., 2000). The wide environmental tolerance of Black Bream made this species suitable for stocking in the salt-affected agricultural regions of inland southern Australia helping to reducing fishing pressure on depleted estuarine populations (Sarre et al., 1999). However, slow growth rates to about 150 mm TL and a lack of naturally-occurring food in these systems limited the economic viability of such ventures (Sarre et al., 2003; Doupé et al., 2005).

In the Blackwood River Estuary, concerns from the sole commercial fisher and declining catch rates of recreational fishers determined from creel surveys and a comparison of two fishery-independent surveys suggested that the abundance of Black Bream had declined (Jenkins et al., 2006; Prior and Beckley, 2007). To increase stocks, an aquaculture-based enhancement program (FRDC 2000/180) was subsequently developed. A total of 70,000 juveniles at 60 mm TL were released in 2002, with a further release of 150,000 smaller fish (40 mm TL) in 2003 (Jenkins et al., 2006). Prior to release, the otoliths of the cultured fish were stained with alizarin complexone, to distinguish them from the wild stock and thus enable the assessment of whether aquaculture-based enhancement was a viable tool to replenish a population of this species (Potter et al., 2008; Gardner et al., 2013). These marks have been retained in the otoliths for over 15 years (Cottingham et al., 2020). Subsequent monitoring demonstrated that the restocked fish made a high contribution to the fish caught by the commercial fisher, i.e. 32% in 2006, 62% in 2009 and 74% in 2010 and up to ~50 % to egg production in some years (Cottingham, Hall and Potter, 2015). Moreover, stocking had a limited effect on the genetic composition of the population of Black Bream in the estuary (Gardner et al., 2013).

Need

Fish and crustacean stocks are under pressure from a range of sources, such as a growing population, increased fishing pressure and anthropogenic changes. These pressures, and the small-scale nature of many fisheries in terms of their economic return, highlight the need to develop cost-effective tools for assessing and valuing these fisheries. Such tools should be able to estimate the social and economic contribution of commercial and recreational fisheries to communities (FRDC 2014/008). However, FRDC 2012/214 has highlighted that 'poor quality data' on the economic value of recreational and indigenous fishing limits the development of optimal policies for these fisheries. Advances in aquaculture provide 'new' options for managers and the ability to restore or enhance target populations by releasing cultured individuals. Increasing interest from recreational fishers in enhancing fishing experiences and the development of government policies for release programs in WA, NSW and Victoria, combined with the creation of Recreational Fishing Initiatives Funds (RFIF), have focussed attention on restocking/stock enhancement as a potential management option. To maximise the likelihood for success, tools are needed to evaluate the potential effectiveness of any release program in increasing target populations. Combining the results of release program bioeconomic models with social and economic data, such as the increased catch (revenue) generation for commercial fishers and the economic returns and social values of recreational fishing, provides managers with improved decision-making abilities based on an understanding of the social and economic implications of those decisions. The ability to assess the social values and economic contributions of fisheries to communities also provides much needed information, particularly on the catch, effort and motivations of recreational fishers, which are currently lacking in WA and can be used in the harvest strategy component of the Marine Stewardship Council certification process and to develop social and economic performance indicators for fisheries (FRDC 2014/008).

Objectives

The project had four objectives.

1. Determine the motivations for using a fishery and the beliefs, attitudes and perceived benefits of release programs and other management options (Section 1).

2. Determine the total economic value of the recreational fishing of each selected fishery (Section 2).

3. Investigate the benefits of release programs in contributing to the optimisation of biological, social and economic objectives for those fisheries (Section 3).

4. Provide training for the next generation of fisheries and social scientists and fishery economists (Honours, PhD students and early career researchers) and community engagement and education (Section 4).

While this project focused on two small-scale multisector fisheries, i.e. that of the portunid Blue Swimmer Crab (*Portunus armatus*) in the Peel-Harvey Estuary and sparid Black Bream (*Acanthopagrus butcheri*) in the Blackwood River Estuary, where possible data was collected and analysed for other aquatic environments in Western Australia where these species are targeted by fishers from either sector.

Section 1. Social dimensions

This section details research relating to Objective 1: Determine the motivations for using a fishery and the beliefs, attitudes and perceived benefits of release programs and other management options. Six components were undertaken.

1.1. Two-phase approach to elicit and measure beliefs on management strategies (PhD studies of Clara Obregón).

1.2. Heterogeneity among recreational fishers' motivations for utilising two estuarine fisheries.

1.3. Perceptions by recreational and commercial fishers on the status and management of crab fisheries in south-western Australia (PhD studies of Clara Obregón).

1.4. Selecting from the fisheries managers tool-box: recreational fisher views of stock enhancement and other management options

1.5. Information sharing and the management of the Peel-Harvey Estuary (PhD studies of Clara Obregón).

Appendix 3. Social dimensions of blue swimmer crab recreational fishing, stock enhancement and other management options in the Peel-Harvey Estuary (Honours studies of Sarah Beukes).

Clara was supervised by Dr Michael Hughes, Dr James Tweedley and Prof. Neil Loneragan at Murdoch University and Dr Ingrid van Putten at CSIRO and Sarah was supervised by Dr Michael Hughes and Dr James Tweedley.

1.1. Two-phase approach to elicit and measure beliefs on management strategies

Obregón, C., Hughes, M., Loneragan, N.R., Poulton, S.J. & Tweedley, J.R. (2020). A two-phase approach to elicit and measure beliefs on management strategies: fishers supportive and aware of trade-offs associated with stock enhancement. Ambio 49(2): 640-649. DOI: 10.1007/s13280-019-01212-y.

1.1.0. Summary

Understanding fisher beliefs and attitudes towards specific management strategies can help inform and improve fisheries management, and thus stock sustainability. Previous studies highlight a lack of fisher awareness regarding environmental issues influencing the systems they utilise and the negative impacts of specific strategies, such as stock enhancement. Our study used a two-phase approach to first elicit common recreational fisher beliefs regarding stock enhancement of an estuarine Blue Swimmer Crab (*Portunus armatus*) fishery in south-western Australia and then measure the strength of these beliefs and associated attitudes. The results demonstrate that recreational fishers believe stock enhancement could have strong positive outcomes, but also recognise that this management strategy could lead to some negative outcomes. This contrasts with previous research on marine fish stocking and demonstrates the value of the two-phase approach. Our study highlights the significance of integrating social sciences into fisheries research, and the need to better understand fishing community beliefs to ensure effective management of the fishery.

1.1.1. Introduction

Understanding and incorporating social dimensions into the management of fisheries is now considered vital, as it can help mitigate conflict and foster fisher and other stakeholder support for management regulations (Mikalsen and Jentoft, 2001; Fulton et al., 2011). Recreational fishing is a significant activity worldwide, in terms of both the numbers of fishers, their fishing effort and the size of their catch (Arlinghaus, 2006c; Cooke and Cowx, 2006; Taylor et al., 2017). Its widespread popularity, and often lack of restrictive regulations and periodic monitoring, results in significant impacts on fish stocks globally, causing changes in abundance, age and size structures (Arlinghaus et al., 2016; Hyder et al., 2018; Arlinghaus et al., 2019). Various management approaches may be used to mitigate or minimise the impacts of fishing on stocks, including aquaculture-based enhancement (*i.e.* stock enhancement, restocking and sea ranching). While such enhancements are generally supported by recreational fishers, they involve trade-offs among ecological, social and economic objectives that may not align with the beliefs, attitudes and associated expectations of recreational fishers (Garlock and Lorenzen, 2017). Understanding the beliefs and attitudes of resource users regarding particular management approaches can help inform and develop positive relationships between users and managers that contributes to more appropriate and accepted management approaches (McPhee, Leadbitter and A. Skilleter, 2002; Sténs et al., 2016). This paper presents research that elicited, then measured recreational fishers' common beliefs and attitudes regarding the potential stock enhancement of a popular estuarine recreational crab fishery. It provides the basis for developing a better understanding of how fishers view stock enhancement as a potential management intervention.

Traditional fisheries management commonly impose input (*e.g.* effort and permissible fishing methods), output (*e.g.* landings and size limits) and access (*e.g.* seasonal and area closures) controls on fisheries to mitigate pressures, such as growth in recreational fishing effort, that might lead to a decline in stocks (Brummett, Beveridge and Cowx, 2013; Lorenzen, 2014; Gallagher et al., 2017). However, these measures can cause hardship for fishers through, for example, reducing the days or areas available for fishing (Mascia, Claus and Naidoo, 2010). Stock enhancement is widely used in freshwater, estuarine and marine environments (Bell et al., 2008; Broadley, Tweedley and Loneragan, 2017; Taylor et al., 2017) and is seen as a means for sustaining both fishing effort and stocks in the face of increasing pressures. Thus, it is commonly used in fisheries and it is considered particularly popular among recreational fishers (Garlock and Lorenzen, 2017). Therefore, its use as a management intervention is projected to grow (Cooke and Cowx, 2006; von Lindern and Mosler, 2014).

Stock enhancement can involve trade-offs whereby negative impacts may counter catch-related benefits for recreational fishers (Camp et al., 2017). For example, negative outcomes of stock enhancement can include: i) biological differences between wild and hatchery-reared populations, which result in cultured individuals being less fit for the natural environments due to a difference in their genetic structure (Lorenzen, 2008; Lorenzen, Beveridge and Mangel, 2012); ii) reduction in the abundance of fish with wild characteristics due to stocked fish interacting with wild fish, through reproduction, predation or competition (Bell et al., 2008; Ingram, Hayes and Rourke, 2011; Camp et al., 2017); iii) increased numbers of smaller individuals and slower growth to maturity, due to density-dependent effects on growth (Satake and Araki, 2012; Anderson and Cason, 2015) and iv) increase in recreational or commercial fishing effort as a response to a boost of the stocks in the exploited system (Hilborn, 1998; Camp et al., 2017). These negative impacts represent a trade-off between maintaining recreational fishing effort and the ecological viability of the fishery (Poorten et al., 2011; von Lindern and Mosler, 2014). Several studies have found that, in general, recreational fishers have unrealistic beliefs about stock enhancement outcomes and are not aware of the potential disadvantages of stock enhancement (Poorten et al., 2011; Garlock and Lorenzen, 2017). This usually leads to the conclusion that recreational fishers require more education to ensure that their beliefs are aligned with those of fishery managers and the available scientific knowledge, and thus avoid conflict, loss of support and less compliance with management (Prior and Beckley, 2007; Arlinghaus et al., 2016). On the other hand, misconceptions from experts regarding fisher beliefs (*e.g.* lack of awareness on negative impacts) about the fishery may result in inappropriate management responses that may also create tensions between fishers and managers (Connelly and Knuth, 2002).

In Australia, the portunid Blue Swimmer Crab (*Portunus armatus*) holds great social and economic importance (e.g. Sumpton et al., 2003; Ryan et al., 2015). Recreational crab fishers may be boat-based or shore-based (jetties, snorkelling or wading), using a variety of simple, cheap equipment such as drop nets and scoop nets (Johnston et al., 2015). In Western Australia, the Blue Swimmer Crab is the most popular target species among recreational fishers (Sumner and Williamson, 1999; Malseed and Sumner, 2001a), with an estimated 900,000 crabs caught by recreational fishers using a boat over the 12 month period from May 2013 to April 2014 (Ryan et al., 2015). Crabbing effort in the Peel-Harvey Estuary alone was estimated to be around 3,200 fisher days in winter, compared to over 80,900 fisher days in summer (Malseed and Sumner, 2001a). This recreational fishery is considered a food-motivated fishery, with the main motivations of recreational crab fishers being to "Catch crabs to eat" (Poulton, 2019). The increased popularity of crab fishing and the growing population of Western Australia, coupled with the closure of a nearby marine embayment (Cockburn Sound) to crab fishing, has resulted in Blue Swimmer Crab stocks in south-western Australian estuaries being subjected to increasing pressures, such as environmental degradation due to urbanisation and fishing pressure (Johnson et al., 2011; Tweedley, Warwick and Potter, 2016).

In light of the pressures on estuarine stocks, Johnston et al. (2011) suggested that restocking should be considered as a way of increasing the stocks of Blue Swimmer Crabs. A small-scale trial was conducted in the austral summer of 2016/17 (December to February) resulting in the release of 3,700 juvenile crabs into the Peel-Harvey Estuary in south-western Australia (Jenkins et al., 2018). While the biological and ecological aspects of *Portunus* spp. aquaculture and restocking are relatively well studied (e.g. Marshall et al., 2005; Paterson et al., 2007), the social dimensions, including fisher beliefs and attitudes, are not well understood beyond a general acknowledgement that crabbing is popular, and that declines in stocks and catch would generate public concern. Thus, the recreational fishery for Blue Swimmer Crabs presented an ideal opportunity for eliciting and measuring the beliefs and attitudes of recreational fishers regarding restocking and its advantages and disadvantages as a management approach.

Our study applied a two-phase approach to first elicit and then measure the beliefs and associated attitudes of recreational crab fishers towards the management of the Blue Swimmer Crab fishery in three estuaries in southern Western Australia (i.e. Swan-Canning, Peel-Harvey and Leschenault; Figure 1.1.1). Our study draws on belief elicitation and measurement techniques associated with the application of the theory of planned behaviour (TPB; Ajzen, 1991). The TPB describes the relationship between human beliefs, attitudes and behaviour within a structured framework. According to the TPB, three categories of belief underpin attitudes and behaviour: behavioural beliefs about the positive or negative outcomes of a behaviour and the evaluations of those outcomes; normative beliefs about personally influential people who may approve or disapprove of a behaviour; and control beliefs about factors that may help or hinder attempts to perform a behaviour (Hughes, Weiler and Curtis, 2012). The aims of the study are:

1. To provide insights into recreational fisher beliefs about the likely outcomes of stock enhancement as a management approach.

2. To relate these beliefs to whether they support stock enhancement as a management intervention.

1.1.2. Methods

Data collection was carried out in two phases: Phase 1 focused on belief elicitation and Phase 2 on belief measurement, adapting techniques used in previous TPB based belief elicitation and measurement research (Hughes, Ham and Brown, 2009; Brown, Ham and Hughes, 2010; Hughes, Weiler and Curtis, 2012). The first phase identified recreational fisher beliefs about the likely outcomes of stock enhancement of Blue Swimmer Crab (Phase 1), with these responses then used to develop the belief measurement survey (Phase 2).

Phase 1: Belief elicitation

This phase followed the belief elicitation procedures applied by Hughes et al. (2009; 2012). Face-to-face interviews were carried out at a range of locations on three estuaries used by recreational crab fishers in south-western Australia. These were i) the Peel-Harvey Estuary, due to the present and historical importance of crab fishing in this system (Mandurah; population ~ 80,813), ii) the Swan-Canning Estuary, being the main urban and most highly populated system in the region (Greater Perth; population ~ 2,039,193) and iii) the Leschenault Estuary, a more rural system (Bunbury; population ~ 32,244), all of which are located within ~180 km of Perth (Figure 1.1.1). A total of 18 sites (*i.e.* jetties, boat ramps and shore line areas frequented by crab fishers) were sampled, providing a representative cross section of Blue Swimmer Crab recreational fishing across south-western Australia. Note that sampling was not conducted south of the Leschenault Estuary, as this species is less abundant in these waters (DPIRD, 2018), which may influence the accuracy of fishers' beliefs.

The survey involved face-to-face interviews, using a structured, open-question format carried out by experienced researchers. The survey was designed to gather, in the fishers' own words, the beliefs associated with stock enhancement of the Blue Swimmer Crab fishery. Belief elicitation questions were paired and focussed on the positive or negative outcomes a fisher might expect from stock enhancement of crabs, and his or her evaluations of those outcomes, drawing on the behavioural belief component of the TPB procedure (Hughes, Weiler and Curtis, 2012). Consenting crab recreational fishers were asked a series of open-ended questions (see Table 1.1.1). The interview was pretested with a small sample of recreational crab fishers, to ensure each question was appropriately worded and clearly understood.

The Phase 1 survey was conducted during times when people were most likely to be crab fishing (*i.e.* morning and afternoon shifts) on weekends and weekdays during the peak of the Blue Swimmer Crab fishing season (austral summer, i.e. November 2017 to March 2018; Malseed and Sumner, 2001a). All recreational crab fishers at each sample site were approached with a request to participate in the interview. The responses were written down by the interviewers using the respondents' own words. A theoretical saturation approach was adopted for belief elicitation. Accordingly, interviews with recreational crab fishers continued over successive weeks across the three estuaries until no new response types were recorded in the sample from each estuary (Hughes, Ham and Brown, 2009; Hughes, Weiler and Curtis, 2012). Theoretical saturation was mathematically confirmed by adapting species accumulation techniques (Ugland, Gray and Ellingsen, 2003), to develop response accumulation curves (Vanwindekens, Stilmant and Baret, 2013). Additional interviews were conducted once saturation was achieved to ensure that no salient beliefs were overlooked.

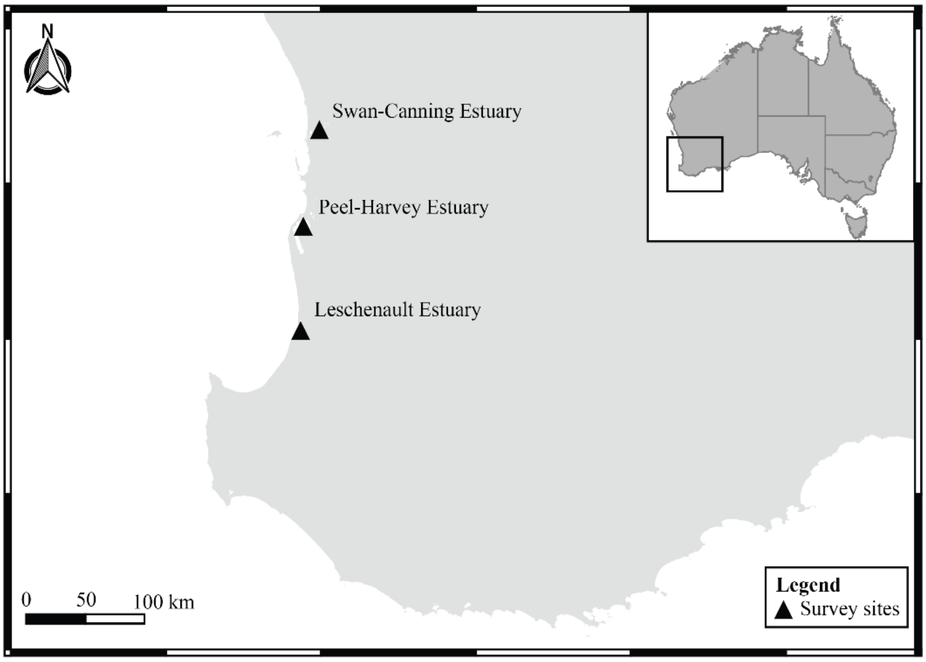


Figure 1.1.1. Location of the three estuaries in south-western Australia where interviews with recreational fishers were conducted.

Responses were transcribed to a spreadsheet and reviewed to develop categories of response representing salient beliefs. Three researchers independently conducted content analysis to group responses by similar meaning and then identify salient beliefs based on their frequency of occurrence. The salient beliefs identified in Phase 1 were then incorporated into Phase 2.

Table 1.1.1. Questions asked to recreational fishers' about their awareness, beliefs and attitude to stock enhancement in the belief elicitation survey.

Stock enhancement awareness
1. Do you know what stock enhancement is? [explain]
2. Are you aware of any past fishery stock enhancement events?
Stock enhancement beliefs
3. What do you think are the advantages or good things that could occur if stock enhancement is used to manage the crab fishery in this estuary?
4. What do you think are the disadvantages or bad things that could occur if stock enhancement is used to manage the crab fishery in this estuary?
Demographics
Age, gender, place of residence

Phase 2: belief measurement

The second phase involved an online, fixed-item questionnaire distributed to the Western Australian crab recreational fishing community. The survey included a range of questions about Blue Swimmer Crab fishing and management. This study specifically focuses on the stock enhancement belief strength (i.e. likely-unlikely) and evaluation (i.e. good-bad) measurement components of the online survey for respondents who self-identified as recreational Blue Swimmer Crab fishers in Western Australia.

Following belief measurement procedures (Ajzen 1991), two questions were asked for each of the salient beliefs, one rating how likely or unlikely the outcome was (strength) and one rating how good or bad the outcome was (evaluation). The dual measures were multiplied together to form a cross-product that represented the belief-based attitude. Based on the coding scheme recommended by (Ham et al., 2008), belief strength was measured on a 7-point scale from 0 ('very unlikely') to +6 ('very likely'). The accompanying belief evaluation was measured on a scale from -3 ('very bad') to +3 ('very good'). The range for resulting cross-products for each belief (*i.e.* the belief-based attitude score) was -18 (very likely/very bad) to +18 (very likely/very good). A separate overall attitude question asked respondents to rate whether stock enhancement was a very bad or a very good thing to do on a 7-point bipolar scale (i.e. -3 to +3). The online survey also included a range of questions focused on when, how often, where and how fishers caught Blue Swimmer Crab, what they do with their catch, evaluations of a range of current and potential crab fishery management approaches and basic demographics of the respondent.

The questionnaire was developed and distributed using the online survey tool Surveygizmo. The online questionnaire was pretested with a small sample of fishers (n=5) before being released to the public on 21 December 2017 and was closed seven months later, on 21 July 2018. Participation in the survey was promoted via a press-release circulated by local print and broadcast media and flyers were posted at sample sites and convenience stores, bait/tackle stores and cafes located close to the estuaries. The survey was promoted through posts on social media, targeting recreational crab fishers and via dedicated fishing forums. All responses to the online survey were analysed using R Studio (Version 3.3.1) and SPSS (Version 24). The non-parametric Kruskal-Wallis and Wilcoxon tests were used to compare the belief and attitude rating scores, as well as comparisons of belief and attitude ratings among groups of respondents (unsupportive, neutral and supportive of stock enhancement).

1.1.3. Results

The respondents of the phase 1 face-to-face interview were mostly male (86.7%) and residents of Western Australia (98.9%). These respondents ranged from 18 years old to > 65, with a modal age group of 35 to 44 years (24.5%). Similarly, phase 2 online survey respondents were predominantly males (83.9%) that resided in Western Australia (99.4%), spread uniformly across the ages from 18 to > 65 years old, with the highest proportion of respondents in the 35-44 years old category (27.1 %). These results show that the face-to-face survey provides a similar representation of recreational crab fishers to that of the online survey.

1.1.3.1. Phase 1: Belief elicitation

Across the three estuaries, researchers approached 109 recreational fishers, of whom 94 agreed to participate in an interview. This response rate (86.2%) was higher than the mean response rates reported by previous interview type studies (e.g. Anseel et al., 2010). Theoretical saturation of responses was achieved for each estuary prior to 25 interviews being conducted, with corresponding response-accumulation curves all reaching an asymptote (Figure 1.1.2).

Salient beliefs associated with positive outcomes of stock enhancement crabs were more frequently stated (91.5% of respondents) than those associated with negative outcomes (39.3%, Table 1.1.2). The two most frequently stated beliefs were that stock enhancement i) would increase the number of crabs in the estuary and ii) would result in more crabs to catch, that is, more crabs of minimum legal catch size. Interestingly, while many respondents indicated there were no disadvantages associated with stock enhancement, almost 40% of respondents reported that stock enhancement Blue Swimmer Crab could result in negative outcomes such as i) environmental impacts on the estuary, other species and the crabs as well as ii) increased fishing pressure. Thus, the elicitation phase (Phase 1) demonstrated that two out of five recreational crab fishers were aware of the potential negative outcomes of stock enhancement. The most frequent beliefs associated with potential positive and negative outcomes of stock enhancement were incorporated into the online survey to measure the belief strength and evaluation.

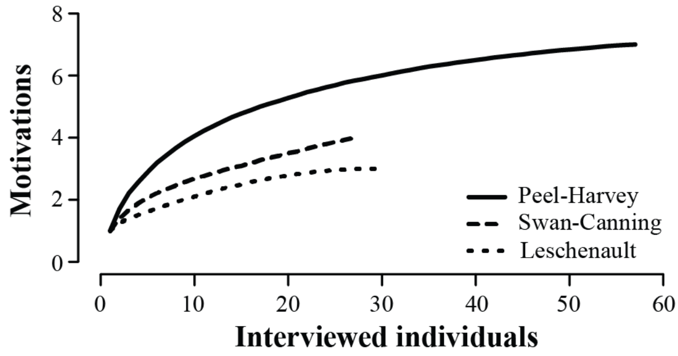


Figure 1.1.2. Response-accumulation curve showing that data saturation was reached during Phase 1 of the surveys with recreational Blue Swimmer Crab fishers in three estuaries in south-western Australia.

Table 1.1.2. Salient (i.e. positive and negative) beliefs recreational fishers associated with the stock enhancement Blue Swimmer Crab in the estuary where they fished, (n = 94).

Questions and answers	Frequency (n)	Percentage of respondents (%)
Q. What are the advantages or good things that could occur if stock enhancement is used to manage the crab fishery in this estuary?		
Increase the number of crabs	41	43.6
More crabs to catch	32	34.0
I don't know/Unclear	13	13.8
None	12	12.8
Good for environment and other species	8	8.5
Good for tourism/economy	5	5.3
More oversized crabs	4	4.3
N/A	1	1.1
Total respondents	**117**	**124.5**
Q. What are the disadvantages or bad things that could occur if stock enhancement is used to manage the crab fishery in this estuary?		
None	47	50.0
Impact on environment and other species	13	13.8
Increase the fishing pressure on the crabs	9	9.6
Unnecessary - there are already heaps of crabs	6	6.4
Cost	5	5.3
I don't know/Unclear	5	5.3
N/A	4	4.3
Affect crabs' genetics and produce diseases	2	2.1
Crabs could leave the estuary	2	2.1
Total respondents	**94**	**100.0**

1.1.3.2. Phase 2 Belief measurement

A total of 575 crab fishers participated in the online survey, with 357 responding to all questions (62% completion rate). The beliefs associated with the advantages of crab stock enhancement (*i.e.* "Increase number of crabs", and "More crabs to catch") were considered to be both likely and good outcomes, resulting in a high belief-based attitude score (Table 1.1.3). The beliefs associated with disadvantages of stock enhancement, *i.e.* (a) "Increase the fishing pressure" and (b) "Impact on environment and other species", were rated significantly less likely than the advantages (Wilcoxon test, W(a)=57464; W(b)=58406, $p < 0.001$), and rated as a bad outcome (*i.e.* bipolar scale of -3 to +3). The belief-based attitude scores associated with the disadvantages of stock enhancement were therefore low and negative. The mean overall attitude rating for crab stock enhancement was +1.75 (scale from -3 to +3; n=308; Figure 1.1.3) indicating general support for the management practice. This was also reflected in the frequencies of response, where 86.4% of responses were positive (supportive), 4% were neutral and 9.4% were negative (not supportive) toward crab stock enhancement (Figure 1.1.3).

Table 1.1.3. Summary of mean belief strength; valuation ratings and cross products associated with stock enhancement of Blue Swimmer Crabs.

Beliefs	Strength 0-6 (unlikely – likely)		Evaluation -3 - +3 (bad – good)		Cross-product -18 - +18 (belief based attitude)	
	N	Mean	N	Mean	N	Mean
Increase number of crabs	337	4.78	351	2.14	319	11.5
More crabs to catch	331	4.82	352	2.17	317	11.54
Increase the fishing pressure on crabs	283	3.05	318	-1.5	265	-4.09
Impact on the environment and other species	284	2.87	278	-1.3	237	-2.47

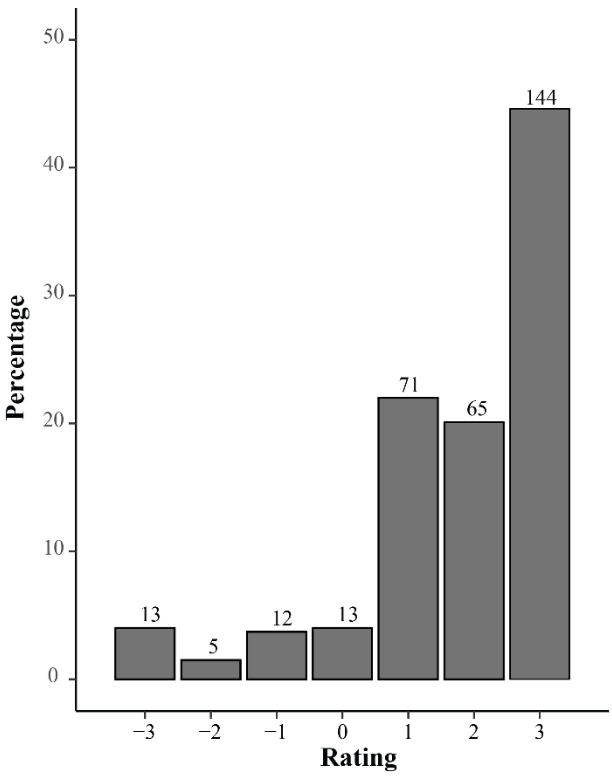


Figure 1.1.3. Responses to question "*Overall, I think using stock enhancement as a management option for Blue Swimmer Crabs in the Estuary where I fish most is:*" indicating the overall attitude of fishers towards stock enhancement as a management approach for the Blue Swimmer Crab fishery.[2]

The mean belief strength and evaluation ratings towards crab stock enhancement differed significantly among the three overall attitude respondent groups (*i.e.* supportive, neutral, not supportive; Kruskal-Wallis $\chi^2_2 = 86.177$, $p < 0.001$; Table 1.1.4). While each group indicated a positive belief-based attitude towards the advantages of stock enhancement neutral and unsupportive fishers rated these outcomes as significantly less likely and less good compared to supportive fishers (Table 1.1.4). In terms of the disadvantages of stock enhancement, all three groups rated these outcomes as equally bad, however, the unsupportive and neutral

[2] The number of respondents who chose each rating is provided above each bar; n = 323.

groups rated them as being significantly more likely than the supportive group. Overall, recreational fishers supporting stock enhancement believe that the disadvantages of using this management approach are less likely to occur, while the advantages are more likely and good, compared to the response of fishers who are unsupportive or neutral about this management approach.

Table 1.1.4. Mean values from the online survey responses regarding the mean belief strength, evaluation ratings and cross products associated with stock enhancement of Blue Swimmer Crabs, for the three fishing groups studied.[3]

Beliefs	Strength 0 - 6				Evaluation -3 - +3 (*bad – good*)				Cross-product -18 - +18 (*belief based attitude*)			
	S	N	US	*n*	S	N	US	*n*	S	N	US	*n*
Increase number of crabs	5.13	3.92	2.57	*295*	2.38	1.50	-0.04	*352*	12.62	6.60	2.04	*287*
More crabs to catch	5.14	4.36	2.25	*331*	2.35	1.42	0.72	*353*	12.63	5.70	2.95	*281*
Increase the fishing pressure on crabs	2.88	4.08	4.15	*283*	-1.44	-1.23	-2.13	*319*	-3.26	-5.00	-9.52	*235*
Impact on the environment and other species	2.87	3.25	4.03	*284*	-1.12	-1.75	-2.28	*278*	-1.21	-5.91	-9.31	*218*

1.1.4. Discussion

By implementing an open-ended interview (Phase 1) followed by an online survey (Phase 2), this paper aimed to provide insight on the beliefs and attitudes of recreational crab fishers towards using stock enhancement as a management approach. It provides information on the social dimensions of a significant recreational fishing activity in south-western Australia, including fishers' perceptions regarding management approaches (Hunt, Sutton and Arlinghaus, 2013). Understanding fisher perceptions can provide insights into how to build support and mitigate conflict associated with fisheries management (Mikalsen and Jentoft, 2001; Fulton et al., 2011). In this regard, Ham et al. (2008) and Hughes, Ham and Brown (2009) noted that expert assumptions about public perceptions of management might not reflect the full range of perceptions that exists within a target group. Published research on fisher perceptions is based mainly on asking fishers to rate predetermined categories provided by expert researchers (Anderson, Ditton and Hunt, 2007; Poorten et al., 2011; Garlock and Lorenzen, 2017). The findings indicate that fishers' support for crab stock enhancement appears to depend on how positively they perceive the elicited advantages of stock enhancement and the perceived likeliness of elicited positive and negative outcomes.

Owing to the pressures on the blue swimmer crab stocks populations, stock enhancement has been considered as a way of increasing the abundance of Blue Swimmer Crabs (Johnston et al., 2011). As a result of this interest in enhancement, a pilot release of 3700 juvenile crabs was made in the Peel-Harvey Estuary to explore the feasibility and logistics of enhancement (Jenkins et al., 2018). While the biological and ecological aspects of *Portunus* spp. aquaculture and stock enhancement are relatively well studied (e.g. Marshall et al., 2005; Paterson et al., 2007), the human dimensions, including fisher beliefs and attitudes, are not well understood. The belief elicitation process was key to identifying fishers' beliefs regarding the potential outcomes of using stock enhancement to manage the Blue Swimmer Crab fishery. This belief elicitation technique revealed that most crab fishers (96.8%) identified catch-related positive outcomes (advantages) of stock enhancement, but fewer (39.4%) identified potential negative outcomes of stock enhancement. This finding on a short-lived invertebrate aligns with those for longer-lived fin-fish (Red Drum *Sciaenops ocellatus*) by Garlock and Lorenzen (2017), and generic modelled results for fish by Poorten et al. (2011), who each noted strong support for stock enhancement as a fisheries management intervention, but with potentially unrealistic beliefs about the potential benefits and negative impacts of stock enhancement. In particular, the common and strongly held belief in the current study, that stock enhancement will result in

[3] Supportive (S); Neutral (N) and Unsupportive (US) to stock enhancement. Population size is specified for each belief in the "n" column.

more crabs in the catch (*i.e.* more crabs of at least minimum legal size), may be an unrealistic belief. While stock enhancement may increase overall numbers, this is typically associated with sizes of the target species becoming smaller, due to density-dependent effects on growth (Hilborn, 1998; Camp et al., 2017). Thus, stock enhancement Blue Swimmer Crab is not guaranteed to increase the number of crabs caught because many will be below the minimum legal-size limit. The catch-related beliefs may be a function of the food/consumptive-focus of the recreational Blue Swimmer Crab fishery, as documented for various fish species in the northern hemisphere (*e.g.* Anderson et al. 2007; Garlock and Lorenzen 2017).

In contrast to previous work, the belief elicitation in our study also identified that a proportion of recreational fishers were aware of the potential negative outcomes (disadvantages) of stock enhancement in terms of increased fishing pressure and impacts on the “wild” crabs as well as other species. These beliefs aligned with those identified in the scientific literature, including increased fishing effort (Hilborn, 1998; Camp et al., 2017), impacts on genetic diversity and fish abundance (Lorenzen, Beveridge and Mangel, 2012), predation and competition between stocked and wild fish, reducing wild fish populations (Bell et al., 2008; Ingram, Hayes and Rourke, 2011; Taylor, 2017a). While the elicitation revealed that a substantial minority of fishers (39.4%) were aware of these potential disadvantages, the belief measurement demonstrated that part of the population of recreational crab fishers rated them as bad, but unlikely outcomes of stock enhancement. These findings suggest that the popularity of stock enhancement among some recreational fishers has a more nuanced explanation than recreational fishers simply being unaware of the negative outcomes resulting from stock enhancement. Perhaps it is not so much a general lack of awareness, but a more interplay between the perceived low likelihood of negative outcomes and the potentially unrealistic, perceived high likelihood of increased catch. Hence, when provided with a list of potential outcomes, recreational crab fishers who support stock enhancement were likely to rate the perceived advantages as likely and positive, while downplaying the disadvantages that are still considered to be bad, but very unlikely. Meanwhile, those who are unsupportive consider the disadvantages to be more likely, while the catch related advantages are seen as very likely but less positive. Although the beliefs regarding stock enhancement and increased catch reflect the findings from earlier studies, *i.e.* most recreational fishers support stock enhancement as a management intervention (Arlinghaus, 2006a), we demonstrate here that some fishers are also aware of the potential for negative outcomes from stock enhancement.

While a minority of fishers were aware of the negative outcomes resulting from stock enhancement, most fishers in this study support stock enhancement as an approach to manage the recreational Blue Swimmer Crab fishery in south-western Australia. As this is a recreational food-motivated fishery, it is likely that recreational fishers support management tools that will result in a population increase of their target species and therefore push for an approach that is believed to increase, or at least secure their current levels of catch.

1.1.5. Conclusion

This study used established belief elicitation and measurement procedures to first identify, then measure beliefs regarding the outcomes of using stock enhancement as a management approach in a recreational crab fishery. Stock enhancement is a management intervention that potentially allows fishing activities to continue, without limiting access to fishing or reducing the quantities of target species taken. As with past studies of recreational fin-fish fisheries, crab fishers appear to support stock enhancement as a tool to manage this fishery. In contrast to other studies, some recreational crab fishers in south-western Australia demonstrate an awareness of the potential negative outcomes of stock enhancement. However, we suggest it is likely that recreational crab fishers, being mainly food-motivated, downplay the negative impacts associated with this management strategy, due to their interest in catching greater numbers of crabs and the belief that stock enhancement will enable this. This is probably due to a cognitive bias that results in a tendency to ignore the possibility of negative occurrences and produces over-optimism, further encouraged by the food-related motivations of Blue Swimmer Crab fishers. Hence, when presented with the disadvantages of stock enhancement statements in Phase 2, they acknowledge these as bad but consider them unlikely. Overall, by describing the disadvantages of stock enhancement as unlikely, the recreational fishing community shows a stronger support for stock enhancement as a management strategy.

1.2. Heterogeneity among recreational fishers' motivations for utilising two estuarine fisheries

Tweedley, J.R., Obregón, C., Beukes, S.J., Loneragan, N.R. & Hughes, M. (2023). Differences in recreational fishers' motivations for utilising two estuarine fisheries. Fishes 8(6): 292. DOI: 10.3390/fishes8060292.

1.2.0. Summary

There is increasing recognition that to manage fisheries effectively there is a need to understand social dimensions, particularly fisher's motivations for fishing. This study firstly elucidated the characteristics of recreational fishers that target two iconic species in Western Australian estuaries, i.e. the Blue Swimmer Crab (*Portunus armatus*) and Black Bream (*Acanthopagrus butcheri*). It secondly determined the salient motivations for fishing for these species and investigated whether these views were homogenous across the population or if they differed depending on the location where fishing took place and/or the characteristics of the fisher. Respondents to an online survey were quantitatively assigned to fisher groups based on their frequency of fishing, fishing methods they employed, experience and skill-level. Seven and five significantly different groups of Blue Swimmer Crab and Black Bream fishers were identified, respectively. Semi-structured interviews (n = 94 for Blue Swimmer Crabs and n = 137 for Black Bream) were used to gather, in the fishers' own words, their salient motivations for fishing and the strength and evaluation of salient motivations were determined using online surveys (n = 571 Blue Swimmer Crab fishers and 151 Black Bream). Crab fishers were strongly food motivated, with 92% fishing for food and were primarily motivated to '*catch big crabs*' and '*catch enough crabs to eat*'. Furthermore, 91% 'always; consumed their catch, with only 2% practicing catch and release fishing. This fishery is known to suffer relatively high levels of non-compliance and only 1% of respondents claimed '*never*' to have exceeded the bag limit of 10 crabs, and 37% admitted to having done this '*sometimes'*. These views were generally consistent across estuaries but differed between fisher groups. In contrast to the food-motivated nature of the crab fishers, 81% of Black Bream fishers did so for the sport/challenge, with the strongest motivation being to catch a bream considerably above the minimum legal length, with '*food*' only selected as motivation by 15% of respondents. Moreover, Black Bream were rarely consumed with most fishers catching and releasing fish. The marked differences between the two fisheries for the two species are likely driven by the accessible nature of the crab fishery, ease of catching crabs, the low cost of fishing equipment required to obtain them (< AUD 25 for a scoop net or crab pot) and the delicacy of the meat. Fishing for Black Bream requires more expensive equipment, patience and a greater skill level, particularly if using lures. Fishers considered crab fishing to have about the same importance as other fishing and outdoor activities, whereas Black Bream fishers considered bream fishing considerably more important, reflecting the trophy nature of this fishery. Few other species in estuaries, such as the Mulloway (*Agryosomus japonicus*) are regarded as trophy species. Fishers of both species stated that if the fishery for their target species in their estuary was unavailable most would fish in a different estuary to obtain that species, highlighting the social importance of these species to their fishers.

1.2.1. Introduction

Fisheries are complex social-ecological system, comprising three inter-related elements, (i) natural system, which includes the ecosystem and the biophysical environment and the fish populations, (ii) human system, which includes the social, economic and cultural environment, the fishing community and those that utilise the fish, and (iii) fishery management system, which includes research, development, policies and planning (Charles, 2001; Salas and Gaertner, 2004; Branch et al., 2006). The interactions between the various components are further complicated in estuaries due to the dynamic nature of the physico-chemical environment, the range of deleterious anthropogenic perturbations they are subjected to, the complex lifecycles of many of their species and their position as transitional systems and thus complex governance structures (Potter et al., 2015b; Elliott et al., 2022). Sound management is therefore needed to ensure that the structure of the social-ecological system is maintained, however, this has not always been achieved, with

Maitland (1990) listing 'fisheries management' as one of the top ten threats to conservation of fish in rivers and estuaries. Typically, management of these resources has focused on the biological and economic dimensions, in an effort to ensure that stocks are sustainable, the environment is protected and that the fishery is profitable (Salas and Gaertner, 2004; Urquhart et al., 2014), but there is increasing awareness of the need to understand the social dimensions of fisheries (Brooks et al., 2015; Barclay et al., 2017).

Recreational fishing is defined as that which does not constitute the individual's primary means of meeting basic nutritional needs, and includes fish and invertebrates caught and not generally sold or otherwise traded on markets (FAO, 2012b, a). In industrialised countries, an estimated 10.5% of the population fishes recreationally (~118 million people), with that figure rising to around 220 million worldwide (Arlinghaus, Tillner and Bork, 2015; 2019), which is considerably more than the 40 million engaged on a full-time, part-time or occasional basis in commercial capture fisheries (FAO, 2018). In Australia, recreational fishing is an integral part of the culture and, as of 2003, involved an estimated 3.4 million people or 16.8% of the population (Henry and Lyle, 2003; Young, Foale and Bellwood, 2016). Participation in the state of Western Australia is greater than the national average at approximately 30% of the population (DPIRD, 2019). This high participation, combined with the state's recent rapidly increasing population, has resulted in the estimated number of recreational fishers more than doubling from 315,000 in 1989/90 to 711,000 25 years later (Ryan et al., 2015).

There has been increasing recognition that recreational fishing has widespread appeal across the broad spectrum of society with participants comprising a diversity of ages, genders, races and socio-economic backgrounds (Floyd et al., 2006; Kyle et al., 2007; Magee et al., 2018). This creates a challenge for management as incorporating the social dimensions of recreational fishers into management may be confounded by the social complexity inherent in the fishing population (Arlinghaus, Cooke and Potts, 2013; Hunt, Sutton and Arlinghaus, 2013). Examples of this complexity may include multiple conflicting values, motivations and priorities that can present significant challenges for managers seeking to identify a preferred policy or course of action that addresses both social and ecological fishery management imperatives.

Fisheries management decisions not only impact on the status of fish stocks, but also the recreational experience of fishers (Homans and Ruliffson, 1999). The ways in which management measures influence recreational experiences can directly impact on the nature and level of public support for management (Radomski et al., 2001). This is particularly important for recreational fishers as they act relatively autonomously, often with limited active management or surveillance, across large areas, compared to commercial fishers who are often required to keep and submit logbooks and subjected to independent human or video observation (Elliott et al., 2022). As an example, approximately 4,000 tonnes of fish are caught annually in South African estuaries of which 60% is obtained illegally (Cowley, Tweedley and Whitfield, 2022). Moreover, the level of poaching is projected to increase as a surge in unemployment following the COVID-19 pandemic led to recreational catches becoming an important, and sometimes only, source of protein to some families (Elliott et al., 2022). Management of recreational fisheries therefore needs to rely heavily on encouraging voluntary compliance with regulations, including through communication strategies (Leisher et al., 2012; Hunt, Sutton and Arlinghaus, 2013; Zorrilla-Pujana and Rossi, 2014). Support for the management of a fishery as a publicly accessed natural resource is directly associated with fisher compliance and is central to its effective management (Sections 1.1 and 1.3).

The Blue Swimmer Crab (*Portunus armatus*) is one of the most popular recreationally-caught species in Western Australia and supports several small-scale commercial fisheries (Ryan et al., 2015; Johnston et al., 2020a). Recreational fishers are boat-based or shore-based and employ a range of methods including baited traps, scoop nets, wire hooks and hands. As of 2019, there is a daily bag limits of 10 crabs per person (except in the Swan-Canning Estuary = 5) and a boat limit of 20. The crabs spawn in the marine environment and their juveniles migrate into the lower reaches of estuaries where they attain sexual maturity and reproduce (Potter et al., 2015b; Poh et al., 2019). Individuals reach 2-3 years old and reach a maximum size of 220 mm carapace width and can weigh up to 600 g (Johnston and Yeoh, 2020; Marks et al., 2020). Black Bream are a long-lived sparid, which grow to a maximum size of 530 mm TL and weight of up to 3.45 kg (Smallwood, Hesp and Beckley, 2013). In contrast to the Blue Swimmer Crab, Black Bream are able to complete their life-cycle in the estuary and typically reside in the upper riverine reaches, particularly around woody debris (Sarre and Potter, 1999, 2000). Recreational fishing for this sparid is conducted using rod and line with both bait and lures from the shore, boats and kayaks. Black Bream is highly prized throughout southern Australia and is also the target species in several fishing tournaments.

Understanding the motivations, or why people participate in recreational fishing, and the characteristics of recreational fishers, enables managers to factor in social complexities inherent in fisheries management (Arlinghaus, Cooke and Potts, 2013; Hunt, Sutton and Arlinghaus, 2013). Thus, this study aimed to elucidate the similarities and differences between the characteristics of recreational Blue Swimmer Crab and Black Bream fishers in estuaries across south-western Australia and determine why they partake in fishing activities. The results will help determine the extent of any heterogeneity among recreational fishers and aids in future management decision making.

1.2.2. Methods

1.2.2.1. Study area and fisheries

Blue Swimmer Crab

Recreational Blue Swimmer Crab fishing is centred around four systems located on the west coast of Western Australia, i.e. the temperate Swan-Canning, Peel-Harvey and Leschenault estuaries all located within 180 km of each other and the sub-tropical marine embayment of Shark Bay, ~900 km to the north (Figure 1.2.1). The Swan-Canning Estuary (55 km^2 in area) is located in the state capital city of Perth and is highly urbanized (Greater Perth population ~2.1 million). Due to its location in a major city, this estuary is subjected to a range of anthropogenic impacts including urbanisation and eutrophication (Tweedley et al., 2017d; 2022). In addition to being a target for recreational fishers (Malseed and Sumner, 2001b), Blue Swimmer Crabs are also caught by a single commercial fisher who deploys gill nets in the lower reaches of the Swan-Canning Estuary.

The Peel-Harvey Estuary, which at 133 km^2 in area is the largest system in the region and is located ~80 km to the south of Perth and close to the city of Mandurah (population ~100,000). This estuary has a long history of crab fishing (Lenanton, 1984; Malseed and Sumner, 2001a) and its commercial and recreational fisheries are certified by the Marine Stewardship Council as sustainable (Morison et al., 2016). However, the recreational crab fishery has one of the highest levels of non-compliance in Western Australia, particularly for retention of undersize crabs during night-time periods (DPIRD, 2018), which has led to the development of novel methods to monitor fishers (Taylor et al., 2018). Leschenault Estuary, which covers an area of 25 km^2 (Veale et al., 2014), is situated in a more rural area of the state with only the City of Bunbury (population ~71,000) nearby. The system used to support a commercial crab fishery, but it closed in 2001 following community concern over perceived declining catches, however, the recreational fishery still operates. Catches of crabs in all three estuaries are classified as '*sustainable*' (Johnston et al., 2020a).

Shark Bay is a large marine embayment (23,000 km^2) in the Gascoyne Region. Its conservation status has been recognised by its declaration as a world heritage site and the inclusion of marine parks and conservation reserves. The town of Denham has a resident population of ~900, however, up to 150,000 tourists visit annually (Christensen and Jones, 2020). The area is a hotspot for recreational fishing with catches dominated by Pink Snapper (*Chrysophrys auratus*), Blue Swimmer Crabs and Grass Emperor (*Lethrinus laticaudis*) (Wise et al., 2012; Taylor et al., 2019b). Blue Swimmer Crabs are also targeted by commercial fishers using traps and obtained as by-catch in prawn and scallop trawl fisheries (Newman et al., 2021). This was the most productive commercial Blue Swimmer Crab fishery (AUD 4 million) before a marine heatwave in the austral summer of 2010/11 led to a pronounced decline in stocks (Chandrapavan, Caputi and Kangas, 2019). The fishery was closed for a period of 18 months in 2012 and 2013 to promote stock recovery and in 2019/20 639 t was caught commercially with another 5.4 t estimated to have been retained by boat-based recreational fishers (Newman et al., 2021).

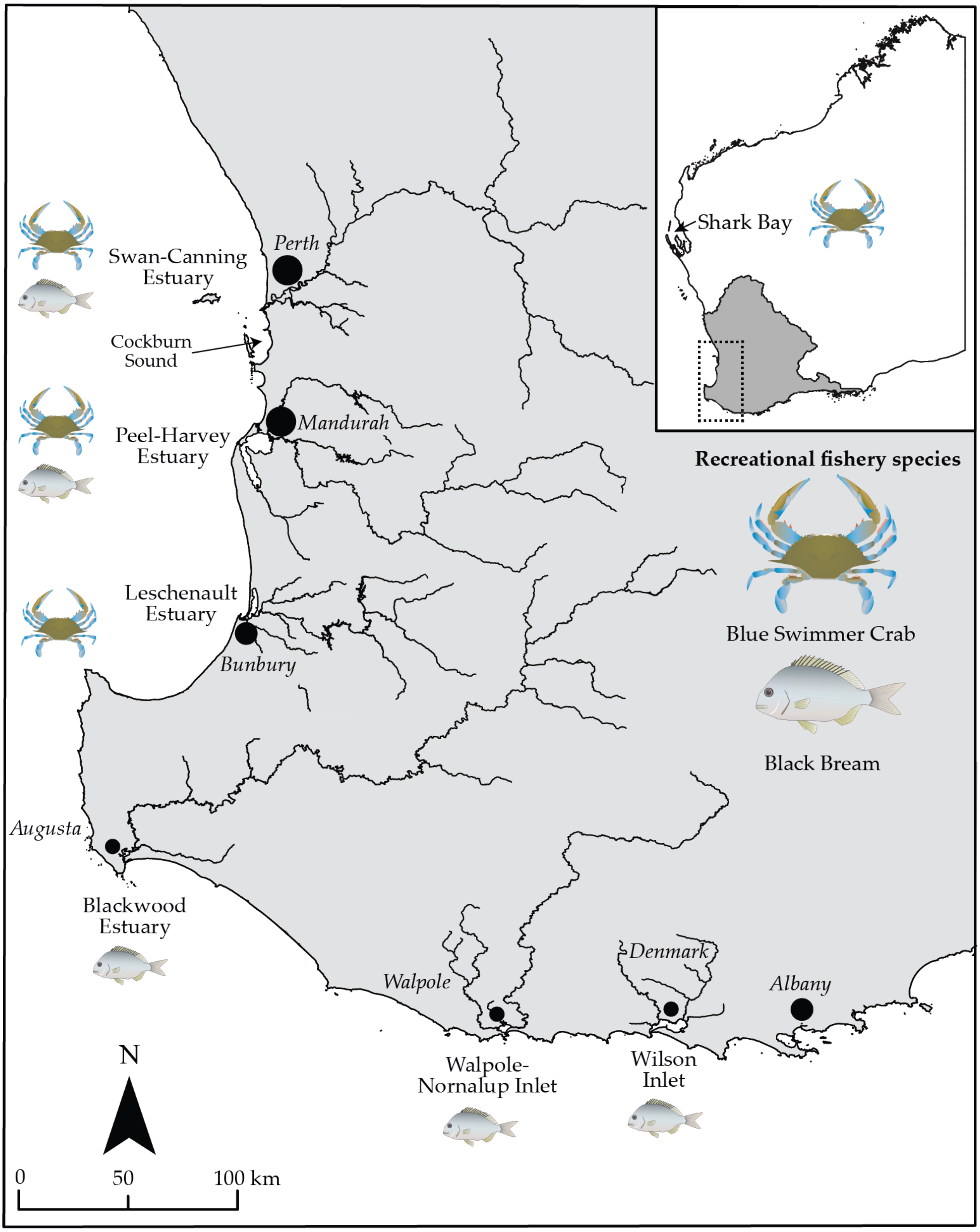


Figure 1.2.1. Map of south-western Australia showing the location of the main estuaries where recreational Blue Swimmer Crab and Black Bream fishing occurs. Inset show the location of this area in Western Australia and also the location of Shark Bay. Black circles denote cities and towns shown in italics.

Black Bream

Recreational fishing for Black Bream occurs in the Swan-Canning and Peel-Harvey estuaries on the lower-west coast (Malseed and Sumner, 2001a, b), but also in a range of estuaries on the south coast of Western

Australia (Figure 1.2.1), including the Blackwood River Estuary, Walpole-Nornalup Estuary and Wilson Inlet (Prior and Beckley, 2007; Smallwood, Hesp and Beckley, 2013). The Blackwood River Estuary (also known as Hardy Inlet) is located near the town of Augusta (population ~1,300) on the south-west corner of Western Australia. The estuary covers an area of 13 km^2 and is permanently-connected to the Southern Ocean (Brearley, 2005). Both the town and estuary are a popular tourist destination and hosts annual Black Bream fishing tournaments (Prior and Beckley, 2007). This estuary is fished by a single commercial license holder.

The Walpole-Nornalup Estuary, ~150 km to the east of Blackwood, is located near the town of Walpole (population ~450). The system covers 14 km^2 and is unique among estuaries on the south coast of Western Australia as its waters are listed as a Marine Park and no commercial fishing is permitted (DEC, 2009). Wilson Inlet is located 60 km further east and adjacent to the town of Denmark (population ~5,000). This 48 km^2 estuary, is among the largest on the south coast and becomes closed-off to the ocean for periods of the year and suffers from eutrophication (Tweedley et al., 2012). The estuary is fished by up to 14 commercial fishers who use gill nets to target a range of finfish species, including Black Bream (State of Western Australia, 2005; Newman et al., 2021).

1.2.2.2. Social surveys

The study used two sequential data collection methods i.e. (Phase 1) face-to-face semi-structured interviews with recreational fishers and (Phase 2) an online questionnaire for recreational fishers. The semi-structured interviews consisted of a series of open-ended questions to gather qualitative data that informed a subsequent closed-question online survey, which generated quantitative data.

The semi-structured interviews (Phase 1) followed the belief elicitation procedures applied by Hughes et al. (2009; 2012) and used in Section 1.1 (Obregón et al., 2020b). The open-ended question format was designed to identify salient motivations for fishing in the fishers' own words. The elicitation approach minimised the imposition of researcher assumptions on the types of possible responses, thus providing a more rigorous, representative and less biased collection of fisher responses (Neuman, 2003). To ensure that the questions were clear and did not cause confusion, the survey was pre-tested with a small sample of fishers (n = 7). The pre-test responses were not included in the current study.

Face-to-face interviews were carried out at a range of estuaries used by recreational fishers in south-western Australia. For Blue Swimmer Crab fishers, a total of 18 sites, i.e. jetties, boat ramps and shoreline areas frequented by crab fishers, were sampled in the Swan-Canning, Peel-Harvey and Leschenault estuaries. Note that sampling was not conducted south of Leschenault Estuary, as this species is less abundant in these waters (DPIRD, 2018), which may influence the accuracy of fishers' beliefs. For Black Bream fishers, a total of 34 sites were sampled in the Swan-Canning, Peel-Harvey Blackwood, Walpole-Nornalup estuaries and Wilson Inlet. All surveys were conducted on weekdays and weekends, during the main fishing times, i.e. from 06:00 to 10:00 and 12:00 to 16:00, and over the austral summer (December to February) when most fishing for these species occurs (Ryan et al., 2019). A total of 94 recreational Blue Swimmer Crab fishers agreed to participate in an interview (Swan-Canning = 24; Peel-Harvey = 42; Leschenault = 28); these are the same respondents as in Section 1.1. Interviews were conducted with 137 Black Bream fishers (Swan-Canning = 29; Peel-Harvey = 28; Blackwood = 23; Walpole-Nornalup = 33; Wilson =24).

The responses were written down by the interviewers using the respondents' own words. A theoretical saturation approach was adopted for belief elicitation. Interviews continued over successive weeks until no new response types were recorded in the sample from each estuary (Hughes et al. 2009; 2012). Theoretical saturation was mathematically confirmed by adapting species accumulation techniques (Ugland et al. 2003), to develop response accumulation curves Vanwindekens et al. (2013), with were shown to reach an asymptote (Figure 1.2.2). Additional interviews were conducted once saturation was achieved to ensure that no salient beliefs were overlooked.

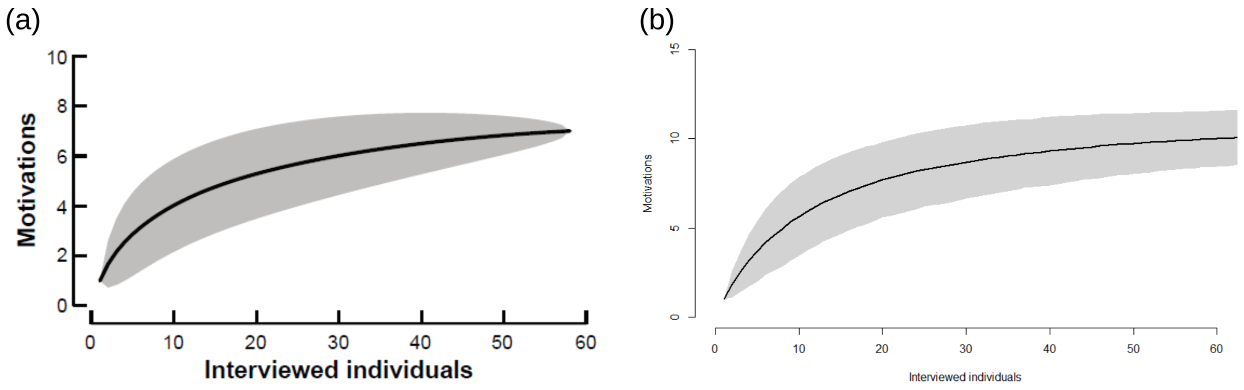


Figure 1.2.2. Response accumulation curve showing that data saturation was reached during the face-to-face surveys with recreational (a) Blue Swimmer Crab and (b) Black Bream in south-western Australia. [4]

Responses were transcribed to a spreadsheet and reviewed to develop categories of response representing salient beliefs. Three researchers independently conducted content analysis to group responses by similar meaning and then identify salient beliefs based on their frequency of occurrence. The most common responses from the semi-structured interviews were used to develop the closed-questions and options for the online survey, i.e. questions with a definite answer or a list of choices, using an online survey tool Surveygizmo. Note that this study uses only those data obtained from the closed-question online surveys.

The purpose of the online questionnaires (Phase 2) was to measure the strength and evaluation of salient motivations for using the Blue Swimmer Crab and Black Bream fisheries identified in the face-to-face interviews. As closed questions are much more specific than open-ended counterparts, they are more suitable to communicate the same frame of reference to all respondents (Reja et al., 2003). The closed question survey is an ideal method for large-scale quantitative research, where the possible responses are already known, which enables comparative statistical analysis of the results (Converse and Presser, 1986; Middlestadt et al., 1996). It is important to reiterate that the closed question response options were developed based on the salient ideas offered by the recreational fishers themselves (during Phase 1), rather than question response options being imposed on the fishers based on the assumptions of the researchers or managers (see Section 1.1; Obregón et al., 2020b).

The online questionnaire included a brief introduction pertaining to the purpose of the survey, followed by various questions with multiple choice answers. An initial question asking how frequently the fisher had been crabbing/fishing over the previous year was used to filter respondents. If the respondent had not fished within that one-year timeframe, they were automatically transferred to the final page of the questionnaire to complete some basic demographic questions and received a thank you message. Such a decision was taken because a respondent's recall when answering questions about activities they have done becomes less reliable as time passes (Bunce et al., 2008; Daw, 2010). A one-year time frame was considered an acceptable compromise between obtaining an adequate sample size of fishers and the reliability of responses provided. When completing the questionnaire, Blue Swimmer Crab fishers answered the following questions: (i) *how often have you fished for Blue Swimmer Crabs over the last 12 months*, (ii) *how long (years) have you been fishing for Blue Swimmer Crabs*, (iii) *where do you fish for Blue Swimmer Crabs* (i.e. shore and/or on the water), (iv) *how do you fish for Blue Swimmer Crabs* (i.e. drop nets, scoop nets etc) and (v) *when compared to other Blue Swimmer Crab fishers, what is your self-assessed level of fishing skill*, where each level of expertise was assigned a numeric value. In the case of fishing frequency, each category was standardised to number of times per year based on the lowest value in the option range selected, e.g. a fisher who fishes 1-2 days a week, would be recorded as fishing 52 times a year. The method of fishing indicated by respondents was coded as follows, 1 = shore only, 2 = both boat and shore, but mainly shore, 3 = both boat and shore equally, 4 = both boat and shore, but mainly boat and 5 = boat only.

[4] Grey shaded area shows the 95% confidence intervals.

A similar approach was taken for Black Bream fishers, albeit using slightly different questions to better suit aspects of this recreational fishery, i.e. (i) *how often have you fished for Black Bream over the last 12 months*; (ii) *how do you most often fish for Black Bream*; (iii) *If you had to replace the fishing gear you currently use to catch Black Bream (i.e. rod, reel, tackle and lures) with the same type of gear, about how much would it cost*; (iv) *how long (years) have you been fishing for Black Bream*; (v) *where do you usually fish from for Black Bream* (i.e. shore, boat, kayak); (vi) *when compared to other Black Bream fishers, what is your self-assessed level of Black Bream fishing skill* and (vii) *in the last 3 years, have you participated in a Black Bream fishing competition?*

The salient fishing motivations identified using the semi-structured interviews were presented in a checkbox question, allowing respondents to select more than one option relating to why they fish. A second motivation question identified what made a fishing trip successful. The options incorporated various statements based on interview respondents and each statement was presented as a rating scale. For example;

Thinking about when you go fishing for Blue Swimmer Crabs, in your opinion, what makes your fishing trip successful? Please indicate your response to each statement by using your mouse to move the slider to the desired position on the scale provided.

Catching as many crabs as I am legally allowed to:

-3 Strongly disagree	-2 Disagree	-1 Slightly agree	0 Neutral	+1 Slightly agree	+2 Agree	+3 Strongly agree

These were followed by suite of questions that focussed on what the fisher does with the catch that could be legally retained (i.e. individuals larger than the minimum size) and how often does this occur. The final questions sought to determine how important fishing is to the fisher and gave a hypothetical situation where fishing for their target species was no longer possible in the estuary where they conducted most of their fishing activities and a range of alternative options for spending their time were able to be selected.

The online surveys, one for each species, were designed using the online tool, Surveygizmo and promoted via a press-release picked up by local print and broadcast media and advertised using flyers posted on survey sites and convenience stores, bait and tackle stores and local cafes located on or close to the estuary. Flyers contained the survey URL and a QR code, to improve the ease of access. Links were also posted on social media, in particular by Recfishwest and on various recreational fishing forums. The online survey for Blue Swimmer Crab fishers was released during the peak period of the crabbing season (*i.e.* December 2017) and closed in February 2018. As fishers may target multiple species, to avoid survey fatigue, the online survey for Black Bream was released in May 2018 and closed in July of that year.

1.2.2.3. Quantitative identification of fisher groups

The CLUSTER-SIMPROF routine in PRIMER v7 (Clarke and Gorley, 2015) was employed to objectively and quantitatively group together Blue Swimmer Crab and Black Bream fishers that had similar fishing characteristics. Note the this was done for 351 of the 571 Blue Swimmer Crab fishers and for 104 of the 151 Black Bream fishers as respondents were required to have answered all of the questions in the fishing characteristics part of the survey to be included in these analyses.

The numeric values for each of the fisher characteristics for each target species were examined separately using pairwise Draftsman plots and Pearson's correlations to visually assess the extent to which the distribution of values for each the five Blue Swimmer Crab and seven Black Bream fisher variables were skewed and thus the type of transformation required to ameliorate any such effect and determine whether any pair of variables were highly correlated. As these plots demonstrated that no transformations were required and that none of the variables were correlated (r = -0.001 to 0.412 and -0.001 to 0.604 for Blue

Swimmer Crabs and Black Bream, respectively), the 'raw' data were normalised to place all variables on a common scale and used to construct two Euclidean distance matrices, one for each target species. Euclidean rather than Manhattan distance was employed as the former resemblance coefficient operates with squared rather than the absolute differences and thus reflects the greatest variation in analysis outcomes (Clarke et al., 2006).

To identify groups of fishers targeting each species who did not differ significantly in their fishing characteristics and thus represent distinct 'fisher groups' each of the above Euclidean distance matrices was, in turn, subjected to hierarchical agglomerative clustering with group-average linking (CLUSTER) and an associated Similarity Profile (SIMPROF) test (Valesini et al., 2009; Tweedley et al., 2013). This SIMPROF test was performed at each node of the dendrogram to determine whether the group of fishers being subdivided contains significant internal structure. The null hypothesis of no significant difference among fishers was rejected if $P < 0.01$. On the resulting dendrograms fishers joined by dashed red lines have similar fisher characteristics and thus represent a fisher group (Figure S1.2.1 and S1.2.2).

Each of the Euclidean distance matrices was used to construct a non-metric Multidimensional Scaling (nMDS) ordination plot to visually display the level of dissimilarity between individual respondents coded for fisher groups (Clarke, 1993). As these plots contained hundreds of samples, a 'simplified' plot was also constructed by subjecting the matrices to the Bootstrap Averages Routine (Clarke and Gorley, 2015) to bootstrap those samples in metric multi-dimensional scaling (mMDS) space. The averages of repeated bootstrap samples (bootstrapped averages) for each fisher group were used to construct a mMDS ordination plot. Superimposed on each plot was i) a point representing the group average (i.e. average of the bootstrapped averages) and ii) the associated, smoothed and marginally bias-corrected bootstrap region, in which 95% of the bootstrapped averages fell. Finally, plots of the means and 95% confidence intervals were constructed for each fisher characteristics to explain quantitatively the differences in fisher groups for each target species.

1.2.2.4. Statistical analyses

In the questions about motivations (i.e. *Why do you fish for Blue Swimmer Crabs/Black Bream?*), what fishers do with their legally-obtained catch (i.e. *Using the scale provided, please indicate what you usually do with the legal sized Blue Swimmer Crabs/Black Bream that you catch?*), their catch rates (i.e. *In terms of numbers caught, when you go Blue Swimmer Crab/Black Bream fishing, do you*) and the importance of fishing for their target species (e.g. *When compared to other types of fishing, please indicate how personally important the activity of Blue Swimmer Crab/Black Bream fishing is to you*), respondents selected an answer from a drop down menu (See Tables S1.2.3-S1.2.7). The resultant count data for each question, for each target species, were used to calculate the percentage of respondents that selected each option and used to construct a Bray-Curtis similarity matrix. This was then subjected to the CLUSTER-SIMPROF routine to determine if the views of respondents utilising the various fisheries and fisher groups differed from one another (Clarke and Gorley, 2015). A similar approach was used for answers to the question "*Thinking about when you go fishing for Blue Swimmer Crabs/Black Bream, in your opinion, what makes your fishing trip successful?".* However, as this asked respondents to rate each option from -3 to +3, rather than tick a box, the data were subjected to the same CLUSTER-SIMPROF routine using a Euclidean distance rather than Bray-Curtis matrix.

1.2.3. Results

1.2.3.1. Demographics

Recreational Blue Swimmer Crab fisher survey participants were predominantly male (83.9%). They ranged from 18 to over 65 years old, with a modal age group of 35 to 44 years old (27.2%) and had been fishing from < 1 to > 40 years, with most fishers (60.4%) having > 10 years' experience; 11-20 years (20.0%), 21-39 years (25.6%) and > 40 years (19.8%; Tables S1.2.1). Recreational Black Bream fisher survey respondents were overwhelmingly male (93.4%) and were slightly younger than the Blue Swimmer Crab fishers, with the most represented age groups being 25-34 (24.5%) and 35-44 years old (27.4) and only 2% being older than 65 years old (Table S1.2.2). Black Bream fishers also had a wide range of experience, the largest percentage (28%) having fished for between 11 and 20 years (Table S1.2.2).

1.2.3.2. Fisher groups

CLUSTER-SIMPROF assigned the 351 crab fishers into seven statistically different fisher groups based on their fishing characteristics (Figure S1.2.1). The distinctness of the various groups is illustrated by the MDS plots (Figure 1.2.3). Fisher group *a*, located on the left had side of both plots, was the most distinct and widely separated from the others. Groups *b*, *c*, *d* and *f* formed a large group of samples on the nMDS plot (centre to right hand side) that was divided in the quarters with limited intermingling, while fishers in groups *e* and particularly *g* were more dispersed throughout this region of the nMDS plot (Figure 1.2.3a). The greater amount of variability in the position of those fishers in group *f* is shown by the broader 95% confidence regions in Figure 1.2.3b, with the boot-strapped averages for the other groups being tightly clustered with small confidence regions.

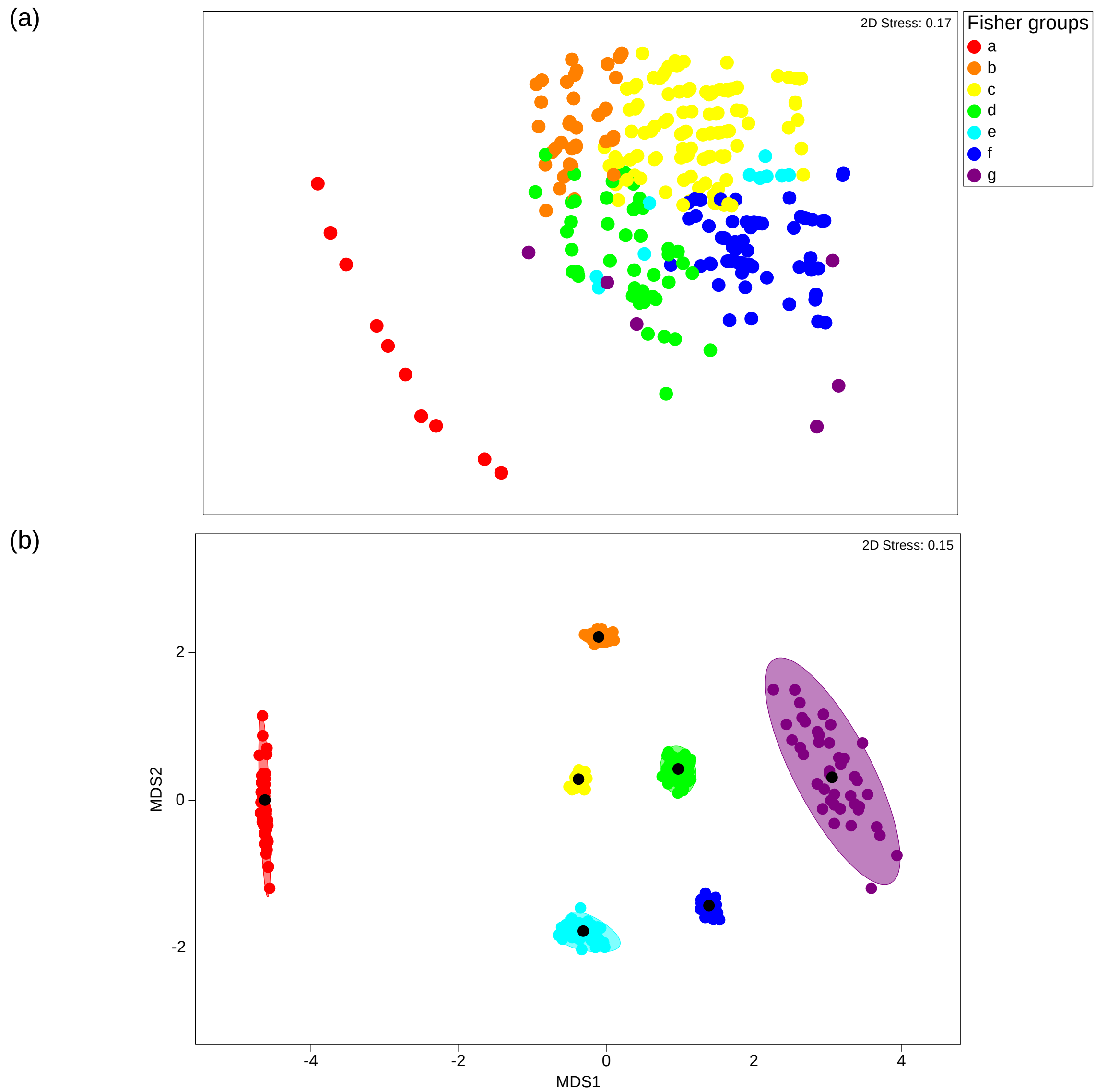


Figure 1.2.3 (a) non-metric multidimensional scaling ordination plots derived from the Euclidean distance matrix of the normalised data for the characteristics of Blue Swimmer Crab fishers and (b) metric multidimensions scaling ordination plot constructed from bootstrap averages for the Blue Swimmer Crab fisher groups. [5]

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[5] Group averages (black circles) and approximate 95% region estimates (shaded areas) are fitted to the bootstrap averages for each fisher group.

Visual interpretation of the mean values of each fisher characteristics allows the differentiating traits of the various fisher groups to be characterised and assigned a name (Table 1.2.1; Figure 1.2.4). Members of group *a,* (Frequent fishers) fish far more regularly compared to those in the other groups (i.e. 156 vs 8 – 20 times per year) and comprise intermediate and expert fishers. Groups *b* and *c,* both comprised boat-based fishers using drop nets who fished, on average, ~16 times a year (Figure 1.2.4). Fishers in these two groups were distinguished based on their experience, with those in *b* having far more fishing experience than those in *c,* i.e. 40 vs 12 years, respectively). Members in the remaining groups (i.e. *d*, *e*, *f* and *g*), tended to fish from shore (although this was highly variable in the case of *g*). Those fishers in group *d* were more experienced than those in *e* and *f,* with average years of fishing experience of 24 vs 7 and 9. Commensurate with this, members of *d* proclaimed a greater skill level with most considering themselves expert. Group *e* and *f* fishers utilise different methods, with those in *e* exclusively utilising drop nets from a jetty (as shore-based), while those in *f* used a range of methods. Finally, members of group *f* were unique in that they predominantly used their hands to catch Blue Swimmer Crabs (Figure 1.2.4).

Table 1.2.1. Description of the typical characteristics exhibited by members of each group of (a) Blue Swimmer Crab and (b) Black Bream fishers identified by CLUSTER-SIMPROF (Figures S1.2.1, S1.2.2).

Blue Swimmer Crab group	Name	Description	Percentage of fishers
a	Very frequent fishers	Fishers that fish > 150 times per year and of intermediate/expert skill level	2.85
b	Experienced boat-based fishers	Fishers that have fished for > 40 years, primarily from a boat using drop nets	16.24
c	Inexperienced boat-based fishers	Fishers that have fished for ~10 years, primarily from a boat using drop nets	40.74
d	Relatively experienced, expert shore-based fishers	Expert fishers that have fished for ~25 years, primarily from the shore using a range of methods	13.96
e	Inexperienced shore-based drop net fishers	Fishers that have fished for ~7 years, primarily from a shore using drop nets	2.85
f	Inexperienced, shore-based novice fishers	Novice fishers that have fished for < 10 years, primarily from a shore using a range of methods	21.65
g	Bi-monthly hand fishers	Fishers that fish every two months and catch their crabs by hand	1.71

Black Bream group	Name	Description	
a	Very frequent fishers	Fishers that fish > 150 times per year and of intermediate skill level	0.96
b	Very frequent, expert lure fishers	Fishers that fish > 150 times per year are of expert skill level, use expensive fishing gear and lures and fish in competitions	2.88
c	Experienced fishers	Fishers that have fished for ~ 40 years, primarily from a kayak/boat and of intermediate/expert skill, some of whom fish in competitions	5.77
d	Inexperienced intermediate skilled fishers	Intermediate skills fishers that have fished for < 10 years, primarily from a kayak using relatively cheap gear and who do not enter competitions	56.73
e	Inexperienced but keen fishers	Intermediate/expert fishers that have fished for < 10 years, using expensive gear and who fish in competitions	33.65

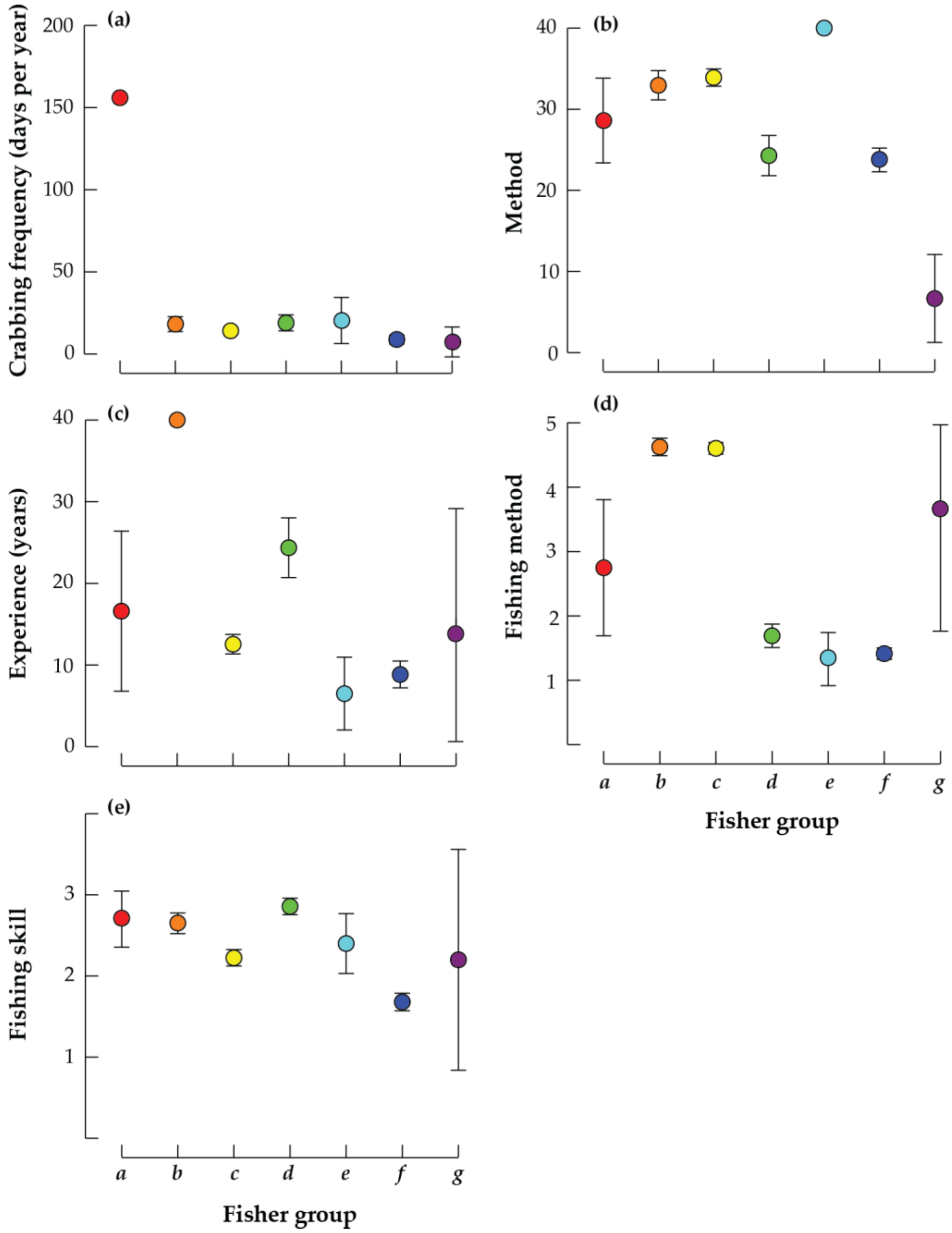

Figure 1.2.4. Mean and associated 95% confidence limits for each of the five characteristics used to create the Blue Swimmer Crab fisher groups.[6]

The 104 Black Bream fishers were quantitatively allocated to one of five groups (Figure S1.2.2), with the points representing fishers being widely separated on the nMDS plot and likewise their 95% confidence regions did not overlap (Figure 1.2.5). Of the basis of their fisher characteristics, group *a* was the most distinct, with the single fisher in this group fishing far more frequently than those in all other groups except *b* (i.e. 150 vs 18 to 36 times per year; Table 1.2.1; Figure 1.2.6). Fishers in groups *a* and *b* are distinguished by the fact that those in the latter group use far more expensive gear (rods and lures), are self-proclaimed experts and fish competitively (Figure 1.2.6). Group *c* fishers were the most experienced (average = 40 years) and mainly fished from kayaks and boats. The remaining fisher groups (d and e) comprised the majority of the fishers, i.e. 59 and 35, respectively and contained fishers that were relatively inexperienced (average = 8 years). Those in group *d,* were of intermediate skill level and did not fish in competitions, whereas those in *e,* were experts, used more expensive gear and partook in competitions (Figure 1.2.6).

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[6] Note there was only a single fisher in Group a and thus the error bars have been estimated based on the common variance across groups.

Separate linkage trees for Blue Swimmer Crab (Figure 1.2.7) and Black Bream (Figure 1.2.8), which represent the allocation of individual fishers into the fisher group identified by the above CLUSTER and SIMPROF procedures, and the quantitative thresholds of the fisher characteristic(s) that best reflect the division at each branching node of the tree have been generated. These trees thus provide a set of quantitative decision rules that enable any new fisher (i.e. someone that did not complete the original survey) to be assigned to a fisher group. Noting that in some cases these fishers may constitute a new group.

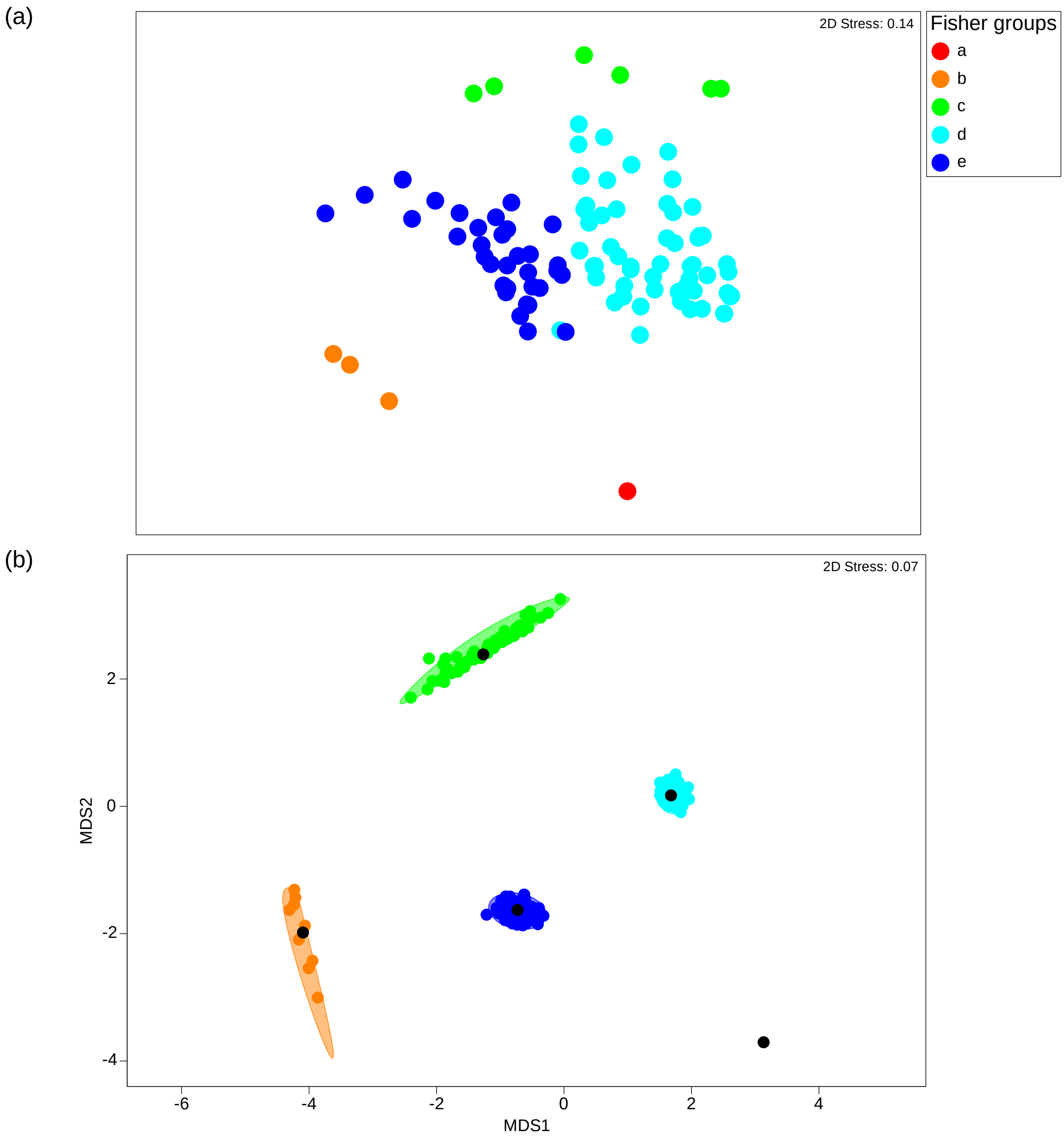

Figure 1.2.5. (a) non-metric multidimensional scaling ordination plots derived from the Euclidean distance matrix of the normalised data for the characteristics of Black Bream fishers and (b) metric multidimensional scaling ordination plot constructed from bootstrap averages for the Blue Swimmer Crab fisher groups.[7]

[7] Group averages (black circles) and approximate 95% region estimates (shaded areas) are fitted to the bootstrap averages for each fisher group.

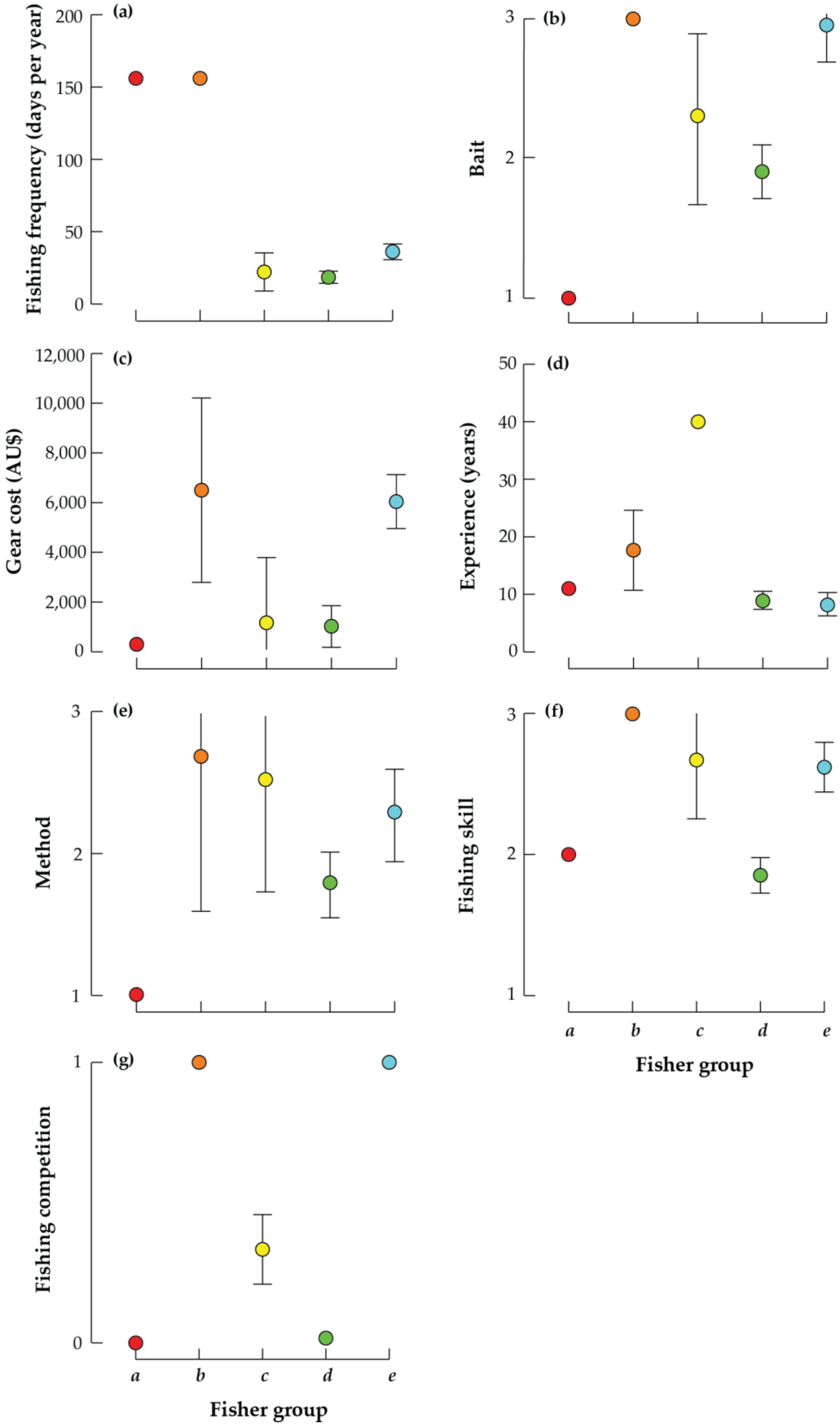

Figure 1.2.6. Mean and associated 95% confidence limits for each of the seven characteristics used to create the Black Bream fisher groups.

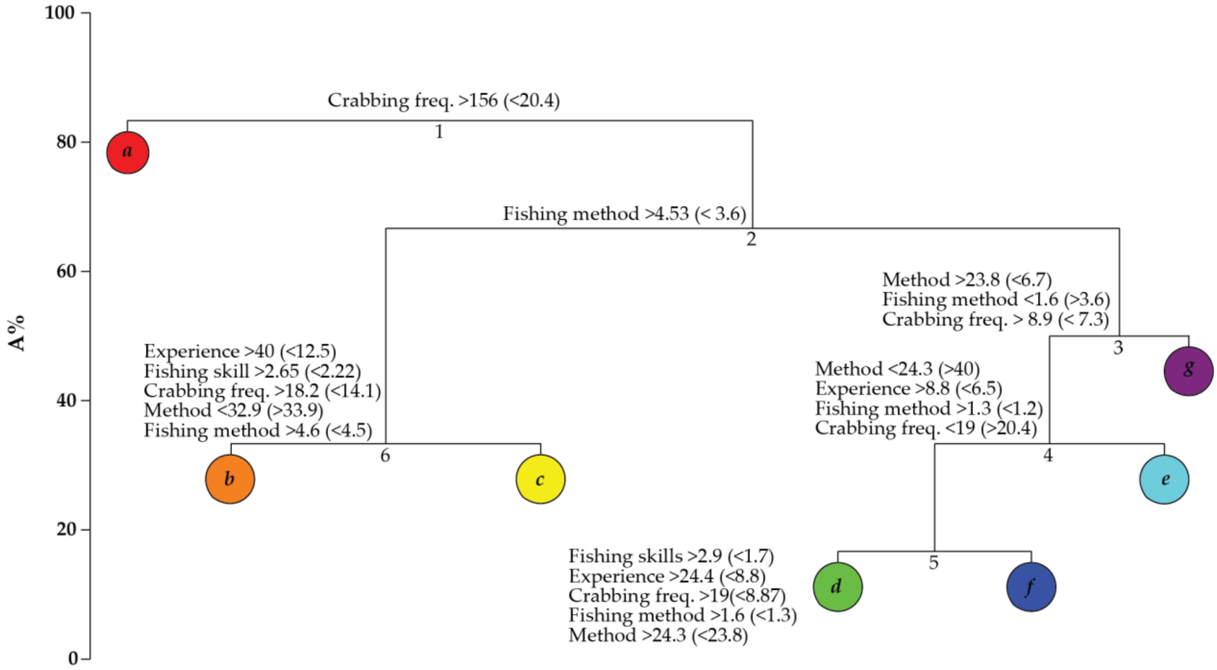

Figure 1.2.7. Linkage tree and associated quantitative thresholds for assigning Blue Swimmer Crab fishers to their appropriate fisher group. Unbracketed and bracketed thresholds given at each branching node indicate that a left or right path should be followed, respectively.[8]

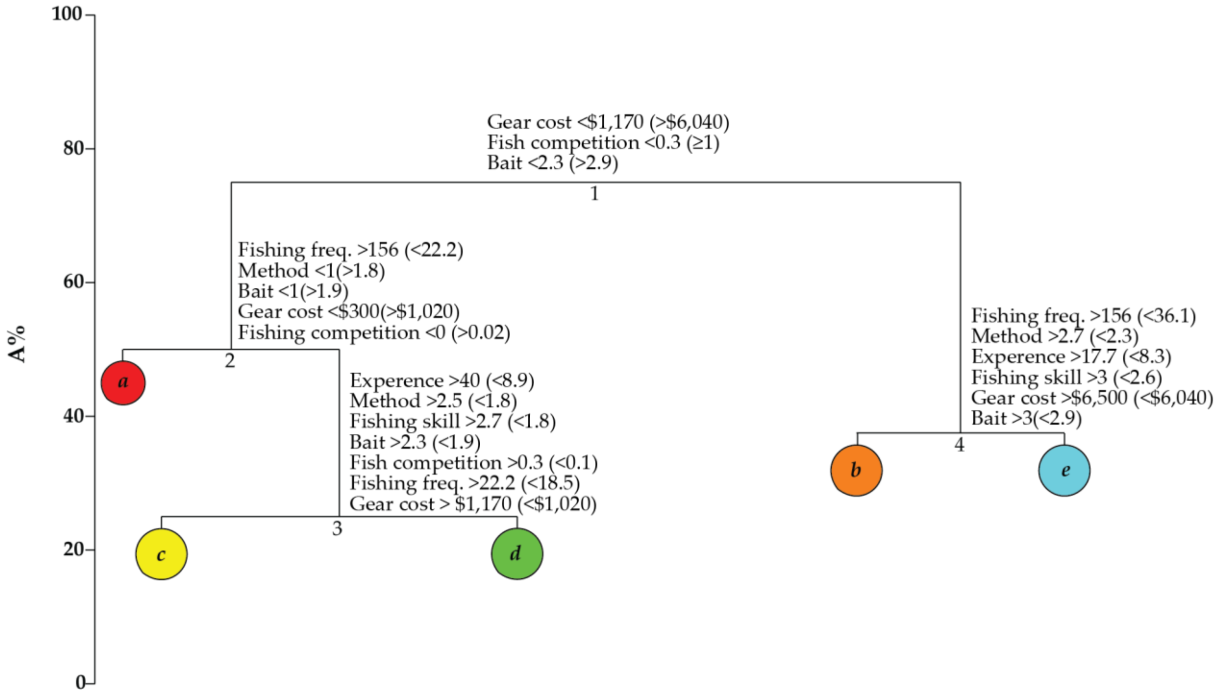

Figure 1.2.8. Linkage tree and associated quantitative thresholds for assigning Black Bream fishers to their appropriate fisher group. Unbracketed and bracketed thresholds given at each branching node indicate that a left or right path should be followed, respectively. [9]

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[8] Note that all threshold values have not been subjected to any form of data pre-treatment. The terminal node represented by a coloured symbol denotes the fisher group to which any new fisher (or sample) belongs. A% reflects the extent of inter-fisher group differences as a proportion of that between the most dissimilar fisher groups.

[9] Note that all threshold values have not been subjected to any form of data pre-treatment. The terminal node represented by a coloured symbol denotes the fisher group to which any new fisher (or sample) belongs. A% reflects the extent of inter-fisher group differences as a proportion of that between the most dissimilar fisher groups.

1.2.3.3. Motivations for fishing

Based on the online survey, when asked '*what is your main motivation to fish for Blue Swimmer Crabs*' 92% of all respondents selected *food*, making this by far the most common driver crabbing (Figure 1.2.9a; Table S1.2.3a). The next most prevalent motivations were *enjoyment of catch*, *enjoyment of outdoors* and *pleasure* (65-67%). *Spending time with family* and *friends* were the least selected options although still shared by many participants (i.e. 51 and 48%, respectively). These motivations were selected consistently by respondents across the four crab fisheries, i.e. those in the Peel-Harvey, Swan-Canning, Leschenault and Shark Bay, with *food* being chosen by between 86 and 94% of respondents and as evidenced by each fishery occurring in the same CLUSTER-SIMPROF group (Table S1.2.3a). Non-catch-related motivations, such as *enjoyment of the outdoors*, were selected less frequently by respondents in Leschenault and Shark Bay, but not enough to result in a significant shift in motivations. The homogeneous motivations of recreational Blue Swimmer Crab fishers utilising different systems was not as pronounced across fisher groups. CLUSTER-SIMPROF detected three different clusters of fisher groups, (i) *a* and *e*, (ii) *b*, *c*, *d* and *f* and (iii) *g* (Figure S1.2.3a,c). Fishers in groups *a* and *e* were strongly food motivated (100% of respondents), with almost all other motivations only being selected by up to 50% of respondents. Respondents from the second cluster shared the views representing the overall population, while those in the third cluster (group *g*) were less food-motivated instead enjoyed spending time with family.

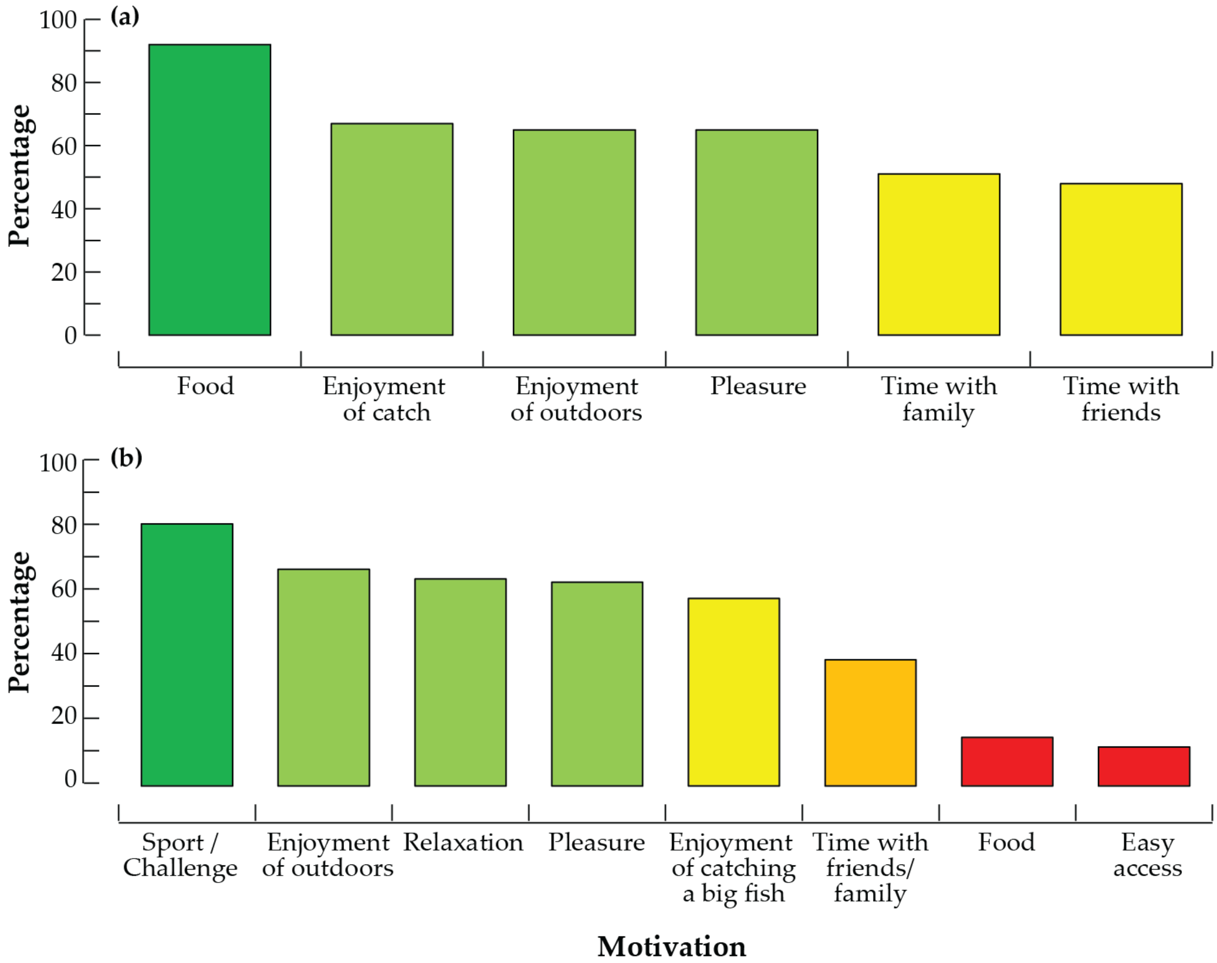

Figure 1.2.9. Percentage number of times a salient motivation for (a) Blue Swimmer Crab and (b) Black Bream fishing was selected from the closed-question online survey.

When asked '*what makes your fishing trip successful?*' Blue Swimmer Crab fishers ranked six perceived success metrics for the fishing trip from -3 to +3. Average values ranged from +1.89 to -0.57, with all being positive, i.e. agree, except *catching some crabs* (Figure 1.2.10a). The metrics that received the highest mean scores were *catching enough crabs to eat* and *catching big crabs* (both +1.89), followed by *being with friends/family* and *outdoors.* Despite the apparent food-motivated nature of the crab fishery *catching as many crabs as I am legally allowed to* was only +0.43. As with the motivations, the views of the Blue Swimmer

Crab fishers as a whole reflected those of users in each fishery (Table S1.2.4a; Figure S1.2.4a). Differences were detected, however, among fisher groups, with those in Group *a* being more food-motivated than those in groups *b-f*, while those in *g* rated spending time with friends/family and outdoors as more important than catching crabs (Table S1.2.4a; Figure S1.2.4c).

In contrast to the general food-motivated driver of crabbing, the majority of Black Bream fishers (81% overall) selected *Sport/Challenge* as their main motivation, with food only selected by 15% of fishers (Figure, 1.2.9b; Table S1.2.3b). Other frequently selected motivations were *enjoyment of the outdoors, pleasure* and *relaxation.* These views were shared by fishers utilising the Blackwood, Peel-Harvey, Swan-Canning and other estuaries and those in different fisher groups (Figure S1.2.3b,d). *Catching a big bream* (i.e. > 30 cm total length) was the highest rated of the success metrics +2.33 with *catching as many bream as I am legally allowed to* rated the lowest at -0.94 (Figure 1.2.10b; Table S1.2.4b). Other highly rated motivations were *catching a legal sized bream (25cm)* and *having a relaxing day.* In keeping with the motivation for sport/challenge, its relevant that in addition to catching larger bream scoring well, the metric *catching a bream no matter the size* scored far lower at +1.08.

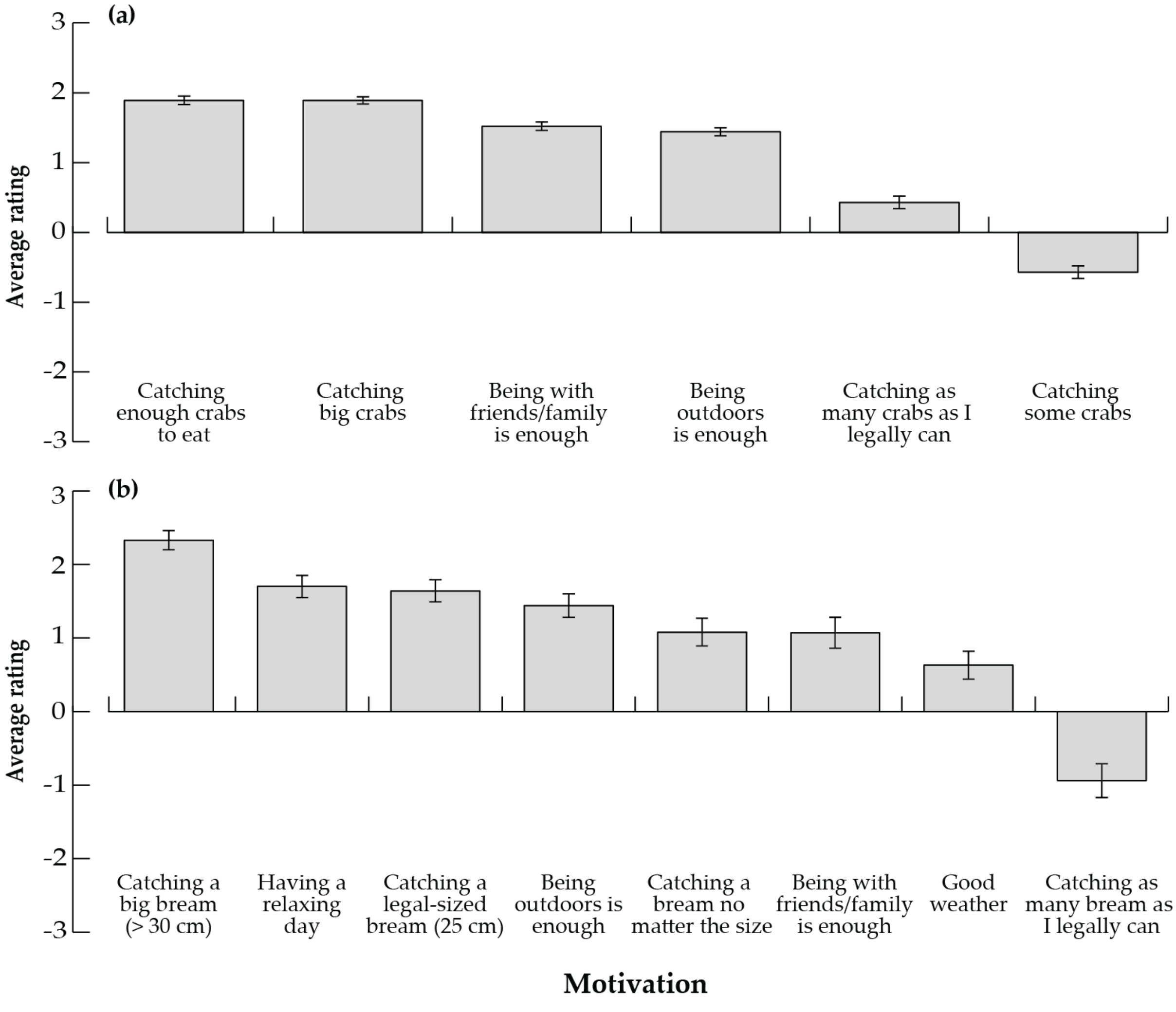

Figure 1.2.10. Average rating and standard error (SE) from -3 to +3 for each salient motivation for (a) Blue Swimmer Crab and (b) Black Bream fishing provided in the closed-question online survey.

The food-motivated nature of the crab fishery was evident from responses to the question *What you usually do with the legal sized Blue Swimmer Crabs that you catch?*. Overall, 91% of fishers ate their catch (Figure 1.2.11), with this trend occurring in all fisheries (92-100%) and across all fisher groups, albeit being a slightly smaller percentage for those in groups *a* and *g* (Table S1.2.5a). Only ~2% of fishers practiced catch and release fishing for crabs (i.e. *Always* releasing their catch) and around a third of fishers *Always* retaining legal sizes crabs. Crabs were not always consumed by the fisher(s) with 75% of respondents *Sometimes* giving their crabs to others. Black Bream fishers rarely *Always* ate their catches, i.e. 9% overall (Figure 1.2.11). Instead, 64% overall *Never* ate a fish they caught, with this value varying across fisheries, being lower in the Blackwood

(45%) and 'other' estuaries (54) and greater in the Swan-Canning and Peel-Harvey (69 and 83%, respectively; Table S1.2.5b). Most recreational Black Bream fishers (76%) practiced catch and release fishing and if they did retain a fish, it was rarely given away with 85% of fishers *Never* having done this (Figure 1.2.11). Fishers in Group *e* (comprising expert fishers with expensive gear who fish in competitions) were more likely to practice catch and release fishing (and not consume their catch) than those in the other fisher groups (Table S1.2.5b; Figure S1.2.5).

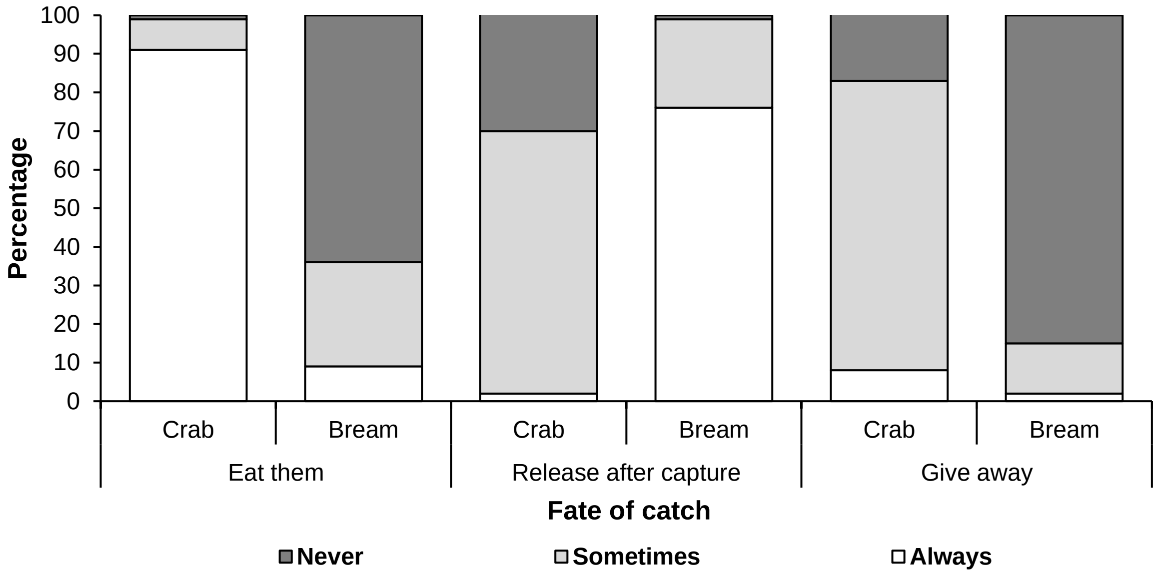

Figure 1.2.11. Percentage number of times Blue Swimmer Crab and Black Bream fishers eat, release and give away legal-sized individuals that they catch.

When asked about how many individuals of their target species Blue Swimmer Crab and Black Bream fishers catch, there were marked differences between fishers (Figure 1.2.12; Table S1.2.6). The vast majority of Black Bream fishers (99%) *Never* caught more fish than allowed (between 2 and 6 depending on the estuary) with this trend occurring in all fisheries (98-100%). Moreover, 85% of fishers overall, and 82-100% across fisheries, *Never* caught as many fish as allowed, with 73% saying they *Always* caught fewer fish than allowed. In contrast, 37% of Blue Swimmer Crab fishers admitted to *Sometimes* taking more than the bag limit of crabs (note that the bag limit was 10 crabs in all fisheries at the time this survey was conducted; Figure 1.2.12). Interestingly only 1% of fishers selected that they *Never* exceeded the bag limit, with the majority (61% overall and 53-75 in the various fisheries claimed they *Don't know* if they had exceeded it (Table 1.2.5). A small minority (12%) of fishers claimed they *Always* obtained the bag limit of Blue Swimmer Crabs, with most (72%) saying they achieved this *Sometimes.* Generally, the trends for the fishers overall were also reflected across fisher groups (Table S1.2.6; Figures S1.2.7; S1.2.8).

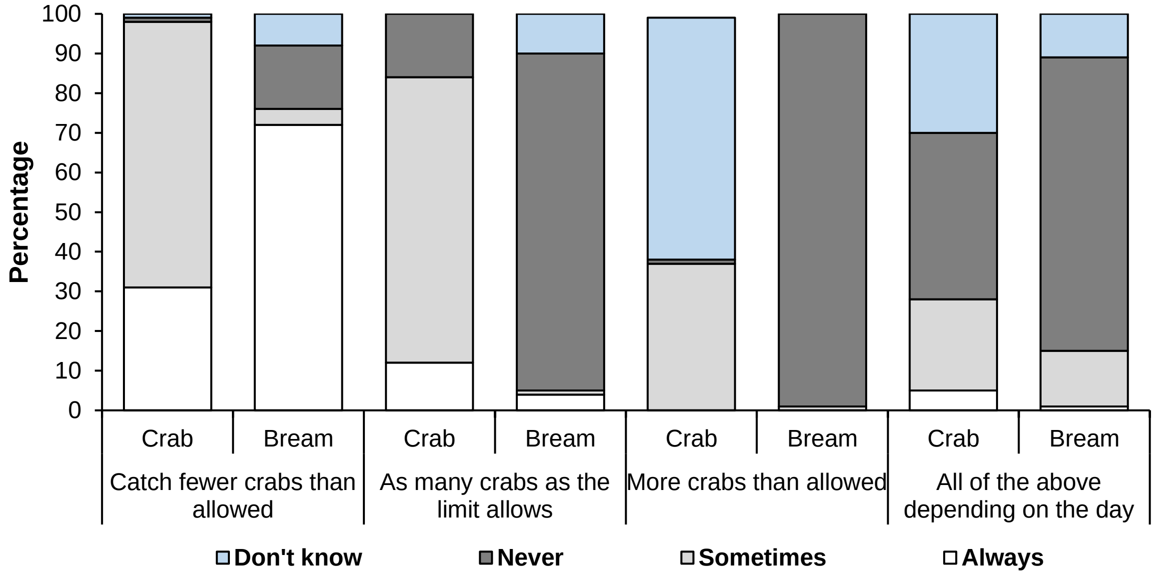

Figure 1.2.12. Percentage number of times Blue Swimmer Crab and Black Bream fishers catch, fewer target individuals than allowed (i.e. the bag limit), the number allows, more than allowed and multiple options.

1.2.3.4. Comparisons to other types of fishing and outdoor activities

When asked *Compared to other types of fishing, how important is crabbing to you?*, 46% of respondents indicated that fishing for Blue Swimmer Crabs was more important (i.e. *more* and *much more* options combined), with 50% stating it was similar to other types of fishing and only 4% saying it was less so (Figure 1.2.13; Table S1.2.7a). These views were fairly consistent across fisheries and fisher groups (Figure S1.2.9), with the exceptions of Leschenault Estuary and fishers in group *a*, where a greater proportion of respondents selected *much more important* than *more important.* A similar suite of responses were received from fishers when asked to compare crabbing to other types of outdoor recreation; 47% said it was more important, 44% the same and 10% less so. Crabbing was relatively more important for fishers from Leschenault Estuary and in group *e*, and less so for those in group *g* (Table S1.2.7a).

In response to a hypothetical scenario in which Blue Swimmer Crab fishing was not able to be conducted at a given location where respondents fished, the majority of respondents (58% overall and 42-70% across fisheries and fisher groups) indicated that they would switch location to continue to catch crabs as opposed to only 19% who said they would target a different species (Figure 1.2.14; Table S1.2.7). The importance of crabbing was further emphasised by only 4% of respondents selecting the option, *loss of the fishery would not affect me* (Table 1.2.7a). While these views were consistent across fisheries and fisher groups, fishers in group *g* (the bi-monthly hand fishers) provided a slightly different range of responses (Figure S1.2.9). The group *g* fisher respondents were more likely to do a *different water-based outdoor activity,* (i.e. not fishing) in response to the scenario.

Overall, 43% of Black Bream fishers considered bream fishing to be more important than other types of fishing, with only 4% disagreeing (Figure 1.2.14; Table S1.2.7b). This view was common across all fisheries except the Blackwood, where fewer people considered it as more important (Figure S1.2.10). Respondents in fisher groups *c* and *d* rated bream as more important than other outdoor recreational activities, which was similar to the overall bream fishers sample response. In contrast a higher percentage of fishers in groups *b* and *e* felt it was *much more important* than other outdoor recreational activities. These scores were similar to those from the Blue Swimmer Crab fishers. However, while ~50% of fishers considered crabbing to be more important than other types of outdoor recreational activities, this value was higher for Black Bream fishers at 81% (Figure 1.2.14). Almost two thirds of Black Bream fisher respondents would target Black Bream in another system if their local fishery was unavailable, with 30% switching to another species (Figure 1.2.14). Fishing is clearly their preferred type of recreation as very few selected non-fishing land or water-based activities and only 1% indicated that the *loss of the fishery would not affect me.*

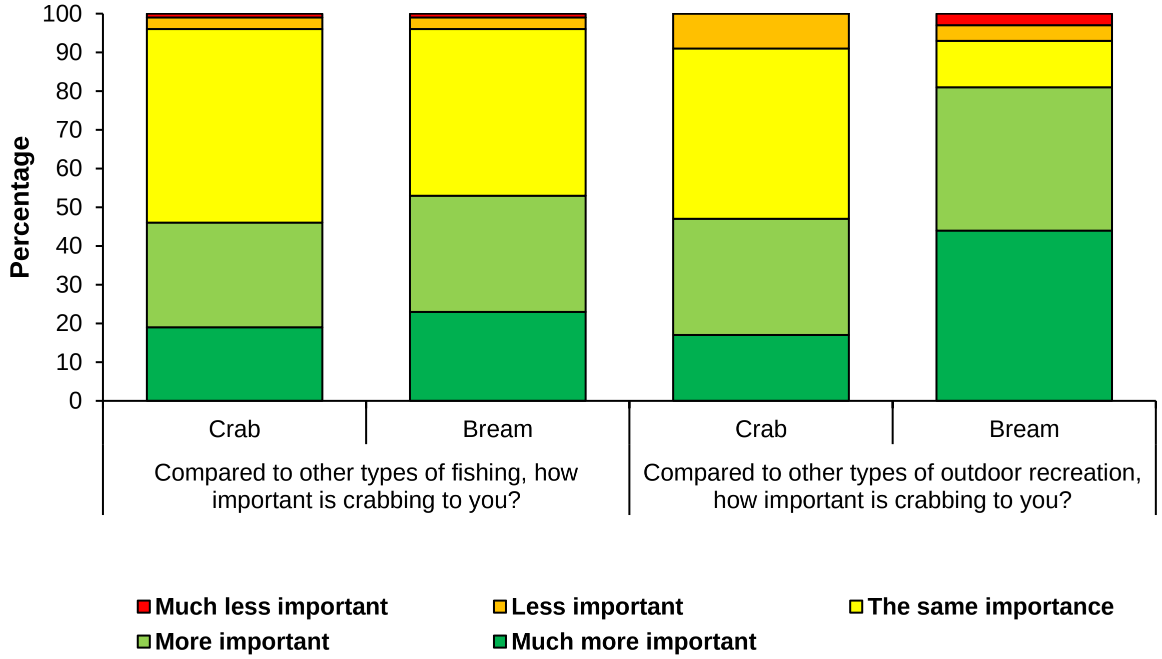

Figure 1.2.13. Perceived importance of Blue Swimmer Crab and Black Bream fishing to fishers that target those species.

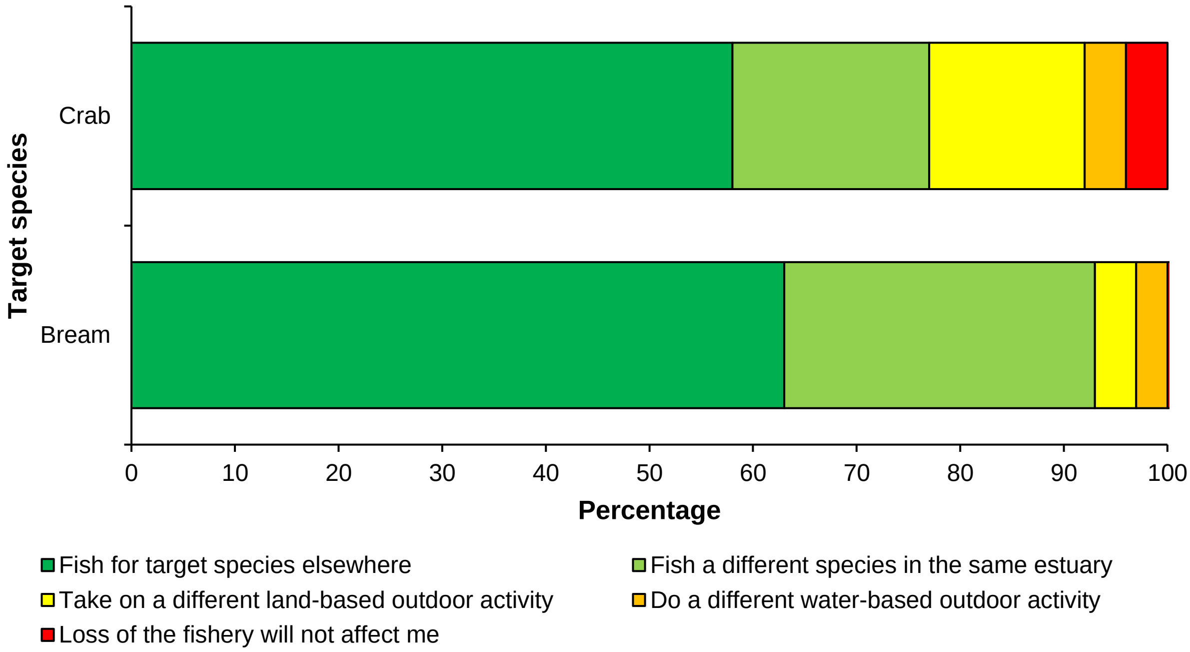

Figure 1.2.14. The percentage of fishers that would undertake different substitute activities if their target species could no longer be fished in the estuary they fish most regularly in.

1.2.4. Discussion

Recreational fishing has widespread appeal across the broad spectrum of society with participants comprising a diversity of ages, genders, cultures and socio-economic backgrounds (Floyd et al., 2006; Kyle et al., 2007; Magee et al., 2018). This diversity makes incorporating human dimensions into the management of recreational fisheries, which are already complex social-ecological systems, difficult (Arlinghaus, Cooke and Potts, 2013; Hunt, Sutton and Arlinghaus, 2013). For example, Arlinghaus et al. (2014) stated that "*An old adage of human dimension studies on recreational fisheries is that the average angler only exists in research reports*". Research from the USA and Germany has demonstrated that recreational fishers in a given area can be divided into subpopulations with fishers in these groups expressing different beliefs, attitudes and preferences regarding fisheries access and management (Bryan, 1977; Arlinghaus, 2006a). While some work has been done in Australia, studies have typically occurred at a fairly broad level. For example, Young, Foale and Bellwood (2016), compared the motivations of recreational fishers in Australia to those of subsistence fishers in the Solomon Islands. Although the average angler may not exist (Arlinghaus et al., 2014), understanding the key characteristics of fishers can help inform effective management (Arlinghaus, Cooke and Potts, 2013; Hunt, Sutton and Arlinghaus, 2013). Thus, this study aimed to elucidate the similarities and differences between the characteristics of recreational Blue Swimmer Crab and Black Bream fishers in estuaries across south-western Australia and determine why they partake in fishing activities. The results will help determine the level of heterogeneity among recreational fishers utilising two iconic fisheries and aid in future management decision making.

1.2.4.1. Identification of recreational fisher groups

Methodologies to characterise fishers were first derived in the 1970s and typically entailed using variable-based approached centered around a specialization (Bryan, 1977; Magee et al., 2018). One of the most well-used examples of this approach was that developed by Salz, Loomis and Finn (2001). This index utilized theory and an a-priori method to generate the index items. Items were derived from the four characteristics (i.e. orientation, experiences, relationships, and commitment) used by Unruh (1979) to place participants in a particular subworld (Hawkins, Loomis and Salz, 2009). A closed-question for each characteristic was written with responses belonging to the various specialization levels (least, moderately, very and highly) and included in a short survey. In these variable-based approaches the focus is on the relationships among variables (e.g. avidity, experience, specialization), however, an alternative approach is to focus on the relationships among individuals; termed person-focused (Muthén and Muthén, 2000). Thus, although variable-based approaches have provided useful insights into the nature of fisher motivations, person-focused approaches are thus more suited to examining the extent of heterogeneity present in a population of recreational fishers and ground individuals into categories (Muthén and Muthén, 2000; Magee et al., 2018).

Studies using a person-centered approach to group recreational fishers have typically employed various types of cluster analysis (e.g. Chipman and Helfrich, 1988; Ditton, Loomis and Choi, 1992; Connelly, Knuth and Brown, 2001) or latent class analysis (e.g. Magee et al., 2018; Pokki et al., 2021; Capizzano et al., 2022). Many of the cluster analysis-based approaches do not, however, demonstrate statistically that the resultant groups actually represent distinct fisher groups nor that any groups do not contain more than one type of fisher (i.e. has no internal heterogeneity). The approach used in this study, i.e. the use of a SIMPROF test in conjunction with CLUSTER, provides an entirely quantitative and thus objective methodology for assigning fishers to groups. This methodology has traditionally been used in ecological studies to group habitat types, faunal communities together and construct food webs (Valesini et al., 2010; French et al., 2013; Tweedley et al., 2013), but has also been used to understand stakeholder perceptions of marine species diversity (Beaudreau, Levin and Norman, 2011).

Given the well-recognised diversity of recreational fishers and their views (see above), it is possible that a survey instrument may not capture the entirety of this diversity. The use of LINKTREE, however, provides quantitatively-defined thresholds at each node of the linkage tree that were most important for separating fishers into their respective groups. This also provides a set of simple, numeric decision rules for assigning any new recreational fisher to an existing fisher group, or, if their characteristics are different, a new group of fishers (Valesini et al., 2010). This is useful for social surveys as, providing the questions and answers remain the same, the survey can be repeated in different areas (fisheries or regions of the world) or repeated temporally, for example as part of a regular state-wide recreational fishing surveys that operate in several Australian states and the results aggregated rather than having multiple iterations of the fisher groups.

1.2.4.2. Motivation for fishing recreationally

This study employed a novel two-phase method to identify recreational fisher's salient motivations for fishing for Blue Swimmer Crabs and Black Bream. This methodology avoided imposing the assumptions of the researchers on to the fisher population, such as the use of categories chosen via expert opinion as these can force fisher responses based on options that may not accurately reflect their views (Section 2.1).

Blue Swimmer Crab

Six salient motivations were identified by recreational Blue Swimmer Crab fishers. These were activity specific, catch related and consumption-orientated (i.e. *food* and *enjoyment of catch*) and also included, general, non-catch related motivations namely *enjoyment of outdoors, pleasure, spending time with family and friends.* The range of motivations identified is similar to those in a study of German anglers (Arlinghaus, 2006a) and a meta-analysis of seventeen surveys of freshwater and saltwater fishers in the USA (Fedler and Ditton, 1994b). While the multiple motivations may reflect a heterogenous experience, our results demonstrate that the main motivation for fishing was to obtain food. This option was selected by 92% of all fishers compared to 67 to 48% for the others. Moreover, this motivation was strongly held by and common across fishers utilising each of the four fisheries (86-93%) and across six of the seven fisher group (90-100%).

The consumption-orientated nature of these fishers was further enforced by their answers to the question *What makes a fishing trip successful?* Across all respondents and those utilising particular fisheries and in fisher groups the motivation with the highest ratings, by far, were *Catching enough crabs to eat* and *Catching big crabs.* Interestingly *catching some crabs* received a negative rating and may suggest that there is a threshold number of crabs a fisher needs to obtain before a trip can be deemed a success. Reaching the bag limit of crabs was rated as only slightly positive, but with amongst the highest variability among motivations, perhaps indicating that for a subset of the respondents reaching this target was important but not for all. Non-catch motivations were all rated as positive, but with a lower rating than some of the catch-related ones.

The strength and consistency of catch-related motivations is likely due to a history of exploiting crab resources in Western Australia, their palatability and catchability. Firstly, recreational crabbing has been documented in newspapers as occurring in the region at least since European settlement in 1829 and since the 1900s crabbing parties have been organised where crabs were caught and cooked on estuary shorelines (Obregón et al., 2022a). There is even an annual Crab Festival held in Mandurah (Peel-Harvey Estuary) which attracts ~100,000 people (www.Crabfest.com.au) and where large quantities of Blue Swimmer Crabs are consumed. These popular family activities are often fondly remembered and passed on from generation to generation, as occurred for the recreational prawning in the Swan-Canning and Peel-Harvey estuaries (Smithwick, Reid and Ensor, 2011; Tweedley et al., 2017c).

Blue Swimmer Crabs are also readily accessible using inexpensive equipment by people of all ages, fitness levels and experience levels. Crabs in shallow waters are easily reached by shore-based recreational fishers wading on the extensive marginal shoals of the estuaries using their hands or a scoop net. Moreover, those crabs in deeper waters can be targeted by drop nets and crab pots from jetties and by boat-based fishers. Finally, catching crabs is relatively easy compared to catching a finfish species, such as Black Bream (see later) using rod and line. When approached, crabs often either immediately burrow into the sediment or remain in position and raise their chelae in self-defense and thus are easy to capture. The wide range of people with varying skills levels could explain why the motivations for recreational Blue Swimmer Crab fishing are relatively consistent across demographics and fisher characteristics. These characteristics of the Blue Swimmer Crab fishery contrast with many other studies where fishers require more specialised equipment and/or higher skill levels to catch fish (Schroeder et al., 2006; Arlinghaus, Tillner and Bork, 2015; Brinson and Wallmo, 2017).

While catching larger sized fish is a common focus for recreational fishers as a means for obtaining a sense of achievement and/or social prestige, it seems that crab fishers focus on size for a different reason. That is, the preference for catching large crabs is more likely to be driven by flesh yield rather than social prestige. It is noteworthy that most crab fishers consumed their own catch (91% overall), a characteristic common across all crab fisheries and fisher groups surveyed. Furthermore, catching enough crabs to eat was the most common motivation identified by the survey. Consumption as the main outcome of a catch indicates a focus on maximising the flesh able to be extracted from the crabs. In this vein, commercial processors report that the average yield for a legal sized crab (~127 mm) is 35%, and that this yield increases with larger body sizes. This contrasts with the Black Bream fisheries for which catching a large fish was the main motivation and releasing the fish after capture was the most common outcome. In addition, there are formal competitions with economic and material rewards focused on catching the largest bream, as well as social media showcasing large sized Black Bream caught. There are no organized crabbing competitions for which catching a large crab is rewarded. Thus, the consumption focused motivations of crab fishers means that large crabs are preferred not necessarily for the prestige but because large crabs more effectively provide enough crab flesh to eat within the confines of the bag limit.

Despite, respondents stating that reaching their bag limit of 10 crabs was not among the strongest motivators, 37% admitted having, at some point, retained more crabs than legally allowed. The results in the current study are supported by those from a survey on non-compliance where 22% of respondents self-reported that their average catch exceeded the bag limit of 10 crabs (Lindley and Quinn, 2022). Monitoring indicates that the Peel-Harvey Estuary has relatively high rates of non-compliance for Western Australia, with 20% of all reported enforcement issues in Western Australia being from this estuary (DPIRD, 2018). At a broader scale, there were 6,462 incidents of non-compliance relating to Blue Swimmer Crabs in the Peel-Harvey between 2009 and 2019, compared to 2,884 across South Australia (Lindley and Quinn, 2023). Exceeding the bag limit and the taking of undersized crabs is highly likely to be related to the consumption-orientated motivations of fishers.

Despite the diversity of recreational crab fishers and complexity associated with managing the human dimensions of fisheries (Floyd et al., 2006; Kyle et al., 2007), the catch-related, consumption-oriented motivation of crab fishers represents a common theme across all fisher groups and each of the four fisheries. Thus, the challenge of managing a broad spectrum of fisher types may be mitigated by focusing on the motivations of fishers rather than the demographics and other fisher characteristics. Several authors note that management focused on motivation types, rather than segmentation based on demographics and other characteristics are more likely to result in desirable management outcomes in the recreation context as motivation is of primary importance in terms of response to management actions (Johns and Gyimothy, 2002; Goeldner and Ritchie, 2011; Carvache-Franco, Segarra-Oña and Carrascosa-López, 2019).

Black Bream

Of the eight salient motivations identified by recreational Black Bream fishers, the most common was *sport/challenge* while *food* was amongst the least selected. As with Blue Swimmer Crabs these motivations were common across all Black Bream fisheries and fisher groups. It is also relevant that 100% of fishers in group *b* (Very frequent, expert lure fishers) selected *Enjoyment of catching a big fish* as a motivation*.* Moreover, when rating motivations *catching a big bream (> 30 cm)* and *catching a legal-sized bream (25 cm)* ranked first and third and the least ranked was *catching as many bream as I am legally allowed to*. A similar result was found for Taimen (*Hucho taimen*) fishing, a salmonid that can reach > 150 cm in length and weigh > 50 kg (https://igfa.org), where recreational fishers preferred to catch fewer trophy-size fish rather than greater numbers of smaller fish (Golden, Free and Jensen, 2019). These data strongly indicate that Black Bream is a trophy-motivated fishery for which the experience of catching a large fish is more important than retention and consumption of the fish (Matlock, Saul and Bryan, 1988; Heard et al., 2016; French et al., 2019).

Black Bream fishers rated being outdoors as a significant component of their recreational experience, with *enjoyment of the outdoors*, *pleasure* and *relaxation* all selected by around 60% of respondents. As with *sport/challenge* motivations, these results were fairly homogenous across the Black Bream fisheries and fisher groups. The enjoyment of the outdoors and relaxation may relate to the nature of Black Bream fishing. Rod-and-line fishing for Black Bream is relatively passive, particularly if using bait rather than lures. Black Bream fishers may spend a significant time focusing on their surroundings while waiting for fish to strike their hook. In contrast, crabbing is a relatively more active fishing method, i.e. wading through water looking down at the benthos to spot crabs, or. dropping and retrieving pots from a jetty or a boat. Thus, recreational crab fishers spend, on average, less time fishing than those targeting Black Bream (cf. Sections 3.1, 3.2).

Being a trophy-orientated rather than consumption-orientated fishery relatively few Black Bream fishers ate their catch (9% of respondents), instead 76% always practiced catch and release with a further 27% doing this sometimes. Similarly, 75% of recreational Red Drum (*Sciaenops ocellatus*) fishers in the southeastern USA release individuals, up from 17% in the 1980s (Vecchio and Wenner, 2007) and Atlantic Bluefin Tuna (*Thunnus thynnus*) fishers in the Hatteras (North Carolina, USA) with a low consumptive orientation were more likely to have a positive attitude toward catch and release fishing and were also more likely to release all individuals caught (Sutton and Ditton, 2001).

There are a number of reasons that may influence the trophy-orientated nature of Black Bream fishing in Western Australia. Firstly, Black Bream are one of the larger species present in the upper reaches of estuaries in the region (Chuwen, Hoeksema and Potter, 2009; Cottingham et al., 2014) and are known to fight hard once hooked relative to their size. Other trophy species present in these waters are the Mulloway (*Argyrosomus japonicus*), which reaches up to 200 cm (but typically individuals in estuaries are up to 100 cm) and the Bull Shark (*Carcharhinus leuca*). However, these species are less numerous and fishing for them is often done using more specialist (heavier) fishing gear and undertaken at night making it less-accessible and therefore less of a family activity. Biological studies have shown that the abundance and biomass of Black Bream in the deeper waters of the Swan-Canning Estuary have declined as fish have moved away from hypoxic waters into the more oxygenated shallow waters (Cottingham et al., 2014; Valesini et al., 2017). This reduces the area of the estuary where fishers are likely to catch Black Bream, but also increases density-dependent effects and slows growth rate (2014; Cottingham et al., 2018b). Thus, there are fewer larger Black Bream, reducing the frequency of catching a trophy-sized fish. The increase rarity may further foster the catch and release mentality by helping to preserve the largest individuals.

In addition to a catch and release philosophy the lack of consumption of Black Bream may be related to their spatial location within estuaries and perceptions on their cleanliness. Black Bream typically reside in the upper reaches, where the effects of estuarine degradation are more pronounced of such as poor water quality, algal blooms (Hallett et al., 2016; Tweedley et al., 2016). These deleterious condition can lead to high profile fish kills in which Black Bream often suffer mortality (Cottingham et al., 2022). Finally, Black Bream are susceptible to epizootic ulcerative syndrome or 'red spot disease' (Callinan et al., 1995; Boys et al., 2012) which caused by an endemic fungus and presents as red lesions or deep ulcers which would make fish unattractive to consume.

1.2.4.3. Management implications

The perceived importance of both fisheries indicated by the data, and the fact that if the fishery was not available fishers for both species would target those species in other systems, could be related to their reputation as iconic fisheries and the fact that the experiences they offer are hard to replicate, albeit slightly less so for crabs. As mentioned earlier, crabbing is an activity suitable for people with a wide range of ages, physical fitness and requires little skill and utilises cheap equipment. Thus, its readily accessible compared to the Western Rock Lobster (*Panulirus cygnus*) fishery which is also very popular in Western Australia (Ryan et al., 2015). However, craypots are more expensive than drop or scoops nets (i.e. ~$150 vs $25) and as this fishing is located in marine waters, a large, and more expensive, boat is typically required. The most analogous crustacean fishing in estuarine waters is that for the Western School Prawn (*Metapenaeus dalli*) and Western King prawn (*Melicertus latisulcatus*) (Smithwick, Reid and Ensor, 2011; Tweedley et al., 2017c). However, despite a successful restocking program, numbers of the former species declined markedly following overwintering mortality and an extreme rainfall event that resulted in extensive hypoxia (Crisp et al., 2018; Tweedley et al., 2019b).

In contrast, there is not direct replacement for Black Bream fishing in the upper reaches of estuaries during daylight hours as Mulloway and Bull Sharks are generally targeted at night and using specialist gear. Fishers would need to head downstream to marginal shoals and partake in ‘flats fishing’ where species such as Tailor (*Pomatomus saltatrix*) and members of the Platycephalidae and Sillaginidae could be targeted. It is also worth pointing out that estuaries offer sheltered environments compared to fishing for demersal or pelagic species using a boat or fishing from rocky platforms from which fishers can be swept and drown (Carvalho, Kennedy and Woodroffe, 2019).

Understanding the common motivations for fishing recreationally can better inform effective management (Barclay et al., 2017). In the case of both Blue Swimmer Crabs and Black Bream, fishers utilising all estuaries and belonging to each of the fisher groups they motivations were fairly consistent, albeit there are subtle differences among fisher groups. However, motivations differed markedly between species despite the fact that the species co-occur in the same estuaries and it is possible that an individual fisher completed the survey for both species. These findings suggest that in Western Australia the motivations for fishing for a Blue Swimmer Crabs and Black Bream are fixed and fairly homogenous, perhaps due to the iconic and longstanding nature of fishing for each species.

Given that Blue Swimmer Crabs are strongly consumption-orientated any management options that restricts the ability of fishers to catch enough crabs to eat, e.g. lowering the bag limit, are likely to be unpopular. On the contrary, any mechanism able to increase the numbers of crabs, such as stock enhancement is likely to be well supported. Similarly, with *Sport/Challenge* being the most common of black bream recreational fishers, and with the high numbers of recreational black bream fishers doing catch and release, bag limits could potentially be a popular approach.

1.3. Perceptions by recreational and commercial fishers on the status and management of crab fisheries in south-western Australia

Obregón, C., Tweedley, J.R., Loneragan, N.R., & Hughes, M. (2020). Different but not opposed: perceptions between fishing sectors on the status and management of a crab fishery. ICES Journal of Marine Science 77 (6): 2354–2368. DOI: 10.1093/icesjms/fsz225.

To reduce duplication with other chapters in this report, sections of this paper have been deleted and reference made to where that information can be sourced elsewhere in the report.

1.3.0. Summary

Fisher perceptions are a useful source of information that allow changes in stocks to be detected quickly and indicate the social acceptability of different management regulations. Yet traditionally, such information is rarely employed when developing management approaches. Face-to-face interviews were used to elicit recreational and commercial fishers' perceptions of a crab (*Portunus armatus*) fishery in three south-western Australian estuaries. Differences in the perceived changes in the average size of crabs and fishing effort, reported concerns and supported solutions were detected among the recreational fishers utilising the three estuaries and between recreational and commercial fishers in the Peel-Harvey Estuary. However, some common views were expressed by recreational and commercial fishers, with both sectors stating concerns over recreational fisher compliance and increased fishing and environmental pressures. While members of both sectors believed that reducing fishing and increasing compliance would benefit crab stocks, the mechanisms for achieving this differed. Recreational fishers favoured increasing the length of the seasonal closure to all fishers, while commercial fishers favoured the introduction of a recreational shore-based fishing license. These findings suggest that sector- and estuary-specific management rules may better facilitate the amelioration of pressures affecting individual estuaries and could contribute towards a more socially and biologically sustainable fishery.

1.3.1. Introduction

Fisheries scientists and managers have traditionally utilised landings or catch data to assess the status of commercially exploited stocks (Pauly, 2016). However, managing fisheries successfully also entails managing human behaviour (e.g. Hilborn, 2007; Gutiérrez, Hilborn and Defeo, 2011). As a result, there have been increasing calls for a transition from traditional catch-related fisheries approaches towards transdisciplinary management, integrating, amongst other elements, data on the human dimensions of fisheries with those more traditional elements of population dynamics and fisheries data (Brooks et al., 2015; Barclay et al., 2017).

While ecosystem-based fisheries management approaches (EBFM) are being used to regulate many fisheries globally, and aim to include ecological, social and economic aspects, rarely have all these elements been translated into practical objectives and management plans (Barclay, 2012; Alexander et al., 2019). Australian fisheries are an example of this transition to full EBFM, and reflect the broader global trends, where the biological and ecological factors receive more focus than human dimensions. For example, Hobday et al. (2016b) assessed 102 Australian fisheries and found that only 22 had a "social" management objective and 25, a social performance indicator. In contrast, almost all fisheries had objectives and indicators for the 'biology' of target, bycatch and protected species and the broader ecosystem. Despite the shortfalls in defining social objectives and performance indicators for fisheries, they are recognised as important for informing policy decisions and to achieve ecologically sustainable development of Australian fisheries (Pascoe et al., 2014a). In addition, government agencies have promoted the concept of triple-bottom-line assessment approaches, a method designed to integrate environmental, social and economic outcomes as part of management goals (Triantafillos et al., 2014), with the aim of facilitating sustainable management of natural resources. To this end, indicators for understanding social sustainability in fisheries, for example, quality of life and social profiles, have been described (Barclay, 2012). However, little is currently known of the human dimensions of fisheries in Australia. Hence, there is a need to develop benchmarks to clarify these aspects of Australian fisheries (Barclay, 2012; Brooks et al., 2015; Barclay et al., 2017).

Co-management has been recognised by managers and scientists globally as a means for integrating human dimensions into fisheries management (e.g. Johannes, 1998; Kearney, 2002). This involves the inclusion of fishers and other key stakeholders in the fishery management decision making process. As well as facilitating fisher support for management decisions, co-management can be a means for accessing and applying local ecological knowledge (LEK; Ulman and Pauly, 2016). Local ecological knowledge includes a range of knowledge based on anecdotal information sharing amongst fishers, such as the current status or perceived changes in catch. While LEK biases need to be taken into account, previous research has demonstrated the value of LEK when other types of data are lacking, or in combination with other types of data to represent trends, and understand stock dynamics (Neis, 1992; Papworth et al., 2009; Ulman and Pauly, 2016). Integration of human dimensions into fisheries management can thus enhance decision making and management effectiveness.

Many species of portunid crabs targeted by commercial and recreational fisheries in the USA, northern Europe, south-east Asia and Australia, have high economic and social values (Guillory et al., 1998; Suwannarat et al., 2017; Johnston, Marks and O'Malley, 2018). Yet, despite the importance of these fisheries to the community, to our knowledge, no previous research has investigated the human dimensions of portunid fishing. The Blue Swimmer Crab, *Portunus armatus*, occurs in estuaries and coastal waters around most of Australia and supports valuable recreational and commercial fisheries (ABARES, 2018). In Western Australia, for example, Blue Swimmer Crab is the most popular recreationally fished species (Ryan et al., 2015; Morison et al., 2016) and has been fished commercially since the early 1900s (Lenanton, 1984; Johnston et al., 2011).

The importance of Blue Swimmer Crab fishing in Western Australia, and particularly in southern regions of the state, is represented partly by the number of people targeting this species, which is much greater in the recreational than commercial sector (Ryan et al., 2015). Moreover, in the 2015/16 fishing season, catches from the recreational sector for the whole of Western Australia (i.e. > 900,000 Blue Swimmer Crab caught, of which > 600,000 were retained) were estimated to be similar in magnitude to, or greater than, those from the commercial sector (Ryan et al., 2015). The recreational Blue Swimmer Crab fishery maintains high profile through its promotion at regional events, such as the annual "Crab Fest" festival on the Peel-Harvey Estuary, which reflects the cultural importance of this crab to the local community and more broadly across south-western Australia. The Peel-Harvey Estuary is part of the Ramsar-listed Peel-Yalgoroup wetland system (Valesini et al., 2019). Its importance as a major natural asset, and the population growth in the region (i.e. the city of Mandurah is located at the mouth of the estuary and is the fastest growing city in the state), create challenges for managing natural resources. Thus, the Peel-Harvey Estuary is also a key focus for fisheries managers and scientists in south-western Australia (Tweedley et al., 2022).

Despite the difficulties of managing a multisector fishery and the impact of environmental variation (Johnston et al., 2011), Blue Swimmer Crab stocks in south-western Australia were generally considered to be sustainable, with the exception of Cockburn Sound, a marine embayment just south of the Swan-Canning Estuary (Figure 4.1). The fishery in this system closed and re-opened twice between 2000 and 2009 and was closed in 2013 and remains so until further notice (Johnston et al., 2011; 2018). Furthermore, both the recreational and commercial sectors of the Peel-Harvey Estuary received Marine Stewardship Council (MSC) certification in 2016, the first joint MSC certification of a fishery globally (Morison et al., 2016). However, due to the iconic nature and popularity of recreational crabbing and the rapidly growing population in the region, there is increasing pressure to reduce the number of commercial fishing licences in estuaries and coastal waters near population centres. In addition, the fishing closure that applies to both sectors of the Blue Swimmer Crab fishery in Cockburn Sound has resulted in increasing fishing pressure in the Peel-Harvey and Swan-Canning estuaries, especially from recreational fishers (Johnston et al., 2011). This has led to growing concerns about the status of Blue Swimmer Crab stocks in the region. As a result, managers initiated a public consultation process in 2017, and conducted a review on the management of the Blue Swimmer Crab resources in south-western Australia.

In Western Australia, this process generally involves the production of a summary of submissions from all sectors and parties (i.e. managers, scientists and other representative bodies) by the Department of Primary

Industries and Regional Development (DPIRD, the state government department responsible for fisheries). The state parliament Minister of Fisheries then considers the submission and holds a meeting with DPIRD representatives to discuss the recommendations presented by that Department and decided which recommendations get implemented. On this occasion, the Minister asked for an additional submission from industry before releasing the new management arrangements for the fishery (Johnston, D. 2019, *pers. comm*.). The extension of the closed season, as well as the buy-out of some commercial licences in the Peel-Harvey Estuary and coastal marine waters, were some of the approved options to reduce fishing pressure (DPIRD, 2018). Other options approved are specific to the recreational sector and include a new bag limit of only five females from the total of 10 crabs allowed in the current bag limit in Geographe Bay (i.e. coastal waters off the Leschenault Estuary), as well as a reduced bag limit of five crabs in the Swan-Canning Estuary.

Changes in fishery management are known to affect not only the exploitation of the resource, but also to influence the human dimensions associated with fisheries (Brooks et al., 2015). For example, fisheries management decisions have led to conflict between the recreational and commercial sectors in many fisheries worldwide, mainly due to policies on the allocation of resources between the sectors (Arlinghaus, 2006c). It is apparent that fully understanding the potential consequences of fisheries management decisions and interventions requires the collection of data on the human dimensions of fisheries. To our knowledge, no studies in Australia or elsewhere have investigated the human dimensions of a portunid fishery. Thus, the overarching aim of this chapter was to identify fishers concerns on issues affecting the fishery and their suggestions for potential management solutions to these issues. Focus was first placed on evaluating whether the views of recreational fishers differed between three estuaries along the west coast of south-western Australia, and secondly between recreational and commercial fishers in the Peel-Harvey Estuary.

1.3.2. Methods

1.3.2.1. Sampling regime

Recreational and commercial Blue Swimmer Crab fishers in south-western Australian estuaries were invited to participate in a face-to-face interview, with a structured, open-ended question format between November 2017 and July 2018. Full details of these surveys are provided in subsections 1.2.2.2 and 1.2.2.3 and Tweedley et al. (2023b). The questions from those surveys related to the current chapter aimed to identify, in the fishers' words, their: i) perceived changes in crab size and fishing effort (i.e. the amount of time taken to catch the same amount of crabs larger than the minimum size limit) from when they started fishing to the present day; ii) concerns on the current status of Blue Swimmer Crab and the management of the fishery; and iii) proposed solutions to their concerns (Table 1.3.1).

Table 1.3.1. Categories of questions (bold italics) and the questions asked of Blue Swimmer Crab fishers' about i) the perceived changes in stocks and the average crab size (perceived changes); ii) their concerns on the issues currently affecting the crab fishery (current concerns and issues); iii) the hypothetical solutions proposed that they would support (solutions supported). Demographic data were also collected.

Perceived changes
1. Has the average size of blue swimmer crab you catch changed over the time you have been fishing?
2. Has the effort needed to catch the same quantity of blue swimmer crab per fishing day/trip increased, decreased or not changed in the last a) 5-10 years b) 10-20 years?
Current concerns and issues
3. Do you have any concerns on the status of the blue swimmer crab populations on this estuary?
4. What do you think are the main issues affecting the blue swimmer crab fishery?
Solutions supported
5. Do you think other management options could be implemented for blue swimmer crab? If so, what?
Demographics
Age, gender, residence, highest level of education, number of years of fishing experience, fishing method

Interviews were conducted with recreational Blue Swimmer Crab fishers who fished in the Peel-Harvey, Swan-Canning and Leschenault estuaries, and with commercial fishers in the first two systems, as the commercial crab fishery in the Leschenault closed in 2001. These three estuaries, which are located along 180 km of coastline (Figure 1.3.1), were chosen because i) they are the hotspots for recreational Blue Swimmer Crab fishing, with no other estuary in the region supporting a crab population large enough to attract fishers; and ii) the variation in the characteristics of the respective systems and fisheries. The Peel-Harvey Estuary, was selected due to the present and historical importance of crab fishing in this system (Lenanton, 1984; Morison et al., 2016) and its proximity to the city of Mandurah (population ~ 80,813). This estuary is also subjected to greater illegal fishing activity, potentially affecting the views of fishers in this estuary (DPIRD, 2018). The Swan-Canning Estuary is located in the state capital city of Perth and is thus highly urbanised (Greater Perth population ~ 2,039,193). Due to its proximity to a major city, this estuary is subjected to anthropogenic impacts, influencing fish populations and fishing activities, including Blue Swimmer Crab fishing. Finally, the Leschenault Estuary is situated in a more rural area (Bunbury; population ~ 32,244; ABS, 2017). This estuary is subjected to the least amount of fishing pressure, due to the lack of commercial fishing and generally lower popularity for crab fishing in the recreational fishing community. As Blue Swimmer Crab is less abundant in waters south of the Leschenault Estuary (Fletcher and Santoro, 2008), sampling was not conducted in these systems.

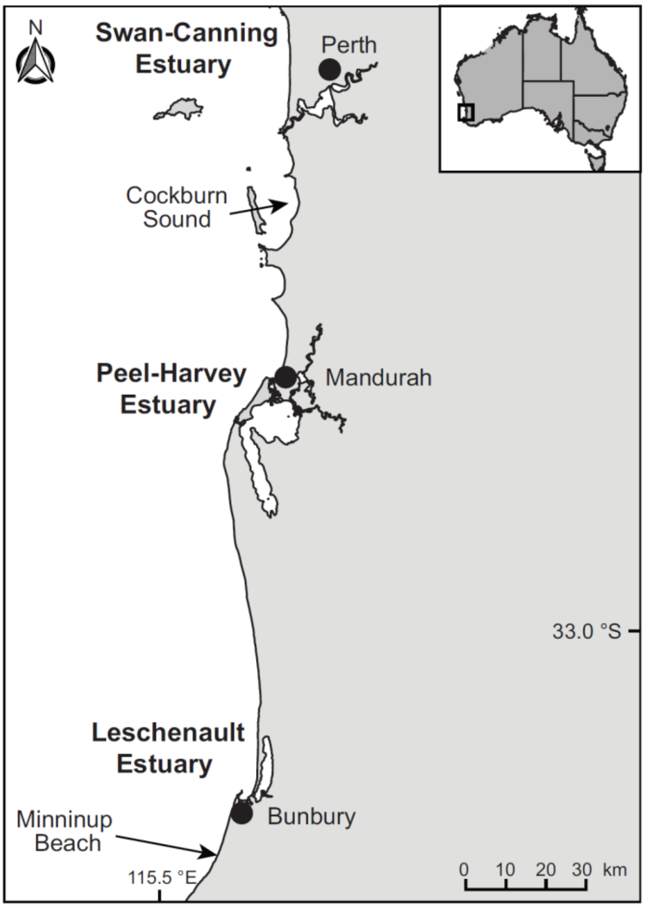

Figure 1.3.1. Location of the three estuaries in south-western Australia where interviews with recreational fishers were conducted.

1.3.2.2. Data analyses

The data from both recreational and commercial fishers were subjected to content analysis, conducted independently by two researchers to categorise responses with similar meanings. Any differences in response categories between researchers were discussed until agreement was reached on an appropriate category of response. Perceived changes in crab catches, as well as salient concerns and solutions about management of the fishery were identified based on the frequency of responses. For the views of recreational fishers, a theoretical saturation approach was adopted to determine when no new categories of response were recorded for each estuary (Hughes, Weiler and Curtis, 2012). Theoretical saturation was then confirmed by adapting species accumulation techniques (Ugland, Gray and Ellingsen, 2003), to plot response type accumulation curves (Vanwindekens, Stilmant and Baret, 2013). Once theoretical saturation was achieved, a small number of additional interviews were conducted to ensure that no salient response category was overlooked. As all commercial fishers operating in both the Peel-Harvey and Swan-Canning estuaries were interviewed, their views represent a census.

Non-parametric Chi-square tests ("fifer" package in R Studio, Version 3.3.1), were used to determine whether i) the reported average size of crabs and ii) the reported effort required to catch crabs of legal-minimum-size differed significantly ($p < 0.05$) among recreational fishers with different levels of experience (three levels; i.e. < 10, 10-30, and > 30 years) and recreational fishing methods (three levels; i.e. boat fishing, shore fishing, both boat and shore fishing). This same approach was applied to test for differences i) among responses of recreational fishers in the three estuaries and ii) between responses of recreational and commercial fishers operating in the Peel-Harvey.

The same Chi-square approach was also used to determine whether the number of recreational fishers concerned with the state of the fishery differed with either fishing experience, method or estuary and between recreational and commercial fishers operating in the Peel-Harvey. These tests were also applied to determine whether the concerns of recreational fishers differed among levels of experience or fishing methods. These latter two tests were also repeated to examine whether the proposed management solutions of recreational fishers differed among estuaries.

The presence/absence of concerns and proposed solutions reported by recreational and commercial fishers, excluding the "NA" and "None" answers, in the three estuaries were used to construct two data matrices (i.e. concerns and solutions for both sectors combined). As some of the recreational fishers reported only a single concern or solution, the views of any two recreational fishers from the same estuary may differ markedly and this variability can mask subtle, but "true", trends in salient concerns and solutions. Thus, the recreational fishers utilising each estuary were randomly sorted into groups of two to four, depending on the total number of fishers surveyed and the data averaged and converted to presence/absence. This mirrors the statistical approach often used in multivariate analyses of fish dietary data as many species consume, at any one point in time, a limited range of prey (Lek et al., 2011; Maschette et al., 2020). Note that all the commercial fishers listed more than one single concern or solution and thus these data were not averaged.

Each of the two data matrices (i.e. concerns and solutions) were used to construct two separate Bray-Curtis resemblance matrices, namely one for recreational fishers in the three estuaries and the other for recreational and commercial fishers in the Peel-Harvey Estuary (four in total). Each matrix was subjected to Analyses of Similarities (ANOSIM; Clarke et al., 2014) to determine if the concerns and solutions of i) recreational fishers in the three estuaries differed significantly and ii) whether they differed significantly between recreational and commercial fishers in the Peel-Harvey Estuary ($P < 0.05$). The relative magnitudes of the main test and any subsequent pairwise tests were assessed using the universally-scaled R-statistic, which ranges from ~ 0, when the average similarity among and within groups (samples) do not differ, to 1, when all samples within each group are more similar to each other than to any of the samples from other groups (Clarke et al., 2014). When a significant difference was detected, Similarity Percentages (SIMPER; Clarke et al., 2014) were used to identify those responses that typified each group and those that were responsible for distinguishing between each pair of groups.

Non-metric Multi-Dimensional Scaling (nMDS) was employed to visualise the trends detected by ANOSIM. Each of the four resemblance matrices was subjected to the Bootstrap Averages routine (Clarke et al., 2014) to bootstrap those samples in non-metric MDS space. The averages of repeated bootstrap samples (bootstrapped averages) for each group of samples (*e.g.* recreational and commercial fishers in the Peel-Harvey Estuary) were used to construct an nMDS ordination plot. Superimposed on each plot was i) a data point representing the group average (i.e. the average of the bootstrapped averages) and ii) the associated, smoothed and marginally bias-corrected bootstrap region, in which 95% of the bootstrapped averages fall (Clarke et al., 2014).

1.3.3. Results

A total of 109 recreational crab fishers were approached to participate in the survey, with 93 agreeing to participate, a response rate of 85%. Theoretical saturation was achieved after about 30 interviews (Figure 1.3.2). All commercial crab fishers actively working in the region (n = 11) agreed to participate in the face-to-face interviews, so these responses represent a census of the views of commercial fishers.

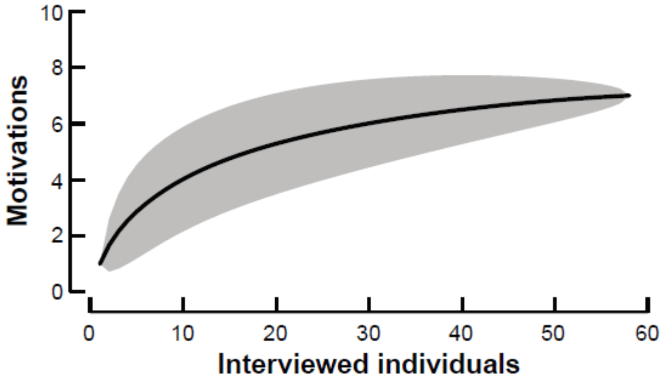

Figure 1.3.2. Response-accumulation curve showing that data saturation was reached after around 30 interviews with recreational Blue Swimmer Crab fishers in Peel-Harvey, Swan-Canning, and Leschenault estuaries in south-western Australia. Grey shaded area denotes the 95% confidence intervals.

Respondents from the recreational sector in south-western Australia had been fishing for Blue Swimmer Crabs for an average of 21.8 years. They ranged from 18 to over 65 years old, with a modal age group of 35 to 44 years old (23.1%). Most of the respondents were male (86.7%) and resided in Western Australia (98.9%). Nine of the eleven commercial fishers (81.8%) were current members of the "Mandurah Licensed Fisherman's Association*"*, a professional fishing association representing the views of commercial fishers operating in the Peel-Harvey Estuary. The two operators in the Swan-Canning Estuary held a single licence for 2017/18 sequentially, one up to February 2018 and the other from February 2018 onwards, i.e. they were independent operators and did not fish during the same years. The professional fishers ranged from 18 to over 65 years old. All except one were male (90.9%) and had been in the industry for an average of 12.4 years.

The motivations for fishers of both sectors were very different, with over 80% of the recreational fishers reporting "food" as their main motivation, whereas "family tradition" and a "love for fishing" were the two main motivations for commercial fishers (72.7%). Fishing as a means of employment, was only mentioned as a main motivation by one commercial fisher (9.1%).

1.3.3.1. Perceived changes in crab size and fishing effort

Changes in size

Across all estuaries, over half (53.8%) of the recreational fishers reported a decline in the average size of Blue Swimmer Crabs caught over the years they had been fishing. Of the remainder, 16.1% reported that the size had not changed, 8.6% that it had increased and 5.4% reported that size varied between years. The perceived changes in the average size of crabs did not differ significantly among recreational fishers with different levels of experience ($X^2_6 = 7.42$; $p = 0.283$) or between fishing methods ($X^2_{12} = 10.85$; $p = 0.541$). However, the perception of size changes differed significantly among estuaries ($X^2_6 = 17.66$; $p = 0.007$). A much greater proportion of fishers utilising the Peel-Harvey Estuary considered that the average size of Blue Swimmer Crabs had declined (70.7%), than respondents in the Leschenault (53.6%) and the Swan-Canning Estuary (25.0%, Figure 1.3.3a).

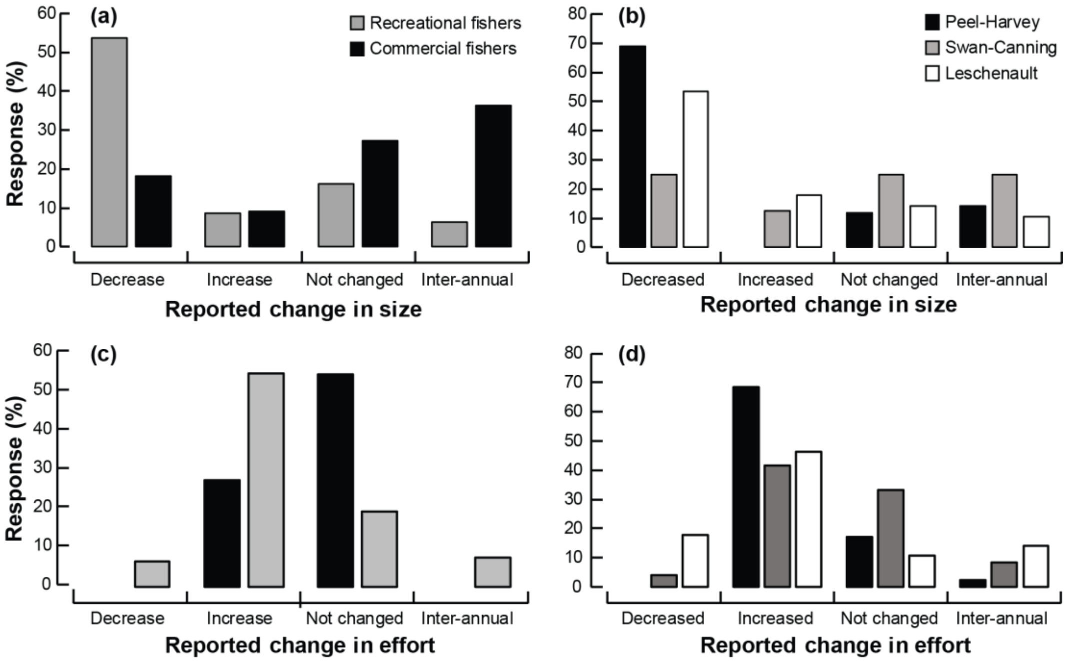

Figure 1.3.3. Perceived changes in average size (a, b) and fishing effort (c, d) of Blue Swimmer Crabs provided by (a, c) recreational (n = 41) and commercial fishers (n = 9) in the Peel-Harvey Estuary and (b, d) recreational fishers (n = 93) fishing in the Peel-Harvey, Swan-Canning and Leschenault Estuary.

Among the commercial fishers, only two fishers (one in the Swan-Canning and one in the Peel-Harvey; 20.0%) reported a decline in average crab size, while 40.0% thought that crabs undergo inter-annual changes in size. In the Swan-Canning Estuary, the most experienced commercial fisher reported a dramatic decline in average crab size during the last decade.

Within the Peel-Harvey Estuary, responses from the recreational and commercial sector differed significantly (X^2_3 = 21.46, $p < 0.001$): 70.7% of recreational fishers reported a decrease in the average size of Blue Swimmer Crabs caught, whereas only one commercial fisher (11.1%) reported a decline (Figure 1.5.3b). For commercial fishers, 33.3% said that size remained unchanged and 44.4% commented that the crabs undergo inter-annual changes in size. These latter two responses contrast with those of recreational fishers, where only 14.3% and 2.4% reported no change or inter-annual changes in size, respectively.

Changes in fishing effort

Across all three estuaries, 54.8% of recreational fishers described an increase in the amount of effort (i.e. time) needed to catch the same number of Blue Swimmer Crabs, i.e. "Crabs are harder to catch". Only 6.5% reported that the effort required to catch Blue Swimmer Crabs had decreased since they first started crabbing. The perceived changes in effort required to catch crabs did not differ significantly among recreational fishers with different levels of experience (X^2_4 = 6.37; p = 0.817) or between fishing methods (X^2_{15} = 16.05; p = 0.379). However, it differed significantly among the three estuaries (X^2_{12} = 27.39; p = 0.006), with proportionally more fishers from the Peel-Harvey Estuary (68.3%) reporting an increase in the fishing effort needed to catch crabs since they started fishing than in the other estuaries (41.7% in the Swan-Canning and 46.4% in the Leschenault; Figure 1.3.3c).

Among the commercial fishers operating in the Swan-Canning and Peel-Harvey estuaries, 30.0% reported an increase in effort, whereas 60.0% perceived no change since they started fishing. In the Swan-Canning Estuary, the most experienced commercial fisher reported an increase in fishing effort

In the Peel-Harvey Estuary, the views of recreational and commercial fishers on changes in effort differed significantly (X^2_1 = 9.73; p = 0.007), with over two-thirds of recreational fishers (68.3%) reporting an increase in effort needed to catch Blue Swimmer Crabs, whereas only 22.2% of commercial fishers held this view (Figure 1.3.3d). Conversely, two thirds of commercial fishers in the Peel-Harvey (66.7%) said that the fishing effort required to catch Blue Swimmer Crabs had not changed over time, compared with only 17.1% of recreational fishers.

1.3.3.2. Concerns on the current Blue Swimmer Crab status and main issues affecting the fishery

When asked whether fishers had any concerns on the current status of crab stocks, 51.6% of recreational fishers interviewed across all estuaries reported no concerns, 41.9% expressed a concern, while 6.5% did not provide a clear answer. While the relative number of concerned fishers did not differ significantly with fishing method (X^2_{12} = 12.92; p = 0.374) or fishing experience (X^2_{2} = 1.20; p = 0.548), they differed significantly among estuaries (X^2_{2} = 7.51; p = 0.023). Of the recreational fishers in the Swan-Canning and Leschenault estuaries, 70.8% and 53.6%, respectively, were unconcerned about the status of the Blue Swimmer Crab population, whereas 4.2% and 14.3% respectively had no opinion on the matter. However, only 39% of fishers in the Peel-Harvey reported no concerns (and 2.4% had no opinion). In contrast, 58.5% of the recreational fishers in the Peel-Harvey Estuary were concerned about stock status.

Most commercial fishers in the Swan-Canning and Peel-Harvey estuaries (88.9%) were not concerned about Blue Swimmer Crab stocks, with only one of nine commercial fishers in the Peel-Harvey (11.1%) expressing concerns. The proportion of concerned fishers in the Peel-Harvey differed significantly between recreational and commercial fishers (X^2_{1} = 5.21; p = 0.023), with more concerned recreational than commercial fishers.

Fishers were given the opportunity to identify the source of their concerns by describing the issues they thought were affecting the Blue Swimmer Crab fishery in the estuary where they fished most regularly. A total of 13 different issues were identified, five of which were shared between recreational and commercial fishers (Table 1.3.2). The four most commonly described issues by recreational fishers across the three estuaries, which collectively accounted for 80% of all responses, were: lack of compliance, overfishing, pollution and more people fishing (i.e. more fishing pressure). The concerns reported by recreational fishers did not differ significantly among levels of fishing experience (X^2_{18} = 20.14; p = 0.325), among estuaries (X^2_{18} = 26.30; p = 0.092) or between fishing methods (X^2_{54} = 34.86; p = 0.98).

Table 1.3.2. Percentage number of recreational and commercial fishers who reported various concerns affecting the Blue Swimmer Crab fisheries in the Peel-Harvey, Swan-Canning and Leschenault estuaries during face-to-face interviews.[10]

	Recreational fishers				Commercial fishers		
Concerns reported (*n*)	**All (*93*)**	**Peel (*41*)**	**Swan (*24*)**	**Lesch. (*28*)**	**All (*11*)**	**Peel (*9*)**	**Swan (*2*)**
Lack of compliance	**29.0**	46.3	20.8	10.7	**18.2**	22.2	
Overfishing	**22.6**	29.3	16.7	17.9	**9.1**		50.0
Pollution	**18.3**	12.2	29.2	17.9			
More people fishing	**10.8**	7.3	12.5	14.3	**36.4**	22.2	100.0
N/A	**9.7**	9.8	12.5	7.1			
Commercial fishing	**6.5**	7.3		10.7			
Environmental factors	**5.4**		8.3	10.7	**27.3**	22.2	–
None	**5.4**	2.4	4.2	10.7	–	–	–
Estuary development	**4.3**	2.4	8.3	3.6	**27.3**	22.2	50.0
Ineffective management	**2.2**	2.4		3.6			
Invasive species	**1.1**		4.2				
Education					**9.1**	11.1	
Market share					**9.1**	11.1	
Not enough food for crabs					**18.2**	22.2	
Pressure to remove commercial fishing					**9.1**	11.1	

[10] The number of fishers surveyed from each sector in each system is given in parentheses.

The most frequent concerns raised by commercial fishers across the Swan-Canning and Peel-Harvey estuaries were environmental factors, estuary development, more people fishing, lack of compliance, and not enough food for crabs (Table 1.3.2). Each of these concerns, except for the last, was also mentioned by recreational fishers, albeit less frequently (Table 1.3.2).

Although ANOSIM detected a significant difference between the perceived concerns of recreational fishers across the three estuaries, the magnitude of that difference was relatively small (ANOSIM Global $R = 0.112$; $P = 0.032$). At a pairwise level, the views of fishers utilising the Peel-Harvey differed from those of fishers in both the Swan-Canning and Leschenault estuaries, which did not differ from each other (Figure 1.3.4a). This is shown graphically on the nMDS plot, with the 95% bootstrapped region for Peel-Harvey Estuary fishers forming a relatively discrete group, while those of the Swan-Canning and Leschenault fishers overlapped substantially (Figure 1.3.4a). A lack of compliance and overfishing were identified by SIMPER as typifying the concerns for recreational fishers in the Peel-Harvey Estuary, whereas pollution and overfishing were the major concerns identified by respondents using the Swan-Canning and Leschenault estuaries (Table 1.3.3a). Lack of compliance and overfishing were more prevalent in the Peel-Harvey Estuary, distinguishing this system from the other two.

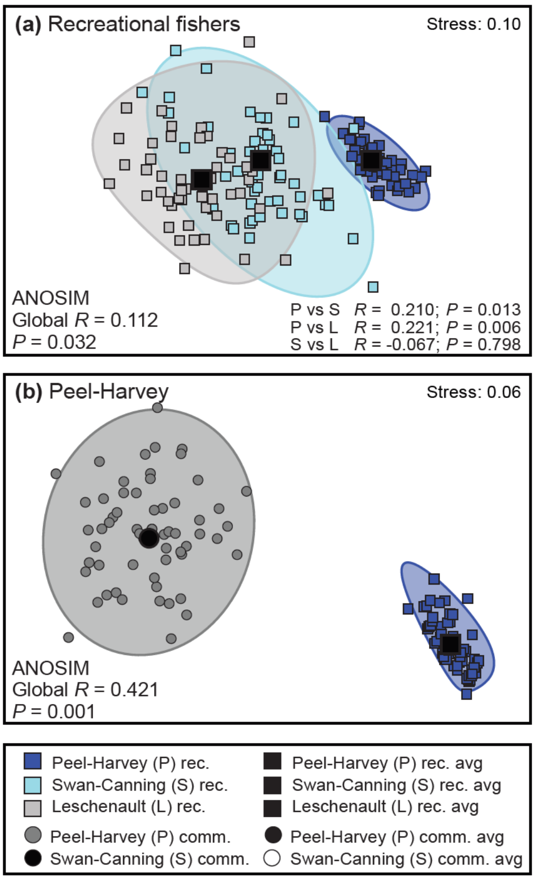

Figure 1.3.4. Two-dimensional nMDS ordination plots constructed from bootstrap averages of the presence/absence of the perceived concerns reported by (a) recreational Blue Swimmer Crab fishers in the Peel-Harvey, Swan-Canning, and Leschenault estuaries and (b) commercial and recreational fishers in the Peel-Harvey Estuary.[11]

When restricted to the Peel-Harvey Estuary, the perceived concerns of commercial fishers differed from those of their recreational counterparts (ANOSIM Global $R = 0.421$; $P = 0.001$). This difference was substantially greater than the corresponding value for the recreational fishers in the three estuaries and is clearly shown on the associated nMDS plot, where the two sectors form entirely discrete groups (Figure

[11] Results of a one-way ANOSIM test are also included on each plot to aid interpretation. Group averages (larger symbols) and ~95% region estimates (shaded areas) fitted to the bootstrap averages are provided.

1.3.4b). A lack of compliance and overfishing typified the concerns of recreational fishers, with the former response together with more people fishing and not enough food for crabs typifying those of the commercial sector (Table 1.3.3b). While a lack of compliance was selected by SIMPER as characterising the views of both sectors, it distinguished the two groups by being raised more by recreational fishers.

Table 1.3.3. Concerns identified by SIMPER analysis that typified (shaded) and distinguished (non-shaded) the views of (a) recreational fishers in the three estuaries and (b) recreational and commercial fishers in the Peel-Harvey Estuary. [12]

(a) Estuary	Peel-Harvey	Swan-Canning	Leschenault
Peel-Harvey	Lack of compliance Overfishing		
Swan-Canning	Lack of compliance *Peel* Overfishing *Peel* Pollution *Swan*	Pollution Overfishing	
Leschenault	Lack of compliance *Peel* Overfishing *Peel* More people fishing *Lesch*		Pollution Overfishing

(b) Peel-Harvey	Recreational	Commercial
Recreational	Lack of compliance Overfishing	
Commercial	Lack of compliance *Rec* More people fishing *Com* Overfishing *Rec*	More people fishing Not enough food for crabs Lack of compliance

1.3.3.3. Proposed solutions for the issues impacting the Blue Swimmer Crab fishery

Overall, 15 solutions (excluding the "NA", "None" and "Unsure" categories) were proposed to help manage the Blue Swimmer Crab fishery in the three estuaries, with four solutions expressed by both sectors (Table 1.3.4). Across all estuaries, recreational fishers proposed two solutions that were supported by considerably more fishers than any of the other proposed solutions (Table 1.3.4): i) increased resources to ensure compliance (20.4%); and ii) support for a closed fishing season (19.4%). Only four of the 93 recreational respondents (4.3%) mentioned the removal of the commercial fishing as a potential solution (Table 1.3.4). The proposed solutions did not differ significantly among fishing methods ($X^2_{64} = 56.27$; $p = 0.742$) or fishing experience ($X^2_{32} = 44.20$; $p = 0.07$). Yet, these differed among estuaries ($X^2_4=16.128$; $p = 0.002$), with recreational fishers from the Peel-Harvey Estuary showing a stronger support for an increase in compliance and longer closed season than in the other two estuaries.

Commercial fishers in the Peel-Harvey and Swan-Canning estuaries identified the introduction of a licence for shore-based recreational fishers (54.5%), followed by an increase in resources to enhance compliance (27.3%; Table 1.3.4) as the most common potential solutions. While the proportions of respondents supporting additional resources to enhance compliance were similar in both sectors (i.e. 29.7% of recreational and 27.3% of commercial respondents), only 4.7% of recreational fishers identified a recreational fishing licence as a potential solution (Table 1.3.4). Both commercial and recreational sectors identified a closed or extended closed season as a solution, but this view was more frequently expressed by recreational (28.1%) than commercial fishers (9.1%).

[12] The text in superscript denotes the group of fishers that each distinguishing response was most selected by. Note ANOSIM did not detect a significant different between the concerns identified by recreational fishers in the Swan-Canning and Leschenault estuaries.

Table 1.3.4. Percentage number of recreational and commercial fishers who reported perceived solutions to improve the management of Blue Swimmer Crab fisheries in the Peel-Harvey, Swan-Canning and Leschenault estuaries provided by recreational and commercial fishers during face-to-face interviews. [13]

	Recreational fishers				**Commercial fishers**		
Solutions reported	**All**	**Peel**	**Swan**	**Lesch.**	**All**	**Peel**	**Swan**
(*n*)	***(93)***	***(41)***	***(24)***	***(28)***	***(11)***	***(9)***	***(2)***
None	**30.1**	14.6	37.5	46.4			
Increase compliance	**20.4**	36.6	12.5	3.6	**27.3**	33.3	
Longer closed season	**19.4**	26.8	4.2	21.4	**9.1**	11.1	
N/A	**6.5**	2.4	12.5	7.1	**9.1**	11.1	
Unsure	**6.5**	2.4	12.5	7.1			
Remove commercial fishing	**4.3**	7.3	4.2				
Waterway management	**3.2**	4.9	4.2				
Education	**3.2**	7.3					
Increase size limits	**3.2**	2.4		7.1			
Licence for recreational fishers	**3.2**	2.4		7.1	**54.5**	55.6	50
Reduce bag limits	**3.2**		4.2	7.1			
Ban female catches	**2.2**	2.4	4.2				
Improve management	**2.2**	2.4	4.2		**9.1**		50
More research	**1.1**		4.2				
No fishing zones	**1.1**	2.4					
Reduce commercial catches	**1.1**		4.2				
Reduce recreational catches					**9.1**	11.1	

One-way ANOSIM detected a significant difference among the views of recreational fishers on management solutions across the three estuaries both overall (Global R = 0.185; p = 0.001) and between all pairwise combinations (pairwise R = 0.124 to 0.248, p = 0.005 to 0.044). This is reflected in the general separation between each 95% bootstrapped region on the nMDS plot (Figure 1.3.5a). The fairly small magnitude of the differences between groups is due to increase compliance and/or closed season typifying the responses from fishers in each estuary (Table 1.3.5a). The difference lies, however, in the fact that increased compliance was identified more by fishers from the Peel-Harvey Estuary than the other two estuaries, whereas fishers from the Swan-Canning wanted more research and those from the Leschenault, a closed season and a licence for shore-based recreational fishers (Table 1.3.5a).

The fisher responses on potential solutions differed significantly between sectors in the Peel-Harvey Estuary (ANOSIM Global R = 0.385; p = 0.001; Figure 1.3.5b). These differences were due, in part, to more commercial fishers suggesting a licence for shore-based recreational fishers, whereas more recreational fishers favoured increasing compliance and a closed season as the proposed solutions (Table 1.3.5b).

[13] The number of fishers surveyed from each sector in each system is given in parentheses.

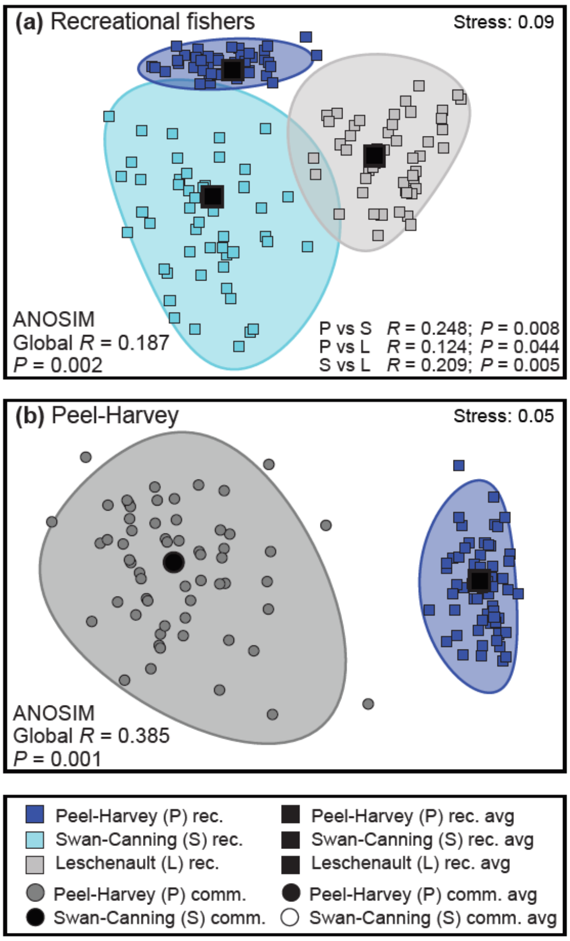

Figure 1.3.5. Two-dimensional nMDS ordination plots constructed from bootstrap averages of the presence/absence of the perceived solutions reported by (a) recreational Blue Swimmer Crab fishers in the Peel-Harvey, Swan-Canning, and Leschenault estuaries and (b) commercial and recreational fishers in the Peel-Harvey Estuary.[14]

Table 1.3.5. Proposed solutions identified by SIMPER analysis (PRIMER v7) that typified (shaded) and distinguished (non-shaded) the views of (a) recreational fishers in the three estuaries and (b) recreational and commercial fishers in the Peel-Harvey Estuary.[15]

(a) Estuary	Peel-Harvey	Swan-Canning	Leschenault
Peel-Harvey	Increase compliance Closed season		
Swan-Canning	Increase compliance [Peel] Closed season [Peel] More research [Swan]	Increase compliance	
Leschenault	Closed season [Lesch] Increase compliance [Peel] Licence for recreational fishers [Lesch] Increase size limits [Lesch]	Closed season [Lesch] Increase compliance [Swan] Licence for recreational fishers [Lesch] Increase size limits [Lesch]	Closed season

(b) Peel-Harvey	Recreational	Commercial
Recreational	Increase compliance Closed season	
Commercial	Licence for recreational fishers [Com] Increase compliance [Rec] Closed season [Rec]	Licence for recreational fishers

[14] Results of a one-way ANOSIM test are also included on each plot to aid interpretation. Group averages (larger symbols) and ~95% region estimates (shaded areas) fitted to the bootstrap averages are provided.

[15] The text in superscript denotes the group of fishers that each distinguishing response was most selected by.

1.3.4. Discussion

This research identified and analysed the perceptions of recreational and commercial crab fishers regarding the current population status, concerns and socially supported solutions for the management of an economically and culturally important recreational portunid fishery in south-western Australia. Despite the importance of such fisheries to communities globally (Guillory et al., 1998; Suwannarat et al., 2017), to our knowledge, this is the first work to investigate the human dimensions of a portunid fishery anywhere in the world. The interview approach used in this research enabled researchers to record and categorise fishers' words as responses (see also Obregón et al., 2020b). This method limited any potential bias from the research as responses were not interpreted by researchers. Although, major differences were found between the views on stocks (abundance and size of crabs) concerns and solutions between commercial and recreational fishers in the Peel-Harvey Estuary, both sectors identified some common concerns and solutions that they would support. Less marked differences were found between the responses from recreational fishers across estuaries, although the responses provided by recreational fishers from the Peel-Harvey Estuary were significantly different from those in the Swan-Canning and Leschenault estuaries.

1.3.4.1. Reported changes in the size of Blue Swimmer Crabs and fishing effort

Recreational and commercial fishers in south-western Australia reported perceived changes in the catches of Blue Swimmer Crab, but the types of changes differed between sectors. The decline in size and increase in time required to catch crabs perceived by recreational fishers across the three estuaries reflects quantitative trends in fishery independent data (DPIRD, 2018). This perceived decline was particularly marked in the Peel-Harvey Estuary, where a rapidly increasing human population has coincided with more intensive farming practices in its catchments and expanding urbanisation around the estuary (Valesini et al., 2019). These changes have negatively influenced the invertebrate and fish faunas of the estuary (Potter et al., 2016; Rose et al., 2019). Tweedley et al. (2014b) showed that between the 1980s and 2000s, macroinvertebrate communities declined to a greater extent in the Peel-Harvey than nearby Swan-Canning Estuary, suggesting a reduction in benthic-habitat quality in the Peel-Harvey.

Cyanobacteria blooms of *Nodularia spumigena* were an issue in the Peel-Harvey during the late 1970s and 1980s (Potter et al., 2016). To alleviate this, a second and artificial entrance channel, known as the Dawesville Cut, was created in 1994. This engineering solution resulted in an ecological shift towards a more marine state, reduced frequency of algal blooms, and increased access for crabs and other marine species into the estuary (Valesini et al., 2019). These changes resulted in an initial increase in the size and abundance of Blue Swimmer Crabs, as well as increased recreational fishing pressure (de Lestang, Hall and Potter, 2003a). Commercial fishers in the Peel-Harvey Estuary also reported changes in the population and size of crabs caught, but considered that these were a result of inter-annual fluctuations, rather than being a long-term trend. Johnston et al. (2011) noted that Blue Swimmer Crab stocks in this region are distributed towards the southern limit of their temperature tolerance and are, therefore, more affected by environmental variation, such as annual temperature and rainfall events than Blue Swimmer Crabs in the northern regions. As a self-recruiting population, with little interaction between Blue Swimmer Crab populations in other water bodies, changes in environmental conditions can lead to inter-annual fluctuations in population abundance and crab size (Johnston et al., 2011).

The analysis of recollections from fishing communities, sometimes referred as local ecological knowledge, may be used to provide an accurate representation of changes in fishery stocks (e.g. Neis, 1992; Johannes, 1998; Strieder Philippsen et al., 2017). While in the current chapter each sector reported a different perception of the types of changes affecting the Blue Swimmer Crab populations, both sectors reported a change affecting the blue swimmer crab stocks. Recreational fishers perceived a reduction in crab size and increase in effort to catch the bag limit, while commercial fishers perceived inter-annual changes in crab size. These different perceptions might be a result of sector-specific bias. It is likely that the difference in time and intensity of fishing for crabs by commercial and recreational fishers influences their view on changes in the crab population. Such sector-specific bias has been recorded in other studies. For example, Carr and Heyman (2012) interviewed 42 commercial spear and trap fishers and 56 island residents representing other sectors (tourism, hospitality, resource managers) in St. Croix (United States Virgin Islands) and found distinct biases in commercial fisher perspectives compared with the other sectors, i.e. fishers were very against large spatial closures as a management option compared with the other sectors, suggesting that fishers can possess a specific, biased perspective that differs to the biases of other stakeholder groups. However, studies comparing the perceptions of different fishery sectors are not common. One exception is a study of local ecological knowledge among different fishing sectors (i.e. artisanal, recreational and bottom trawl sectors) in Turkey, which found that the perceived changes in resource abundance by fishers in each sector matched four-fold declines in CPUE over 43 years (Ulman and Pauly, 2016).

If different biases have influenced the responses of the two sectors in the Peel-Harvey Estuary, it may be that both the inter-annual variations (perceived by the commercial fishers), and the long-term changes (reported by the recreational fishers) are occurring. Greater understanding regarding the differences in biases from various fishing sectors is needed (Shepperson et al., 2014). Because the responses from each sector are not consistent, historical quantitative records on Blue Swimmer Crab stocks from different sources (*e.g.,* fishing diaries, newspaper records, among others) are needed. A comparison between both datasets will help determine if catches have declined or if these results are based on individuals' perceptions. The perceptions of the two sectors together may highlight issues that managers may not otherwise prioritise. Further insight into the reasons for differences in perception would provide a greater understanding of the biases affecting the different fishing groups and may clarify the validity of fisher perceptions for assessing long-term trends.

1.3.4.2. Concerns on the status and reported issues affecting the fishery

The main issues reported by the respondents across the three estuaries were i) lack of compliance, ii) overfishing (and more people using the estuary) and iii) pollution. More recreational fishers were concerned about lack of compliance and overfishing in the Peel-Harvey than in the Swan-Canning and Leschenault estuaries. The greater level of concern in the Peel-Harvey Estuary parallels the perceptions regarding long-term changes affecting crab size and numbers associated with rapid human population growth and development in the region.

As with perceptions of changes in size and fishing effort, the reported concerns about lack of compliance in the Peel-Harvey Estuary and overfishing appear to be complimented by documented evidence. For example, the Peel-Harvey crab fishery has the highest-recorded levels of non-compliance in the state, with 20% of all reported enforcement issues along the Western Australian coast being from this estuary (DPIRD, 2018). The fact that the Peel-Harvey Estuary is the most popular site for crabbing in the state, combined with its large area (surface area ~ 134 km^2), means that enforcing the Blue Swimmer Crab fishery regulations is challenging. Furthermore, despite the use of thermal camera technologies that allow night-time monitoring (Taylor et al., 2018), the difficulties and dangers of monitoring fishing activities and enforcing regulations are much greater at night than in the day (Cooke et al., 2017), which is likely to contribute to the high rate of non-compliance in the estuary. The high rate of documented non-compliance could be due to higher rates of infringement, but also because more observers report suspicious fishing activities due to greater population and concentration of fishers in the Peel-Harvey. Whether more infringements are committed, or more people observe non-compliance activities, fishers' perceptions indicate that non-compliance in the Blue Swimmer Crab fishery is a cause for greater concern in this system compared to the Swan-Canning and Leschenault estuaries where crab fishing is also popular. Compliance affects fisheries globally, and has been described as key to achieve sustainable fisheries management (Hauck, 2008). Fishers' perceptions of non-compliance could potentially be used as an indicator to identify a change in non-compliance rates in a fishery system.

In terms of overfishing concerns, the Peel-Harvey Estuary has long been popular for recreational Blue Swimmer Crab fishing, with many fishers travelling from areas outside the region to catch crabs in this estuary. Furthermore, research demonstrates that the recreational crab fishers are active 24 hours a day, seven days a week (Taylor et al., 2018). The different methods used to catch crabs (*i.e*. boat and shore-based) allow recreational fishing effort to occur in the shallow and deeper waters during the day and night. Additionally, local promotional events such as "Crab Fest", aim to increase the appeal of the Peel region for crab fishing, encouraging more recreational fishers to fish in this estuary (Johnston et al., 2011). Therefore, the concerns highlighting overfishing and more people using the estuary, specifically in the Peel-Harvey Estuary, could be founded on a greater increase in fishing pressure on the stocks in this system, compared to the Swan-Canning and Leschenault estuaries. Anthropogenic pressure and increasing fishing pressure affect fishery systems globally. It is key to determine when the level of fishing pressure might exceed sustainable levels. The recollection of fishers' perceptions and local ecological knowledge on historical catch of a fishery could help managers and scientists in detecting high levels of pressure in a fishery system (Ulman and Pauly, 2016).

In contrast to the concerns about compliance and overfishing in the Peel-Harvey Estuary, concerns about pollution were most frequently reported by recreational fishers in the Swan-Canning and Leschenault estuaries. No data currently exists on what influences fishers' perceptions in south-western Australia. However, studies elsewhere have shown that users classify water quality based on visual attributes such as colour, smell of the water and presence/absence of water plants (Smith, Cragg and Croker, 1991). For example, when a pollution-related event occurs in the Swan-Canning Estuary (*e.g*. algal bloom, major fish kill), the effects are readily visible to the public as most of the shoreline of the estuary is urbanised (Swan River Trust, 2000). In contrast, the City of Mandurah is mainly located at the mouth of the Peel-Harvey Estuary and major pollution events usually occur in upstream areas of the Peel-Harvey catchment, within the Murray and Serpentine Rivers, which are less urbanised. Hence, pollution-related events may be less directly visible to the general public and crab fishers in the Peel-Harvey Estuary than in the other two estuaries. In the 21st century, the general public is increasingly aware of some of the impacts anthropogenic activities have on the environment (Gelcich et al., 2014). Yet, it is still unclear how the concern of an impact on the environment is accepted by a local population, and considered important enough to be shared among the community (Kollmuss and Agyeman, 2002). Understanding what triggers individuals' perceptions of potential factors impacting the environment is an important aspect for managers, scientists and educators as it provides them with a better understanding on the knowledge gaps and effective ways to help develop environmental awareness among local communities (Kollmuss and Agyeman, 2002). Understanding the reasons behind fishers' perceptions on the status of the stocks and their concerns also informs managers and scientists of the priorities of these stakeholder groups, and if these align with current management goals and regulations. This information could ultimately inform ongoing efforts to integrate the human dimensions in fisheries management to achieve biological and social objectives (Copsey et al., 2011).

1.3.4.3. Solutions proposed

The introduction of a closed season, or the extension of the existing closed season, were more commonly suggested by recreational fishers in the Peel-Harvey and Leschenault estuaries than in the Swan-Canning. In the Peel-Harvey Estuary, recreational fishers showed greater support for this management approach than the commercial sector. Other studies have previously reported a preference by fishers for restricting fishing activities compared with other management options. For example, seasonal closures appeared to be acceptable among commercial fishers in Portugal (Silva et al., 2019) and Northern Ireland (Yates, 2014). Temporal fishery closures are widely used to conserve stocks as they have proved effective, especially during specific times of the year, *e.g*. during spawning (Neis, 1992; Johannes, 1998). Thus, the suggestion of a closed season across the three estuaries provides managers with insights into a management option more likely to be supported by recreational crab fishers in these estuaries.

It is important to note that the "no solutions" response by recreational fishers was more prevalent for the Swan-Canning and the Leschenault estuaries than the Peel-Harvey Estuary. This parallels the finding that fewer recreational fishers in the Swan-Canning and Leschenault reported concerns on the status of the Blue Swimmer Crab stocks than in the Peel-Harvey Estuary. Such responses suggest that in general, recreational crab fishers in the former two estuaries do not believe new approaches are necessary to manage their stocks. Therefore, future management changes may receive less support from recreational fishers in these two estuaries relative to the Peel-Harvey. As previously highlighted by Young (2002) and Ostrom (2007), governance of social-ecological systems requires the development of a governance framework specific to the system's dynamics. Estuary-specific management rules based on the local concerns and priorities of the fishing communities may obtain greater support among the fishers in an estuary and compliance within estuaries could potentially be enhanced by system specific measures.

Interestingly, the solution of buying out commercial fishing licences as a means of reducing fishing pressure was not a priority for recreational fishers in any of the three estuaries. Even so, this action was introduced after the consultation phase for Blue Swimmer Crab fisheries in south-western Australia (DPIRD, 2018). The decisions resulting from the review of this fishery do present some estuary-specific changes, yet these do not seem to relate to the estuary-specific concerns described by fishers in this chapter. Understanding how fishers' views vary between locations can help managers understand the range of fisher responses to management interventions and so, help tailor potential management approaches for each of those locations (Johannes, 1998).

The commercial fishers proposed a licence for shore-based recreational fishing as a solution for management and more reliable crab stocks estimates. Currently, recreational crab fishers only need a boat fishing licence (a general license, not specific for crabs) to catch crabs from a boat and do not require any form of license when fishing from shore (Johnston, Marks and O'Malley, 2018). A universal recreational fishing licence has also been advocated as a management approach by fisheries managers and scientists globally (Arlinghaus and Cooke, 2005). This is due to concerns about the impacts of recreational fishing on fish stocks and the general lack of regulation for most recreational fisheries compared to commercial fisheries. A lack of regulation also results in a lack of a continuous time series data to evaluate the impact that this sector may be having on wild stocks (Arlinghaus and Cooke, 2005; Cooke and Cowx, 2006; Arlinghaus et al., 2019). An effectively implemented recreational fishing licencing system would allow the recreational catch to be more reliably estimated based on the number of licences issued each year, and independent fishery assessment of the catches from the recreational sector (Lowry and Murphy, 2003; Ryan et al., 2015). It also provides personal information to enhance the collection of additional information from follow-up surveys and creates opportunities for additional data to be collected through a voluntary logbook system. The proposal from commercial fishers in the Peel-Harvey Estuary to introduce such a licence is probably a reaction to the increasing popularity of recreational fishing in the region, leading to an increase in catches (*i.e*. regulated and unregulated), and thus, an unaccounted increase in fishing pressure on the stocks (Arlinghaus and Cooke, 2005; Carr and Heyman, 2012). Hence, their proposed management solution implies the limitation of the recreational sector's catch (by restricting fishing activity due to the new cost associated with the proposed license), as well as enhanced monitoring. This aligns with previous studies that have highlighted commercial fishers' support for a strict regulation of the recreational sector as a means to reduce fishing pressure; *e.g*. such as the white fish, lobster, pot fishing and scallops fisheries in Northern Ireland (Yates, 2014).

While some key differences were found between the views of recreational and commercial crab fishers, the solutions proposed by both sectors for the future management of the Blue Swimmer Crab fishery focused on reducing fishing pressure rather than other options, such as stock enhancement, through the release of juveniles raised in aquaculture. Both sectors also suggested more effective monitoring and enforcement to improve fisher compliance. A key difference between the sectors was, however, that recreational fishers primarily supported closed seasons, while commercial fishers gave more support to licenses for recreational fishers. This provides managers with useful insights as it indicates that resistance towards certain fishing restrictions, such as increasing surveillance and enforcement, from the fishing community may be minimal. Interestingly, the reported support for restrictions on fishing activity by both sectors seems to parallel the support for these management strategies from fishing communities globally (Yates, 2014; Silva et al., 2019). Yet, depending on the restriction measures put in place for Blue Swimmer Crab fishing, support might be more pronounced from one sector, but not necessarily the other. In fact, commercial fishers are likely to strongly oppose an extended closed season, as they consider licensing for recreational crab fishing should be prioritised over the closed season option. Conversely, recreational crab fishing licensing is likely to receive equally strong opposition from the recreational sector as they consider a closed season as a better option. These differences should be taken into consideration when discussing future sector-specific management approaches.

Following the management review undertaken for Blue Swimmer Crabs in 2018, the new measures applied to the fishery include some estuary specific approaches, such as to limit the number of females allowed to be retained in Geographe Bay, or the reduction in the bag limit (female and male crabs) for the Swan-Canning Estuary, as well as a longer closed season in most waters. Yet, these measures do not fully relate to the concerns of recreational and commercial fishers in each fishery, or their reported solutions. Despite being implemented in the new management approach, this chapter shows that the buy-out of commercial licences was not considered as a key solution suggested by either sector. Concerns on increasing fishing pressure were most important in the Peel-Harvey Estuary, yet the adjustments to bag limits affect estuaries other than the Peel-Harvey. A longer closed-season on most waters appeared as one of the most supported measures by the recreational sectors in the Peel-Harvey and Leschenault estuaries, but was less so in the Swan-Canning Estuary (i.e. < 5% respondents). A licence for recreational shore-based fishers was not introduced as part of the management review for Blue Swimmer Crab fishing, although this option was supported by more than half of the commercial fishers in the region. Finally, no future amendments tackling an increase in compliance have been included following the management review. The introduction of approaches improving current compliance of the fishery was, overall, the most popular solution, and was also common to both commercial and recreational fishers. The recent management review of the Blue Swimmer Crab fishery has taken into account some elements of human dimension resulting from previous research, such as the validity of using system-specific measures to manage the fishery. Yet, the human dimensions of the Blue Swimmer Crab fishery were not fully understood at the time of the management intervention and therefore could not be included in the decision process.

1.3.4.4. Importance of fisher's viewpoints for management

Research on social-ecological systems and ecosystem based fisheries management (EBFM) has demonstrated that traditional fisheries management methods are delayed by bureaucratic inertia and are generally not able to adapt to developing issues, causing a delay in the management responses (Carr and Heyman, 2012). Nowadays, managers are transitioning towards the inclusion of fishers in the management of a fishery. This is usually achieved either by collecting local ecological knowledge from fishing communities (i.e. information sharing on catches) and including these data in their analyses when assessing fishing stocks (Neis, 1992; Ulman and Pauly, 2016), or by using various degrees of involvement with the different stakeholder groups (i.e. co-management), particularly with fishing communities (Kearney, 2002).

Fishers often criticize management agencies and fisheries scientists for being ineffective and reacting too late to change in stocks. This has been a problem in the past, where fishers have reported a change in catches to resource managers, and management agencies have either not listened to the fishing community or not introduced actions to conserve stocks in a timely fashion, aggravating the collapse of fisheries worldwide (Walters and Maguire, 1996). Delays in action often reflect a lack of confidence in the validity of data collected from non-traditional sources by the scientific community. Yet, examples exist where the integration of fishers' viewpoints has resulted in success stories and enabled effective management of fisheries. Studies on co-management of commercial abalone fisheries in Australia have shown the benefits of involving fishing communities in the management process (through forums, workshops and other methods) to build trust among fishers, managers and scientists as well as improve cooperation between the stakeholders (Gilmour, Dwyer and Day, 2013).

Fishers perceptions can provide valuable information that, when integrated with other types of fisheries data, provides managers with a broader perspective of the potential changes in different regions, and the potential scale of some of the indirect impacts of these changes (Frezza and Clem, 2015). The views of fishers can also provide guidance to managers on approaches that would be supported by the local community (Stankey and Shindler, 2006), which could help increase compliance. In their recent study of commercial octopus fishers in Portugal, Silva et al. (2019) highlight that the more effective integration of fishers within the fisheries management process/decision making facilitates knowledge sharing and transfer between the scientists, managers and fishers. This sharing build trust and respect between stakeholders and management agencies and could, potentially, increase compliance. Other studies have noted that fishers tend to be more dissatisfied with management rules if they are not involved in the decision-making process (Pita, Pierce and Theodossiou, 2010) (Bender et al., 2014). It is worth noting that most commercial Blue Swimmer Crab fishers participating in the current chapter are part of a fishing association (*i.e.* the Mandurah Licensed Fisherman's Association) and appear as having "one voice". Yet, as reported by Carr and Heyman (2012), and as the current chapter shows, within their union, the commercial fishing community might have a range of views. For an integration of fishers in management to succeed, these differences in views need to be understood and recognized (Carr and Heyman, 2012).

1.3.4.5. Study limitations

This chapter provides anecdotal data and describes fishers' perceptions on the status and management of the Blue Swimmer Crab fishery. The assessment of the significance of night-time fishing for crabs in the Peel-Harvey Estuary is very recent (Taylor et al., 2018). Since no night surveys were carried out for this chapter, we cannot determine whether night fishers have different motivations, concerns and views on management to those fishing during the day, which has been recorded in studies of various finfish species worldwide (Cooke et al., 2017). Recreational night-fishers' perspectives might vary from recreational crab fishers fishing during the day. The perspectives of night-fishers should be surveyed in future research.

While the data collected from commercial fishers in this chapter represents a census sample of the commercial Blue Swimmer Crab fishing community of south-western Australia, the size of this community is very small compared to the recreational fisher community. This difference in sample size could influence the analysis conducted and is thus another limitation of the chapter.

The use of open-ended questions in face-to-face interviews provided a voice to recreational and commercial Blue Swimmer Crab fishers in south-western Australia. The open-ended format was designed to minimise the imposition of researcher assumptions regarding the types of responses that could subsequently prejudice the results (Neuman, 2003; Obregón et al., 2020b). However, interview respondents can be susceptible to social desirability bias, i.e. they may provide responses that they think will be viewed favourably by others (Duffy et al., 2005). Interview questions were carefully designed to minimise response bias while researchers conducting the interviews were careful to maintain a neutral, objective tone (see also Obregón et al., 2020b). The open-ended question method enabled fishers to freely present their views and concerns, as well as contribute their experience and knowledge to researchers.

1.3.5. Conclusion

This chapter used established face to face interview procedures with an open-question format to identify commercial and recreational fishers' perceptions on changes affecting stocks status; concerns for the future and support for management strategies of a portunid fishery (Blue Swimmer Crabs). As with past studies, perceptions from each sector varied, yet common views on support for increased compliance and fishing restrictions were also recorded. Introducing fishers' perceptions to resource management can help fisheries scientists and managers in two different ways. Firstly, it can help detecting more subtle changes in the stocks, and also understanding what type of change might be occurring. Although the reported changes on Blue Swimmer Crab abundance and size provide an impression of potential changes affecting stocks, this cannot be taken directly as an indicator. However, these data are useful for providing a historical perspective on the results of quantitative fisheries assessments. Further research on anecdotal information related to the fishery, before the monitoring of the fishery started, would provide an important insight into the current status of the stocks. This would also help to clarify the reliability of anecdotal data. Secondly, the research in this chapter allows fishers to have a say regarding the social acceptability of management approaches and enables managers to understand which approaches are likely to receive fisher support if implemented.

Overall, this work highlights that, despite the differences between recreational and commercial fishers, both sectors share some common perceptions about fishery stocks and management solutions. Understanding the similarities and differences can help managers comprehend the concerns of fishers, potentially increasing trust and respect between stakeholders, and as a consequence, enhanced compliance. Differences in views between commercial and recreational fishers should be taken into consideration in future management approaches. The results show that estuary-specific management rules may facilitate the amelioration of specific pressures affecting particular systems. In this case, management agencies have taken this into account and the recently implemented management changes vary between estuaries. Yet these still do not reflect, entirely, the estuary-specific concerns reported by fishers throughout this chapter. The inclusion of fishers' views in the management process could strengthen the relationship between fishers, managers and researchers, by building trust and enhancing cooperation among these stakeholders.

1.4. Selecting from the fisheries managers' tool-box: recreational and commercial fishers' views of stock enhancement and other management options

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1.4.0. Summary

Estuaries and their component fisheries are subject to a multitude of pressures and often require a suite of management measures to maintain or improve sustainability. There is increasing evidence of the impact of recreational fishing on stocks and, due to the often large numbers of recreational fishers and the fact they act relatively autonomously, management often relies heavily on encouraging voluntary compliance with fishing regulations. Therefore, engaging fishers and understanding their thoughts on management options can be beneficial. This study evaluates recreational and commercial fisher salient views on issues affecting the Blue Swimmer Crab (*Portunus armatus*) and Black Bream (*Acanthopagrus butcheri*) fisheries in south-western Australia, current and potential management arrangements for these two species, and how they perceive stock enhancement as a management option. It also determined the strength of these views and investigated whether these views were homogenous among fishing locations and fishers. Most recreational fishers targeting crabs and bream did not agree with the statement that there were no issues affecting the fishery and, of those issues they identified, taking undersize individuals and overfishing raised the most concern. Few recreational fishers considered climate change a major issue for either fishery. Minimum size limits were considered to be mainly acceptable or very acceptable and fisher restrictions and spatial closures were the least acceptable management options among fishers for both species, in addition to maximum size limits for crabs. These views were not always consistent across estuaries for each species and among types of crab fishers indicating recreational fisher heterogeneity. Stocking was the most acceptable of the management measures not already utilised for crabs and among the most popular of all measures for bream fisheries. Moreover, these views on stocking were shared by all users of different estuaries and all fisher groups (i.e. they were homogeneous). Recreational fishers of both species believed stock enhancement could have strong positive outcomes for the abundances of their target species and increase their subsequent catches. While they also recognised that this management strategy could lead to some negative outcomes, such as increase fishing pressure and environmental issues, they considered them unlikely to occur. Commercial crab fishers generally did not support crab stocking as it was not considered to be needed, although some commercial Black Bream fishers, who fished an estuary where restocking had occurred, were supportive of bream stocking. The vast majority of recreational crab fishers would consume hatchery-reared crabs if they caught them. These results could be useful if new management measures need to be applied to these estuaries in the future to help mitigate the effects of climate change and/or increasing fishing pressure from a growing population.

1.4.1. Introduction

Fisheries provide nutrition, livelihood and recreation, but due increasing population growth and demand for seafood, together with deleterious anthropogenic influences, such as habitat degradation and eutrophication, many require management of their stocks to ensure productivity and to maintain these benefits (Allison and Ellis, 2001; Arlinghaus et al., 2019; FAO, 2020). Fishery management tools can generally be considered to fit into three categories (i) *input controls* e.g. limited entry (licensing), time restrictions, gear restrictions, (ii) *output controls* e.g. quotas and catch shares and (iii) *technical measures* e.g. size limits, time-area closures and marine protected areas (Sutinen and Soboil, 2003; Selig et al., 2017). Such controls seek to limit both the amount of fishing effort and fish harvested and also the location where those resources are removed. There is a long history of the use of fishery regulations, with Sumerian and Babylonian texts from ~4,000 years ago stating the rules and infringement penalties (Sahrhage and Lundbeck, 1992). However, in addition to having a biological effect on the target species and accompanying effect on the ecology of the surrounding ecosystem, regulations can result in significant economic and social impacts (Mascia, Claus and Naidoo, 2010).

Marine aquaculture-based enhancement (Lorenzen et al., 2021), is an alternative approach, applied mainly from the 1950s onwards; (Ramm et al., 2021) to increasing stocks of fisheries species. Although most effective when utilised in conjunction with restrictive measures (e.g. size limits, bag limits and temporal closures), enhancements can allow fishing to continue by releasing individuals grown in aquaculture into a natural system to replace those removed via fishing activities. The three types of release programs are: (i) *stock enhancement*, i.e. release of hatchery reared juveniles to <u>improve</u> an already sustainable population, (ii) *restocking*, i.e. releases of hatchery reared juveniles to <u>increase severely depleted</u> stocks and (iii) *sea ranching*, i.e. releases of hatchery reared juveniles into a <u>put, grow, and take</u> system (Bell et al., 2008; Taylor et al., 2017). Aquaculture-based enhancement is, however, not a 'magic bullet' and there may be some trade-offs relevant to fishers, including reduction in the abundance of wild individuals, reduced growth-rates and increased numbers of smaller individuals as well as increases in fishing effort and pressure (Ingram, Hayes and Rourke, 2011; Anderson and Cason, 2015; Camp et al., 2017; Loneragan, Taylor and Tweedley, 2018). Despite these potential negative impacts, stock enhancement and restocking is commonly supported by recreational fishers (Arlinghaus and Mehner, 2003; Garlock and Lorenzen, 2017) and also presumably by commercial fisheries whose catch is reliant on releases of fish (Masuda and Tsukamoto, 1998).

While commercial fishers can be subject to a range of compliance monitoring, e.g. log-books, independent observers and vessel tracking (e.g. Gezelius, 2006; Cotter and Pilling, 2007; Bastardie et al., 2010), monitoring of the often far larger numbers of recreational fishers is challenging (National Research Council, 2006). This is because recreational fishers act relatively autonomously, often with limited active management or monitoring, across large geographical areas (Magee et al., 2018). Although novel monitoring techniques are being developed (e.g. Hartill et al., 2020; Provost et al., 2020), management often relies heavily on encouraging voluntary compliance with regulations (Leisher et al., 2012; Magee et al., 2018). Thus, engaging with fishers is vital when designing and implementing new regulations and policies and can result in reduced conflict and increase compliance (Fedler and Ditton, 1994b; Dimech et al., 2009). A first step in this process is to understand fishers' motivations to fish and their opinion of various management options (Section 1.2).

Estuaries are highly productive ecosystems that are heavily utilised by humans and generate considerable ecosystem services (Costanza et al., 2007; Tweedley, Warwick and Potter, 2016). In a fisheries context, this includes the production of finfish and crustaceans which can be used for economic or social gain (Lellis-Dibble, McGlynn and Bigford, 2008; Potter et al., 2015b). For example, species that use estuaries for all or part of their life-cycle contribute more than 75% of commercial fish catch in Australia, and in some regions, up to 90% of all recreational angling catch (Creighton et al., 2015). Although, estuaries in microtidal, south-western Australia, are important areas for fisheries species (Valesini et al., 2014; Tweedley, Warwick and Potter, 2016), these systems are particularly susceptible to anthropogenic degradation (Tweedley et al., 2014b; Warwick, Tweedley and Potter, 2018). For example, their limited flushing capacity and highly seasonal rainfall leads to the occurrence of hypoxia and algal blooms and, in some systems, extreme hypersalinity (Hallett et al., 2016; Tweedley et al., 2016; 2019a). These perturbations can have lethal effects on fish and crustaceans, resulting in mass mortality events (Hoeksema, Chuwen and Potter, 2006; Krispyn et al., 2021). Although not as obvious to the public, a range of sublethal effects have been observed. Decreased riverine input, as expanded hypoxic areas reducing benthic invertebrate populations and resulting in habitat compression and fish moving away from deeper, hypoxic waters into more well-oxygenated shallows. In the highly-sought after sparid Black Bream (*Acanthopagrus butcheri*), these effects are manifested in a slower growth rate and as a consequence longer time taken to reach the minimum legal length for retentions and a decline in body condition (Cottingham et al., 2014; 2018b).

The Blue Swimmer Crab (*Portunus armatus*) is one of the most targeted recreational species in Western Australia and supports several small-scale commercial fisheries (Ryan et al., 2015; Johnston et al., 2020a). The crabs spawn in the marine environment and their juveniles migrate into the lower reaches of estuaries where they attain sexual maturity and reproduce (Potter et al., 2015b; Poh et al., 2019). Populations of Blue Swimmer Crabs in south-western Australian estuaries are currently regarded as '*adequate*' (Newman et al., 2021), however, recreational fishers have reported a decline in their size over time (Obregón et al., 2022a) and stocks in a nearby marine embayment collapsed over a decade ago and have failed to recover (Johnston et al., 2011; Marks et al., 2020; Newman et al., 2021). An aquaculture-based enhancement program was suggested as a possible solution to restoring the Blue Swimmer Crab population in Cockburn Sound, but to date only experimental scale releases have occurred (Johnston et al., 2011; Jenkins, Michael and Tweedley, 2017).

Black Bream are a long-lived sparid that typically reside in the upper riverine reaches, particularly around woody debris (Sarre and Potter, 1999, 2000). The species is targeted by recreational fishers, throughout south-western Australia and is caught in a commercial gill net fishery on the south coast of the state (Smallwood and Sumner, 2007; Smith and Brown, 2008). A restocking program was initiated as a response to consistently low catches in the Blackwood River Estuary, with the hatchery-reared fish making substantial contributions to commercial catches (up to 75%) and egg production (50%) in some years (Cottingham, Hall and Potter, 2015; 2020).

While Blue Swimmer Crabs and Black Bream co-occur in the same estuaries the motivations of the recreational fishers that target them were very different, with crabbers being consumption-orientated whereas the Black Bream fishery was a trophy/sports fishery and fishers practiced catch and release fishing (Section 1.2). This chapter increases knowledge on the social dimensions of these two multisector fisheries by determining recreational and commercial fisher's opinions on the current status of Blue Swimmer Crab and Black Bream fisheries in south-western Australian estuaries. The social acceptability of a range of current and potential management options are investigated together with than an assessment of the level of support for stock enhancement as a management intervention. For each species, fishers' view on current and potential future management options are compared among estuaries (and Shark Bay for Blue Swimmer Crabs) and among the different fisher groups identified in Section 1.2.

1.4.2. Methods

Information on the study area and fisheries are provided in subsection 1.2.2.1 and Tweedley et al. (2023b).

1.4.2.1. Surveys of recreational and commercial fishers

The data from recreational fishers analysed in this chapter was obtained from face-to-face semi-structured interviews (Phase 1) and an online questionnaire (Phase 2). Full details of these surveys are provided in subsection 1.2.2.2 with only novel elements described here.

In the online surveys, the initial questions were designed to determine the *possible issues that could affect the Blue Swimmer Crab/Black Bream fishery in the estuary where you fish* and respondents selected if they agreed, disagreed or were unsure with issues provided during the face-to-face survey and about *current state of the fishery compared to when you first started fishing* and whether a range of effects (e.g. the size of their target species) had increased, decreased or remained the same. The questions then addressed respondent's thoughts on the current state of fishery management (i.e. agree, disagree or unsure), the acceptability of various management measures (i.e. very acceptable, acceptable, neutral, unacceptable, very unacceptable) and whether a range of existing management measures (e.g. bag limits) should be increased, decreased, remain the same or they were unsure. The identified salient beliefs relating to stock enhancement from the face-to-face interviews were presented to respondents as a rating scale and organised into rating pairs (Middlestadt et al., 1996; Brown et al. 2010). The first scale gave an indication of the strength of belief in the statement, while the accompanying second scale indicated the evaluation of the belief. These were followed by a question that was solely focussed on the overall attitude towards the implementation of stock enhancement. Finally, those fishers using the Blue Swimmer Crab fishery, where the majority of crabs are consumed (Section 1.2), were asked what they would do if they caught a hatchery-reared crab, e.g. would they eat it, release it or keep for a friend/family member.

Interviews were also conducted with the small number of commercial Blue Swimmer Crab fishers who fished in the Peel Harvey and Swan-Canning estuaries but not in Leschenault Estuary as the commercial crab fishery in that system closed in 2001. A one-on-one meeting or a phone call was arranged with each fisher operating, at the time of the survey, in the Peel-Harvey (n = 9) and Swan-Canning estuaries (n = 2). To gather responses from commercial Black Bream fishers, a one-on-one meeting was arranged with each fisher actively operating in the Blackwood River Estuary (n = 2) and Wilson Inlet (n = 2). Responses from commercial fishers were recorded following the same method described above for recreational fishers (subsection 1.2.2.2). All commercial fishers actively working in the region agreed to participate in the face-to-face interviews, so these responses represent a census of the views of commercial fishers.

1.4.2.2. Data analyses

The dual belief and evaluation coding schemes were recoded to follow the scheme in Francis et al. (2004). Thus, while the belief strength remained on a scale from -3 (very bad) to +3 (very good), the accompanying belief evaluation was placed on a unipolar scale from 0 (very unlikely) to +6 (very likely). The measures associated with each question were subsequently multiplied together to form a cross-product for each belief, which ranged from -18 (very likely and very bad) to +18 (very likely and very good; Table 1.4.1). The cross-product represents the belief-based attitude, which provides an indication of how strong the belief is, and whether the belief is associated with a positive or negative attitude.

Table 1.4.1. The belief strength (grey) and belief evaluation (white) rating scales and the subsequent cross-product values (i.e. the belief-based attitude; colour).

Belief strength		***very unlikely***	***unlikely***	***somewhat unlikely***	***neutral***	***somewhat likely***	***likely***	***very likely***
Belief evaluation		***0***	***1***	***2***	***3***	***4***	***5***	***6***
very bad	**-3**	0	-3	-6	-9	-12	-15	-18
bad	**-2**	0	-2	-4	-6	-8	-10	-12
somewhat bad	**-1**	0	-1	-2	-3	-4	-5	-6
neutral	**0**	0	0	0	0	0	0	0
somewhat good	**1**	0	1	2	3	4	5	6
good	**2**	0	2	4	6	8	10	12
very good	**3**	0	3	6	9	12	15	18

The count data for each question and for each target species, were used to calculate the percentage of respondents that selected each option and used to construct a Bray-Curtis similarity matrix. This was then subjected to the CLUSTER-SIMPROF routine to determine if the views of respondents utilising the various fisheries and fisher groups differed from one another. A similar approach was used for belief strength, belief evaluation and belief-based attitude, however, as this asked respondents to rate each option the resultant data are numbers rather than a percentage composition, and so were subjected to the same CLUSTER-SIMPROF routine using a Euclidean distance rather than Bray-Curtis matrix. The social acceptability of each of the potential management options were compared by firstly converting the ranking to a number (i.e. very unacceptable = 1 through to very acceptable = 5). The rating of each management option, for each target species separately, was compared using an independent-samples Kruskal-Wallis test using SPSS v24. If a significant difference was detected ($P < 0.05$), pairwise Dunn's post hoc tests were used to determine homogeneous subsets.

1.4.3. Results

Demographic information for recreational fishers is provided in Subsection 1.2.3.1 and Tables S1.2.1 and S1.2.2. Due to the small numbers of commercial fishers operating in the fisheries demographic information has not been provided.

1.4.3.1. Perceived fishery issues and effects on catches

When asked to comment on the veracity of the potential issues affecting Blue Swimmer Crab fisheries across south-western Australia only 2% of recreational fishers stated there were no issues, with 88% disagreeing with this statement, saying that these fisheries experienced problems (Figure 1.4.1a). Of the ten salient issues identified in the face-to-face interviews between 23 and 75% of respondents in the online survey agreed that all 10 were present. The top five issues related to fishing, (i) i.e. taking of undersized crabs (75% agree), (ii) overfishing (68%), (iii) catches exceeding the bag limit (68%), (iv) recreational fishing (62%) and (v) commercial fishing (59%; Figure 1.4.1a; Table S1.4.1). Non-fishing issues, i.e. pollution and climate change, were selected by comparatively very few fishers (both 23%). With the exception of the retention of undersize crab by recreational fishers, which was selected by more fishers utilising the Peel-Harvey (80%) and than the Swan-Canning (67%), the views of fishers were relatively consistent between these two adjacent systems (Figure S1.4.1). The views of individuals fishing in the Leschenault Estuary differed in some cases, with proportionally fewer people agreeing that overfishing, commercial fishing, and a lack of education were affecting the fishery, but conversely that the taking of undersized crabs and pollution were more important issues.

Similarly to Blue Swimmer Crab fishers, only 3% of recreational Black Bream fishers considered there to be no issues affecting the fishery, with the proportion of those who highlighted various issues as important ranging from 19 to 70% (Figure 1.4.1b). The issues that most fishers agreed to were the taking of undersized fish (70% agree), lack of education (67%), overfishing (66%) and exceeding the bag limit (57%). Climate change was the least supported issue with only 19% of Black Bream fishers considering this an issue. The above issues were fairly consistent across estuaries, except for the taking of undersized fish and exceeding the bag limits which were more prevalent in fishers in the Peel-Harvey and Swan-Canning estuaries than in the Blackwood River Estuary, with the reverse being true for their views on climate change (Table S1.4.2; Figure S1.4.2).

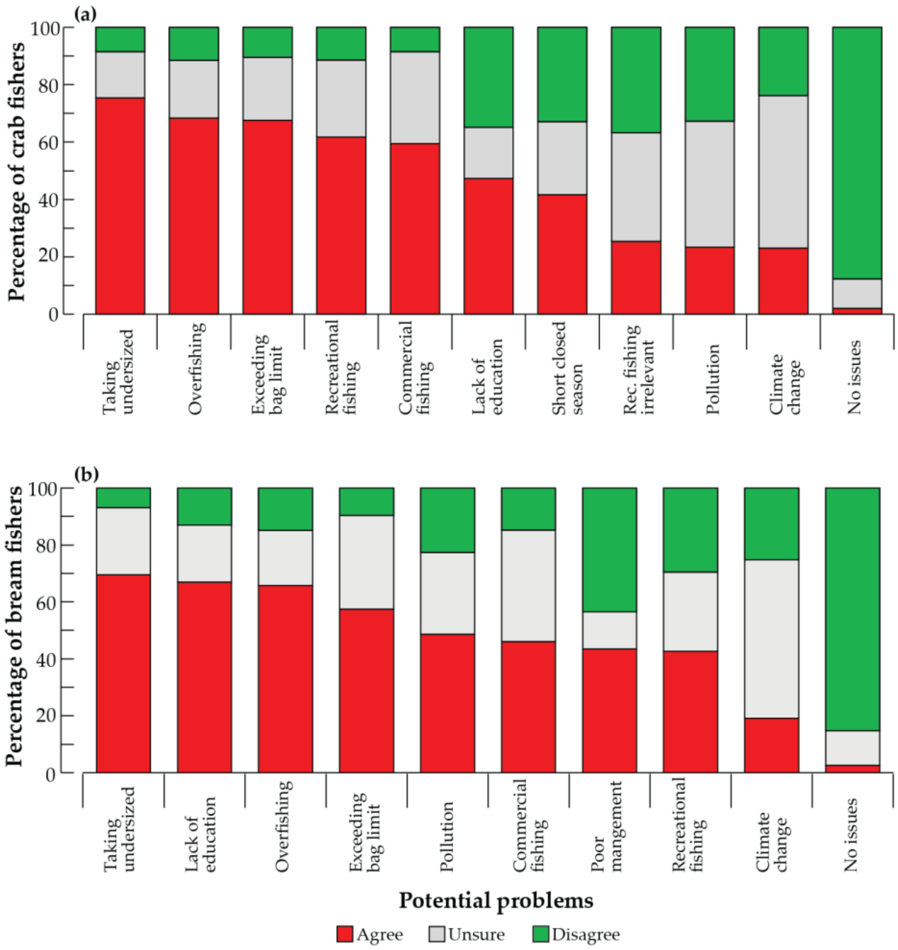

Figure 1.4.1. Stacked bar graph of the percentage number of recreational (a) Blue Swimmer Crab and (b) Black Bream fishers that agreed, disagreed or were unsure about the effects of potential issues on their chosen fishery. Issues ranked by the percentage of respondents who agreed.

Compared to when they started fishing, most recreational fishers stated that their catches of Blue Swimmer Crabs had declined over time (56% overall), with these trends being stronger in the Leschenault Estuary (70%) and Shark Bay (100%) than in the Peel-Harvey and Swan-Canning estuaries (57 and 53%, respectively; Figure 1.4.2a). The abundance of Blue Swimmer Crabs was said to have declined overall and, in each system (69-83%), with around one third of respondents stating that this decline was also true for other species. It should be noted, however, that 50-67% of fishers said this has not changed (Table S1.4.3; Figure S1.4.3). Fishers also stated that both the number of people fishing (81%) and the time spent fishing in order to catch crabs increased (59%), however, most felt that the number of sites (56%), depth of those sites (75%) and distance they needed to visit to catch crabs (58%) remained similar.

In general, recreational fishers stated that both the size and abundance of Black Bream had declined (60 and 56%, respectively), however, the proportion of these fishers who thought this varied among estuaries (Figure 1.4.2a). It was greatest for size in the Blackwood (81%) and Swan (86%) and least in the Wilson (0%) and intermediate in the Peel (37%). The perceive decrease in Black Bream abundance was also greatest in the Blackwood (81%) and least in the Wilson (0%). The proportion of fishers perceiving a decline was larger in the Peel (79%) than Swan (56%; Table S1.4.4; Figure S1.4.4).

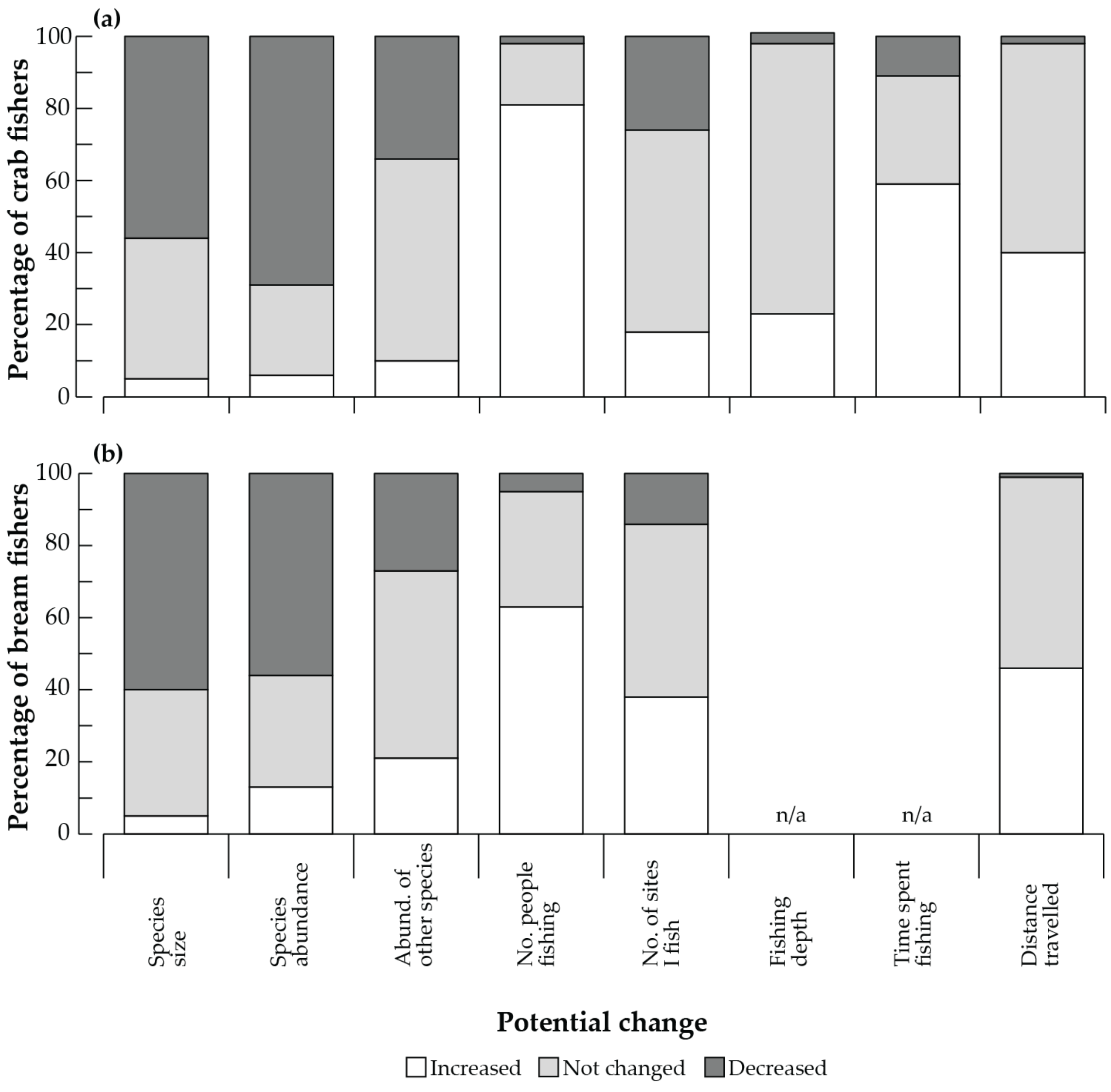

Figure 1.4.2. Percentage of recreational Black Bream fishers that considered that measures of their catches and fishing trips had changed.[16]

[16] Note Black Bream fishers were not asked questions about fishing depth and time spent fishing.

1.4.3.2. Views of current management and management tools

Looking at recreational Blue Swimmer Crab fisheries across Western Australia, 27% of fishers agreed that they were well managed with 39% disagreeing (Figure 1.4.3). The highest proportion of fishers agreeing that an individual fishery was well managed where those utilising the Swan-Canning (36% agree and 34% disagree), followed by the Peel-Harvey and Shark Bay and lastly the Leschenault (0% agree and 50% disagree; Table S1.4.5). The majority of fishers, overall (69%) and in each fishery (66-85%), thought that better management of stocks was needed, with fishers in the Leschenault and Shark Bay appearing as the most concerned. Around 50% of respondents were very unhappy with both the abundance and size of the Blue Swimmer Crabs, with this proportion increasing significantly in Shark Bay (Table S1.4.5; Figure S1.4.5).

Like Blue Swimmer crab fishers, more recreational Black Bream fishers disagreed (46%) than agreed (14%) that the fishery was well-managed. Most (69%) considered that stocks needed to be better managed and they were unhappy about the number (61%) and size (63%) of Black Bream (Figure 1.4.3). In their answers to all four questions a smaller proportion of Black Bream fishers were satisfied than Blue Swimmer Crab fishers (c.f. Tables S1.4.5, S1.4.6). The views of Black Bream fishers were fairly consistent across fisheries, except that, in all cases, fewer fishers that used 'other' estuaries were unsatisfied and that this was also true when considering management of the fishery in the Swan-Canning, i.e. far fewer respondents disagreed with the statement that is was well managed (38%) compared to the Blackwood River Estuary (62%) and Peel-Harvey Estuary (79%; Table S1.4.6; Figure S1.4.6).

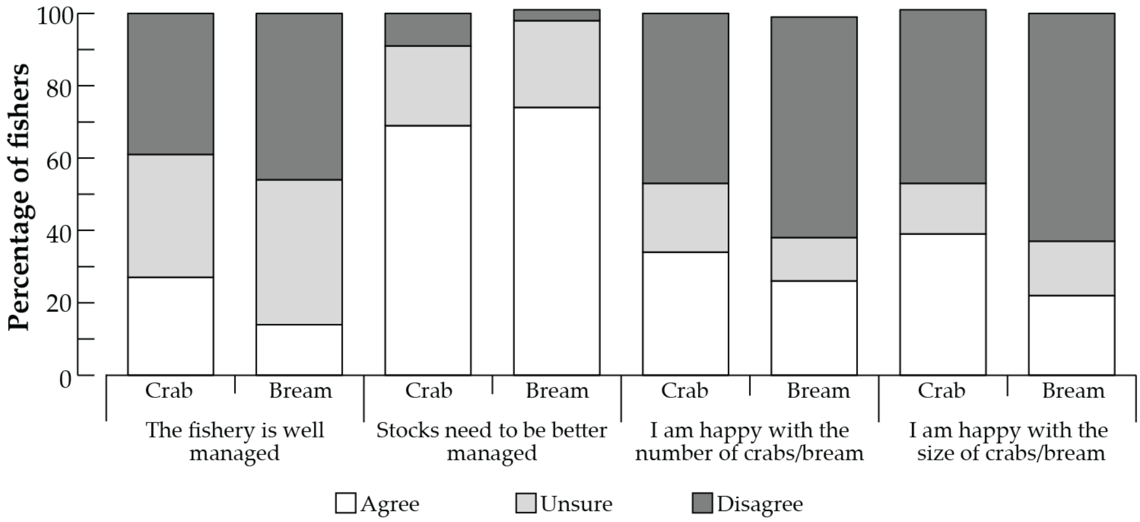

Figure 1.4.3. Percentage of recreational Blue Swimmer Crab and Black Bream fishers that agreed, disagreed or were unsure about aspects of the management of their species fisheries.

When asked to consider the acceptability of a range of current and potential fishery management measures to regulate recreational catches of Blue Swimmer Crabs, those currently in place (except for gear restrictions) were deemed, on average, very acceptable, whereas those that have not been implemented were less popular, except for stocking. Means for the acceptability of the nine management options, on a scale of 0 (very unacceptable) to 5 (very acceptable), ranged from 4.72 (minimum size limits) to 2.75 (maximum size limited; Figure 1.4.4a). A Kruskal-Wallis test demonstrated that there was a significant difference among the options (H = 781.9, $p < 0.001$), with subsequent pairwise tests identifying four groups of options that differed in their acceptability (Figure 1.4.4a). Eighty four percent of respondents considered minimum size limits to be very acceptable and had the highest mean score of 4.72, which was significantly greater than that for all other options. The group of the next most acceptable options (mean scores = 4.32 - 4.46) contained a suite of existing measures, i.e. temporal closure, monitoring fishers, education and bag limits, and stocking. These were deemed 'very acceptable' by between 58 and 66% of fishers, which rose to 81-90% including those who also found them 'acceptable'. Generally, only ~5% of respondents considered these as either 'unacceptable' or 'very unacceptable'. Gear restrictions and spatial closures, however, were less popular with around 35% of fishers considering this 'very acceptable'. The less acceptable measure, with a mean score of only 2.75 was maximum size limits. Only 24% of fishers considered this either 'very acceptable' or 'acceptable' compared to 45% who selected 'unacceptable' or 'very unacceptable' (Figure 1.4.4a).

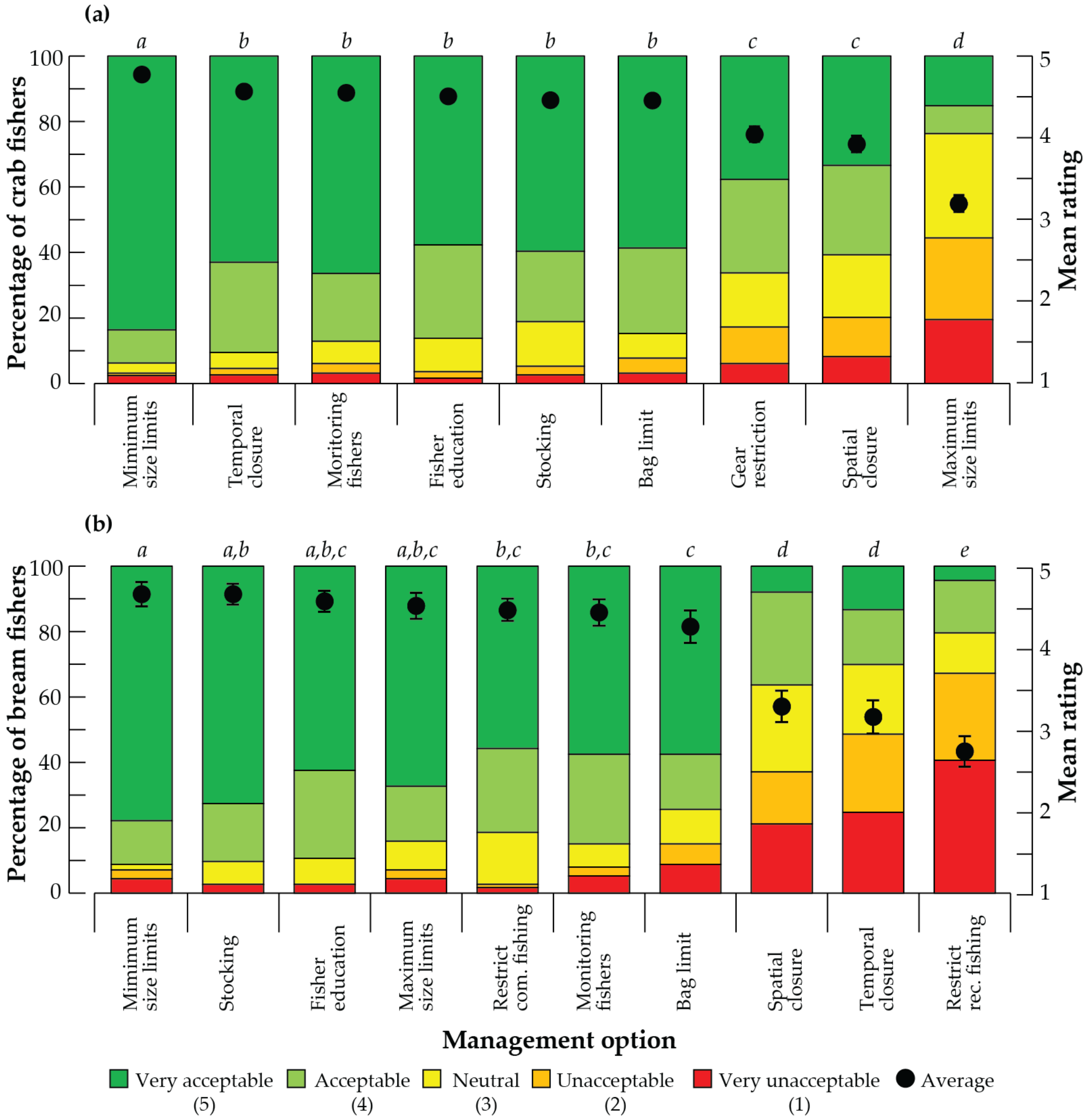

Figure 1.4.4. Mean ratings (±95% confidence limits) and a stacked bar graph of the number of recreational fishers that chose a management acceptability rating for each of the nine and ten management options that currently are or could potentially be used to manage (a) Blue Swimmer Crab and (b) Black Bream fisheries, respectively, in south-western Australia.[17]

The views of fishers on managing crab fisheries differed among fisher groups and locations, except for stock enhancement (Table S1.4.7; Figure S1.4.7i,j). Between 50 and 67% of respondents selected stocking as very acceptable, being least among fishers utilising Shark Bay and greatest among fishers in group *g* (bi-monthly hand fishers; Table S1.4.7). Fishers crabbing in the Peel-Harvey and Swan-Canning estuaries had similar view on the acceptability of all measures (Figure S1.4.7) and these differed to those of fishers in Leschenault for five of the nine measures and to those in Shark Bay for eight of the nine. In general, a smaller proportion of fishers in Leschenault found the measures very acceptable, although often more selected 'acceptable'. The trend for lower proportion of fishers finding measures very acceptable was even more marked for those utilising Shark Bay (0% for maximum size limits to 50% minimum size limits). Views towards management measures were less varied among respondents in the various fisher groups, with any differences mainly due to a greater proportion of fishers in groups *a* (Very frequent fishers) and *g* (bi-monthly hand fishers) finding measures very acceptable proportionally more than in the other groups (Table S1.4.7).

[17] Management options ordered by mean rating (i.e. acceptability). Letters in the management tool legend indicate significant differences between groups as determined by pairwise Kruskal-Wallis tests.

The acceptability of a range of current and potential fishery management measures to regulate the catch of Black Bream ranged from 4.58 (minimum size limits and stocking) to 2.17 (restricting access to recreational fishers; Figure 1.4.4b) and differed significantly among measures (Kruskal Wallis H = 420.2, $p < 0.001$). Pairwise tests identified five groups of measures that differed in their acceptability, although some measures, e.g. fisher education, were selected in multiple groups (Figure 1.4.4b). The measures deemed most acceptable were minimum size limits and stocking, with >90% of respondents finding these 'very acceptable' or 'acceptable'. Fisher education, maximum size limits, restricting commercial fishing, monitoring fishers and bag limits were all relatively similar in their acceptability with mean values ranging between 4.46 and 4.08 (Table S1.4.8). On average, fishers had neutral views towards spatial closures (2.86) and temporal closures (2.70), with few fishers finding these measures either 'very acceptable' or 'acceptable' (total 30-36%; Figure 1.4.4). The least acceptable measure, with a mean score of only 2.17 was restricting recreational fishing where only 20% of fishers considered this either 'very acceptable' or 'acceptable' (Figure 1.4.4b).

As with Blue Swimmer Crabs, recreational Black Bream fishers had a consistent view about the acceptability of stock enhancement across all estuaries, with this also being true for fisher education, maximum size limit, spatial closure and restricting recreational fishing (Table S1.4.8; Figure S1.4.8). Among the measures whose acceptability differed among estuaries, minimum size limits were most acceptable in the Blackwood (92% very acceptable) followed by the Swan-Canning (79%) and then the Peel-Harvey and 'other' estuaries (71 and 72% respectively). Both restricting commercial fishing and increasing fisher monitoring were found to be more acceptable by fishers utilising the Peel-Harvey than the other estuaries, but the reverse was true for bag limits (Table S1.4.8).

When asked whether any of the existing management measures for Blue Swimmer Crab fishers should change the majority of recreational fishers across all fisheries and representing different fisher groups considered that the minimum size limit, bag limit and boat limit should remain the same, but that fisher surveillance and education should be increased (Table S1.4.9). Marked differences in opinions about temporal closures were present among respondents utilising different fisheries, with ≥60% of those in Peel-Harvey and Shark Bay saying the closure should be extended compared to 42 and 45% in the Swan-Canning and Leschenault.

When the same questions were asked of recreational Black Bream fishers, most fishers wanted the minimum size limit to remain the same, particularly those very frequent fishers (group a), although a substantial proportion wanted it to increase. Support was elicited for an increase in fisher education (75 - 100% of fishers in all locations) and the level of fisher surveillance to increase (Figure 1.4.5b; Table S1.4.10). Fishers' views towards bag and boat limits were split between those supporting a decrease and those wanting the limits to remain the same. Views towards changes in existing measures were similar among all locations except for increasing fisher education which was supported by 75% of fishers utilising the Blackwood compared to between 86 and 100% of fishers in the other estuaries.

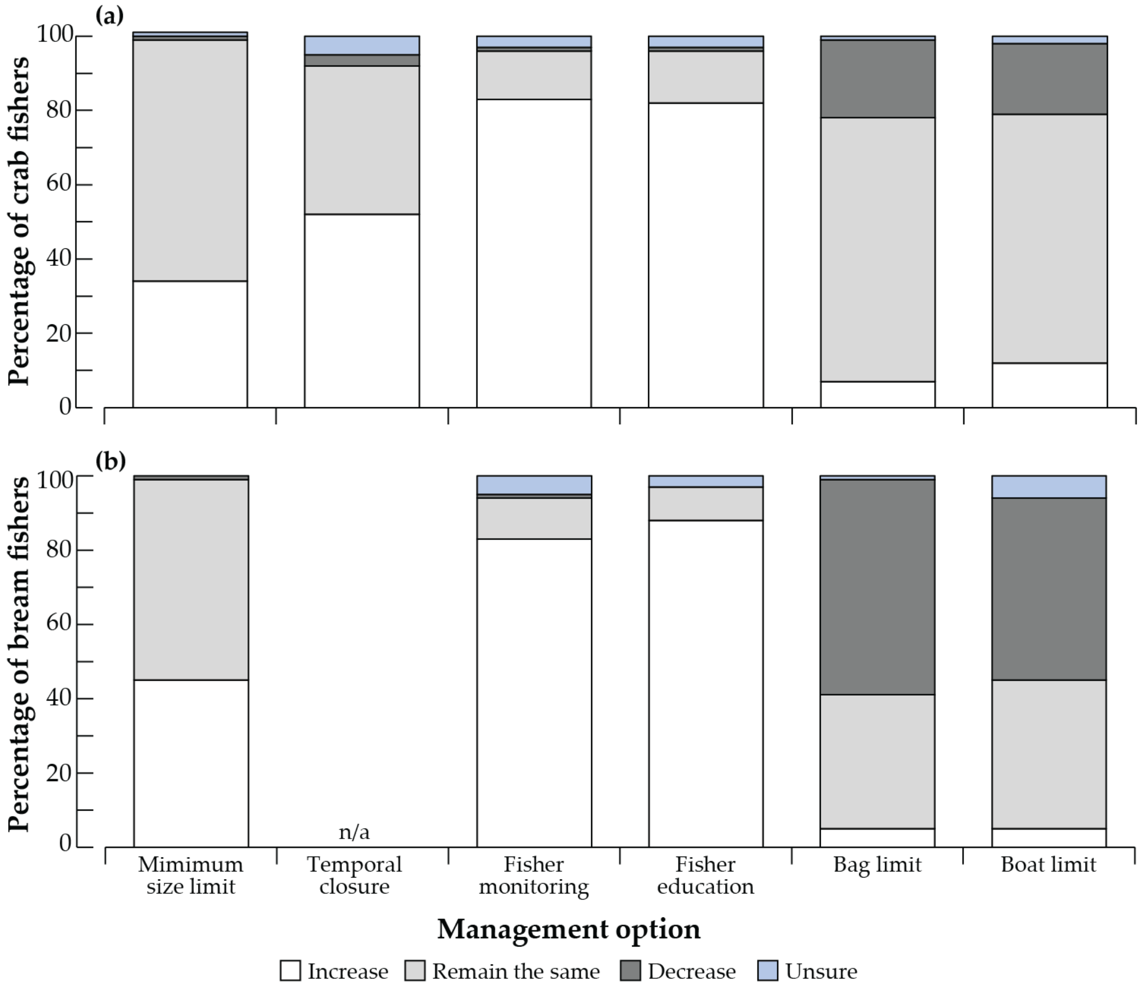

Figure 1.4.5. Percentage of recreational Blue Swimmer Crab fishers that chose an option about whether management option should change or remain the same.

1.4.3.3. Beliefs and attitudes to stock enhancement

The mean strength for each of the six behavioural beliefs identified in the face-to-face interviews and rated by recreational crab fishers on the online survey, i.e. the likelihood of each belief to occur if stock enhancement of Blue Swimmer Crabs is implemented, ranged from +4.78 to 2.20 (on a scale of 0 to 6; Table S1.4.11a) and differed significantly (H = 498.5; $p < 0.001$). Pairwise tests demonstrated that the beliefs fell into three groups (all $p < 0.05$; Figure 1.4.6a); (1) outcomes that were considered likely, i.e. that stock enhancement would '*increase in the number of crabs*', result in '*more crabs to catch*' and also '*more fishers fishing*' for the Blue Swimmer Crabs (4.78 – 4.54), (2) outcomes where fishers were unsure (i.e. neutral) of what would happen *i.e.* an '*increase in fishing pressure*' (3.05) and '*impact on the environment'* (2.87) and (3) those that were slightly unlikely following stock enhancement, i.e. '*no change in the abundance of crabs*' (2.20). These views of all fishers (overall) were consistent across all fisheries and fisher groups, except those utilising Shark Bay, where the views in belief groups 2 (increase in fishing pressure and environmental impact) and 3 (no change in crab abundance) were considered more unlikely (Table S1.4.11a; Figure S1.4.11a,b).

The mean evaluation for each behavioural belief, i.e. whether the outcome from any stock enhancement program would be good or bad, ranged from +2.14 to -1.50 (on a scale of -3 to +3) and differed significantly among beliefs (H = 985.5; $p < 0.001$; Figure 1.4.6b). Three groups of beliefs were identified ($p < 0.01$; Table S1.4.11b); group 1 contained the two of the outcomes associated with a positive judgement, i.e. '*increased number of crabs*' and '*more crabs to catch*' (2.14 and 2.17, respectively), group 3 beliefs were associated with a negative effect, i.e. '*increase in fishing pressure*' (-1.50), '*no change in crab abundance*' (-1.31) and '*impact on the environment*' (-1.30). The remaining group, group 2 contained neutral-somewhat bad (-0.55) view about the potential for '*more fishers fishing*'. The views of fishers were consistent among the various fisheries but differed between fisher groups (Figure S1.4.11c,d). Generally, the view of fishers in groups *b*, *c*, *d* and *f* were consistent with the overall Blue Swimmer Crab fishing community, but those in group *a* (very frequent fishers) considered '*no change in crab abundance*' to be worse than other groups, those in group *e* (inexperienced shore-based drop net fishers) were more optimistic that no change in crabs following stock enhancement is not a bad as other groups and were less worried that it would '*impact on the environment*' (Table S1.4.11b).

The mean cross-product, i.e. the belief strength × belief evaluation (belief-based attitude), for the six behavioural beliefs of Blue Swimmer Crab fishers to stock enhancement ranged from +10.45 to -3.41 (on a scale of +18 to -18) and were found to differ significantly (H = 884.2; $p < 0.001$; Figure 1.4.6c). As with the belief evaluation, only an '*increase in crab number*' (+11.45) and '*more crabs to catch*' (+10.39) were positive and different to all other beliefs; ($p < 0.001$;). The beliefs that there will be '*more fishers fishing',* '*no change in crab abundance*', and an '*impact on the environment*' and, were all negative going from bad, but unlikely (-1.18 and -1.28), to likely and somewhat bad (-2.10). Each of these beliefs differed significantly from every other belief, except for '*increased fishing pressure* (-3.41; Table S1.4.11c).

The cross-products of the six beliefs differed significantly among fisheries and fisher groups (Figure S1.4.11e,f). Fishers in the Leschenault and Shark Bay had a more positive view of more '*more fishers fishing'* and the '*impact the environment*' than those in the Peel-Harvey and Swan-Canning (Table S1.4.11c). Among fisher groups those in *b, c, d* and *f* were similar to the overall population of fishers, with those in *a* and particularly *g* being more concerned about the impact of '*increased fishing pressure*' and in the case of the latter group also '*more fishers fishing'.* Fishers in group *e* had positive belief-based attitudes.

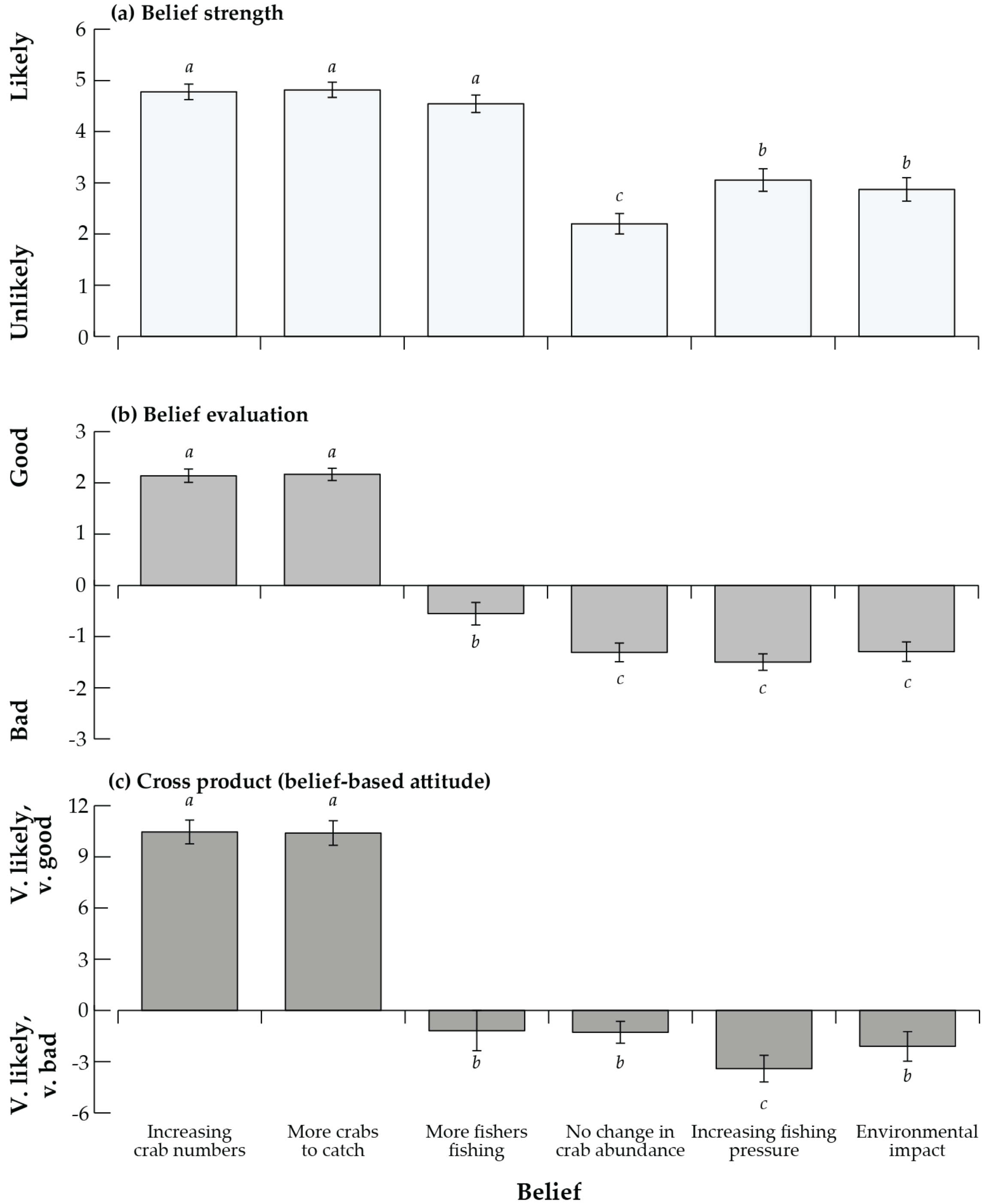

Figure 1.4.6. Mean ratings and ±95% confidence limits for each stock enhancement belief across (a) belief strength, (b) belief evaluation and (c) cross-products for stock enhancement of Blue Swimmer Crabs.

The mean strength for each of the five behavioural beliefs identified by recreational Black Bream fishers that could occur if stock enhancement is implemented, ranged from +5.34 (increasing number and more bream to catch) to 1.08 (too many bream) and differed significantly (H = 285.2; $p < 0.001$). Pairwise tests demonstrated that the beliefs fell into three groups (all $p < 0.05$; Figure 1.4.7a). These were, (group 1) outcomes that were considered very likely, i.e. '*increase in the number of bream*' and '*more bream to catch*' (both ~ 5.3); (group 2) outcomes where fishers thought were somewhat unlikely would happen i.e. an '*increase in fishing pressure*' (2.02) and (group 3) those considered unlikely following stock enhancement, i.e. '*less bream surviving*' and *'too many bream'* (~1.1). These views represented all fishers were consistent across all fisheries and fisher groups, except those utilising Wilson (Figure S1.4.12a,b), where almost all beliefs were considered 'somewhat likely' to 'likely' to occur (Table S1.4.12a).

The mean evaluation for each behavioural belief ranged from +2.58 to -2.41 and differed significantly (H = 317.9; $p < 0.001$), with pairwise testing identifying four groups of beliefs (Figure 1.4.7b). Three of the five outcomes were associated with a positive judgement, with '*increased number of bream*' and '*more bream to catch*' (2.57 and 2.58, respectively) having significantly higher values than all other beliefs (KW $p < 0.001$; Table S1.4.12b). The other positive belief was that there would be '*too many bream*' (1.44). An '*increase in fishing pressure*' (-1.98) and '*less bream surviving*' (-2.41) were considered to be the worst outcomes from stock enhancement and each of which was different from all other beliefs (all $p < 0.05$). The views of fishers were consistent among the various fisher groups but differed between fisheries (Figure S1.4.12c,d). The fishers' evaluation of the beliefs were generally fairly consistent except for '*too many bream*', with those utilising the Blackwood, Peel-Harvey, Swan-Canning considering this to be somewhat good – good, those in the Wilson and 'other' had a more neutral view (Table S1.4.12b).

The mean cross-product for the six behavioural beliefs of Black Bream fishers to stock enhancement ranged from +13.54 to -2.84 and differed significantly (H = 321.7; $p < 0.001$; Figure 1.4.7c). As with the belief evaluation, both '*increase in bream numbers*' (+13.45) and '*more bream to catch*' (+13.28) were strongly positive (i.e. good and likely) and differed from all other beliefs; ($p < 0.001$; Table S1.4.12c). The beliefs that there will be '*less bream surviving,* '*increasing fishing pressure'* were both slightly negative (i.e. -1.77 and -2.84, respectively) meaning they were considered bad but unlikely. Overall, beliefs about their being '*too many bream*' were neutral (+0.54).

The cross-products of the behavioural beliefs for the fishers of both species revealed similar trends, i.e. that stock enhancement would lead to increase numbers of both target species and more individuals to catch, with these being slightly more positive amongst Black Bream fishers (i.e. ~13.5 vs ~10.5). Moreover, in both species, beliefs relating to the potential deleterious effects of stock enhancement, i.e. '*increased fishing pressure*' (both species), '*environmental impacts*' (Blue Swimmer Crab only) and '*less bream surviving*' were all regarded as unlikely and only somewhat bad (range = 0.54 to -3.4).

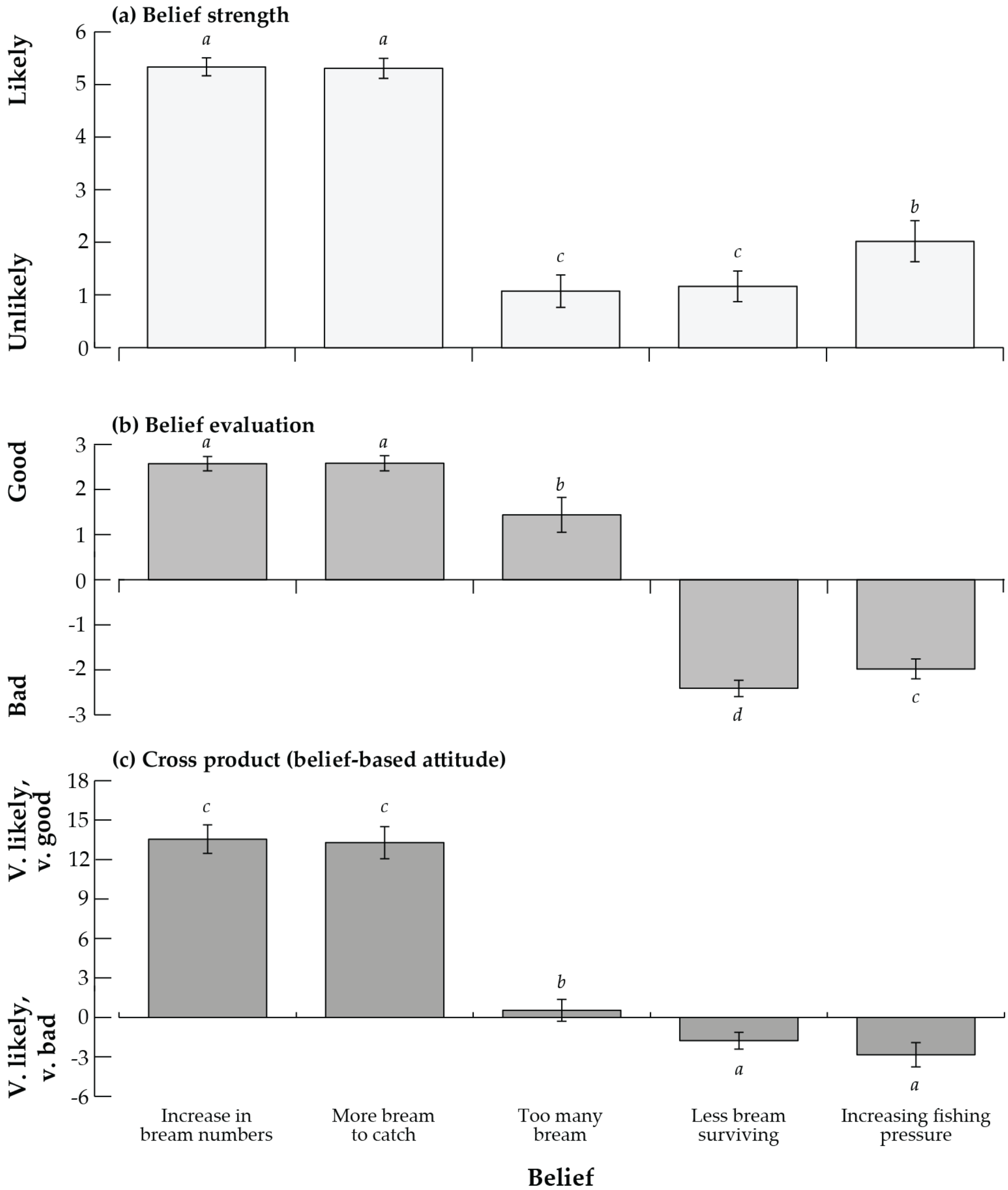

Figure 1.4.7. Mean ratings and 95% confidence limit for each stock enhancement belief across (a) belief strength, (b) belief evaluation and (c) cross-products for stock enhancement of Black Bream.

More than 85% of respondents agreed with the statement that stock enhancement of Blue Swimmer Crabs would be a good thing to do, with 45% stating that it will be very good. In contrast only 4% of fishers thought that it will be a very bad thing to do (Figure 1.4.8). The views of these fishers were found by a Kruskal-Wallis test to be similar among both fisheries (H = 4.06; p = 0.254) and fisher groups (H = 9.35; p = 0.156). An even higher percentage of Black Bream fishers considered stock enhancement as a good thing, i.e. 93%, with 63% stating it would be very good. Although these views were consistent among fisheries (H = 2.15; p = 0.543), they differed significantly among fishers in groups *d* and *e,* i.e. those with large enough numbers of respondents to provide a rigorous test (H = 7.23; p = 0.007). Both groups were strongly supportive of enhancement, however, a small minority of fishers in group *d* had negative opinions of this management measure (i.e. 3.7% very bad and 3.7% somewhat bad). In contrast no respondents from fisher group *e* selected one of the negative options and, in fact, 82% selected very good and 15% good (Figure 1.4.8).

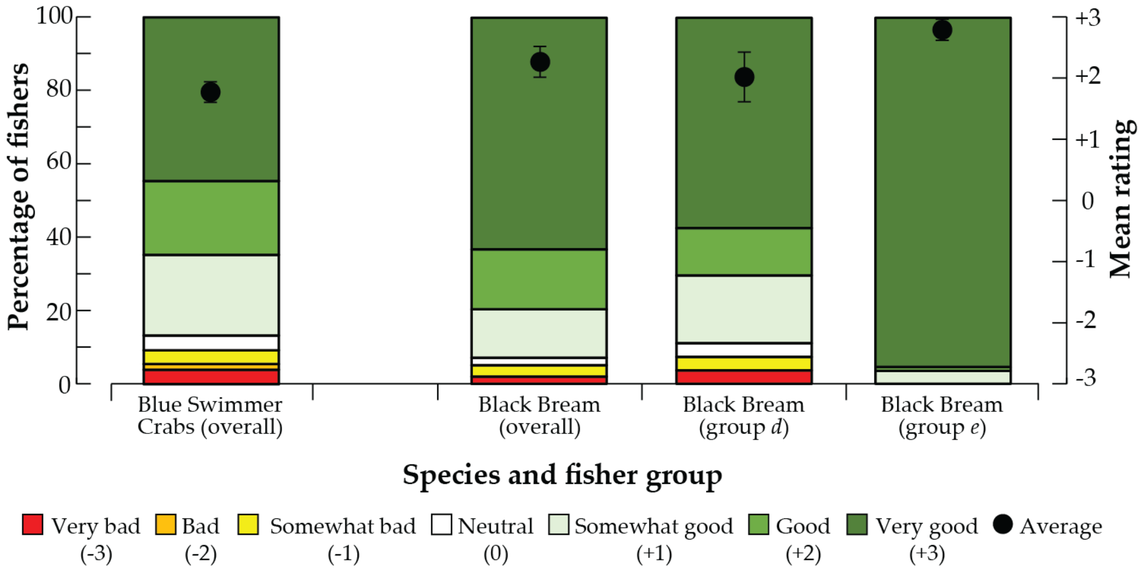

Figure 1.4.8. Mean ratings and stacked bar graph of the percentage of recreational fishers that selected each attitude category for the question '*Overall, I think using stock enhancement as a management option* for all Blue Swimmer Crabs and Black Bream fishers and those bream fishers in groups *d* (Inexperienced intermediate skilled fishers) and *e* (Inexperienced but keen fishers).

1.4.3.4. Implications of any stock enhancement

If stock enhancement was to occur 88% of recreational Blue Swimmer Crab fishers and 96% of recreational Black Bream fishers stated they would continue to fish for their target species (Table S1.4.13a). These views were consistent across all crab fisheries (87-89%; $p > 0.05$) and fisher groups (82-100%; $P > 0.05$) except for those fishers utilising Shark Bay and those in group *g* (bi-monthly hand fishers), where the proportion of fishers who agreed with the statement was less and those that were unsure increased (Table S1.4.13a; Figure S1.4.13a,b). The views of Black Bream fishers regarding whether they would fish after enhancement were homogenous across fisheries and fisher groups ($P > 0.05$; Figure S1.4.13,c,d).

As the main motivation for recreational fishing for Blue Swimmer Crabs is food (Section 1.2), fishers were asked a series of questions about what they would do if they caught a hatchery-reared crab. The vast majority (84%) agreed with the statement that they '*would eat it as if it was wild crab*' with only 3% disagreeing (Figure 1.4.9). A similar trend was exhibited by fishers in all fisheries (81 to 95%), and between all fisher groups (80 to 88%) except *a* and *g,* where a greater proportion of fishers disagreed (20% and 17%, respectively vs 0-6% for the other groups), although this did not reduce the proportion of those fishers that agreed (Table S1.4.14). Fishers were generally unsure whether they would prefer cultured to wild crabs with responses spread fairly uniformly amongst the three options but with most in the '*don't know*' category. Most fishers stated that they disagreed with the following statements '*I would not eat it myself but would keep it for family/friends*' and '*I would release after capture, I don't like aquacultured crabs*' further reinforcing their earlier statement about eating stocked crabs as if they were wild-spawned (Table S1.4.14).

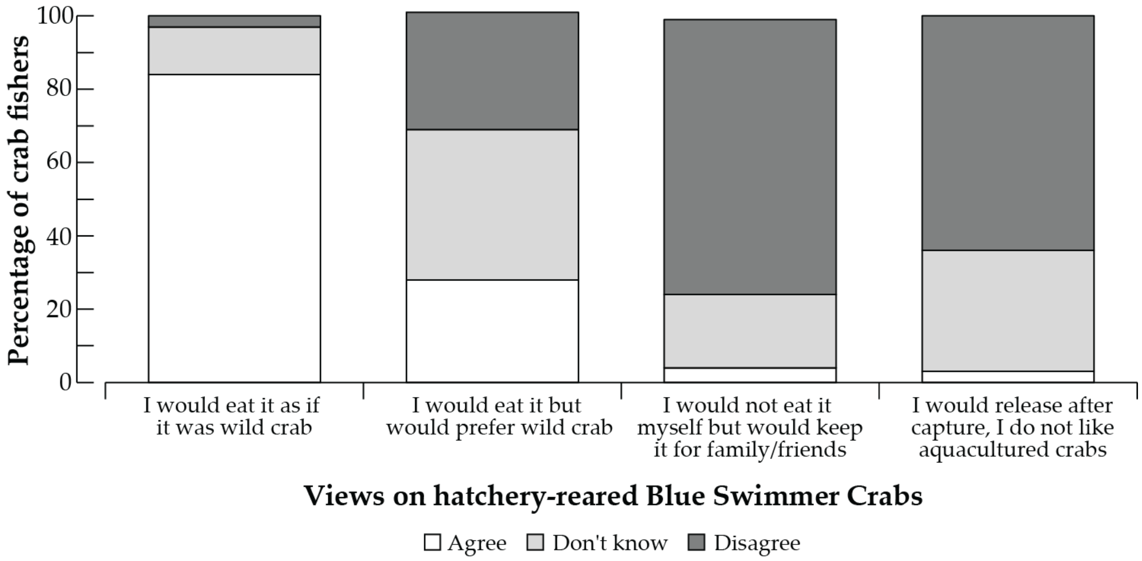

Figure 1.4.9. Percentage of Blue Swimmer Crab fishers that chose options related to what they would do if they caught a hatchery-reared crab.

1.4.3.5. Views of commercial fishers

Among commercial Blue Swimmer Crab fishers '*family tradition*' and a '*love for fishing*" were the two main motivations for fishing (72.7%). Fishing as a means of employment, was only mentioned as a main motivation by one commercial fisher (9.1%). In contrast to recreational fishers, most commercial fishers (88.9%) were not worried about Blue Swimmer Crab stocks, with only one from the Peel-Harvey (11.1%) expressing concerns. The most frequent issues raised by commercial fishers were '*environmental factors*', '*estuary development*', '*more people fishing*', '*lack of compliance*', and '*not enough food for crabs*'. Similar motivations were expressed by commercial Black Bream fishers with 75% fishing because of a '*family tradition*' and the remainder because they '*love it*'. None of the fishers were concerned about the current state of the fishery in the Blackwood River Estuary or Wilson Inlet, although one fisher from the Blackwood said that they have no concerns following the restocking of that system between 2001 and 2003 as before then Black Bream were not very abundant.

Most commercial fishers targeting Blue Swimmer Crabs in the Peel-Harvey Estuary were not supportive of using stock enhancement as a management approach in the future (Figure 1.4.10a). The majority of respondents (80%) stated that stock enhancement was not needed or had no advantages for the Blue Swimmer Crab stocks, with only two fishers (20%) reporting that this management approach would benefit the fishery by *'increasing the number of crabs in the system'* and '*increasing the number of crabs that will be caught by the fishery'*. Most fishers identified some disadvantages linked to using stock enhancement as a management approach (Figure 1.4.10b). For example, one fisher mentioned that this approach could affect the genetic pool of the wild population. Six fishers expressed concerns about stocking; two fishers were concerned that the system would not be able to provide food for more Blue Swimmer Crabs; two that with more crabs in the estuary, recreational fishing pressure would increase too (29%); and two fishers said that this method would not be effective as Blue Swimmer Crabs migrate between the estuary and the ocean, therefore not forcibly increasing the population of crabs in the estuary. Among commercial Black Bream fishers, there was a general agreement that stock enhancement would bring more fish to the system and therefore more stock to support the fishery, though one commercial fisher said that he saw no advantages. Overall, two fishers saw no disadvantages in using stock enhancement as a management approach and two fishers mentioned concerns that this approach could cause an ecosystem imbalance and result in poor breeding success (Figure 1.4.11).

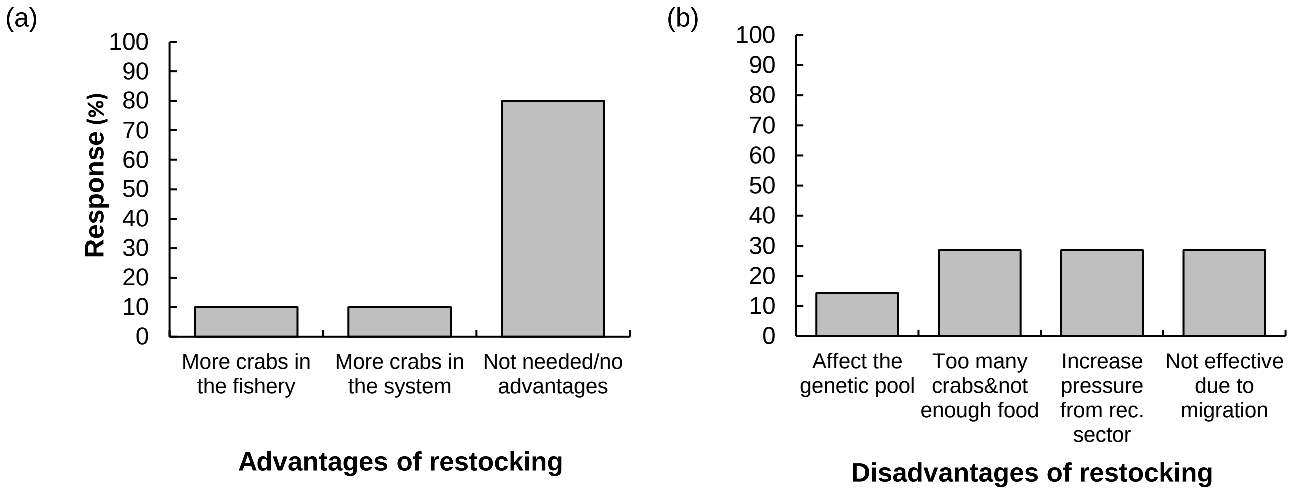

Figure 1.4.10. Perceived (a) advantages and (b) disadvantages of using stock enhancement as a management option for Blue Swimmer Crabs as stated by commercial fishers in the Peel-Harvey (n = 9).

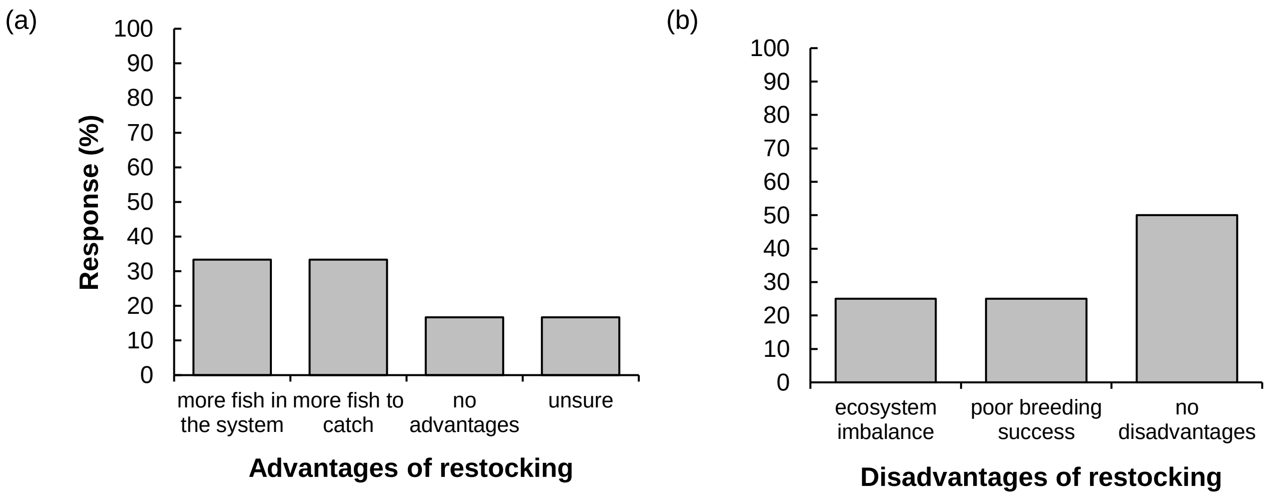

Figure 1.4.11. Perceived (a) advantages and (b) disadvantages of using stock enhancement as a management option for Black Bream as stated by commercial fishers in Blackwood River Estuary and Wilson Inlet (n = 4).

1.4.3. Discussion

Estuaries and their component fisheries are subject to a multitude of pressures, some of which are competing, and often require a suite of management measures to maintain or improve sustainability. Engaging fishers and understanding their thoughts on management options can be beneficial and boost community support for those measures and, as a result, increase compliance. This is particularly valuable for recreational fishers who act relatively autonomously and thus their management often relies heavily on encouraging voluntary compliance. This study evaluated the salient views of recreational and commercial fishers on issues affecting the Blue Swimmer Crab (*Portunus armatus*) and Black Bream (*Acanthopagrus butcheri*) fisheries in south-western Australia, current and potential management arrangements for these two species, and how they perceive stock enhancement as a management option.

1.4.3.1. Perceived fishery issues

The vast majority of recreational crab fishers considered their fisheries to be experiencing problems and elicited ten issues of which, the top five were all catch-related, i.e. taking of undersize crabs, overfishing, exceeding the bag limit and commercial and recreational fishing. Similar results were obtained from recreational bream fishers, with the taking of undersized fish, lack of fisher education, overfishing and exceeding the bag limit as the main issues. The focus of fishers on catch-related issues is not-surprising given that the main motivations of crab and bream fishing are catch-orientated, albeit for consumptive and trophy reasons, respectively (Section 1.2), compared to, for example, a bushwalker or kayaker, who may likely focus more on environmental issues, such as climate change or pollution.

Inter-estuarine differences among recreational crab fishers were mainly due to i) the retention of undersize crabs being raised by more fishers in the Peel-Harvey than the Swan-Canning and ii) fewer fishers in Leschenault selecting commercial fishing as an issue. It is thus relevant that the Peel-Harvey crab fishery has the highest-recorded levels of non-compliance of any fishery in Western Australia, with 20% of all reported enforcement issues along the Western Australian coast being from this estuary (DPIRD, 2018) and stories of infringements are often reported in print, broadcast and social media. This highlights the issue and raises awareness among fishers and could thus have influenced their views. Commercial crab fishing was occurring in the Swan-Canning and Peel-Harvey estuaries at the time of the surveys, but operations ceased in Leschenault in 2001 (Johnston, Harris and Yeoh, 2020) explaining the reduced concerns about this issue in that estuary. For most of the elicited issues, a similar proportion of recreational fishers for both species agreed, however, a greater proportion of crab fishers mentioned exceeding the bag limit, which could reflect the consumption-oriented nature of crab fishing and the fact that many bream fishers catch-and-release (Section 1.2).

Non-catch issues such as pollution and climate change were identified by far fewer crab and bream fishers. Although, many estuaries globally are focal points for industrial activities (Kennish, 2002; Tweedley, Warwick and Potter, 2015), aside from port facilities at the mouths of the Swan-Canning and Leschenault estuaries, there is limited evidence of industrialisation in estuaries in the region (Brearley, 2005) and there are no regular signs of contamination, e.g. chemical/oil spills. Furthermore, although many of the estuaries in south-western Australia have high levels of nutrients due to run-off from their catchments (Brearley, 2005) resulting in poor water quality and high densities of phytoplankton, unless these perturbations reach manifestable levels (e.g. visible micro-and macroalgal blooms and fish kills (e.g. Potter et al., 2021; Cottingham et al., 2022)) the local community may not be aware these issues exist (e.g. Lepesteur et al., 2008). It is noteworthy that a larger proportion of bream than crab fishers raised pollution as an issue as typically algal blooms and fish kills occur in the more upstream reaches of estuaries where Black Bream reside (Hoeksema and Potter, 2006; Hallett et al., 2016) and thus fishers may witness such perturbations more frequently than those fishers targeting crabs in more downstream areas.

In terms of climate change, a survey by Ryan et al. (2021) on recreational fishers in Western Australia demonstrated that most accepted that climate change was occurring, albeit this proportion was less than that for the broader Australian population (Leviston , Greenhill and Walker, 2015), and 60% had noticed changes in the species caught, for example finding tropical species in temperate waters (e.g. Coulson et al., 2023). To account for the discrepancy in acceptance of climate change between the above two studies, Ryan et al. (2021) suggested that the reduced acceptance of climate change observed among fishers may be due to the potential attribution of changes to a range of factors, e.g. natural variability in abundance, fishing effort, water quality and habitats and so it is difficult to disentangle the effect of climate change. Moreover, although there is evidence to suggest that due to climate change, the growth rates of Black Bream are slowing (Cottingham et al., 2014; Cottingham et al., 2018b), this information it not well-known in the fishing community, reflecting differences in the methods of communication among stakeholders (Obregón et al., 2020a). Thus, while the presence of fish outside their normal spatial distribution is relatively easy to detect and attribute to climate changes, other effects are less obvious, such as reduced dissolved oxygen levels or changes in prey availability (Asch, Stock and Sarmiento, 2019; Pauly, 2021).

1.4.3.2. Views on current catches and management

The majority of recreational fishers for both species stated that, in their opinion, both the abundance of crabs and bream and their sizes had decreased and that the number of fishers targeting them had increased. The views of crab fishers in this online survey are consistent with that from separate face-to-face surveys in the Swan-Canning and Peel-Harvey estuaries, with the declines in size of crabs in the former system supported by scientific monitoring data and those relating to size and abundance in historical newspaper records (Obregón et al., 2022a). The reported reduction in size and abundance of Black Bream is also mirrored by declines in growth and body condition of individuals and a movement from deeper, offshore waters in to shallower, nearshore waters due to decreased freshwater flow and an increase in the extent of hypoxia (Cottingham et al., 2014; Cottingham et al., 2018b). The reported increase in the number of fishers reflects Western Australia rapidly increasing population, which has resulted in the estimated number of recreational fishers more than doubling from 315,000 in 1989/90 to 711,000 25 years later (Ryan et al., 2015) and the iconic nature of these fisheries.

Commercial fishers had contrasting views to their recreational counterparts, with ~90% of commercial crab fishers not worried about catches as were none of the bream fishers. Although those in fishing in the Blackwood stated that they were worried before a restocking program (see Jenkins et al., 2006) was initiated in the early 2000s. These different perceptions might be a result of sector-specific bias (Obregón et al., 2020c). It is likely that the difference in time and intensity of fishing by commercial and recreational fishers influences their view on the target species. Such sector-specific bias has been recorded in other studies (e.g. Carr and Heyman, 2012). For example, in the Peel-Harvey Estuary, recreational fishers reported a decline in the size of crabs, whereas the majority of commercial fishers considered the crabs to have remained a similar size. Scientific surveys conducted between 2006 and 2019, which may be shorter than the duration of time some recreational fishers have been fishing, indicate there has not been a decline in size (Obregón et al., 2022a).

In general, recreational fishers perceived crab fisheries to not be well managed, with the Swan-Canning Estuary rated as the best and Shark Bay as among the worst (i.e. 34% and only 17% of respondents stating the fishery was well-managed, respectively). As fisher's motivations are strongly consumption-orientated, with fishers wanting to '*catch enough crabs to eat*' and '*catch big crabs*' (Section 1.2), it is likely their views are influenced by their catch success. It is thus relevant that fishers perceive crabs from the Swan-Canning as being larger than those from the Peel-Harvey; a view supported by scientific data (Obregón et al., 2022a). Furthermore, high numbers of non-compliant recreational fishers have been caught in the Peel-Harvey (DPIRD, 2018), which could influence the views on management for this system compared to the Swan-Canning. In the case of Shark Bay, crab catches declined by ~95% following a marine heatwave in 2010/11 promoting a fishery closure in 2012 to allow for stock recovery (Chandrapavan, Caputi and Kangas, 2019). The commercial fishery returned to full recovery status in 2018, which was the same year as the survey was released and thus the decline in stock may have been in the forefront of respondent's minds.

Recreational bream fishers also considered their fisheries to be more poorly managed than crab fishers. This could be linked to the obvious signs of degradation present in the upstream areas of estuaries in the region

(Hallett et al., 2016; Tweedley et al., 2016). Additionally, as fishers regard Black Bream as a trophy species (Section 1.2), declines in growth mean there are fewer larger fish (Valesini et al., 2017), which may have impacted on their fishing experience and thus perceptions of management. The estuaries where people were least unhappy where in the 'other' category, which includes systems such as the Beaufort and Stokes inlets that are located in regional areas and so are less-heavily fished (Smallwood and Sumner, 2007; Ryan et al., 2015). Noting that this survey was conducted before a major fish kill occurred in Beaufort Inlet (Krispyn et al., 2021).

While fisher's views on management appear to hold true at a nuanced level (i.e. between species and among fisheries) some biases may be present. For example, although Australian fisheries have a reputation as typically being well-managed (Elliott et al., 2022) and the Peel-Harvey Blue Swimmer Crab fishery has Marine Stewardship Council certification (Morison et al., 2016), recreational fishers may have a tendency to inform to news that confirm that fisheries are not well managed/could be better managed (i.e. confirmation bias). Additionally, some fishers may hope that their response to a survey will result in an output therefore giving an answer that may be biased (i.e. response bias).

1.4.3.3. Opinions on management tools

As management of recreational fishers often relies heavily on encouraging voluntary compliance there is value in accessing the acceptability of various management options. In the case of Blue Swimmer Crab fishers, existing measures were the most popular, i.e. minimum size limit, followed by temporal closure, fisher monitoring, fish education and bag limits. Of potential management options not currently in use stock enhancement received the most support. These results are consistent with Garlock and Lorenzen (2017), who found that fishers showed more support for various restrictive strategies, such as bag limits and minimum size limits, compared to stocking. Similarly, Rubio, Brinson and Wallmo (2014) found that minimum size limits along with habitat-related management strategies were the most preferred interventions for coastal recreational fisheries in the USA. This trend may be explained by the familiarity that fishers have with the management policies, with fishers potentially preferring those regulations that they currently comply with and understand (Wilde and Ditton, 1991). For example, when fishers were offered a list of alternative fishery regulations, they commonly selected those that were most similar to existing ones (Renyard and Hilborn, 1986; Helfrich, Chipman and Kauffman, 1987). Fishers are familiar with minimum size limits as these are commonly-used to manage recreational fisheries (FAO, 2012b), easy to interpret and they comprehend the logic behind them (i.e. protecting stock until its sexually-mature) and communicated widely through fishing apps and websites and also interpretative signs at fishing locations. Given the well-publicised level of non-compliance, particularly in the Peel-Harvey (DPIRD, 2018; Lindley and Quinn, 2023), it is not surprising that fisher surveillance and education was strongly supported..

Although, bag limits are among the most widely utilised management tools (FAO, 2012b), this option ranked low among options proposed by recreational fishers. This likely reflects the consumption-orientated motivation of crab fishers. For example, despite, respondents stating that reaching their bag limit of 10 crabs was not among the strongest motivations, 37% admitted having retained more crabs than legally allowed (Section 1.2). A survey on non-compliance found that 22% of respondents self-reported that their average catch exceeded the bag limit of 10 crabs (Lindley and Quinn, 2022). The least supported management options were spatial closures and maximum size limits. Previous studies have shown that fishers attitudes towards no take zones vary with fisher's motivations and their specialization (McNeill, Clifton and Harvey, 2019). Particularly for the Blue Swimmer Crab fishery in south-western Australia, as closed areas have been previously introduced in popular fishing locations. For example, recreational crabbing was permitted in the nearby marine embayment of Cockburn Sound until 2006 when it was closed and remains closed today, except for a 10 month re-opening in 2009-10 (Johnston et al., 2011). Thus, fishers may be worried that if recreational crab fishery closed it would remain closed. Maximum size limits were the least popular reflecting the strong primary motivation fishers have for '*catching big crabs*' (Section 1.2).

Similar results were obtained from Black Bream fishers, with existing measures (e.g. minimum size limits, education, restricting commercial fishing, fisher monitoring and bag limits) are the most accepted. Stocking, and maximum size limits were the options that rated well but have not been widely employed. The support for stocking reflects the generic support for this option and that it has been used successfully before (see below), while that for maximum size limit is likely related the trophy nature of the fishery (Section 1.2). Given that the highest rate motivation for Black Bream fishing was to "*catch a big bream (> 30 cm)*" and that the growth rates of this species have declined (making larger fish rarer) it seems logical this management option would be well-supported, despite is not being widely employed in Western Australia (DPIRD, 2022). Management options that would limit the opportunity for fishers to catch Black Bream were the least acceptable, i.e. spatial and temporal closures and restricting recreational fishing a finding also reported from Germany (Klefoth et al., 2023). Spatial and temporal closures were substantially less popular amongst recreational bream than crab fishers. It is relevant that recreational fishing was listed as the eighth biggest issue of the nine identified by bream fishers, with 43% of fishers agreeing and 30% disagreeing), in contrast, it was listed fourth of ten by crab fishers (62% agree and only 11% disagree). Moreover, most bream fishers reported utilising catch and release fishing, whereas crab fishers consumed their legal-sized catch. Based on this, recreational bream fishers likely feel their fishing has less of an impact on fish stocks and so management measures that restrict access are not considered acceptable.

Combining their views on the fishery status and the acceptability of various existing and potential management measures, recreational fishers think management needs improving and have identified that the current fishery regulations are relatively socially acceptable. In other words, they support the way the fishery is managed, but think it needs to be better managed. Crab fishers advocated for catch-related measures, i.e. size limit and bag and boat limit, to remain the same and fisher education and surveillance to increase. This would allow stock to be protected by reducing non-compliance, without impeding catches reflecting the consumption-orientated nature of the fishery. Among the three estuaries, increases in fisher surveillance were most strongly supported in the Peel-Harvey estuary where non-compliance is greatest (DPIRD, 2018). Differences in the level of support for temporal closures were detected, with fishers from the Peel-Harvey more supportive than those in the Swan-Canning and Leschenault. At the time of the survey a temporal closure was only in place for the first estuary and thus the stronger support may reflect fishers familiarity with this regulation (Renyard and Hilborn, 1986; Helfrich, Chipman and Kauffman, 1987).

With the exception of fisher education (increase) and surveillance (increase) recreational bream fishers were generally split in their opinions on the acceptability of management measures. For example, 58 and 49% overall wanted bag and boat limits to decrease, compared to 36 and 40% who thought they should remain the same. While these views are relatively consistent across estuaries, they differ markedly among fisher groups. This showcases the heterogenous view of fishery users (Muthén and Muthén, 2000; Magee et al., 2018), with avid and skilled fishers who fish in competitions wanting these measures to be increased (Section 1.2; Tweedley et al., 2023b).

1.4.3.4. Stocking as a management option

Stocking was rated as among the most acceptable of the management options provided and the most acceptable of those options not already in use for both crabs, a short-lived invertebrate species targeted as a food source, and for bream, a longer-lived finfish species targeted as a sport. Thus, despite the differing biological characteristics and motivations for fishing, stocking was a popular management option. Moreover, in comparison to some of the other management options where the level of support differed among systems or among fisher groups (i.e. heterogenous views), the views of fishers on stocking were homogenous. While there had been limited work on support for stocking in Australia (Obregón et al., 2020b), studies in Europe and North America suggest that there is considerable support for such a program (Arlinghaus, 2006c; Poorten et al., 2011; Garlock and Lorenzen, 2017). Belief elicitation identified that, regardless of the species (crabs or bream), fishers thought stocking would result in increasing numbers of their target species and, in turn, there would be more to catch. Beliefs that releasing fish leads to improved catches has also been reported by Hunt, Gonder and Haider (2010). It is likely that fishers prefer this management option over measures that reduce access and catches. Stocking for Blue Swimmer Crabs is only at an experimental stage in Western Australia (Jenkins, Michael and Tweedley, 2017; Jenkins et al., 2018) and that for Black Bream has only occurred in the Blackwood Estuary (Jenkins et al., 2006). Thus, fishers views on stocking are likely deep-rooted (Arlinghaus et al., 2014) and/or based on the their familiarity with local programs, e.g. for trout in freshwaters (Molony, 2001) and the recently initiated Snapper Guardians program in coastal waters.

Unlike in other studies, a moderate proportion of fishers identified some negative outcomes that may result from a stocking program. These included an increase in fishing pressure and deleterious impacts on wild-spawned individuals. These included increased fishing effort (Hilborn, 1998; Camp et al., 2017), impacts on genetic diversity and abundance (Lorenzen, Beveridge and Mangel, 2012), predation and competition between stocked and wild stock, reducing wild populations (Bell et al., 2008; Ingram, Hayes and Rourke, 2011; Taylor, 2017a). The elicitation demonstrated, however, that fishers considered these negative impacts as only fairly likely at best and slightly bad. These views could reflect the strong desire for catch-related outcomes from their fishing (i.e. consumption or trophy-orientated) and so fishers may downplay the negative impacts associated with this management strategy, due to their interest in catching greater numbers of their target species and the belief that stock enhancement will enable this. This is probably due to a cognitive bias that results in a tendency to ignore the possibility of negative occurrences and produces over-optimism, further encouraged by the motivations of the fishers (Obregón et al., 2020b).

In contrast to the recreational fishers, commercial fishers, and particularly those targeting crabs, were not supportive of stocking. Crab fishers utilising the Peel-Harvey Estuary considered there to be sufficient numbers of juvenile crabs in the system and that releasing more may increase pressure on food resources. Simulation modelling (Section 3.1) conducted after the interviews with commercial fishers were completed suggested that there are strong density-dependent effects, and that the density of wild crabs would need to decrease before stocking would lead to increased catches. Moreover, dietary work on Blue Swimmer Crabs in the Peel-Harvey Estuary has shown that individuals consume smaller volumes of high-calorie prey, i.e., polychaetes, small bivalves and teleosts, and instead ingest greater proportions of calcareous material than twenty year previous (Campbell et al., 2021). This marked shift in dietary composition parallels changes in benthic macroinvertebrates in the Peel-Harvey Estuary (Wildsmith et al., 2009) and suggest prey limitation could be occurring.

Commercial Black Bream fishers were slightly more supportive of stocking, with some suggesting that it would increase stocks. The views of these particular fishers comes from their experience with the restocking program for Black Bream Blackwood Estuary that released 220,000 juveniles (Jenkins et al., 2006). Subsequent monitoring demonstrated that stocked fish contributed up to 74% of the commercial catch and ~50 % to egg production in some years (Cottingham, Hall and Potter, 2015). Moreover, while one of the commercial crab fishers was concerned about the genetic implications of a stocking program, Gardner et al. (2013) found that stocking had a limited effect on the genetic composition of the population of Black Bream in the estuary.

There is no evidence to suggest that any stocking program would result in recreational fishers no longer fishing. Moreover, the vast majority of crab fishers would eat a hatchery-reared crab as if it was wild-spawned and only 3% of people would release an aquacultured crab if it was legal-size. This is relevant as any stocking program would have associated costs, which could, if needed, be recouped from a licence fee or through increased recreational expenditure (Section 3.3). A study from British Columbia suggested that stocking leads to an increase in participation and license sales (Dabrowska, Haider and Hunt, 2014). At a local level, anecdotal evidence from the stock enhancement of the Western School Prawn (*Metapenaeus dalli*) in the Swan-Canning Estuary (Tweedley et al., 2017c) suggested that recreational effort in this consumption-oriented fishery increased together with expenditure on fishing gear.

1.4.3.5. Conclusions and management implications

This study has shown that, most recreational fishers consider Blue Swimmer Crab and Black Bream fisheries in Western Australia to be poorly managed with a range of catch-related issues present. The acceptability of the number of management options were determined, with the most supported measures being those currently in place along with stock enhancement, reflecting the consumption-oriented and trophy-oriented motivations of crab and bream fishers, respectively. Fisher education and surveillance were considered important as, if successful, these would increase compliance and sustainability of the fisheries without impeding personal catches. As managing recreational fishers heavily on encouraging voluntary compliance involving these fishers in the management process (co-management) could be useful and this process could be informed by this surveys (Salas and Gaertner, 2004). The more homogenous views of crab than bream fishers may make co-management of the former fisheries easier due to a greater variety of opinion among bream fisher groups.

While stocking was universally-accepted by recreational fishers of both species in all locations and among fisher groups, commercial fishers were far-less supportive, citing generally a lack of need for such a management option at the current time. The support from recreational fishers for stock enhancement was due to their strong beliefs that such programs would increase stocks and catches of their target species. While some negative impacts of stocking were suggested by fishers, they considered these unlikely to occur. Any co-management would need to address the expectations of both fishery sectors while counterbalancing these with the biological impact of hatchery-reared fish on wild stock and increased in fishing pressure. If any stocking program was to be initiated these expectations need to be managed.

1.5. Information sharing and the management of the Peel-Harvey Estuary

Obregón, C., Admiraal, R., van Putten, I., Hughes, M., Tweedley, J.R. & Loneragan, N.R. (2020) Who you speak to matters: social network analysis on information sharing to inform the management of a small-scale fishery. Frontiers in Marine Science. October 2020 (7): 578-14. DOI: 10.3389/fmars.2020.578014.

1.5.0. Summary

Sustainable natural resource management requires collaboration, adaptability and coordination between science, policy and stakeholders. Communication of scientific information through social networks is integral to effective governance. Social network analysis was employed to investigate information flow between stakeholders associated with the Blue Swimmer Crab (*Portunus armatus*) fishery in the Peel-Harvey Estuary, south-western Australia. Although the fishery received Marine Stewardship Council certification in 2016, a preliminary study conducted between 2017 and 2018 revealed that fishers were concerned about its status and management. Consequently, 85 face-to-face interviews were conducted with commercial and recreational fishers, academics, government bodies, representatives of fishing organizations, non-governmental organizations, and tourism organizations to understand the flow of information and the influence on perceptions of sustainability. The results showed that: i) Few individuals were key for sharing information within and between different organizations forming the fishery network and only two of the six groups (government bodies and the commercial fishing sector) were highly connected and appeared as key for information sharing; ii) After the public sector stakeholders, academic groups were the second-least connected, despite having actively researched the Peel-Harvey Estuary and the Blue Swimmer Crab fishery for over 40 years; iii) Recreational fishers exchanged information mainly with other fishers and the regional fisheries department; iv) Modes of communication used with the recreational fishing sector differed greatly between the fisheries department (i.e. mainly via phone/email) and the recreational fishing organisation (i.e. strong online presence, social media and phone/email); v) Issues of inclusiveness and representation were highlighted for some of the groups and organizations. Logistical and institutional challenges to communicating information regarding the science, management and environmental issues related to a small-scale crab fishery have been identified and suggestions to enhance information flow in the network made.

1.5.1. Introduction

Fisheries are a classic example of natural resources that are vulnerable to management conflict (Hardin, 1968). Interactions between human populations and natural resources (such as a fishery) form complex adaptive social-ecological systems (SES), defined by uncertainties, natural variations and nuanced dynamics that can be challenging to manage effectively (Berkes, Folke and Colding, 2000). Effective management of SES ideally requires the inclusion of human dimensions such as stakeholder perceptions and knowledge (Bodin and Crona, 2009). Hence, calls for a transition from traditional fisheries management to a transdisciplinary and inclusive approach (*i.e.* incorporating human dimensions) are gaining support. In the last two decades, the concept of ecosystem-based fisheries management (EBFM) has been increasingly used globally and appears to be the main stated approach to guiding regulation and exploitation of natural aquatic resources in developed countries (Pitcher et al., 2009), although implementation remains limited (Link and Marshak, 2019).

The challenge of EBFM is deepened further by the existing pressures resulting from climate change. Predictions for temperate, south-western Australia suggest that this region will have reduced winter rainfall (25% - 72% reduction according to different global climate models), and that sea levels will increase by 20 to 84 cm above its current levels by the end of 2100 (Hallett et al., 2018). The combination of increased air temperature, sea level rise and reduced rainfall is expected to result in increased salinity and residence time of water in closed or semi-closed environments, such as estuaries. Furthermore, reduced water exchange and salinity stratification would be expected to increase the frequency and severity of algal blooms, hypoxia and fish kill events (Gillanders et al., 2011; Cowley, Tweedley and Whitfield, 2022). As a result, ecosystems are anticipated to undergo shifts in their community structure and function which will affect the abundance of species targeted by fishers (Caputi, Jackson and Pearce, 2014). More marine conditions in estuaries will result in greater occurrence of marine species, and this might encourage a greater use of these systems by fishers (Valesini et al., 2019). If an increase in fishing pressure occurred, estuarine fisheries, such as the Blue Swimmer Crab (*Portunus armatus*) in Western Australia, which is the focus of this paper, will require new and adaptive management approaches.

Despite the acknowledgement that a transition towards EBFM is needed, in practice, the ecological and human dimensions of fisheries are rarely considered equally, particularly the social, cultural, and institutional aspects, which are often overlooked (Barclay, 2012). The inclusion of stakeholders in the management process (i.e. co-management), along with the study of social networks is fundamental when assessing fishery management approaches. One way to integrate the study of social networks in fisheries research is by better understanding information-sharing within the network and how the structure of the network influences this exchange (Leonard et al., 2011). Information exchange often depends on making and maintaining positive interactions with key individuals and organizations. Thus, understanding the structural pattern of interactions between social network actors, particularly how information is shared, provides insight into the key elements that facilitate and impede efficient communication within the network.

Social network theory derives from graph theory, a mathematical approach used to represent complex systems. Social network analysis (SNA) is a commonly used method to analyze and graphically represent the exchange of resources, such as information and behavioural patterns, amongst individuals, groups, or organizations (Rogers, 1995). This method is increasingly recognized as an interdisciplinary tool with potential to clarify the implications of network properties for natural resource management (Turner, Polunin and Stead, 2014). In social networks, interactions between actors can affect individuals' views, decisions, and behaviours. The structure of the social network of fishers and managers, such as the engagement or disengagement of local users and all stakeholders in the design and implementation of management regulations, can influence the effectiveness and efficiency of both adaptive management and EBFM (Bodin and Norberg, 2005). Understanding these networks and the connections within them provides a key to understanding the reasons behind the success of management and governance of a fishery (Cárcamo, Garay-Flühmann and Gaymer, 2014).

Social networks can influence the resilience of local communities as well as the capacity for adaptation to ecosystems changes. Indeed, previous research has demonstrated that social network structure greatly influences the potential for collective action (Bodin and Norberg, 2005). It has also shown the importance of collaboration and information sharing (Cohen, Evans and Mills, 2012), as well as the significance of particular organizations, partnerships (Berdej and Armitage, 2016) and individuals (Gutiérrez, Hilborn and Defeo, 2011) for successfully managing natural resources, such as fisheries. Effective information flow between stakeholders is a key element for the success of fisheries management worldwide as well as for setting realistic management objectives at a regional or local scale (Barnes-Mauthe et al., 2015). To our knowledge, however, no studies have investigated the patterns of information-sharing through an Australian fishery network.

The Blue Swimmer Crab fishery is one of the most important fisheries in south-western Australia, both from a recreational and a commercial perspective, particularly in the Peel-Harvey Estuary. Both sectors of the Peel-Harvey Blue Swimmer Crab fishery (hereafter PHBSC) were certified in 2016 as sustainable by the Marine Stewardship Council (MSC), in a world first joint certification (Morison et al., 2016). Information sharing between individuals and organizations participating in the PHBSC fishery network is a major element to facilitate an efficient management of this resource. Despite the fishery's sustainability certification, a previous study that analysed fishers' perceptions on current management approaches, revealed that fishers were concerned about the fishery´s status and management (Obregón et al., 2020c). Consequently, this chapter used social network analysis to empirically investigate information-sharing patterns among actors in the SES of the PHBSC fishery. We explored different network configurations: i) Relations based on information sharing between individual stakeholders actively involved in the management and the study of the fishery (i.e. not including recreational fishers); ii) Relations based on information sharing between organizations, and iii) Relations based on information exchange between recreational fishers and some organizations belonging to the PHBSC fishery network. The analysis of this small-scale fishery network in south-western Australia provided insight into specific points of intervention and ways forward to help enhance innovative and adaptive management of regional fisheries.

1.5.2. Methods

1.5.2.1. Study area and target species

Fishing is an important activity in Western Australia (WA), both culturally and commercially. It is estimated that ~700,000 Western Australians fish recreationally (Ryan et al., 2019), representing a significant proportion of the state's total population of 2.6 million people. Commercial fishing in WA contributes around AUD 1 billion and provides direct employment to over 5,000 people (WAFIC, 2020). The Blue Swimmer Crab fishery comprises a significant component of the WA recreational fishery catch. For example, in 2017/2018, recreational boat fishers were estimated to have caught ~660,000 crabs in WA (Ryan et al., 2019). Additionally, a significant number are caught by shore-based fishers in WA's estuaries and coastal embayments. Events organized to celebrate the catch of crabs in WA, such as the annual celebration of "crabfest" in Mandurah, reflect the cultural importance of blue swimmer crabs in this region. This species is also targeted by the commercial sector, which employs more than 80 people directly and is valued at ~AUD 3.5 million per year (Johnston, Marks and O'Malley, 2018). The commercial catch in WA was 518.2 t in 2017 (Fletcher, Mumme and Webster, 2017).

Located about 80 km south of Perth, the Peel-Harvey Estuary is the largest estuary in south-western Australia (area ~130 km^2, Figure 1.5.1) and it is also one of the most popular locations for Blue Swimmer Crab fishing, and is also part of the Ramsar-listed Peel-Yalgorup wetland system (Valesini et al., 2019). The City of Mandurah (population ~80,000) is located at the mouth of the estuary and is the fastest growing city in the state and second fastest growing regional city in Australia (PDC, 2019). The estuary's importance as a major natural asset and the population growth in the region create challenges for managing the natural resources depending on this environment.

To achieve certification of the PHBSC fishery by the MSC, fishery stakeholders were required to demonstrate its sustainability. The certification process required pooling data from various groups (*e.g.*, government bodies, fishing sectors and other organizations) on the status of the fishery and its environment, as well as its management and other elements related to decision making (MSC, 2019). Consequently, as part of the certification process much information was shared between individuals and organizations participating in the PHBSC fishery network. Both fishery sectors were required to engage in providing pre-certification information and contribute to annual audits. The information shared among the network of stakeholders was a key element in this process.

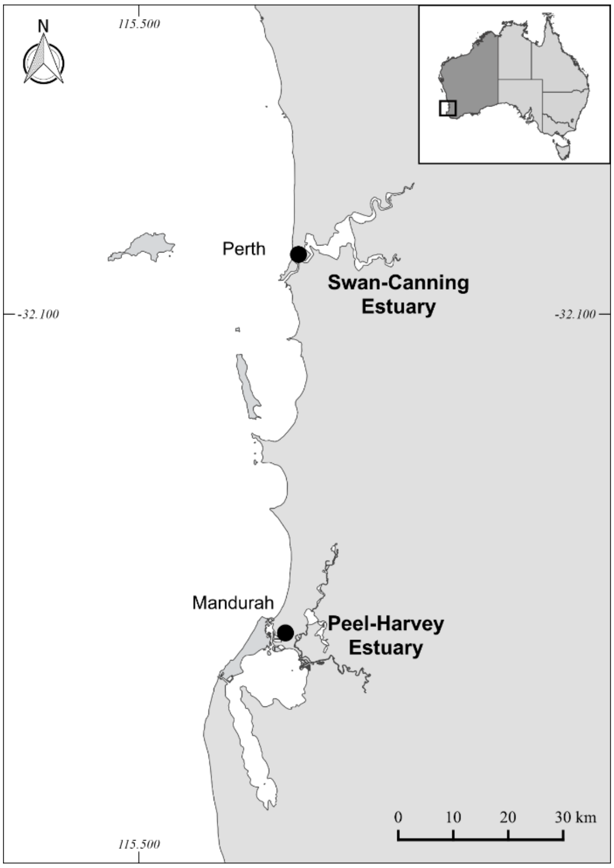

Figure 1.5.1. Map of Western Australia showing the location of the Peel-Harvey Estuary and the cities of Mandurah and Perth.

1.5.2.2. Data collection

The target population for the social network analysis is the PHBSC fishery network, which includes a diverse range of stakeholders, such as non-governmental organization (NGO) representatives, government bodies, academics, and fishing sectors representatives (Table 1.5.1). Potential survey participants from each organization were identified in a three-step process, which included a preliminary identification of primary participants who were known to the researchers and who were actively involved in the fishery. These 33 primary participants were contacted via email, and 23 agreed to be interviewed. Snowball sampling was used to identify and survey other stakeholders (econdary participants; Maiolo, Johnson and Griffith, 1992). To be invited to participate in the survey, secondary participants had to be nominated by at least two primary participants. This process continued for three waves (i.e. three interview sets where, if survey participants named new stakeholders twice or more, these people were contacted and invited to participate in the survey). Despite some recreational fishers being mentioned during these interviews (Table 1.5.1), no individuals were mentioned by two or more participants, and therefore recreational fishers not invited to participate in the survey. Recreational fishers were therefore interviewed separately.

Table 1.5.1. Organisations forming the PHBSC fishery network and acronyms used for each organisation, groups they are affiliated with, description of each organisation and total individuals mentioned (N) and individuals interviewed (n) for each organisation.

Group	Organisation	Acronym	N	n	Description of each organisation
Commercial fishing sector	Commercial fishers	MLFA	10	2	Commercial fishers in the Mandurah licensed Fishermen Association (MLFA)
	Southern Seafood Producers of WA	SSPWA	1	1	Association for professional seafood producers in south-western Australia
	WA Fishing Industry Council	WAFIC	6	2	Main organisation representing commercial fishing in the State of WA
Recreational sector	Recfishwest	RFW	5	5	Main organisation representing recreational fishing in the State of WA
	Recreational fishers	Rec. fishers	6	0	Recreational fishers actively involved in the discussions on the management of the fishery
	Mandurah offshore fishing and sailing club	MOFSC	1	0	Recreational fishing club in Mandurah
Government body	City of Mandurah	CoM	4	1	Council for Mandurah
	Department of Biodiversity, Conservation and Attractions	DBCA	2	0	State government department for the management of WA's environment and its conservation
	Department of Primary Industries and Regional Development	DPIRD	38	17	State government department for WA fisheries management
	Department of Water and Environmental Regulation	DWER	5	1	State government department for water regulations in WA
	Fisheries Research and Development Corporation	FRDC	1	0	National body for research, development and extension of fisheries and aquaculture sectors
	Peel Development Commission	PDC	2	1	Regional commission for the Peel region (including the Peel-Harvey Estuary)
	Politicians	-	2	0	Local politicians
Academics	Murdoch researchers	-	12	2	Post-graduate students and established academics involved in Blue Swimmer Crab research
	University of Western Australia researchers	-	1	0	Established academics involved in Blue Swimmer Crab research
NGOs, Conservation groups	Birdlife Australia	-	1	0	Non-profit, non-governmental organisation (NGO) for the conservation of Australian birds
	Marine Stewardship Council	MSC	1	1	Non-profit, NGO providing a certification scheme of sustainable seafood
	Peel-Harvey Catchment Council	PHCC	6	1	Non-profit, NGO community-based organisation for the management of natural resources in the Peel-Harvey Estuary Catchment
	Scientific Certification Systems	SCS	1	1	Third-party organisation providing independent assessment of sustainability
Public awareness, Tourism	Dolphin Watch	-	1	0	Partnership between the DBCA, Murdoch and Curtin Universities for the conservation of dolphins in the region
	General public	-	2	0	General public (not necessarily fishers) actively involved in the discussions on the management of the fishery
	Mandurah Cruises	-	1	0	Tour operator conducting river and coastal cruises, based in Mandurah
	Mandurah Times	-	1	0	Local newspaper based in Mandurah
	Peel Bright Minds	-	1	0	Community-based organisation promoting events and regional activities in the Peel region
	Western Angler Magazine	WAM	1	0	WA recreational fishing magazine

The approach used to interview recreational fishers differed from the method used with the rest of respondents. While individual meetings were arranged with non-recreational fisher respondents, recreational fishers were randomly selected at popular fishing spots throughout the summer season (peak time for Blue Swimmer Crab fishing in the region) and invited to be interviewed.

A total of 85 semi-structured interviews were conducted between November 2018 and November 2019, from 6 am to 2 pm to collect network data, respondents' attitudes and perceptions towards information sharing efficiency, and individuals' demographics. Note that recently, monitoring by DPIRD has found a significant number of recreational fishers fishing throughout the evening (Taylor et al., 2018). No interviews were carried out during the night and therefore we have no information on whether the night fishers represent a different group to those interviewed during the day. Relations which involved information-sharing were elicited by asking stakeholders i) to name up to 10 individuals with whom they exchanged information on the Blue Swimmer Crab fishery; ii) how frequently information-sharing interactions occurred; and iii) their perceptions of the utility of the information shared. Recreational fishers refused to provide individual names of the people they shared information with, as they considered this to be a breach of their privacy. Consequently, the survey for recreational fishers was adapted to not require mentioning individual names. Instead, recreational fishers were asked to identify the organizations they had been or were in contact with (rather than naming individual stakeholders) from a list of key organizations (including an "other" option) that had been produced based on the fishery network. This difference in the data collected required a separate data analysis for the individual recreational fishers included in the network, as the recreational fishers provided information on organizations, whereas the non-recreational fisher stakeholders identified and provided information on individuals.

The network data collected included a description of the relations/edges (*i.e.* interactions between actors), directionality of information-sharing (i.e. who shared the information and who received it), mode of communication used (*e.g.* face-to-face, telephone, e-mail), topic discussed (*i.e.* fishery science, management, or environment), frequency of interaction, length of the relationship between the two individuals, and the perceived quality of interaction, defined as the quality of the information received and the perceived efficiency of the interaction, quantified on a three-point scale (1 = low, 2 = medium, 3 = high). Data of each respondent/node were also recorded, including the name, affiliation, age and level of seniority (as represented by role) in the organization. To preserve respondent privacy, names of respondents were replaced with a unique identifier code, and organization names were categorized into six broad groups (i.e. commercial sector, recreational sector (formed by organizations representing and managing the recreational fishing sector only), government body, academics, NGOs and conservation groups, public awareness and tourism) according to the general purpose of each organization (Table 1.5.1). Individual recreational fishers were not included in the recreational fishing sector group as these responded to a different survey and therefore were analysed separately.

Qualitative data were also collected to provide context regarding the information-sharing relations. These included questions about personal satisfaction with their own information sharing, perceived fishers' satisfaction on the management of the fishery by other stakeholders and public events where information on the Blue Swimmer Crab fishery was shared.

1.5.2.3. Network and data analyses

Social network analysis was used to describe, analyse, and map how individuals, organizations, and stakeholder groups interacted and shared information. We considered three forms of networks based on the different types of data, as follows:

1. An egocentric network of non-recreational fisher stakeholders (hereafter "egocentric network of stakeholders") and only their direct information sharing relations.

2. A full network of the previously described closed population (hereafter "closed population network") and all information sharing relations among respondents who were part of this closed population. We also

considered a network of organizations and relations among these organizations corresponding to this closed population.

3. A bipartite network of surveyed recreational fishers and the organizations with which they shared or received information (hereafter "bipartite network of recreational fishers and organizations").

These networks are described in more detail below.

The statistical analysis of these networks was carried out in R using the 'sna' (Butts, 2019), 'network' (Butts et al., 2019), 'statnet' (Handcock et al., 2019), and 'igraph' (Dickey et al., 2019) packages. This included calculating descriptive statistics, such as various measures of centrality (relating to out-ties or sharing of information, see Table 1.5.2 for a description of these measures, and prestige (relating to in-ties or reception of information). Eigenvector centrality and prestige were considered, although we do not present measures of these forms of centrality and prestige, as it did not provide any additional insights to those obtained from the analysis of degree centrality, betweenness centrality and degree prestige. When applied to a network of organizational relations, measures were weighted by the number of relations between organizations (or groups). In addition to measures of centrality and prestige, we also examined attribute-based mixing (*i.e.* cross-tabulations of relations between actors based on certain attributes for both actors involved in the relation and fit statistical models for networks, specifically exponential random graph models (ERGMs).

Table 1.5.2. Individual and organisational level network metrics of centrality, definitions, and descriptions.

Centrality measure	Definition	Description
Degree centrality	Count of number of outgoing edges to the node. We present normalized degree centrality to account for network size.	Actors with a high degree centrality have a greater capacity to share information and have a greater information-sharing power.
Betweenness centrality	Calculations of betweenness for a particular actor are based on the quantity of shortest paths between other nodes that go through that particular node. We present normalized betweenness centrality to account for network size.	This measure gives information on which nodes (*i.e.* actors) receive information more frequently. They are important for controlling the flow of information between nodes. The more 'in between' an agent is, the more that agent will be able to receive and share different types of information among others.
Degree prestige	Count of number of incoming edges to one node/actor. We present normalized degree prestige to account for network size.	Actors with high degree prestige potentially have a greater influence in the network and have a greater information-sharing power.

1.5.2.4. Egocentric network of stakeholders

The egocentric network of stakeholders examined only the local networks of primary survey participants (i.e. the respondents and those with whom they directly shared or received information). These included individuals surveyed from the PHBSC organizations representing different stakeholder groups but excluded recreational fishers since, as previously described, recreational fishers provided a different type on information of the network, and therefore were analysed separately, as a bipartite network (see section below for more details).

An examination of attribute-based mixing for age, gender, education level and organizational affiliation elucidated whether there was a tendency for homophily (i.e. individuals preferring information sharing relations with others who were similar to themselves) or heterophily (i.e. individuals preferring to share information with others who were different than themselves). Attribute-based mixing is important because it has implications for information diffusion between different groups and opportunities for new information to enter a network (Peel, Delvenne and Lambiotte, 2018).

1.5.2.5. Closed population network

The closed population network included only individuals who had been interviewed by the researchers and their information sharing relations between each other (i.e. it excluded relations with people outside of this closed network). We examined this network at two levels: i) an actor-level scale where individuals and their relations were considered, and ii) an organization-level scale where organizations and interactions between organizations were considered. For confidentiality reasons, in the actor-level network we report organizations according to the previously described groups relating to the purpose of the organization (Table 1.5.1). In the organization-level, on the other hand, we present results according to the individual organizations.

1.5.2.6. Bipartite network of recreational fishers and organizations

Data extracted from the recreational fishers questionnaire were used to produce a network of recreational fishers and the organizations from which they received or with whom they shared information (*e.g.*, if they needed to report something related to the Blue Swimmer Crab fishery). Thus, the network for the PHBSC recreational fishery was considered a bipartite (*i.e.* two-mode) network, as it describes interactions between two disjoint entities in the community—individuals and organizations (Chizinski et al., 2018). We treated this bipartite network as undirected *(i.e*. interest was simply in terms of which organizations recreational fishers interacted with). We considered degree centrality with a focus on organizations (*i.e.* identifying the organizations with which recreational fishers most commonly interact) and perceived quality of information from each organization in contact with recreational fishers.

1.5.2.7. Qualitative data analysis

Qualitative data, other than demographics, were analyzed separately for non-fisher stakeholders and recreational fishers. Summary statistics were used to describe stakeholder perceptions (fishers and non-fishers), sources available to obtain information on the fishery and its management, as well as fishers' satisfaction with the fishery management (rated on a three-point scale).

1.5.3. Results

We describe the structure of the closed population network where we focus on the individual and organization level. Finally, we describe the bipartite network of recreational fishers and organizations, discussing the modes of communication used to share information and the perceived quality of the information shared. We use qualitative data to help understand gaps and impediments in the process of information sharing. Finally, we discuss potential implications for the management of the PHBSC fishery.

1.5.3.1. Demographics

In total, 85 individuals from 13 different organizations were interviewed, including 74 face-to-face interviews and 11 conducted by phone. A total of 50 recreational fishers and 35 non-recreational fisher stakeholders (related to government organizations, the commercial sector, etc.) were interviewed (see Methods).

Most survey participants were male (76%) and ranged in age from 18 to 65+ years with the largest portion of participants (30%) between 45 and 54 years of age. The highest level of education completed by most interviewees (51%) was a higher degree education (i.e. technical certificates, diplomas and/or University studies), while 39% had completed secondary education.

1.5.3.2. PHBSC fishery stakeholders

A total of 194 stakeholders from 28 different organizations and 571 information sharing relations were identified for the PHBSC fishery network. Overall, 377 relations related to the management of the fishery, 199 relations focused on information related to the scientific research of Blue Swimmer Crab populations, and 63 relations related to the broader environment of the Peel-Harvey Estuary. Note that some information sharing relations involved multiple topics.

The consistency of respondents' reports on information sharing for relations was checked where both respondents were interviewed. This consistency was necessarily restricted to a closed population network consisting only of those people who were sampled and the relations/edges between them. Respondents agreed on the presence and directionality (i.e. who shared information with whom) for only 25.1% of the reported information sharing relations. When ignoring directionality (i.e. simply focusing on whether there is some form of information sharing between two people), still only 38.7% of relations between primary respondents were reported by both parties.

1.5.3.3. Egocentric network of stakeholders

The egocentric network of stakeholders was comprised of 35 non-recreational fisher stakeholders and their 458 direct information sharing relations with other stakeholders. These direct information sharing relations involved a total of 113 unique individuals. Of these information sharing relations, 264 related to the management of the fishery, 199 focused on the scientific research of Blue Swimmer Crab populations, and 63 related to the environment of the Peel-Harvey Estuary. Note that some of the relations related to more than one topic.

Centrality and prestige of stakeholders

Certain stakeholders in the egocentric network were identified as more important for information flow in terms of information sharing relations (Table 1.5.3). The individual with highest degree centrality (i.e. direct information sharing relations) and highest degree prestige (i.e. direct information receiving relations), normalized for unique individuals identified in the network, was affiliated with the commercial fishing sector (ID: 33, degree centrality = 0.295, degree prestige = 0.214). These measures of degree centrality and degree prestige reflect that this individual shared information with 29.5% and received information from 21.4% of the 113 unique stakeholders identified in the egocentric network. Two individuals affiliated with a government body (IDs 6 and 12, degree centrality = 0.268 and 0.214, degree prestige = 0.205 and 0.188, respectively) and one affiliated with the recreational fishing sector (ID: 32, degree centrality = 0.170, degree prestige = 0.188) were also identified as being important. The top five ranked individuals included more recreational and commercial fishing sectors representatives than government body representatives.

Attribute-based mixing

To assess whether people in the network tended to share information within their own groups or with those who were similar to them, we examined attribute-based mixing for organizational affiliation, seniority level in the organization, age group, and gender of individuals using an ERGM (Table 1.5.4). Examining each of these attributes, we found evidence of homophily (i.e. preference for those with similar attributes beyond what would be expected under random selection) for those who were more senior in their organizations (*e.g.*, directors, senior research scientists, professors) and based on organization. For example, the highest number of information relations occurred between individuals from DPIRD (129 relations), with this number being significantly higher than what would be expected if there was no clear preference to share information with people from particular organizations (p = 0.042; see Table S1.5.1 and S1.5.2).

Table 1.5.3. Individual identifier (ID) for the 10 stakeholders with highest degree centrality and degree prestige metrics forming the egocentric PHBSC fishery network and the groups they belong to.[18]

Individual ID	Group	Degree centrality	Degree prestige
33	Commercial sector	0.295	0.214
6	Government body	0.268	0.205
12	Government body	0.214	0.188
32	Recreational sector	0.170	0.188
34	Commercial sector	0.161	0.152
18	NGO, Conservation groups	0.152	0.143
22	Government body	0.152	0.116
9	Government body	0.134	0.098
28	Government body	0.134	0.054
2	Government body	0.125	0.125

When looking at age groups, there is evidence of homophily with individuals in the age groups of 45-54 years and older sharing information with each other more frequently than what would be expected if there was no preference for relations based on age (p = 0.0001; see Table S1.5.3). This is likely to be related to the homophily observed for higher seniority levels, where individuals in higher seniority levels exchanged information more frequently with individuals of a similar seniority level than would be expected if information sharing was not related to seniority level. At the same time, those aged 45-54 years old shared information with others in the age group of 25-34 years more frequently than would be expected (p = 0.001; see Table S1.5.3), and these younger individuals also tended to establish information-sharing relations with those 45-54 years and older more frequently than would be expected if there was no preference for relations based on age (p = 0.010; see Table S1.5.3), evidence of heterophily.

1.5.3.4. Closed population network

The closed population network was comprised of 35 non-recreational fisher stakeholders and 242 information sharing relations among these individuals. We examined this network in terms of the importance of various individuals (for an actor-based network) and organizations (for an organization-based network) for information flow.

Actor-based network

To assess the importance of individuals for information flow, we considered degree centrality and degree prestige (as above), and also considered betweenness centrality, which provides a measure of the number (or proportion, when normalized) of shortest paths between individuals that go through a given actor (Barnes-Mauthe et al. 2015).

The two individuals with highest degree centrality and degree prestige when considering the egocentric network (IDs 33 and 6) also had the highest degree centrality and degree prestige when considering the

[18] Individuals are ranked according to their degree centrality (i.e. out-degree) and degree prestige (i.e. in-degree).

closed population network (Table 1.5.5, Figure 1.5.2). Here, however, their relative rankings were swapped (Tables 1.5.3 and 1.5.5). Given that the closed population network includes only those relations between members of the closed population (i.e. individuals who were surveyed) whereas the egocentric network considers all direct ties for an individual (i.e. both individuals who were and were not surveyed), this means that a significant number of ties for individual 33 are with individuals with whom other members of the closed population do not have contact. Considering that individual 33 is one of the few representatives from the commercial fishing sector, this is not terribly surprising and indicates that this person has a number of ties outside of key stakeholder groups (e.g. to other commercial or recreational fishers) and could be a central liaison between these key stakeholder groups and other groups that are less represented in the network. We note that individuals 6 and 33 also have the highest measures of betweenness centrality for the closed population network. This suggests that these individuals are not only high-volume sharers and recipients of information directly to and from others in the network, but also that they are important "gatekeepers" for the indirect transmission of information between individuals. Note, however, that neither of these individuals had formal information-sharing roles but were taking responsibility for sharing information in an unofficial capacity.

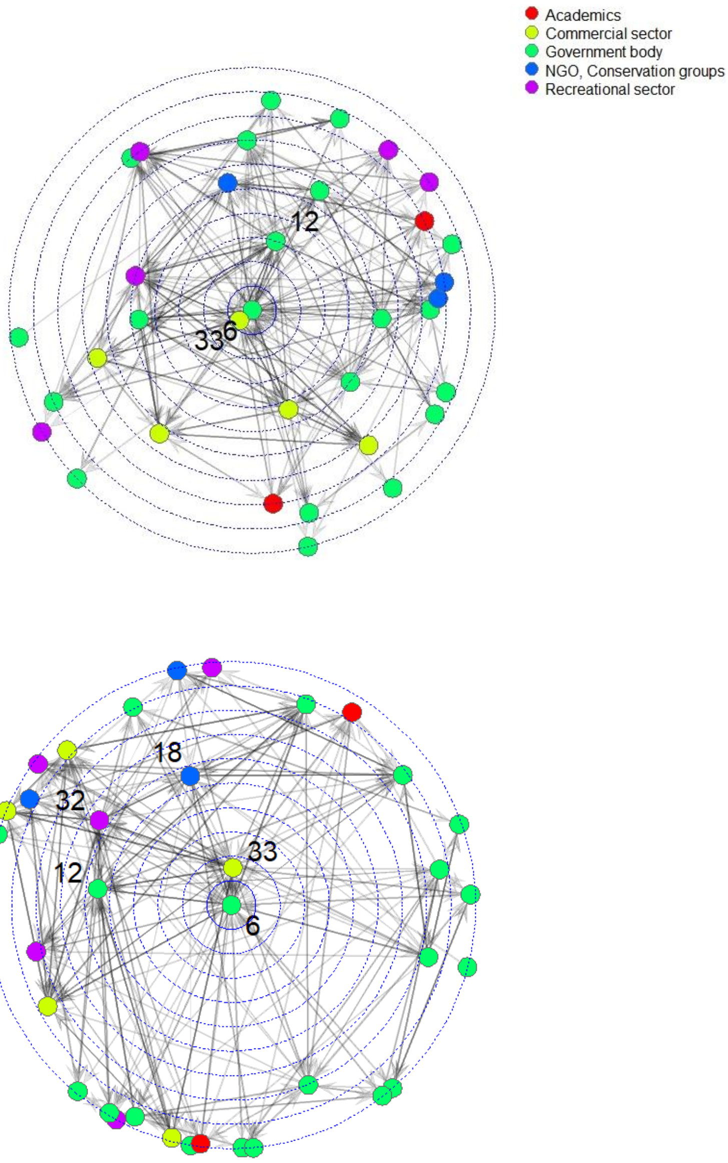

Figure 1.5.2. Target plot of degree centrality (top) and betweenness centrality (bottom) for individuals forming the closed population network. Individuals with higher centrality appear near the centre of the plot.

When examining those individuals with the highest measures of degree centrality for the closed population network and egocentric network, we note that the same people comprise the top 10 most central actors, although their relative rankings have changed with those associated with government bodies being more central in the closed population network (Tables 1.5.3 and 1.5.5). The largest drops in relative ranking were for those associated with the recreational fishing sector (ID 32) and an NGO or conservation organization (ID 18), which would be consistent with these individuals from groups with low representation (in terms of raw numbers) in this chapter having a number of key information-sharing relations outside of the key stakeholder groups and potentially being important for the transmission of information to the recreational sector and the general public and other NGOs or conservation organizations, respectively.

When considering degree prestige, the five highest ranked individuals belonged to the commercial fishing sector (IDs 33 and 34), government bodies (IDs 6 and 12), and the recreational fishing sector (ID 32; Table 1.5.5). Both commercial fishers maintained (in the case of ID 33) or increased (in the case of ID 34) their relative rankings in terms of degree prestige from the egocentric network to the closed population, indicating that most of those who are reported to share information with these individuals come from central stakeholder groups. This suggests that relevant government agencies and Blue Swimmer Crab fishery bodies are ensuring that the commercial sector is well-informed.

Organisation-based network

The 35 individuals comprising the closed population network represented 10 organizations, and we considered a network of information sharing relations between these organizations, restricted to the relations within the closed population. For this network, directed relations/edges between organizations were weighted by the frequency with which they occurred in the closed population, and measures of centrality and prestige for this network accounted for edge weights. Additionally, self-ties (i.e. relations within the organization) were permitted to reflect information sharing within an organization. Figure 1.5.3 shows the structure of this network with edge widths reflecting the frequency of directed relations between organizations and node sizes reflecting degree centrality (Figure 1.5.3a) and betweenness centrality for organizations (Figure 1.5.3b). Self-ties are represented by loops.

When considering degree centrality, the analysis of the closed population network based on organizations presented DPIRD and MLFA as the organizations with highest scores (degree centrality = 0.727 for both). The Peel-Harvey Catchment Council (PHCC) appeared as the third organization in the ranking (degree centrality = 0.636). These are the organizations sharing most often information to others in the network, and since these are affiliated to three different groups, information sharing relations will take into account a diversity of topics, including the management of the commercial and recreational fishing sector and the environment of the estuary. For example, the topic of discussions started by PHCC focused mainly on environmental and management topics (45% for both) and less so on the fishery science (10%), whereas DPIRD and MLFA talked mainly about management (47.1% and 69.2% respectively) as well as the fishery (47.1% and 23.1%) with little information exchange focusing on the environment of the estuary (5.78% and 7.7% respectively).

When considering degree prestige, the analysis of the closed population network based on organizations presented again DPIRD and MLFA as the organizations receiving most information (degree prestige = 0.818 and 0.727 respectively). Recfishwest (RFW) appeared as the third organization in the ranking (degree prestige = 0.636). These are the organizations receiving most often information from others in the network. This is not surprising as these organizations represent the main managing bodies and the primary users of the fishery, which are expected to receive and share information with each other.

Finally, when looking at the bridging capacity (i.e. betweenness centrality) of these organizations, DPIRD, MLFA and PHCC had betweenness centrality scores considerably higher than the rest (betweenness centrality = 0.135, 0.138, 0.089 respectively; see Table 1.5.6 and Figure 1.5.3). These organizations belonged to three different groups (government body, commercial fishing sector and NGOs & conservation organizations). Having access potentially to different types of information, these organizations have the highest capacity to share it among other organizations that otherwise might not receive it. Despite having greater measures of degree centrality and degree prestige, RFW bridging capacity was lower than Murdoch University's (betweenness centrality = 0.043). Murdoch University appeared as 4th ranked among organizations when looking at its bridging capacity (betweenness = 0.067). This is interesting as no individuals from the group of academics, to which this organization is affiliated to, had appeared in previous analyses (Tables 1.5.3, 1.5.5; Figure 1.5.2, 1.5.3), suggesting that despite the individuals having low connectivity, the organization as a whole is seen as key gatekeeper of information and has an influence in information sharing between groups that otherwise would not be connected to each other.

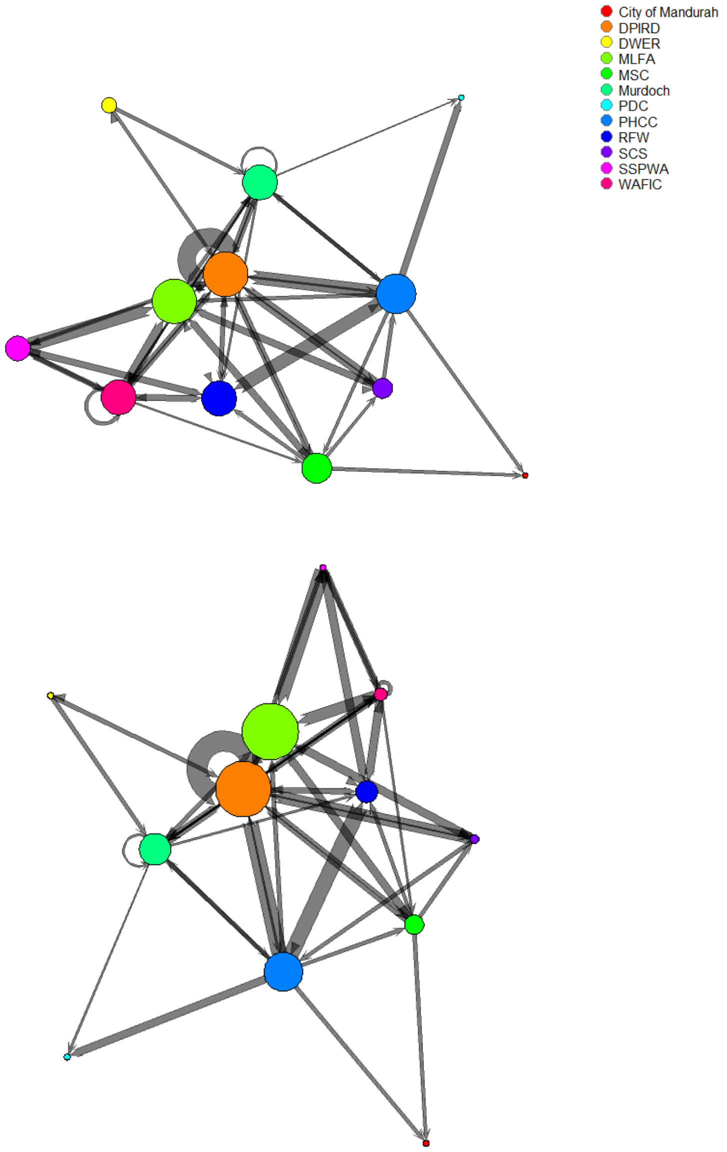

Figure 1.5.3. Plots of the network of organisations represented in the closed population network with edge widths representing the frequency of relations between organisations and node sizes representing weighted degree centrality (top) and betweenness centrality (bottom) for organizations.

Table 1.5.4. Exponential random graph model (ERGM) results for attribute-based mixing for individual stakeholders forming the egocentric PHBSC fishery network.[19]

Attribute	*p*-value
Gender	0.134
Seniority	<0.001
Age	<0.001
Organisation	<0.001
Group	0.137

[19] See Tables (Table S1.5.1 - S1.5.5) for more details.

1.5.3.5. Bipartite network of recreational fishers and organizations

In surveys of recreational fishers, respondents mentioned sharing with or receiving information from nine organizations or sources. Of these, four were identified only by recreational fishers and not by other stakeholders. Three of these organizations (i.e. a local fishing club, an angling magazine, and a journalist) do not focus solely on the Blue Swimmer Crab fishery, but rather aim to share general information on local recreational fisheries with the general public. For this component of the chapter "recreational fishers" were defined as an organization, as many recreational fishers exchanged information on the PHBSC fishery.

An undirected bipartite network (i.e. a two-mode network) was used to map information exchange between two classes of actors (i.e. recreational fishers and the organizations with which they exchanged information). Analysis of centrality measures for each organization forming the bipartite network highlighted that the recreational fishers mostly exchanged information with four organizations or groups: i) Other recreational fishers (degree centrality = 0.402); ii) MLFA (degree centrality = 0.196); iii) DPIRD (degree centrality = 0.188); and iv) RFW (degree centrality = 0.161) (Table 1.5.7). This highlights that the primary sources of information are other fishers instead of the organizations responsible for the management of the fishery. The network map highlights recreational fishers as being the main source of information for other recreational fishers (Figure 1.5.4, and further analysis below).

The perceived quality of information received by recreational fishers differed significantly among organizations (from low = 1, to high = 3). Recreational fishers perceived information quality they received from RFW (median quality = 1; mean quality = 1.73) to be significantly lower quality than the information received from DPIRD (median quality = 3; mean quality = 2.82), MLFA fishers (median quality = 3; mean quality = 2.78), and other recreational fishers (median quality = 3; mean quality = 2.76; Kruskal-Wallis test: p = 0.029, 0.044, and 0.036, respectively). Recreational fishers considered the information from DPIRD as of the highest quality. When looking at the information shared by recreational fishers to organizations, no significant differences in the perceived quality of information were found.

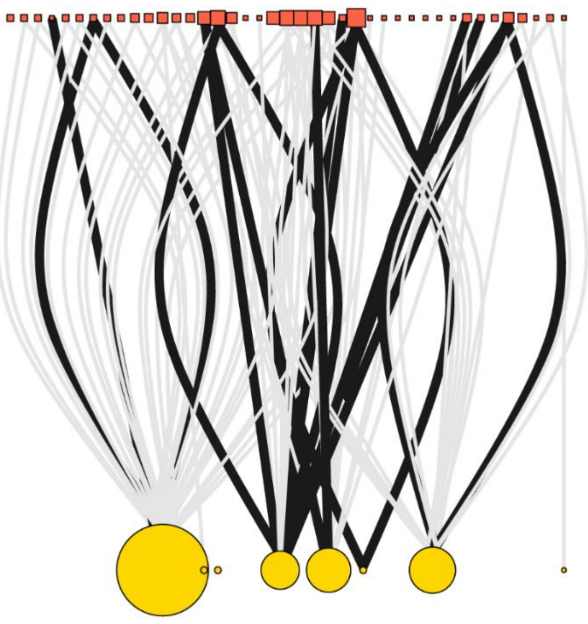

Figure 1.5.4. Bipartite network of recreational fishers' network and the organizations with which they exchange information.[20]

[20] Recreational fishers are denoted by red squares, while organizations are represented by yellow circles. Organizations with degree centralities exceeding 0.1 are labelled, and node size reflects the degree centrality. Edges that are wider and black highlight information exchanges that are perceived by recreational fishers to be of low quality.

There was also considerable variation in terms of the mode of communication used in information exchange between recreational fishers and different organizations (Figure 1.5.5). Most information exchange with DPIRD was via email or website updates, while information exchange between recreational fishers was primarily face-to-face, though they also used social media, and to a lesser degree, email and phone or official websites to share and receive information. Commercial fishers used only face-to-face communication when exchanging information with the recreational fishing sector. Recfishwest used social media and their website to share information more than other organizations, along with email subscriptions and phone calls, though few exchanges were done face-to-face with recreational fishers. Information from DPIRD was mainly sourced via phone and email by recreational fishers, and rarely available by face-to-face meetings, social media or their website. This highlights a mismatch between the way information is exchanged among fishers and other stakeholders.

Table 1.5.5. Results showing individuals with highest degree centrality and prestige metrics forming the closed population network and the organisations they belong to.

ID	Group	Degree centrality	Degree prestige	Betweenness centrality
6	Government body	0.882	0.647	0.198
33	Commercial sector	0.824	0.706	0.168
12	Government body	0.618	0.559	0.089
34	Commercial sector	0.500	0.471	0.028
22	Government body	0.471	0.382	0.024
32	Recreational sector	0.441	0.588	0.071
9	Government body	0.441	0.294	0.039
18	NGO, Conservation groups	0.412	0.441	0.088
28	Government body	0.412	0.176	0.033
2	Government body	0.382	0.382	0.024

Finally, qualitative data analysis provided insight into various elements of fishers' satisfaction with the fishery, fishers' perceptions on information sharing, and public events available. Non-recreational fisher stakeholders' satisfaction with how they shared information with other stakeholders was also recorded. On a five-point Likert scale (with 1 being the lowest rating, and 5 the highest), non-recreational fisher stakeholders seemed largely satisfied with how they shared information with others (mean = 4).

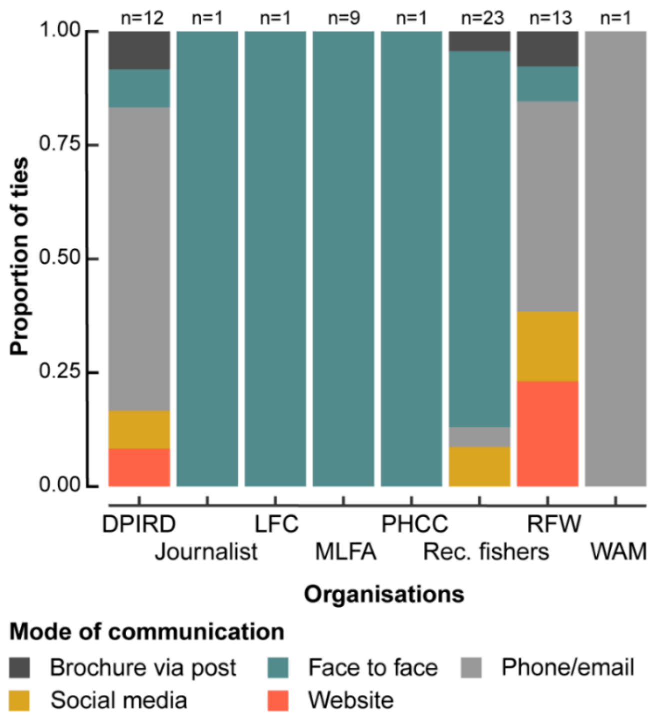

Figure 1.5.5. The proportion of information exchanges between recreational fishers and organizations involving various modes of communication, as reported by recreational fishers.[21]

[21] Sample sizes (n) on which these proportions are estimated are also presented.

Non-recreational fisher stakeholders also reported on public events for fishers to receive information on the management and science of the fishery. In total, seven events perceived as useful for sharing information on the fishery were mentioned by 31 of the 35 non-recreational fisher stakeholders interviewed. These included crabfest (37.2%); the annual management meetings organised for the peak bodies representing the fishery stakeholders (AMMS, 34.8%); events organised by the MSC (11.6%); community presentations at PHCC (6.9 %); the annual boat show (4.6%); seafood week (2.3%) and public forums (2.3%). When asked if they found these events useful to share information on the management and the science of the fishery, 45.1% of non-recreational fisher stakeholders reported these events to be useful, 38.7% reported these to be somewhat useful, and 16.1% reported these were not useful to share information among fishers.

The qualitative data as reported by recreational fisher stakeholders showed that six of the 50 recreational fishers interviewed were aware of two of the seven events that were available to recreational fishers. Both, crabfest and the annual boat show were cited by different fishers. The rest of the participants (86.9%) reported they were unaware of events providing information on the management and science of the PHBSC fishery. When asked if they would consider informative events to be beneficial in the future, 70% were supportive of this, whereas 26.7% were not. The fact that one fourth of the interviewees perceived public events as not needed could be due to a lack of interest in the information itself or that the information was not presented in a useful manner.

Table 1.5.6. Results showing centrality and prestige measures for organisations represented in the closed population network.

Organisation	Degree centrality	Degree prestige	Betweenness centrality
DPIRD	0.727	0.818	0.135
MLFA	0.727	0.727	0.138
PHCC	0.636	0.364	0.089
RFW	0.545	0.636	0.043
Murdoch	0.545	0.455	0.071
WAFIC	0.545	0.455	0.019
MSC	0.455	0.364	0.036
SSPWA	0.364	0.364	0.000
SCS	0.273	0.364	0.007
DWER	0.182	0.091	0.000

Table 1.5.7. Results showing the organisations mentioned by recreational fishers and their degree metrics. Organisations are ranked according to their degree centrality.

Organisation	Degree centrality
Rec. fishers	0.402
MLFA	0.196
DPIRD	0.188
RFW	0.161
Journalist	0.018
WAM	0.018
LFC	0.018
PHCC	0.009

1.5.4. Discussion

This chapter showed the value of empirical research in understanding stakeholder connections and information flow processes for informing the management of fisheries. We provide an empirical basis for identifying the suite of individuals and range of organizations involved in the Peel-Harvey Blue Swimmer Crab (PHBSC) fishery network, representing NGOs, governmental bodies, tourism operators, commercial and recreational fishing sectors, academic groups, and community-based organizations. We examined the fishery through the lens of i) an egocentric network of non-recreational fisher stakeholders; ii) a closed population network of non-recreational fisher stakeholders (both individual- and organisation-based analysis); and iii) a bipartite network of recreational fishers and organizations. To our knowledge, this is the first study looking at information sharing in an Australian fishery social network and one of the few network studies looking at information sharing between small-scale fishery stakeholders globally (Bodin and Norberg, 2005; Leonard et al., 2011; Turner, Polunin and Stead, 2014).

1.5.4.1. The PHBSC fishery network

Of the 28 organizations identified in the PHBSC network, two were most prominent in terms of measures of centrality and prestige: the government body responsible for the management of the fishery (DPIRD) and commercial fishers (MLFA). This is evidence of a high engagement of the MLFA fishers in information-sharing and is potentially a way for the commercial fishing sector to be included and directly involved in discussions related to the fishery management, instead of being involved in these discussions only through the organization representing the commercial fishing sector in WA (i.e. WAFIC). This is consistent with previous studies showing how the inclusion of fisher-knowledge in management discussions can benefit adaptive management decision making, as fishers adapt their methods and their learning with environmental changes and uncertainty (Grant and Berkes, 2007). Stakeholders from both the commercial and recreational fishing sector figured prominently in the network in terms of measures of centrality and prestige. Increases in degree prestige and decreases in degree centrality for commercial and recreational fishers, relative to other stakeholders for the closed population network, is consistent with commercial and recreational PHBSC fishing representatives largely receiving information from key government bodies, community-based organizations, NGOs, etc., but then disseminating that information outside of that group, to others involved in Blue Swimmer Crab fishing.

The PHBSC fishery network showed a tendency for individuals to form significantly more ties with similar individuals (homophily). Individuals within the Department of Primary Industries and Regional Development (DPIRD) were more likely to share information with others affiliated to DPIRD, and individuals in the network with a senior role were more likely to interact with others at a similar level in the hierarchy of the organisation. This tendency has previously been reported in fishery networks, for example commercial fishers in Hawaii sharing information with other commercial fishers of their same ethnic background, rather than other backgrounds (Barnes-Mauthe et al., 2015). Homophily generally limits interactions between individuals from different organizations and hinders the inclusion of new knowledge among the individuals of the network (McPherson, Smith-Lovin and Cook, 2001; Bodin and Crona, 2009). Overall, homophily has the potential to reduce the efficiency of resource management and therefore reduce the capacity to adapt management if change occurs (Bodin and Crona, 2009; Turner, Polunin and Stead, 2014). Heterophily, the preference for establishing relations with different types of individuals, was also present in the PHBSC fishery network, particularly among different age groups. Younger and less experienced stakeholders across all the groups tended to exchange information with older and more experienced ones in the network more often than expected by chance. These results are consistent with previous studies that described less experienced individual fishers seeking advice from more experienced fishers (Mueller et al., 2008; Turner, Polunin and Stead, 2014).

Discrepancies in actors' reports on shared relations are common due to poor memory recall, the manner in which relational information is elicited, or bias in reporting (Admiraal and Handock, 2015). Although, the relatively low level of agreement between actors may be partially due to the fact that participants were asked to name a maximum of 10 people with whom they interacted rather than all people with whom they exchanged information, forcing respondents to select the individuals they interacted with the most. In so doing, we assume that inconsistencies between respondents are not due to errors or bias in reporting but rather to restrictions on the number of reported information-sharing relations and incomplete memory recall. We also observed inconsistencies in the reported mode of communication, frequency of communication, and duration of the information-sharing relations. The percentage of relations for which there were such inconsistencies were 31.1%, 37.7% and 41%, respectively. The highest level of inconsistency was observed for the topic of the information exchanged (41%). Inconsistencies can occur for a variety of reasons, including confusion about the definition of a topics' definitions (particularly between the topics "fishery" and "management", as these can overlap), an incomplete reporting of modes of communication, or miscalculating the frequency or duration of communication. These inconsistencies can result in changes for some edge attributes (i.e. the details of an interaction), but they do not influence the overall network structure.

The Peel-Harvey Catchment Council (PHCC), a community-based non-governmental organization (NGO) that promotes an integrated approach to protecting, restoring and generally managing the Peel-Harvey catchment, and Recfishwest (RFW), the main NGO and advocate for recreational fishing in WA, were the two other organisations most highly connected, after DPIRD and MLFA. RFW, was one of the most connected organizations in the network. Unlike commercial fishers, it is common for recreational fishers to be represented by a broad recreational fishing organization, as they are often not affiliated to one group or association (Kearney, 2002). The degree prestige of this organization suggests that most information received is sourced from government bodies and other groups responsible for the management of the fishery. Though a decrease in the degree centrality, combined with a relatively low betweenness centrality suggests that this organization is sharing information with other stakeholders outside of these group, and not so much within it. The PHCC is the only organization that is not directly involved in the fishery, the research on Blue Swimmer Crab or its management. This organization had a high degree centrality compared to its degree prestige, suggesting that it shared information with the main organizations forming the PHBSC fishery network (included in the closed population network) though, it received information from other stakeholders outside these groups. Its bridging capacity was the third highest in the PHBSC closed population network, suggesting that through sharing information with stakeholders within and outside the PHBSC network, this organization connects groups that otherwise would be disconnected, making it a key bridging organization in the PHBSC network. A greater inclusion of PHCC in the fishery management network would enable new information coming into the network to be disseminated and facilitate information-exchange in the network.

These four organizations (i.e. DPIRD, MLFA, RFW and PHCC) represent stakeholders with different objectives for the development and the protection of the natural resources of the Peel-Harvey Estuary. The strong degree centrality, degree prestige and/or betweenness centrality of these four groups enable the inclusion of management, science and environmental topics and issues as part of the main discussions between stakeholders. However, most discussions focused on the management of the fishery and its science, and a reduced focus was put on the environment of the estuary.

Other organizations, such as conservation organizations other than PHCC, academics, and the tourism and public sector generally had lower measures of centrality and prestige than the four groups described above. This may be due to an issue of representation and inclusiveness of participation (Berdej and Armitage, 2016) as the number of stakeholders from government bodies far exceeded that of any other group in the PHBSC fishery network. In contrast, individuals from other groups, such as other NGOs and members of the academics or the tourism sector, had very few stakeholders involved in information-sharing relations. Organizations such as the Western Australian Fishing Industries Council (WAFIC), representing commercial fishers in WA, and the Marine Stewardship Council (MSC), one of the main certification bodies for sustainable seafood globally, had low measures of degree and betweenness centrality and degree prestige in the Blue Swimmer Crab fishery network. The low centrality and prestige metrics of MSC could very well be due to having only one representative in WA, who is responsible for managing the certifications for all WA fisheries. The low measures of degree centrality and degree prestige for WAFIC may relate to the strong connectivity of the MLFA in the network. MLFA is a member of WAFIC, and through the commercial fishers being highly engaged in information exchange in the network, it is potentially not necessary for WAFIC to be highly connected too. These smaller groups are potentially not well represented in the network and might not be sharing information effectively with other stakeholders. If individuals from all relevant organizations forming the network are not effectively included and their meaningful participation is hindered, different views on the management approaches considered and other decision-making actions related to the fishery could be overlooked (von Heland, Crona and Fidelman, 2014; Berdej and Armitage, 2016). This might affect the social license to operate of the fishery, local acceptance within the community and potentially lead to conflict and failure of efficient management implementation.

The connectivity of academics, particularly from Murdoch University, was low despite a 40-year history of research on fish and invertebrate biology and ecology in the Peel-Harvey Estuary (e.g. Potter et al., 1983; 2016). This issue is quite common as scientists, and particularly academics (Cvitanovic et al., 2018), are usually sources of high-quality information yet, have traditionally mainly shared their knowledge with their peers (*i.e.* other academics and scientists) and to a lesser degree with relevant organizations such as key stakeholders in the field of study (Fullwood and Rowley, 2017). Restricting knowledge exchange within an organization or group impedes the diffusion of information outside the entity and can create clusters or silos of high-quality information that is not shared across the network. As an organization, Murdoch's bridging capacity was among the five highest of all organizations, and mainly shared information with DPIRD and RFW, and less so with groups such as PHCC or WAFIC. This high bridging capacity highlights that despite having relatively fewer interactions with others, the established interactions are with different organizations or groups, and suggests that Murdoch could play a more important role connecting groups that otherwise would be disconnected through information sharing.

1.5.4.2. *Network of recreational fishers*

The bipartite network analysis highlighted that recreational fishers were mostly connected with their peers, such as family or friends that also fish or other fishers they meet at fishing spots. Other studies have previously described the value of information-sharing relationships among different fishers, and the different strategies used for information sharing, for example commercial lobster fishers in Maine, United States, exchange information on fishing sites and catch (Palmer, 1991). Interestingly, our results showed that while mainly interacting with other recreational fishers, this sector also commonly exchanged information with commercial fishers, which mainly involved fishing spots, catches, bait used and shared opinions on the catches during the season. This is probably a result of sharing the same fishing locations and launching their boats from the same boat ramps. Though these discussions are very informal, they are relevant for the social acceptability (or social license to operate) of the commercial sector in the region. In fact, social license to operate is an increasingly important issue for commercial fishers throughout Australia, as the recreational sector grows, and the commercial sector is pushed out of some fisheries (Cullen-Knox et al., 2017). Conflict between recreational and commercial fishers over a resource has often been reported worldwide (Voyer et al., 2017). Previous studies have demonstrated the importance of communication between stakeholders for achieving understanding between groups, reaching consensus and gaining a social license to operate for commercial resource users (Voyer, Gladstone and Goodall, 2015). Commercial fishers in WA have previously reported that gaining an enhanced social license to operate was a key reason for initiating the certification process of the PHBSC fishery with the Marine Stewardship Council (van Putten et al., 2020).

It has been reported previously that bridging organizations face difficulties in fully representing the views of large numbers of constituents (Berdej and Armitage, 2016). Recreational fishers' perceptions of the quality of information provided by various organizations showed a contrast between how they viewed information related to the Blue Swimmer Crab fishery from DPIRD (rated as highest quality) and that from RFW (lower quality). Individual perceptions are strongly linked to prior beliefs and/or expectations (Ajzen, 1991; Stern et al., 1999), and while understanding the elements that could potentially influence perceptions was beyond the scope of this chapter, the perceived lower quality of the information provided by RFW as well as its lower centrality in the bipartite network of recreational fishers and organizations, could be related to the diverse views of thousands of Blue Swimmer Crab recreational fishers. It should be noted that the lower perceived quality of information described here is specific to the Blue Swimmer Crab fishery, and therefore it does not necessarily apply to RFW's communication strategy for other recreational fisheries in WA or in general.

1.5.4.3. *Impediments to information flow in the network*

The current modes of communication used within the PHBSC recreational fishery network could potentially be an impediment for sharing information effectively with the recreational fishing sector, thus reducing the capacity for sharing high-quality information. Though, both DPIRD and RFW rarely shared information using a face-to-face approach, RFW used a greater diversity of communication modes for recreational fishers to find information than DPIRD. This is an important element as the recreational fishing sector is composed of individuals of different social groups with different cultural and socio-economic backgrounds. Previous research has demonstrated that different social groups might access information differently. For example, younger individuals are likely to use social media more extensively than older individuals (Correa, Hinsley and de Zúñiga, 2010). Thus, a greater diversity of modes of communication will facilitate the diffusion of information through the social network. The diversity of communication modes used by RFW means that the perceived lower quality information is potentially more accessible to others in the network, than information shared through DPIRD, which is perceived as of higher quality.

A mismatch between the public events available with a focus on the fishery and their potential to share information among resource users was identified. While at least seven public events that shared information on the management and science of the fishery occurred over the course of this study, only a minority of the recreational fishers were aware of them. Furthermore, those who were aware of the events could only identify at most two of the seven, suggesting that the promotion of public events among the PHBSC fishery resource users and, subsequently, the effectiveness of sharing information through these events is poor. These events could greatly enhance the communication of high-quality information as both non-fisher and fisher stakeholders considered them useful and supported having more public events promoting the fishery and sharing information on its status and management. This chapter shows that resource users and the general public, who have low degree centrality and degree prestige and were not present in the closed population network, are highly dependent on bridging organizations to receive information from government bodies and other organizations responsible for the management of the fishery. The PHCC and RFW, could potentially enhance the promotion of these events by sharing the information with groups that are not central in the fishery network. This aligns with the organizations' strategic plans. The utilization of effective modes of communication, such as having a strong presence online, as well as face-to-face interaction would also benefit the promotion of such events.

1.5.5. Conclusion

In general, very little is known about how information is shared through a fishery social network or about the influence of network structure on information sharing and its consequences for fisheries management (Alexander, Armitage and Charles, 2015). Social network analysis can disentangle some of these questions using an interdisciplinary approach with an emphasis on the human dimensions of fisheries. This chapter demonstrated empirically that i) a few individuals were key for sharing information within and between different organizations forming the fishery network and only two of six stakeholder groups appeared as key for information sharing (a Government body and the commercial fishing sector); ii) academic groups were the least connected despite having actively researched the Peel-Harvey Estuary, including research on the biology of Blue Swimmer Crabs for over 40 years; iii) recreational fishers exchanged information mainly with other fishers and the regional Fisheries Department, and less with the organization representing this sector, highlighting a potential impediment to share information on the status and management of the fishery; v) issues of inclusiveness and representation were highlighted for some of the groups and organizations. From these, we have identified logistical and institutional impediments to communicating information on the science, management and environmental issues related to small-scale crab fisheries. The findings provide managers and other stakeholders with a pathway to action to enhance resource management. In terms of small-scale fishery networks this chapter demonstrated the importance of: i) communication modes including face-to-face interactions with fishers, and the use of online resources such as social media; ii) effective integration of bridging organizations in the network who do not necessarily have primary responsibility for fisheries research and management; and iii) the need for academics to actively create connections with other stakeholders in the network.

The sustainability of fisheries management requires an understanding of the different elements composing a fishery system. Each stakeholder group is required to provide information available on the fishery to enable the assessment of the fishery status. Understanding information-sharing pathways and assessing their performance is determinant to enable the sustainability of fisheries management, as information might be incorrectly interpreted or even overlooked. This could potentially affect the social license to operate of the fishery, its local acceptance within the community and could even lead to conflict and failure of efficient management and implementation. The results from this chapter also illustrate the value of empirical research in understanding stakeholder connections and information flow processes for informing the management of fisheries.

Section 2. Economic dimensions

This section details research relating to Objective 2: Determine the total economic value of the recreational sector of each selected fishery. Two components were undertaken, both during the PhD research by Denis Abagna at Murdoch University, supervised by Professor Malcolm Tull, Dr Anne Garnett and Dr James Tweedley at Murdoch University, and Dr Sean Pascoe at CSIRO. Note that this study originally aimed to determine the gross value added of the small-scale commercial fisheries, however, due to low numbers of fishers and a buyout of some licences during the project it was not feasible or ethical to report on the economics of the commercial sector. Thus, focus was places solely on the recreational sector.

2.1. Economic value of recreational Blue Swimmer Crab fishing in south-western Australian estuaries.

2.2. Economic value of recreational Black Bream fishing in south-western Australian estuaries.

2.1. Economic value of recreational Blue Swimmer Crab fishing in south-western Australian estuaries

Abagna, D., Tweedley, J.R. Garnett, A.M. (2019). Small in scale, but not small in value. Economic valuation of recreational crab fishing in south-western Australian estuaries. West Australian Agricultural and Resource Economics Conference. Perth, Australia. 1-26.

2.1.0. Summary

Traditionally, fisheries management has focused on the biology of the target species and stock assessments, but there is growing recognition of the need to use a whole-of-environment approaches and incorporate social and economic dimensions. Recreational fishing is an important pastime for people in Western Australia and, due to a high participation rate and population growth, the number of recreational fishers has doubled in the last 25 years. While a recent state-wide survey estimated annual recreational fishing expenditure, the economic contribution of individual fisheries is generally unknown. As the fishery for Blue Swimmer Crabs (*Portunus armatus*) is iconic and, on the basis of numbers caught, the most popular in the state, this chapter aimed to estimate its economic value in three estuaries in south-western Australia (Swan-Canning, Peel-Harvey and Leschenault). An economic survey was pre-tested on recreational fishers at numerous estuaries and then transcribed to an online platform where recreational fishers provided information on their fishing frequency and expenditure on a trip. These data were used to calculate their direct expenditure and, using the Travel Cost Method, their non-market costs of travel and fishing time. Consumer surplus (i.e. the difference between the maximum amount that a person is willing to pay for a good or service and the amount they actually pay) was estimated using Poisson and Negative binomial models. Average direct per trip expenditure (excluding licence fees, boats and food/drink) was AUD $87 and ranged, on average, between $55 and $114 depending on the estuary, being highest in the Swan-Canning Estuary and lowest in the Leschenault Estuary. These values were accompanied by average opportunity costs of between $38 and $48 among estuaries (average = $43). For each estuary, analysis using a negative binominal model for the number of fishing trips found the round-trip cost to be significant and negative, indicating that as costs increase the frequency of trips decreases. Travel cost opportunity was also significant but positive, suggesting that due to the iconic nature of the Blue Swimmer Crab fishery, fishers will still crab despite an increase in the opportunity cost of travel time. Consumer surplus values varied markedly among estuaries being $20.49 per trip in the Swan-Canning and $9.71 and $3.30 in the Peel-Harvey and Leschenault, respectively. Combining the total trip expenditure, opportunity cost and consumer surplus, the annual total economic values of the Blue Swimmer Crab fisheries in the three estuaries are as follows; Swan-Canning ~$8.1 million; Peel-Harvey ~$11.5 million; and Leschenault ~$500,000. On a per fisher annual basis this equates to $334, $189 and $58, respectively, in the three estuaries.

2.1.1. Introduction

Across the industrialised world, an estimated 10.5% of the population fish recreationally, or around 118 million people, with that figure rising to around 220 million worldwide (Arlinghaus, Tillner and Bork, 2015; 2019). The number of recreational fishers is considerably more than the 40 million engaged on a full-time, part-time or occasional basis in commercial capture fisheries (FAO, 2018). Recreational fishing is an integral part of Australian culture, and as of 2003, involved an estimated 3.4 million people or 16.8% of the population (Henry and Lyle, 2003; Young, Foale and Bellwood, 2016) and this is higher than in other countries. Furthermore, participation in the state of Western Australia is greater than the national average at approximately 30% of the population, albeit declining slightly since the late 1990s (DPIRD, 2019). This high participation, combined with the state's recent rapidly increasing population, has resulted in the estimated number of recreational fishers more than doubling from 315,000 in 1989/90 to 711,000 25 years later (Ryan et al., 2015). Thus, these numbers dwarf those of the commercial fishers in Western Australia, which comprise ~1,500 fishing boat licences and including fishers, processers, exporters and retailers provides employment for ~10,000 people (WAFIC, 2022).

Traditionally, fisheries management has focused on the biology of the target species and stock assessments, but there is growing recognition of the need to use a whole-of-environment/ecosystem approach, e.g. Ecosystem Based Fishery Management (Hall and Mainprize, 2004; Pikitch et al., 2004b), and to incorporate social and economic factors, e.g. Human Dimensions (Arlinghaus et al., 2016; Rindorf et al., 2017; Stephenson et al., 2017). This would be akin to the Triple Bottom Line approach proposed by Elkington (1994) and change the fisheries management paradigm from single-species stock assessment and management focused around sustainability, to the environmental, economic, and social management of complex, often data-limited multispecies/multisector fisheries that are robust to environmental climate drivers and social demands (Dichmont et al., 2020). In-order for such management to exist knowledge gaps need to be filled. As an example, Hobday et al. (2016b) in a meta-analysis of 102 Australian commercial fisheries found that almost all had objectives and indicators for the 'biology' of target, bycatch and protected species and the broader ecosystem, but only 22 had a "social" management objective and 25, a social performance indicator and only 37 had an economic management objective, including none of the 41 fisheries studied in Western Australia.

In Western Australia, the focus of the current chapter, the Department of Primary Industry reports on the annual Gross Value of Product ($AUD) for each commercial fishery into six levels to measure their relative economic importance Level 0 = nil; 1 = < $1 million; 2 = $1-5 million; 3 = $5-10 million; 4 = $10-20 million and 5 > 20 million (Newman et al., 2021). In contrast, the economic value of recreational fisheries in this state is largely unknown. Raguragavan, Hailu and Burton (2013) used data from the 2000/2001 National Survey of Recreation Fishing (Henry and Lyle, 2003) and a random utility model with a supporting negative binomial model of angler-specific expected catch rates to estimate the site access values for 48 locations around Western Australia. More recently, McLeod and Lindner (2018a) estimated that the aggregate annual expenditure of recreational fishing in Western Australia was $1.8 billion, with $1.2 billion spent on fishing trips (excluding food) and $389 million and $160 million on boats and fishing gear, respectively. While this broad-scale study provided valuable information at a bio-regional level in Western Australia, it did not estimate the economic contribution of individual recreational fisheries.

Blue Swimmer Crabs (*Portunus armatus*) occur in estuarine and inshore coastal environments (< 50 m deep) throughout the Indo-West Pacific and are present along the entire coastline of Western Australia, albeit less so in the cooler waters off the southern coast of the state (Johnston et al., 2020b). Individual crabs can live for 2-3 years and reach a maximum size of 220 mm carapace width and 600 g in weight (Marks et al., 2020; Johnston and Yeoh, 2021). These crabs are caught in ten commercial fisheries across, Western Australia, South Australia, New South Wales and Queensland, with a total annual catch between 2010 and 2019 ranging from 800 to 1,850 t (Johnston et al., 2022). Blue Swimmer Crabs are a popular target for recreational fishers throughout Australia (Leland et al., 2013; Harris et al., 2016). In terms of numbers of individuals caught, this crab species was the most popular recreational species among boat-based fishers in Western Australia, with the total catch exceeding 900,000 in 2013/14 (Ryan et al., 2015). Moreover, this species is also heavily targeted by shore-based fishers using scoop nets and wading/snorkelling/scuba equipment, with an estimated 30% of the catch from the Peel-Harvey Estuary obtained from the shore (Malseed and Sumner, 2001a). Fishing for Blue Swimmer Crab does not only occur during daylight hours, as is typical for recreational fisheries, but also at crepuscular and nocturnal times making estimating the number of fishers and their catch difficult and thus numbers of crabs caught by shore-based fishers in the latter survey are likely an underestimate (Taylor et al., 2018).

Catches of Blue Swimmer Crabs in the West Coast Bioregion, which comprises Cockburn Sound (currently closed), Warnbro Sound the Swan-Canning and Peel-Harvey estuaries and coastal waters between Mandurah and Bunbury was estimated to be 80.8 t from commercial fishers in 2019/20 (Newman et al., 2021). Most of the catch comes from the Peel-Harvey, with 57 t obtained by the commercial sector in 2019/20, a reduction of ~10 t from the previous year and provided employment for 16 people. This has an estimated gross value of production of $0.65 and 0.74 million in 2019/20 and 2018/19, respectively and with a weighted average price paid by fish processors of $8.10 kg^{-1} (Newman et al., 2021). The estimated recreational harvest for Blue Swimmer Crabs in the West Coast Bioregion from only boat-based fishers was steady at 54 t (95% CI 45–63) in 2017/18, an increase from 44 t (95% 37–51) in 2015/16 (Ryan et al., 2019). However, a previous survey of recreational catches from boat-based fishers, and also those fishing from the shore, canals and houseboats was significantly higher at 107–193 t.

In the context of the triple bottom line, a range of information exists on the biology of Blue Swimmer Crab (e.g. de Lestang, Hall and Potter, 2003b; Johnston et al., 2020a; Campbell et al., 2021), the motivations of recreational and commercial fishers utilising these fisheries (Sections 1.2, 1.3; Obregón et al., 2020c) and economic data from commercial fishery (Newman et al., 2021). However, little is known about the economic contribution made by recreational crab fishers. Thus, the aim of this chapter is to collect information on the economic costs of a Blue Swimmer Crab fishing trip, and the number of trips and locations where such fishing occurs. This data is used to estimate the non-market values (e.g. the time spent fishing) of recreational Blue Swimmer Crab fishing in south-western Australia.

2.1.2. Methods

Information on the study estuaries and their Blue Swimmer Crab fisheries are provided in subsection 1.2.2.1.

2.1.2.1. Survey design and procedures

This chapter estimates the total economic value of fishing for Blue Swimmer Crabs in three south-western Australian estuaries i.e. the Swan-Canning, Peel-Harvey and Leschenault. The consumer surplus, i.e. the difference between the maximum amount that a person is willing to pay for a good or service and the amount they actually pay, per person per year from fishing each of the, is estimated based on data from an online economics survey. The amount paid is usually given by the market price, however, since recreational factors, such as the enjoyment of a fishing trip, spending time with friends/family, relaxing and sight-seeing, have no market value, their non-market value must be determined.

Measuring non-market value

Numerous methodologies are used to value non-market goods and services, which can broadly be classified as revealed preference or stated preference approaches (Freeman, Herriges and Kling, 2014). Revealed preference approaches use observed behavioural data to estimate the willingness to pay for non-market goods and services and include hedonic pricing and the travel cost method. Hedonic pricing is most often used in property valuation to estimate the premium that households paid to purchase a property near or far from an environmental amenity or dis-amenity (Boyle, 2003). The travel cost method is commonly used to estimate the benefits of recreational fishing (Alberini, Zanatta and Rosato, 2007; Rolfe and Prayaga, 2007; Pokki et al., 2018; Hwang et al., 2021). This method uses information from observed behaviour and expenditures of recreational fishers to estimate the non-market value of recreational fishing. Travel cost, travel time, on-site fishing expenditure (boat fuel, baits/lures and ice), annual recreational fishing expenditure (fishing gear cost and annual recreational fishing license fees), on-site fishing time, socio-economic variables (age, gender, income, education and employment) and fishing site attributes were considered to explain recreational fishing demand for Blue Swimmer Crabs.

The main limitation of revealed preference approaches is their inability to measure non-use values. As stated earlier, the second purpose of this chapter was to determine how the possible implementation of aquaculture-based enhancement may affect recreational fishing. Stated preference approaches use hypothetical data to estimate the willingness to pay for proposed non-market goods and services before they are actually provided. Choice experiments and contingent valuation are the common types of stated preference approaches (Perman et al., 2003). These methods can be used to estimate both use and non-use values. The traditional travel cost model cannot account for intended visitation patterns as it depends on actual behaviour data. Contingent valuation allows the assessment of intended policy changes by asking respondents contingent behaviour questions about their intended use if a specific policy were to be implemented. For example, based on current levels of fishing and catch rate at the estuaries, a hypothetical case of enhancement was developed in this current research and respondents were asked directly how their fishing and catch rate would be affected.

Contingent valuation has been found to provide reliable estimates of the value of non-market resources. Wheeler and Damania (2001) tested the validity of this method by estimating the value of recreational fishing in New Zealand. The results were found to be both reliable and intuitively plausible and no embedded or strategic bias was detected. Therefore, the authors recommended contingent valuation as a guide for allocating marine resources between recreational and commercial sectors in New Zealand.

To determine the economic value of recreational Blue Swimmer Crab fishing south-western Australian estuaries, a model was developed which combines the revealed preference and stated preference approaches. For example, there is no revealed preference data on behavioural change of recreational fishers when a proposed enhancement is to be introduced to an estuary. Stated preference surveys can be designed to collect data for this hypothetical policy change and the data can then be combined with revealed preference data to make estimations beyond what is historically known about recreational fishing at various sites. Therefore, combining the two approaches allows the travel cost model to be extended beyond the limited range of historical experience (Cummings, Brookshire and Schulze, 1986; Whitehead, Haab and Huang, 2000; Alberini, Zanatta and Rosato, 2007).

Pilot survey

This chapter employed both face-to-face semi-structured interviews and online surveys to estimate the value of recreational Blue Swimmer Crab fishing in three estuaries in south-western Australia. The survey was pretested during 23 face-to-face interviews with fishers onsite at the Peel Harvey and Swan-Canning estuaries. These sites were chosen because they are well known Blue Swimmer Crab fishing sites (Malseed and Sumner, 2001a). This ensured each question was appropriately worded and clearly understood. After analysing the responses, it was clear that some of the survey questions required clarification to enable respondents to better understand what was being asked of them. Further, some additional questions were added into the surveys to better ascertain the observed and contingent behaviour of the respondents. This survey and the subsequent main survey were conducted under Murdoch University Human Ethics Permit 2018/115.

Main survey

Using the basis of the feedback from the semi-structured interviews, the questions were modified where needed and transcribed to the online survey tool Surveygizmo. Participation in the survey was promoted via a press-release circulated by local print and broadcast media and flyers were posted at sample sites and convenience stores, bait/tackle stores and cafes located close to the estuaries. The survey was promoted through posts on social media, targeting recreational crab fishers and via dedicated fishing forums.

The survey comprised three major sections, i.e. revealed preference, stated preference and demographic information. Note that the methodology and results of the stated preference component are given in Section 3.3. In the revealed preference section, respondents were asked if they had gone fishing in the last year and the number of times they had fished in popular estuaries in south-western Australia. This is because a respondent’s recall when answering questions about activities they had done becomes less reliable as time passes (Bunce et al., 2008; Daw, 2010). A one-year time frame was considered an acceptable compromise between obtaining an adequate sample size of fishers and the reliability of responses provided. Other questions were asked about the number of years of fishing experience respondents had and how they usually catch crabs, i.e. from boat, shore or both. They also answered questions on the number of crabs they catch from each estuary as well as the percentage catch eaten by their households or given to other households. This section also sought information about the factors that constitute a successful fishing trip. Respondents were asked where they did their most recent fishing, together with the factors that made them choose that particular site as well as their motivation for their most recent fishing trip. There was also an “other” option, where respondents could write in their own answer if an appropriate answer was not listed.

Recreational fishers were asked to indicate the means of transport they used to get to their most recent fishing site, how far they had to travel to get there and the time it took to travel and the number of Blue Swimmer Crabs they caught or kept from this fishing trip. They were also asked why they stopped at the number of crabs caught on their most recent fishing trip. This was followed by questions seeking to understand whether respondents were satisfied with the number of Blue Swimmer Crabs they caught or kept, the size of the crabs, and if they were satisfied with the time it took to catch them. The survey participants were also asked to estimate their average onsite fishing time. This was followed by questions about the costs they incur on a typical fishing trip. Costs included boat fuel, baits/lures, ice, and fishing gear. The survey also asked for the number of people who accompanied the recreational fisher in the recent fishing trip and their relationship to them so that children and group travel could be accounted for.

In the demographics section, respondents provided information on their gender, postcode, highest level of education, age, employment status and level of income. Survey participation was voluntary with 192 respondents of which 120 completed all questions. This completion rate of 63% is comparable to similar studies on recreational crab fishing (Obregón et al., 2020b). Note that the answers from only those respondents that completed all questions were used in the analyses.

2.1.2.2. Econometric specification of the model

Background

The demand function for recreational fishing was estimated using proxies for the quantity and price variables. The quantity variable is the number of trips to the recreational fishing site and the price variable is the sum of the travel cost and the opportunity cost of time used in travelling to the site. Most researchers argue that travel time costs are related to the individual’s wage rate (Parsons, 2003).

The results from the estimated demand function is the consumer surplus derived from the recreational fishing trip or the amount of benefit the recreational fisher receives beyond the price paid. The demand curve is calculated assuming that a recreational fisher will continue to participate in fishing until the marginal benefit of the last trip equals its marginal cost (Kerkvliet, Nowell and Lowe, 2002). Generally, the demand curve is negative sloping, meaning as travel cost increases, recreational fishers tend to make less trips. To determine the relationship between travel cost and the number of trips, regression analysis was used. A Poisson regression is appropriate for modelling this kind of relationship because the dependent variable (number of trips) includes only count data (Cameron and Trivedi, 2010). The probability of a count is determined by the Poisson distribution, i.e. assuming that the variance is equal to the mean. However, many data violate this assumption resulting in a problem called over-dispersion bias. Over-dispersion bias mostly results in Type I errors - a variable is found to be statistically associated with the number of trips when it really is not (Palmer et al., 2007). Over-dispersion also results in the over-estimate of consumer surplus (Nakatani and Sato, 2010). A negative binomial model is considered to be an alternative to the Poisson when over-dispersion is a problem (Heberling and Templeton, 2009). Thus, both these regression techniques were used in this chapter, however, the most robust results were obtained from negative binomial regression models, as discussed below.

Some of the empirical concerns associated with the use of the travel cost method are the valuation of travel time, treatment of on-site time, substitutes and multi-destination sites. Travel time and time spent fishing is time that could have been used to do work, i.e. work is considered the opportunity cost of travel time and time spent fishing. Travel time is a significant component of travel costs and has, therefore, received significant attention in the literature. Most researchers argue that travel time costs are related to the individual’s wage rate. Therefore, omitting travel time costs would bias the results of the travel cost coefficient. The relationship between the travel time costs and wage rate is justified in theory as long as work time can be substituted for leisure at the margin (Parsons, 2003). Time cost is usually treated as a proportion ranging from one-fourth to the full wage rate of the individual (Cesario, 1976b; McConnell and Strand, 1981; McKean, Johnson and Walsh, 1995). Earnhart (2004) suggested that for those who are unemployed, in unpaid work or retired, one-sixth of the wage rate should be used. This is to recognise that their time still has value, albeit less than those who are in paid employment.

The opportunity cost of on-site time is usually valued at zero and excluded from the model. This is because the time spent on the site provides the individual with utility, which is equal to the opportunity cost of time, all things being equal (McConnell and Strand, 1981; Whitehead, Haab and Huang, 2000). However, some authors choose to include just the time spent doing the activity in the model since it may help explain trip behaviour (Simões, Barata and Cruz, 2013a).

According to economic theory, price and availability of substitutes is an important determinant of demand. When the prices for substitute sites are excluded, the estimates of consumer surplus may be inflated (Rosenthal, 1987). Prices of substitute sites should therefore ideally be included in the model. However, there may be instances where the exclusion of prices of substitute sites is necessary if there are no reasonable substitutes (Alberini and Longo, 2006; Blaine et al., 2015).

Multi-destination trips have typically been excluded from models (e.g. Loomis, Gonzalez-Caban and Englin, 2001; Parsons, 2003). Respondents were asked to identify their trips specifically for Blue Swimmer Crab fishing to separate multi-destination trips from the sample.

Model employed

Poisson

All data analysis was conducted using STATA 14 software package. The following illustrates the estimation of the Travel Cost Model (TCM). The Poisson model can be applied to count data estimations given the integer nature of the reported recreation frequency from data collection. The estimations are a discrete probability density function and non-negative. The Poisson function below was used to estimate the count data (Parsons, 2003).

1) $P\,(R) = \frac{\exp(-\,\lambda)\,\lambda^{R}}{R\,!}$, R = 0, 1, 2, …., R

where λ represents the value of the mean and variance of the random variable, R implies trip frequency, and all values must be positive for this function. When the mean and variance are not equal, there will be an error in the model; thus, correction steps are discussed below. Here, λ it will always be greater than zero leading to an exponential function:

2) $\lambda = \exp(\rho_i\,\beta)$

where ρ_i represents the vector of variables influencing demand and β represents the parameters used to estimate TCM. The estimation of this single-site model results in the following equation:

3) $R = \beta_{tc\,r}\; tc_r + \beta_y y\; +\; \beta_z\, Z$

the β coefficients are estimated for the single-site model, where the number of trips is the dependent variable. The independent variables used to estimate the model are travel cost to the site, income and other demographic variables. The parameters within this function can be estimated using maximum likelihood. The following equation is the likelihood function (Haab and McConnell, 2002):

4) $L\,(\beta\,/\,\rho_i R\,) = \prod_{i\,=\,1}^{T} \left[\frac{(\exp[-\exp(\rho_i\beta)])\;(\exp\;\;(\rho_i\beta) R_i)}{R_i!}\right]$

and the log-likelihood function is:

5) $\ln\ [L\ (\beta\ /\ \rho_i R)]\ =\ \sum_{i=1}^{T}\ [-\exp(\rho_i\ \beta) + (\rho_i\ \beta)\ R_i - \ln(R_i!)]$

These equations are concave using the listed parameters, where the maximum likelihood estimation (MLE) will converge. The conditional mean of the Poisson model is λ, using the following equation for expected trips

6) $E\ (R_i\ /\ \rho_i\ \beta) =\ \lambda = \exp\ (\rho_i\ \beta)$

The following is the estimated model of the Poisson using the previously discussed parameters:

7) $E\ (R_i /\ \rho_i) = \exp\ (\beta_{tc}\ tc_r +\ \beta_y\ y +\ \beta_{\ z}\ z)$

The beta coefficients $\beta_i{}'s$ are the coefficients estimated in the model. The Poisson model has limitations since the dependent variable's conditional mean and variance are equal because of restrictions in the estimation parameters. The variance does not deviate from the mean, and when the variance is more significant than the mean, and over-dispersion is present in the data.

Negative binominal

Cameron and Trivedi (2010) suggest that the Poisson regression model is usually too restrictive for count data. The presence of over-dispersion may result from the failure of an assumption of independence of events that is implicit in the Poisson process. This is due to unobserved heterogeneity generated by the process; the rate parameter is unavailable to be specified (random variable). The remedial process for over-dispersion count-data involves relaxing the conditional mean and variance constraint using the negative binomial model (NB).

An additional parameter is added to the model to control for over-dispersion. The reduction in over-dispersion will also result in a narrower confidence interval than the Poisson regression. The NB utilises the same conditional mean from the Poisson model. There are several versions of NB, but for this chapter, the following was adopted using the conditional mean of the Poisson model and the unobserved error:

8) $\log\ [\ E\ (R_i)] =\ \rho_i\ \beta +\ \theta_i$

where $\theta_{\ i}$ represents the unobserved heterogeneity. Equation 8 will provide the random variation needed across all observations. By substituting the equation from the right-hand side of the equation into the probability for the Poisson model, the number of trips based on the condition of $\theta_{\ i}$ is:

9) $\Pr\ (R_i\ /\theta_i)\ = \left[\frac{(\exp(-\exp(\rho_i\beta + \theta_i)])(\exp\ [\rho_i\ \beta + \theta_i])}{R_i!}\right]$

where, $\exp\ (\theta_i = v_i)$ is the gamma normalised distribution, with $E(v_i) = 1$, and the density for v_i is defined as $h(v) = \frac{\alpha^{\alpha}}{r(\alpha)} \exp(-\alpha v)\ v^{\alpha - 1}$. This is the unconditional probability function for trips, R_i by the process of integration of v which gives the following:

10) $\Pr(R_i) = [(\frac{\Gamma\left(R_i + \frac{1}{\alpha}\right)}{\Gamma(R_i+1)\Gamma\left(\frac{1}{\alpha}\right)})(\frac{\frac{1}{\alpha}}{\frac{1}{\alpha}+\lambda})\quad \frac{1}{\alpha}(\frac{\lambda}{\frac{1}{\alpha}+\lambda})\quad R_i]$

$\Gamma(.)$denotes the gamma integral, the basis to a factorial for an integer argument. The parameter α represents over-dispersion in the model. Special cases of the NB include the Poisson when $\alpha = 0$, which implies there are no occurrences of over-dispersion, thus, reducing the equation to the Poisson model. When $\alpha > 0$ there is an indication of over-dispersion and $\alpha < 0$ represents under dispersion. The values of an NB must be non-negative similar to the Poisson model stated above for the equation to hold. The correction process will reduce but does not eliminate issues relating to over-dispersion. The estimation process of the NB model is similar to the process of the Poisson model when using equation 7 and interpretations of the coefficients.

In addition to over-dispersion, endogenous stratification can occur when conducting an onsite data collection, leading to frequent site users being oversampled, resulting in the biatcs of the β estimates (Shaw, 1988). The method for correcting this occurrence is by removing one trip count $R - 1$ from the reported trips. The estimated travel cost coefficient from the Poisson and NB models can be used to calculate the consumer surplus (CS) of recreational users travelling to the estuaries. The following equation calculates the CS per household visit to the estuary:

11) $\overline{CS} = \frac{1}{-\beta_{tc_i}}$

12) $\overline{CS} = \frac{1}{-\ln[\beta_{tc_i})} * (mean\ of\ travel)$

Where $\overline{CS}$ represents the total consumer surplus for the site and β_{tc_i} is the coefficient for travel cost. Equation 11 is used when the travel cost variable is linear in the TCM and equation 12 when the travel cost variable is in natural logs in the TCM.

The second equation represents the calculation for consumer surplus when the variable is a natural log of the travel cost. The mean of the travel cost is multiplied by the coefficient. To calculate the total consumer surplus of the estuary, the following equation can be used:

13) $TCS = \overline{CS} * (Current\ trips)$

After deriving the consumer surplus per trip per individual, this value is then used to estimate the aggregated surplus value by multiplying it by the total number of recreational fishers (Parsons, 2003). As the actual number of recreational fishers utilising each of the three estuaries is unknown and difficult to calculate given the large size of the estuaries, e.g. the Peel-Harvey Estuary is 133 km^2 in surface area and has a perimeter of 224 km (Krispyn, 2021), and because of the crepuscular and nocturnal activities of fishers (Taylor et al., 2018), the number of recreational fishers operating in each of the three estuaries was estimated using the following logic. There were an estimated 612,000 recreational fishers in Western Australia at the time the survey was released in 2018 (95% CI = 535,000 - 690,000), of which 134,174 held a fishing from a boat licence in 2013/14 (Ryan et al., 2015; DPIRD, 2019). A total of 50% of those recreational fishers live within the Perth Metropolitan and West Coast Bioregions in which the Swan-Canning, Peel-Harvey and Leschenault estuaries are located (DPIRD, 2019). Assuming the proportion of recreational fishers to those with a boat licence nationally is consistent (22%), the 306,000 fishers located within the study region comprise ~67,000 boat-based and ~239,000 shore-based fishers. Ryan et al. (2015) demonstrated that 17% of boat-based fishers utilise estuaries, while they estimated this proportion is much higher for shore-based fishers (80%) as they cannot fish in inshore or offshore marine or lacustrine environments. From our on-field observations across the three estuaries, 60% of people observed fishing were targeting Blue Swimmer Crabs, reducing the estimated number of estuarine fishers in the region from ~203,000 (total) to ~122,000 for those crabbing. Finally, a survey of recreational crab fishers showed that 50, 20 and 7% of them fished in the Peel-Harvey, Swan-Canning and Leschenault estuaries, respectively (Recfishwest, 2018a), resulting in an estimated number of recreational Blue Swimmer Crab fishers of 60,761, 24,304 and 8,506, in each system respectively. Given the level of uncertainty around these estimates of fisher population size economic values are also given per fisher and for each estuary.

2.1.2.3. Computation of travel cost and opportunity cost of travel time

Postcodes of the residential address of the respondents were used to estimate the distance to the various estuaries. This approach has been applied in similar studies (Simões, Barata and Cruz, 2013b; Blaine et al., 2015).

The round-trip travel cost was calculated by multiplying the round-trip travel distance by $0.68, which is the amount in the Australian Taxation Office's cents per kilometre method for claiming motor vehicle expenses for the 2018/2019 financial year when a private vehicle is used for business travel. This figure incorporates vehicle running expenses and depreciation. This formula was applied only to respondents who travelled to their fishing sites using motorised vehicles. Those who walked or used bicycles had zero travel costs.

The opportunity cost of travel time was calculated by multiplying the round-trip travel time in hours by \$16.89. The Full-Time Adult Average Weekly Ordinary Time Earnings for the year 2018 was \$1,604.90 suggesting that earnings were \$16.89 per hour, assuming a 38-hour week and 40% private time (ATO, 2018). Only people who were fully employed or doing a casual job were assigned this value. The opportunity cost of those who were unemployed, retired or on a pension was valued at zero.

2.1.3. Results

2.1.3.1. Demographics

Of the respondents that completed every question on the online survey 84% were male and 15% were female (Table S2.1.1). This mirrors the proportion of male vs female Blue Swimmer Crab fishers who completed face-to-face interviews on ground during fishing activities (Obregón et al., 2020b; Section 1.5) and participated in online surveys of the social dimensions of crabbing (Sections 1.2, 1.4). The 5.6:1 male:female ratio for Blue Swimmer Crab fishers is markedly higher than the 1:1 ratio for the population of Western Australia (ABS, 2016), indicating a strong male dominance. Respondents for each of the age groups ranged from 18-24 to > 65 years old, noting that people < 18 years old were not invited to complete the survey as per our Human Ethics Permit. Among the respondents, ~75% belonged to the 25-34, 35-44 and 45-55 groups (each = ~25%; Table S2.1.1), which is slightly greater than the state-wide contribution made by people in these age groups over the age of 18 of 66% (ABS, 2016). Thus, most fishers are of working age.

The vast majority of respondents (93.3%) had their highest level of educational attained as secondary school or above, with 39 and 32% completing technical or further educational institution and university (Table S2.1.1). Note that 4% did not state any level of education. About 79% of the respondents were in full-time and part-time/casual employment, with only 3% identifying as unemployed, compared to a ~6% of the population across Western Australia in 2018 (ABS, 2018). The relatively high proportion of employment resulted in only 8% of respondents reporting a negative or no personal income, with annual gross salaries up to the AUD \$286,000 and \$337,999 category (Table S2.1.1). Of those 87% of respondents who selected a personal income option, 68% ranged between AUD \$20,800 and \$142,999, with 41.6% reporting a salary in an income category greater than the 2021 median Western Australian value of \$76,544 (ABS, 2022) and 41.6% below.

2.1.3.2. Fisher and fishing trip characteristics

Recreational Blue Swimmer Crabs fishers had been fishing for between 1 and 55 years, with mean and median of 17.5 and 12.0, respectively. The most represented experience categories were 1-5 years (23%), 6-10 years (22%) and 16-20 (13%), and it is also worth noting that 15% of respondents had fished for > 35 years (Table 2.1.1). Boat-based fishing was practised by 39% of fishers, with 21% fishing exclusively from the shore and the remaining 40% fishing from both vessels and the shore depending on the trip.

Recreational Blue Swimmer Crab fishers utilised a wide range of estuarine and marine waters in south-western Australia. Fishing activity was centred on the west coast with 48, 44, 24 and 20% of the respondents utilising the Peel-Harvey Estuary, Swan-Canning Estuary, Leschenault Estuary and coastal waters on the west coast, respectively (Table 2.1.2). Far lower proportions of fisher's went crabbing in estuarine or coastal waters on the south coast of Western Australia (≤ 5% for all three options). Fishers utilised between one and four of the eight listed aquatic environments, with 55% of fishers fishing in one option, 36% in two and 8% in three (Table 2.1.2).

The next set of questions in the survey focused on the respondents most recent fishing trip. A similar spatial pattern of fishing effort was reported when asked '*Where did they most recently fish for Blue Swimmer Crabs?'* compared to the last year. The Peel-Harvey and Swan-Canning estuaries were the most visited

(> 31%), followed by the Leschenault Estuary and coastal waters on the west coast (i.e. 20.6 and 8.5%, respectively; Table 2.1.2). Only 3.5% of respondents had utilised aquatic environments on the south coast on their last crabbing trip.

Table 2.1.1. Number and percentage of recreational Blue Swimmer Crab fishers with different years of fishing experience.

Years	n	%
0-5	29	22.8
6-10	28	22.1
11-15	8	6.3
16-20	17	13.4
21-25	3	2.4
26-30	10	7.9
31-35	2	1.6
36-40	13	10.2
41-45	1	0.8
46-50	3	2.4
51-55	2	1.4
56-60	0	0.0

Table 2.1.2. Number and percentage of recreational Blue Swimmer Crab fishers that visited each location over the last twelve months (annual visitation) and on their last crabbing trip (last visit). Note that fishers often visited more than a single location and so values to do not sum to 100.

		Annual visitation		Last visit	
Location	Coast	n	%	n	%
Swan-Canning Estuary	West	53	44.2	44	31.2
Peel Harvey Estuary	West	58	48.3	49	34.8
Leschenault Estuary	West	29	24.2	29	20.6
Other estuaries	West	5	4.2	2	1.4
Coastal waters (e.g. Geographe Bay)	West	24	20.0	12	8.5
Blackwood River Estuary	South	1	0.8	1	0.7
Other estuaries (e.g. Wilson Inlet)	South	6	5.0	2	1.4
Coastal waters	South	5	4.2	2	1.4

On their most recent crabbing trip the vast majority of fishers (86%) used a car of some description, with 48% using a four-wheel drive vehicle, and ~19% either a ute (utility vehicle) or small car (Table 2.1.3). Only 5% of fishers walked to their fishing site. Blue Swimmer Crab fishers travelled between 0.1 and 700 km to go fishing, producing a mean of 39.9 km and median of 20.0 km (95% confidence limits = 13.4 km). Trips were generally short with 26% of respondents travelling < 5 km and only 7% > 100 km. This reflects the fact that when asked why they chose that particular site, the most commonly selected response was *it is local/convenient* (60%). The next most popular responses were about safety (48%) and size of the crabs at that site (37%). Other reasons related to the abundance and ease of catching crabs and the level of congestion were all fairly similar (~30%; Table 2.1.4).

Table 2.1.3. Transport methods used by Blue Swimmer Crab fishers to get from their home to fishing location on their most recent fishing trip. Options ranked from most to least selected.

Transport method	n	%
Four-wheel drive vehicle	56	47.9
Ute	22	18.8
Small car	22	18.8
Boat	8	6.8
On foot (walking)	6	5.1
Bicycle	1	0.9
Motorcycle	1	0.9
Other	1	0.9

Table 2.1.4. Reasons recreational Blue Swimmer Crab fishers chose a fishing site on their most recent fishing trip. Options ranked from most to least selected. Note respondents were able to selection more than one option. Note that fishers often visited more than a single location and so values to do sum to 100.

Reason for choosing a fishing site	n	%
It is local/convenient	84	60.0
Safe to fish for Blue Swimmer Crabs there	67	47.9
Good size Blue Swimmer Crabs available	52	37.1
Not crowded	46	32.9
Easy to catch Blue Swimmer Crabs	42	30.0
Lots of Blue Swimmers Crab there	29	27.9
Other	15	10.7

Catching Blue Swimmer Crabs to eat (74%) was the most common motivation followed by being outdoors, the enjoyment of fishing, relaxing and spending time with family (53-66%; Table 2.1.5). The primary food-motivated nature of the fishery further reinforced by the fact that fishers on average caught 17 crabs (± 9 95% confidence limit) per person (37 crab per fisher party) and retained 5 crabs per person (± 1.3 95% confidence limit). On the basis of the bag limit of 10 crabs at the time the survey was conducted 85.5% of fishers caught less than the bag limit, 9.4% the bag limits, while 5.1% admitted to exceeding the legal limits and some markedly so (i.e. up to 50 crabs per person). When asked why they stopped fishing for Blue Swimmer Crabs, the most common of the reasons provided were *caught the bag limit* (29%) and *that was all I could catch* (26%), followed by *ran out of time* (20%). *Poor weather* was a minor influence being selected by only 4%, while 21% of respondents provided an open answer (data not shown). The majority of respondents were satisfied with the number of Blue Swimmer Crabs they caught (69%), kept (74%), their size (69%) and the time it took to catch them (69%).

Table 2.1.5. Motivations for recreational Blue Swimmer Crab fishers go crabbing on their most recent fishing trip. Options ranked from most to least selected. Note respondents were able to selection more than one option. Note that fishers often visited more than a single location and so values to do sum to 100.

Motivation	n	%
Catch Blue Swimmer Crabs to eat	104	74.3
To be outdoors	92	65.7
For the enjoyment or challenge of catching crabs	80	57.1
To relax	75	53.6
To spend time with family	74	52.9
To spend time with other friends	46	32.9
Catch Blue Swimmer Crabs to share with friends	38	27.1
To be on your own	14	10.0
Other	2	1.4
Participate in a competition	1	0.7

2.1.3.3. Average costs of a crabbing trip

Among the Blue Swimmer Crab fishing trips conducted by the respondents in the previous 12 months from the survey date, the locations that were most frequently visited were the Swan-Canning and Peel-Harvey estuaries (> 400), followed by the Leschenault Estuary (200) and other estuaries on the west coast of the state (115; Table 2.1.6a). The respondents fished aquatic environments on the south coast far less frequently (59 trips year^{-1}; or <5% of the total number of trips). The high total number of fishing trip to the Swan-Canning and Peel-Harvey estuaries were due to the combination of a greater proportion of fishers utilising these systems (> 44%) and the fact they conducted more fishing trips per year in these systems than the others (i.e. ~3.5 vs 0.08 to 1.67 trips year^{-1}).

The respondents who completed all questions on the survey, together with their fishing companions, claimed to have caught 14,829 Blue Swimmer Crabs and kept 7,603 of them (51%; Table 2.1.6b). The numbers of crabs caught on each fishing trip varied greatly, ranging from 72 in the Peel-Harvey to 0.04 in the Blackwood River Estuary. Catches were far greater on the west than south coasts, with relatively high average numbers of crabs caught per trip in the Swan-Canning (28) and Leschenault (13) estuaries. Despite the substantial difference in the average numbers of crabs caught between the Peel-Harvey and Swan-Canning (72 vs 28 per trip) the average numbers of crabs retained by a fishing party was similar (28 vs 22 per trip) and far greater in these systems than the others (0.04 to 6.4; Table 2.1.6c). Among the systems where > 500 crabs were caught, release rates were greatest in the Peel-Harvey (61%) and Leschenault (53%) estuaries and least in the Swan-Canning estuary (22%).

Very rarely did Blue Swimmer Crab fishers practice catch and release fishing, i.e. < 4% in all locations except coastal waters on the west coast (17%; Table 2.1.6). Fishers estimated that, on average, 82% of their catch was eaten by members of their household, with 15% given to another household. Essentially no Blue Swimmer Crabs were used for other purposes, with only a single fisher selecting this option and then only using 20% of their catch for this purpose.

The number of people partaking in a fishing trip ranged from 1 to 10, with the vast majority of participants (88%) being between 1 – 4, with 2 being the most common number of people (42% of trips; Table 2.1.7). Members of the respondents fishing party tended to be a friend of the respondent (46%) or their children (43%) or partner/spouse (40%).

Table 2.2.6. (a) Total number of trips, average number of trips per fisher, standard deviation, range, and proportion of fishers that visited each location to catch Blue Swimmer Crabs. Total number of crabs, average number of crabs per fisher, standard deviation, range, and proportion of fishers (%F) that (b) caught and (c) kept Blue Swimmer Crabs at each location.[22]

(a) Number of trips							
Location	**Total**	**%**	**Avg**	**SD**	**Range**	**#F**	**%F**
Swan-Canning Est.	428	34.5	3.57	7.29	0-50	53	44.17
Peel-Harvey Est.	419	33.8	3.49	5.90	0-36	58	48.33
Leschenault Est.	200	16.1	1.67	4.27	0-30	29	24.17
Other WC estuaries	20	1.61	0.17	1.05	0-10	5	4.17
WC marine waters	115	9.27	0.96	2.96	0-20	24	20.00
Blackwood River Est.	10	0.81	0.08	0.91	0-10	1	0.83
Other SC estuaries	28	2.26	0.23	1.45	0-12	6	5.00
SC marine waters	21	1.69	0.18	1.17	0-10	5	4.17

(b) Blue Swimmer Crabs caught							
Location	**Total**	**%**	**Avg**	**SD**	**Range**	**#F**	**%F**
Swan-Canning Est.	3377	22.8	28.14	68.94	0-500	51	42.50
Peel-Harvey Est.	8618	58.1	71.82	207.28	0-1500	54	45.00
Leschenault Est.	1616	10.9	13.47		0-300	27	22.50
Other WC estuaries	185	1.25	1.54	10.18	0-100	5	4.17
WC marine waters	799	5.39	6.66	23.86	0-200	24	20.00
Blackwood River Est.	5	0.03	0.04	0.46	0-5	1	0.83
Other SC estuaries	151	1.02	1.26	8.10	0-70	5	4.17
SC marine waters	78	0.53	0.65	4.92	0-50	4	3.33

(c) Blue Swimmer Crabs kept								**% crabs released**	**Catch & release fishers**
Location	**Total**	**%**	**Avg**	**SD**	**Range**	**#F**	**%F**		
Swan-Canning Est.	2619	34.4	21.83	50.24	0-300	50	41.67	22.45	1.96
Peel-Harvey Est.	3390	44.6	28.25	61.55	0-400	55	45.83	60.66	3.70
Leschenault Est.	764	10	6.37	23.86	0-200	26	21.67	52.72	3.70
Other WC estuaries	128	1.68	1.07	4.98	0-40	8	6.67	30.81	0.00
WC marine waters	498	6.55	4.15	14.54	0-120	21	17.50	37.67	16.67
Blackwood River Est.	5	0.07	0.04	0.46	0-5	1	0.83	0.00	0.00

[22] The percentage number of Blue Swimmer Crabs released by fishers utilising each location and the percentage of fishers that practice catch & release fishing is also provided. WC = West coast; SC = South coast; F = fishers.

Other SC estuaries	121	1.59	1.01	6.21	0-50	5	4.17	19.87	0.00
SC marine waters	78	1.03	0.65	4.92	0-50	4	3.33	0.00	0.00

Table 2.1.7. Number of recreational Blue Swimmer Crab fishers in the party for a fishing trip and their relationship to the respondent Note respondents were able to selection more than one option if applicable for the relationship to the respondent (i.e. a friend and child) and so the percentages do not sum to 100.

Number of fishers	n	%	Relationship to respondent	n	%
1	21	17.6	Friend	56	46.7
2	50	42.0	Partner/spouse	48	40.0
3	21	17.6	Parent	16	13.3
4	13	10.9	Children	51	42.5
5	8	6.7	Extended family	22	18.3
6	3	2.5	Other	3	2.5
7	1	0.8			
10	2	1.7			

The average total trip costs accrued by recreational Blue Swimmer Crab fishers on a single fishing trip in south-western Australia was $87.25. On each trip, fishers spent an average of $30 on fishing gear, $20 on boat fuel, $18 on other items, $11 on bait and $9 on ice to keep the catch cool (Table 2.1.8a). Incorporating an average trip of 2 ½ hours with ~3 people fishing (some of whom were below working age) the opportunity cost of crabbing was $43. The 'total cost' of a fishing trip varies among estuaries and coastal waters from $100 (Leschenault) to $162 (Swan-Canning). Some costs were fairly consistent across locations, i.e. the opportunity cost ($38-49), due to the trip length and number of participants being similar, and bait ($10-15). Other costs differed, however, for example, respondents fishing in Leschenault spent less money on boat fuel ($13) than those crabbing in other locations ($20-22) and fishers in the Swan-Canning claimed to spend, on average, $20 on ice compared to ~$5 elsewhere. Also, fishers utilising estuaries in the Metropolitan area (Swan-Canning and Peel-Harvey) spent a greater amount on other items, i.e. $31 and 19, respectively; Table 2.1.8).

On the basis of average market expenditure per fishing trip, divided by the number of fishers the cost, per person, of crabbing in the Swan-Canning, Peel-Harvey and Leschenault is $51.62, $29.61 and $18.40, respectively. Using the same process, average estimates of opportunity cost per person are as follows; Swan-Canning ($21.78), Peel-Harvey ($14.95) and Leschenault ($13.53). Finally, incorporating the above estimates, together with both the average of number of trips made by a fisher and the fisher population size for each estuary sums of the market and non-market expenditure for recreational Blue Swimmer Crab fishing are

Swan-Canning Estuary = total trip cost $4,474,282 and total opportunity cost $1,888,150; total cost = $6,362,432.

Peel-Harvey Estuary = total trip cost $6,274,675 and total opportunity cost $3,168,289; total cost = $9,442,963.

Leschenault Estuary = total trip cost $260,814 and total opportunity cost $191,862; total cost = $452,676.

The total estimated expenditure for recreational Blue Swimmer Crab fishing for these three estuaries was $16.26 million per annum, with ~67.7% of estimated direct expenditure and 32.3% of opportunity cost.

Table 2.1.8. Average and standard deviation (SD) market and non-market costs (AUD$) associated with a Blue Swimmer Crab fishing trip on the west coast of Australia.

(a) Overall	Avg	SD
Boat fuel (AUD$)	19.49	33.85
Bait (AUD$)	10.82	14.26
Ice (AUD$)	9.04	47.81
Fishing gear (AUD$)	29.46	55.07
Other costs (AUD$)	18.45	69.85
Total trip cost (AUD$)	*87.25*	*147.03*
Time spent fishing (h)	2.54	1.39
No people fishing	2.73	1.62
Opportunity cost (AUD$)	*42.87*	*23.41*
Total cost (AUD$)	**130.12**	

	Swan-Canning Estuary		**Peel-Harvey Estuary**		**Leschenault Estuary**		**Other estuaries**	
(b) Estuaries	Avg	SD	Avg	SD	Avg	SD	Avg	SD
Boat fuel (AUD$)	20.86	37.71	21.85	40.60	13.40	21.83	20.00	0.00
Bait (AUD$)	9.84	12.98	12.03	17.01	11.28	14.54	15.00	7.07
Ice (AUD$)	20.20	85.46	4.59	5.98	4.12	5.29	5.00	7.07
Fishing gear (AUD$)	32.70	58.34	27.95	41.34	20.20	33.56	0.00	0.00
Other costs (AUD$)	30.78	115.38	19.36	44.64	8.40	22.11	15.00	21.21
Total trip cost (AUD$)	*114.39*	*212.13*	*85.77*	*118.68*	*57.40*	*85.53*	*55.00*	*35.36*
Time spent fishing (h)	2.86	1.50	2.56	0.96	2.50	1.73	3.00	0.00
No people fishing	2.22	0.98	2.90	1.43	3.12	2.03	3.50	2.12
Opportunity cost (AUD$)	*48.27*	*25.40*	*43.31*	*16.23*	*42.23*	*29.25*	*50.67*	*0.00*
Total cost (AUD$)	**162.67**		**129.08**		**99.63**		**105.67**	

	Geographe Bay		**Other marine waters**	
(c) Marine waters	Avg	SD	Avg	SD
Boat fuel (AUD$)	20.00	4.08	21.43	16.76
Bait (AUD$)	13.75	4.79	12.57	13.89
Ice (AUD$)	3.75	4.79	4.29	5.35
Fishing gear (AUD$)	32.50	47.17	64.29	140.22
Other costs (AUD$)	5.00	10.00	2.86	7.56
Total trip cost (AUD$)	*75.00*	*55.83*	*105.43*	*156.52*
Time spent fishing (h)	2.25	1.26	2.33	1.16
No people fishing	2.75	1.50	2.14	1.07
Opportunity cost (AUD$)	*38.00*	*21.25*	*39.33*	*19.67*
Total cost (AUD$)	**113.00**		**144.76**	

2.1.3.4. *Economic value of recreational crabbing*

The economic value of recreational Blue Swimmer Crab fishing in the Swan-Canning, Peel-Harvey and Leschenault estuaries, i.e. those where most fishing occurs, was firstly modelled using a Poisson model. While the round trip cost was highly-significant ($p < 0.001$, 0.01 and 0.001, respectively; Table 2.1.9), there was also a significant alpha value in the Swan-Canning Estuary, indicating that over-dispersion was present. To account for this the data for each estuary were modelled again, only this time using a negative binomial model.

Using the negative binominal model, in addition to the round trip cost being significant so was the opportunity cost of travel time to the estuary only this was positive (Table 2.1.9). The number of crabs caught and kept for food was also significant and positive. Within the category of 18-24 years of age, recreational fishers made significantly more fishing trips to the Swan-Canning Estuary than people aged 35-44. People in the very high-income categories of $182,000-$233,999 and $286,000-$337,999 were estimated to have made more trips to this estuary than recreational fishers with very low incomes of between $1 and $20,799 per annum. On the basis of the model outputs, the consumer surplus of recreational Blue Swimmer Crab fishing in Swan-Canning Estuary was estimated to be $20.49 per fisher per trip. Accounting for an estimated 24,304 fishers utilising this system and each fisher undertaking, on average, 3.57 trips per year, the estimate aggregated surplus value is $1,776,161.

In the Peel-Harvey, the number of crabs kept and the male variables were also significant and positive and, unlike the Swan-Canning, recreational fishers in the higher income categories fished significantly less than those in the lowest income category. The consumer surplus of a single recreational crab fishing trip in Peel-Harvey Estuary is $9.71, which is around half that estimated for the Swan-Canning Estuary, although the average number of trips per year (3) was similar. As a greater number of crab fishers utilise the Peel-Harvey Estuary (60,761), the aggregated surplus value was estimated as $2,060,046.

Crab fishing in Leschenault Estuary per fisher per trip had by far the lowest consumer surplus value of the three estuaries at $3.30. The opportunity cost of travel time, age, number of crabs caught and the gender of the recreational fishers were significant. However, the opportunity cost of fishing time, number of crabs kept, fishing experience, income and the other costs of recreational fishing were not. In addition to the low expenditure, the average number of trips per year in this estuary was also the lowest, at 1.67. Assuming 8,506 recreational crab fishers, the aggregated surplus value of this fishery is estimated to be only $46,783.

Combining the total trip cost, total opportunity cost and the consumer surplus, the annual total economic values of recreational crab fishing the three estuaries are as follows; Swan-Canning is ~$8,1 million, Peel-Harvey is ~$11.5 million and Leschenault is ~$500,000. On a per fisher basis this equates to $334, $189 and $58, respectively.

Table 2.1.9. Results of Poisson and Negative Binomial (nbreg) models for recreational Blue Swimmer Crab fishing in the Swan-Canning, Peel-Harvey and Leschenault estuaries in south-western Australia.

	Swan-Canning		Peel-Harvey		Leschenault	
Variable	**Poisson**	**nbreg**	**Poisson**	**nbreg**	**Poisson**	**nbreg**
Cost of roundtrip	-0.0359***	-0.0488***	-0.0427**	-0.103**	-0.297***	-0.303***
	(-4.11)	(-3.84)	(-3.07)	(-3.10)	(-6.24)	(-4.81)
Opportunity cost of travel time	0.200***	0.254***	0.183***	0.415***	1.148***	1.186***
	-6.4	-5.14	-3.75	-3.54	-6.29	-4.92
Opportunity cost of fishing time	-0.00539	-0.0072	0.000183	0.0000385	0.00207	0.00338
	(-1.09)	(-1.08)	-1.11	-0.11	-0.66	-0.71
Fuel cost	0.0187	0.0167	0.0214	0.0258	-0.141**	-0.11
	-0.64	-0.44	-0.96	-0.6	(-3.04)	(-1.69)
Bait cost	0.0353	0.0301	-0.00488	-0.00817	0.0769*	0.0648
	-1.35	-0.86	(-0.25)	(-0.22)	-2.44	-1.34
Ice cost	-0.0318	-0.0534	-0.0488*	-0.0422	0.119*	0.123
	(-1.06)	(-1.29)	(-2.02)	(-0.94)	-2.03	-1.49
Fishing experience	-0.0168	-0.0136	0.000684**	0.000509	0.00447	-0.0142
	(-1.79)	(-1.17)	-2.96	-0.67	-0.32	(-0.62)
No. crabs caught	0.00668	0.00635	0.0122***	0.0155**	0.00843**	0.0128*
	-0.77	-0.56	-7.72	-3.16	-2.73	-2.27
No. crabs kept	0.0049	0.00553	0	0	0.0104*	0.00787
	-0.5	-0.44	(.)	(.)	-2.2	-0.96
Female	0	0	0.500*	1.136*	0	0
	(.)	(.)	-2.09	-2.16	(.)	(.)
Male	1.141*	1.085	0	0	-1.041**	-1.453*
	-2.12	-1.74	(.)	(.)	(-2.94)	(-2.28)
18 to 24 years	0	0	-1.003***	-0.507	0	0
	(.)	(.)	(-3.94)	(-0.95)	(.)	(.)
25 to 34 years	-1.027*	-0.915	-0.5	-0.057	1.971**	2.668*
	(-2.35)	(-1.64)	(-1.90)	(-0.10)	-2.95	-2.53
35 to 44 years	-1.716***	-1.487*	-0.716**	0.106	2.170**	2.961*
	(-3.33)	(-2.32)	(-2.92)	-0.17	-2.94	-2.43
45 to 54 years	-1.242**	-1.067	0.403	0.799	1.053	2.608
	(-3.03)	(-1.91)	-1.31	-1.11	-1.02	-1.76
55 to 64 years	-0.898	-0.569	-1.963***	-1.666	-1.003	-0.356
	(-1.32)	(-0.69)	(-3.52)	(-1.71)	(-0.89)	(-0.23)
65+ years	-2.647	-2.762	0	0	-16.98	-29.13
	(-1.39)	(-1.11)	(.)	(.)	(-0.00)	(-0.00)
$1-$20,799	0	0	-1.331***	-1.724*	0	0
	(.)	(.)	(-4.28)	(-2.41)	(.)	(.)
$104,000-$142,999	0.96	0.983	-2.114***	-3.305***	0.484	-19.43
	-1.24	-1.11	(-5.96)	(-3.56)	0	(-0.00)
$143,000-181,999	1.247	0.959	-1.596***	-2.245**	18.26	11.55
	-1.62	-1.08	(-4.76)	(-2.90)	0	-0.01
$182,000-$233,999	1.562*	1.839*	-1.046***	-0.972	19.95	14.03
	-2.06	-2.05	(-3.42)	(-1.50)	0	-0.02
$20,800-$41,599	0.58	0.713	-13.73	-16.82	19.61	13.6
	-0.72	-0.77	(-0.02)	(-0.00)	0	-0.02
$286,000-$337,999	4.137***	4.441***	-2.201***	-4.154**	-2.745	-21.37
	-4.19	-3.71	(-4.68)	(-2.70)	(-0.00)	(-0.00)
$234,000-$285,999	1.792	1.912	-1.431***	-1.630*	-0.869	-20.23
	-1.03	-0.84	(-4.56)	(-2.39)	(-0.00)	(-0.00)
$41,600-$62,399	-1.506	-1.51	-0.832**	-1.173	21.46	15.26
	(-1.64)	(-1.40)	(-3.17)	(-1.82)	0	-0.02
$62,400-$83,199	1.116	0.958	-0.828**	-0.462	19.86	13.54
	-1.45	-1.09	(-3.01)	(-0.71)	0	-0.02
$84,000-$103,999	0.753	0.797	-0.695	-0.781	18.78	12.52
	-0.97	-0.92	(-1.93)	(-0.96)	0	-0.01
No income ($0)	1.338	1.263		0.00213	20.16	13.51
	-1.76	-1.36		-0.18	0	-0.02
Constant	-1.663	-1.904	0.898*	-0.78	-22.26	-16.78
	(-1.79)	(-1.74)	-2.27	(-0.87)	(-0.00)	(-0.02)
Lnalpha						
Constant		-1.819**		-0.388		-0.828
		(-2.91)		(-1.30)		(-1.50)
AIC	292.3	290.9	434.7	373.6	213.6	211.3
BIC	357.9	358.9	498.1	441.7	266.6	279.4

Note: t statistics in parentheses; significant terms shaded in grey * = $p < 0.05$, **= $p < 0.01$, ***= $p < 0.001$.

2.1.4. Discussion

There is growing recognition of the need to use a whole-of-environment/ecosystem approaches such as Ecosystem Based Fishery Management (Hall and Mainprize, 2004; Pikitch et al., 2004a), and to incorporate social and economic factors (Arlinghaus et al., 2016; Rindorf et al., 2016; Stephenson et al., 2017). In-order for such management to exist, knowledge gaps need to be filled particularly the economic contribution made by recreational fishers. Thus, information on the economic costs of a recreational Blue Swimmer Crab fishing trip, and the number of trips and locations where such fishing occurs were collected. These data were used to estimate the economic value (consumer surplus) of recreational crab fishing in south-western Australia, which was combined with observed trip expenditure and opportunity cost of time to determine the total economic value of recreational crab fishing.

2.1.4.1. Demographics and motivations

As recreational fishing is a popular leisure activity particularly in the developed world, policymakers can benefit from understanding participation rates (Brownscombe et al., 2019). Participation can be influenced by demographic factors such as culture, socioeconomic status, fishing ground availability, age, gender, household composition, ethnicity, working status, weather conditions and urban residency and so rates vary among fisheries (Arlinghaus, 2006b; Arlinghaus, Tillner and Bork, 2015; van der Hammen and Chen, 2020).

Of the respondents that completed every question on the online survey 84% were male and 15% were female. This mirrors the proportion of male vs female Blue Swimmer Crab fishers who completed face-to-face interviews on ground during fishing activities (Section 1.1) and participated in online surveys of the social dimensions of crabbing in the same part of Western Australia (Section 1.2). The 5.6:1 male:female ratio for Blue Swimmer Crab fishers is markedly higher than the 1:1 ratio for the population of Western Australia (ABS, 2016), indicating a strong male dominance. More broadly, in a survey of recreational fishing in the, UK and Ireland, Copeland et al. (2017b) also observed that recreational fishers are mostly males. Fishing has long been considered a gendered activity, with women more likely than men to face constraints that may reduce fishing participation and contribute to a gendered 'leisure gap'. For example, women have greater caregiving and housework responsibilities (Hochschild and Machung, 2012), smaller chunks of leisure time (Bittman and Wajcman, 2000; Beck and Arnold, 2009) that may be incompatible with fishing compared to other leisure forms, and feel less safe while participating in outdoor activities (Bialeschki and Huh, 1999). It is thus relevant that Taylor et al. (2018) found that up to 11 and 27% of recreational crabbing effort in the Peel-Harvey Estuary occurred at crepuscular and nocturnal times, where women may be less likely to fish due to safety concerns.

Survey respondents varied in age from 18 to > 65. The lower limit was set as 18 as children were not surveyed as per the conditions of the Human Ethics Permit. It should be noted, however, that 42% of fishers stated that they fished with their children. The wide range of ages of crab fishers reflects the fact that crabbing is not a strenuous activity and can be done, for example, by lowering a crab pot (< 1 kg) several meters from a jetty or wading in the shallows of the estuary (< 1.5 m deep) and scooping crabs. The majority (78%) of the respondents were employed reflecting the relatively low unemployment rate (seasonally adjusted unemployment rate of 5.0 per cent in December 2018), with salaries of $1-4,499 a week. This suggests the average weekly income of most of the fishers is ~$2,250, which is considerably above the Australian Bureau of Statistics, the Full-Time Adult Average Weekly Total Earnings in May 2018 which was $1,653. Therefore, most of the recreational fishers surveyed earn above the AWOTE for 2018 and have enough disposable income to undertake recreational fishing. Typically, disposable income is spent on leisure activities including as dining out and participating in sporting activities (Henderson and Thisse, 2004).

The recreational crab fishers surveyed had been fishing for between 1 and 55 years, with a mean and median of 17.5 and 12.0, respectively. This relatively long time indicates that these fishers value the Blue Swimmer Crab fishery and that fishing in engrained in local culture. Crab fishing in the region is iconic with an annual crab fishing festival and with news reports dating back to 1908 (Obregón et al., 2022a). Around 71% of the respondents attended technical or other tertiary educational institutions, with 94% completing at least primary school. These results were expected though, as Australia is a developed country with an adult literacy rate of 99% (WorldAtlas, 2022). Moreover, Copeland et al. (2017b) found that about three-quarters of Australian recreational fishers have post-high school qualifications (e.g. trade certification, Diploma and/or Degree).

Recreational Blue Swimmer Crab fishers utilised a wide range of estuarine and marine waters in south-western Australia. Fishing activity was centred on the west coast with 48, 44, 24 and 20% the respondents utilising the Peel-Harvey Estuary, Swan-Canning Estuary, Leschenault Estuary and coastal waters on the west coast, respectively. Similar results were also obtained from a survey conducted by the peak body representing recreational fishers in Western Australia who found that ~47% fished in the Peel-Harvey and 20% in the Swan-Canning Estuary, with the lower value for the latter estuary explained by the fact that fishers could only choose a single estuary in that survey (Recfishwest, 2018b). The fact that most recreational crab fishers utilise the two largest estuaries on the lower-west coast of WA is mirrored by estimated catches with Department of Primary Industries and Regional Development (2018a) stating that 92% the total recreational crab catch in Western Australia comes from this coastline. This likely reflects the locations of the cities of Perth and Mandurah, which are the largest in the state, and to a lesser extent Bunbury along this coast.

Lastly, it was observed that the primary motivation for crabbing was to catch crabs to consume them (i.e. a consumption-orientated fishery). Recreational fishing frequently serves subsistence purposes, a phenomenon that has grown rapidly in recent years and complicates the distinction between fishing for recreational or subsistence purposes (Giovos et al., 2018). The food-focused nature of recreational crabbing can be explained by the fact that the crabs are iconic locally and known for their edibility, with a sweet flavour and very low in fat and calories (Keenan, 2004; City of Mandurah, 2017; Santhanam, 2018). Crabs sell for between $15 and $45 per kg (2022 price AUD) and with the average weight at the minimum legal length of ~187 g (Johnston and Yeoh, 2020), then a bag limit of 10 crabs would equate to at least $28 – 84. Moreover, the crabs are easy to catch by people of all ages and experience levels using inexpensive equipment. For example, south-western Australian estuaries are typified by extensive shallow margins, < 1 m deep (McComb and Lukatelich, 1995; Valesini et al., 2014), which are easily accessible by fisher's wading and using a scoop net or by simple grasping the crab with your hand (Section 1.2). Fishing can also be conducted in deeper waters using drop nets, which are baited and left unattended, either tied to a jetty or deployed from a small boat. Thus, in addition to be highly valued for their flavour, catching crabs is relatively easy compared to finfish species using rod and line.

2.1.4.2. Cost of a fishing trip (direct expenditure)

The estimation of direct expenditure is a common method that is utilised in the process of calculating the contribution of recreational fishing to a regional economy. The average total trip costs accrued by recreational Blue Swimmer Crab fishers on a single fishing trip in south-western Australia was $87.25. On each trip, fishers spent an average of $30 on fishing gear, $20 on boat fuel, $18 on other items, $11 on bait and $9 on ice to keep the catch cool. The relatively low expenditure of crabbing gear is due to the relatively cheap cost of appropriate gear, for example a scoop net is ~ $25 and drop nets and crab pots $15 and $25, respectively and the latter two items can often be cheaper if multiple are purchased together. These types are gear are substantially less expensive that rods and reels, which for estuarine fishing could be $100s to $1,000s depending on the quality (Section 2.2). Moreover, scoop netting and hand fishing (including snorkelling) do not require the use of bait as the crabs often 'stand their ground' rather than flee when the spot a fisher and so do not require bait or expensive soft plastic lures. Moreover, as opportunistic scavengers (Campbell et al., 2021), a wide variety of cheap baits can be used include cheap cuts of food-grade meats, e.g. lamb necks and any fish carcass caught from line fishing (recfishwest, 2021). Note that in other Australian states the use of bone, meat, offal or the skin of an animal, including birds is prohibited.

On their most recent crabbing trip the vast majority of fishers (86%) used a car of some description and traveled on 40 km (median = 20 km). The relatviely short distances travelled by fishers to go crabbing likely reflects the fact, as of 2021, that 80% of the 2.7 million people in Western Australia live in the capital city of Perth (Australian Bureau of Statistics, 2022b), which boarders the Swan-Canning Estuary and is fairly close (< 80 km) to the Peel-Harvey Estuary on which the City of Mandurah (80,000 people is located).

Comparisons in economic expenditure from recreational fishing can be provided from surveys conducted in other Australian states. These indicate that the average cost of crabbing in this chapter ($87) is considerably less than that from other Australian States. For example, in Victoria, the average direct cost of a fishing trip, accounting for food and accommodation, tackle, equipment and bait was almost three times higher at $244 (Ernst & Young, 2020). Note that, these workers, also estimated annual ad-hoc expenditure items, e.g. clothes for fishing, club fees and camping gear (not covered on the current chapter), totalled $643 or $95 per fishing trip to give a grand total of $339 per trip. In New South Wales, McIlgorm and Pepperell (2013) estimated that the average costs of a recreational fishing trip in freshwater and saltwater was $225 and $223, respectively. Of these monies, about two-thirds was spent on travel-related expenses and the remainder on gear, bait and fuel. Lyle et al. (2014) estimated that in 2012-13 annual recreational fishing expenditure was or $1,008 per fisher ($1,840 per fisher household), of which 56% was spent on boat and trailers, 12% on fishing gear, 12% on fuel and the remainder on maintenance and insurance/registration. Context for the annual costs are provided by most individuals fishing < 5 days per year, with a small proportion of particularly keen or avid fishers contributed disproportionately to the total effort, with 20% of fishers accounting for over half (55%) of the total fishing effort.

Getting to a destination for recreational fishing requires the investment of time, and time is a limited resource (Freeman, 2003). Therefore, in order to accurately reflect the true recreational benefit that a visitor receives from visiting a recreational site, the direct travel costs should be supplemented with an opportunity cost which accounts for the amount of time spent traveling (Cesario, 1976a). On average, a recreational fishing trip to target Blue Swimmer crabs was 2.5 hours and involved 3 people fishing, some of whom were below working age, giving an opportunity cost of $43. Interestingly, despite different estuaries having different abundances and sizes of crabs (Obregón et al., 2022a), which would influence the time taken to obtain your catch, opportunity costs were fairly consistent among estuaries ranging from $38 – 51, due to similar numbers of participants and duration of the trip (*e.g.* 2.25 – 3 hours). The opportunity cost constitutes 32.3% of the travel-related expenditure.

2.1.4.3. Consumer surplus

The economic value estimates per recreational crabbing trip for the various estuaries are based on the economic theory of marginal utility, which is the additional satisfaction a consumer gains from one more unit of a good or service. An economic value estimate for recreational Blue Swimmer Crab fishing, for example, encompasses the experiential value of the fishing trip and food value of the fish. The experiential value includes the wider trip experience irrespective of whether any crab is caught and kept or released. The food value is connected to the kept catch of crabs. The experiential value of the recreational fishing trip has economic importance to the recreational fisher that is why the trip was undertaken. However, the experiential value is not traded in the market but is an important component of social welfare. It was observed that the motivation for recreational Blue Swimmer Crab fishing trips included the enjoyment of the challenge of catching fish, to spend time with other friends, to spend time with family, to be on their own, to be outdoors, to relax, to participate in a fishing competition and to catch fish for food. The economic value estimates capture these experiences in monetary terms.

The significant and negative coefficient of roundtrip travel cost indicates that crabbing in those sites is a normal good and recreational fishing follows the law of demand or the demand theory. This means that as roundtrips cost increases, recreational fishers tend to make a fewer number of trips. This finding is consistent with other recreational fishing studies (Rolfe and Prayaga, 2007; Ezzy, Scarborough and Wallis, 2012). Typically, fisheries economists assume that recreational fishers make decisions that optimise their own utility, which may depend on the state of the fishery and the regulatory environment (Scheld et al., 2020). The results of a research conducted to determine the recreational value of the non-commercial Southern Bluefin Tuna (*Thunnus maccoyii*) catch in Portland, in south-west Victoria, are reported by Ezzy, Scarborough and Wallis (2012). The log-linear trip generation function was selected for further investigation since it can be easily calculated and is independent of the zone from where the visit is performed. The chapter fitted various functional forms of the travel cost model. In all the functional forms, the travel cost coefficient was significant and negative. The findings show that Portland's recreational harvest is sizable and, as a result, important for the management of the fisheries. The fishery also has significant non-market recreational values, with on-site consumer surplus valued at between $33 and $132 per person every visit and an on-site yearly recreational use value of the fishery assessed at between $449,533 and $1,325,124 for a single season. For three significant freshwater impoundments in Queensland, Australia, (Rolfe and Prayaga, 2007) reports estimates of value for recreational fishing using both trip cost and contingent valuation methodologies. Two important subgroups of recreational anglers—frequent and occasional anglers—have unique consumer surpluses that are estimated using various variations of the travel cost method. A significant and negative travel cost coefficient was discovered. The findings of the trip cost research offer compelling proof that recreational values range between various groups of anglers and between places. Data analysis revealed that the only independent variable in the model with a considerable capacity for explanatory power was the cost of travel. The number of crabs caught and kept for food was also significant and positive, implying that when fishers catch more crabs they tend to make more trips. Several studies have shown that fisheries management strategies that enhance recreational fishers' catch rates increase the benefits to the fisher's so they tend to make more recreational fishing trips (Beardmore et al., 2015; Cooke et al., 2021). Such a finding suggests that management measurements like aquaculture-based enhancement and/or habitat restoration which have an economic cost, if successful, may generate increased economic return to offset their costs (Section 3.3).

The opportunity cost of time was not imputed into the round-trip travel cost but included as an independent variable to help investigate a long-standing debate about whether to include opportunity cost of travel time in round trip travel cost or not. For example, Ward and Beal (2000) assign zero (0%) to the wage rate based on the argument that people visit recreational sites during times of remunerated leave, such as holidays and so these individuals face no loss of income (Martínez-Espiñeira and Amoako-Tuffour, 2008). Indeed, the opportunity cost of time was significant but positive in all the models pointing to the possibility that the recreational Blue Swimmer Crab fishers went fishing when they are on remunerated leave such as holidays or during weekends. For that matter they face no loss of income and could make more trips even with increasing opportunity cost. It is therefore recommended that before the opportunity cost of time is added to round trip travel cost, investigations should be made to find out if the fishers are taking their trips because it is a public holiday or they are on leave. In Australia, weekends and public holidays are usually peak recreational fishing periods especially during summer.

The economic theory of marginal utility is the basis for the concept of consumer surplus (Vives, 1987). Marginal utility can be defined as the increased level of satisfaction that a consumer receives from purchasing one more unit of an item or service. When a good's price (or its total cost) goes down, the consumer surplus associated with that good always goes up, but it goes down when the price of that good goes up (Vives, 1987). The total economic cost of recreational crabbing in Peel-Harvey Estuary was estimated to be higher than in the Swan-Caning Estuary. As a result, it is anticipated that the Peel-Harvey Estuary will have a lower consumer surplus than the Swan-Canning Estuary. It was calculated that recreational fishers who fished for Blue Swimmer Crab in the Swan-Canning Estuary generated a consumer surplus of $20.49 per trip. There is a consumer surplus of $9.71 associated with a single trip of recreational crab fishing in the Peel-Harvey Estuary. Peel-Harvey and Swan-Canning estuaries are located close to major population centres (Perth, Mandurah). Therefore, there is a significant amount of recreational fishing done in such estuaries. When compared to the Peel-Harvey Estuary, which is located further away from Perth the main population centre, the Swan-Canning Estuary has lower travel and opportunity costs due to typically shorted travelling distances and times. The Leschenault Estuary has the lowest consumer surplus value of the three estuaries at $3.30 per fisher and per trip for crab fishing. This might be the case given that fishing in this estuary is not as important to crabbers as seen in the lower numbers of respondents, which would explain its low value and low consumer surplus.

2.1.4.4. Total economic value

There is competition for access to marine resources between recreational and commercial fishers in many countries, including Australia (Mazur et al., 2020). A consistent framework for the allocation of resources between recreational and commercial sectors in Australia has recently emerged as a topic of policy debate at both the federal and state levels. In this context, "allocation" refers to the distribution of resources. On the basis of the historical catch shares, only two states in Australia, i.e. South Australia and Western Australia, have a formal allocation between the sectors (McShane, Knuckey and Sen, 2021). Other states, such as Queensland, New South Wales, and Victoria, have also instituted zoning laws, such as those prohibiting the use of fishing nets in certain areas, in order to spatially distribute resources in accordance with findings from expenditure analyses of recreational fishing (McPhee and Hundloe, 2004). Catch shares have also been reallocated in the case of Western Australian fisheries, and this was done according to the perceived socio-economic value of the various sectors (Crowe et al. 2013). To help determine the relative economic value of recreational Blue Swimmer Crab recreational fishing, this chapter Combined the total trip cost, total opportunity cost and the consumer surplus to estimate the annual total economic values of ~$11.50 million in the Peel-Harvey Estuary, ~$8.10 million in the Swan-Canning Estuary and ~$0.50 million in Leschenault Estuary. The total economic value estimated for the recreational sector in the current study will provide managers and policymakers with valuable information that will assist them in allocating fisheries resources among competing uses and users. Such data are useful as there is now legislative requirement to manage Australian recreational fishing to enhance its economic and social value as outlined in priority number five in the National Fisheries Plan (Australian Government, 2022). As a broad comparison, the commercial Blue Swimmer Crab catch in the West Coast Bioregion (which includes the first two estuaries) for 2020 had an estimated gross value of production of ~$0.65 million and has been up to $0.80 million in recent years (Johnston et al., 2020c). It should be stressed that, unlike the estimates provided for the recreational sector, the commercial gross value of production is not a measure of the total economic value of this sector. If this was to be estimated in a future study, gross value added would enable a robust comparison. This method has been used by Pascoe et al. (2016) for commercial inshore pot, net and line fisheries in Queensland (Australia) and by García-de-la-Fuente et al. (2020) for marine commercial and artisanal fishing in Asturias (Spain).

2.2. Estimation of the economic value of recreational Black Bream fishing

2.2.0. Summary

Estuaries are dynamic environments and subject to a range of natural and anthropogenic stressors that can deleteriously impact fish stocks. Any changes in the abundance of a species will have a biological effect on the ecosystem, but also corresponding social and economic impacts on the humans who utilise that fishery. As Black Bream (*Acanthopagrus butcheri*) is an iconic finfish targeted by rod and line fishers in southern Australia, this chapter aimed to fill a knowledge gap and estimate the economic value of fishing for this species in estuaries in south-western Australia to help inform management. Data on the fishing frequency and expenditure provided by recreational fishers in an online survey were used to calculate their direct expenditure and, using the Travel Cost Method, their non-market costs of travel and fishing time. Consumer surplus was estimated using Poisson and Negative binomial models. Average direct per trip expenditure (excluding licence fees, boats and food/drink) was AUD $298 and ranged, on average, between $132 and $917 depending on the estuary. These values were accompanied by average opportunity costs of between $99 and $363 among estuaries (average = $233). These are substantially greater than for Blue Swimmer Crab fishing, which occurs in many of the same estuaries, due to increased expenditure on bream fishing gear (including bait and lures) and the greater time Black Bream fishers spend fishing on a trip. For each estuary, analysis using a negative binominal model for frequency of fishing trips found that the round trip cost was significant and negative, indicating that as costs increase the frequency of trips decreases. Opportunity costs were also significant but positive, suggesting that, due to the iconic nature of Black Bream fishing, fishers will still fish despite an increase in the opportunity cost of travel time. Although the consumer surplus for the Swan-Canning Estuary ($12.52) was far lower than that for the Walpole-Nornalup ($28.90), more fishers utilise the former estuary located in a metropolitan area and also the do so more frequently (i.e. 15 vs 0.8 times a year). Combining the total trip expenditure, opportunity cost and consumer surplus, the annual total economic values of the Black Bream fishery in the Swan-Canning Estuary was estimated at ~$64.4 million and at ~$2.5 million for that in the Walpole-Nornalup. On a per fisher annual basis this equates to $3,200 and $205, respectively.

2.2.1. Introduction

Estuaries, being located at the interface between marine and freshwater ecosystems, are highly dynamic in their physio-chemical conditions and therefore are stressful places for fauna to occur (Elliott and Quintino, 2007; Tweedley, Warwick and Potter, 2016). These 'natural stressors' are compounded by anthropogenic perturbations such as urbanisation and industrialisation, intensive agriculture and eutrophication, population growth and climate change (Jackson et al., 2001; Warwick, Tweedley and Potter, 2018). Finally, these transitional ecosystems often have complex governance structures with various departments responsible for different aspects of their functioning and ecosystem services and, in large, urbanised areas, parts of them may fall under the jurisdictions of different local government authorities (Elliott et al., 2022). In all aquatic systems, but estuaries in particular, sustainable natural resource management requires collaboration, adaptability and coordination between science, policy and stakeholders, many of which may have differing opinions and motivations (Obregón et al., 2020a).

Management of fish stocks in estuaries is complex and, as such, ecosystem-based fisheries management is increasing being adopted to attempt to ensure sustainability (Essington and Punt, 2011; Link and Marshak, 2019). While they are a multitude of criteria used in such a management approach, Arkema, Abramson and Dewsbury (2006), categorised them to three broad types, i.e. ecological, human dimension (including both social and economic factors) and management, thus these include the aspects of the triple bottom line (Dichmont et al., 2020) and the four pillars of sustainability (Stephenson et al., 2017). Historically, emphasis has been placed on determining and utilising biological dimensions, e.g. abundance and stock structure, to manage stocks. However, numerous authors consider that the potential success of ecosystem-based fishery management has been impeded by a lack of explicit social, economic and institutional objectives and an absence of frameworks to integrate these dimensions (Stephenson et al., 2017; Pascoe et al., 2019). However, just as conducting a stock assessment requires an understanding of the biological characteristics of the target species, setting social and economic objectives requires a baseline knowledge of these dimensions and their variability.

The Black Bream (*Acanthopagrus butcheri*) is a relatively large (530 mm total length) and long-lived (31 years) sparid found in southern Australia (Smallwood, Hesp and Beckley, 2013). These fish occur in the upper reaches of estuaries, particularly in association with submerged woody debris (Sarre and Potter, 2000; Cottingham et al., 2018a). Black Bream are known to complete their life-cycle within the estuary in which they were spawned (Sarre and Potter, 1999) and although tolerant to a wide range of environmental conditions, mass mortality events have occurred (Hoeksema, Chuwen and Potter, 2006; Krispyn et al., 2021). Such events are particularly deleterious for Black Bream as, being a solely estuarine species (Potter et al., 2015a; Whitfield et al., 2022), individuals are unlikely to recruit to the estuary from nearby systems or the ocean. The biological characteristics of these species are plastic and, for example, growth rates, body condition and size at maturity differ between estuaries and have changed over time in response to declines in rainfall and increases in the spatial extent of hypoxia (Cottingham et al., 2014; 2018b). This poses challenges for fishery managers, particularly as this species is the subject of multisector fisheries.

Black Bream are targeted by commercial gillnet fishers in the West Coast and South Coast bioregions in Western Australia. To maintain confidentially, catches obtained by the sole fisher in the Blackwood River Estuary (West Coast Bioregion) are not published, however, annual catches in the South Coast Bioregion between 2016 and 2020 ranged from 50.9 to 76.8 t (Newman et al., 2021). Based on an average price per kilogram paid to the fisher by land-based processor in Western Australia of $5.45 in 2019/20 (Newman et al., 2021), the gross value of production could be crudely estimated to ~$277,000 - 419,000. This species is one of the most iconic finfish for recreational fishers and are caught by shore- and boat-based rod and line fishers using bait and soft plastic lures in estuaries in both the West and South Coast bioregions (Ryan et al., 2019). Black Bream were the most caught species by boat-based fishers in estuaries across Western Australia, with 13,162 estimated to have been caught in 2017/18 on the west coast and 18,437 on the south coast. These catches, however, are highly variable among years with the estimated ~32,000 caught in 2017/18 the lowest in the four surveys, being around 45,000, ~110,000 and 95,000 in 2015/16, 2013/14 and 2011/12, respectively (Ryan et al., 2019). It is also important to note that as these surveys only include boat-based fishers they substantially underestimate of the total recreational catch.

As presented in Section 1.2, survey results strongly indicated that the motivations for fishing for Black Bream was predominantly as trophy fishery (Section 1.2), with a high release-rate of capture fish (the latter also found by Ryan et al., 2019). These fishers were also unhappy with the size and abundance of Black Bream in many systems and were highly supportive of a range of management measures, including minimum and maximum size limits and stock enhancement (Section 1.4; Tweedley et al., 2023a). However, aside from gross value of production estimates for the commercial fishery little is known about the economic dimensions of this fishery. Thus, the aim of this chapter is to collect information of the economic costs of a Black Bream fishing trip, the number of trips and locations where such fishing occurs. These data are used to estimate the non-market values of recreational Black Bream fishing in Western Australia.

2.2.2. Methods

Information on the study estuaries and their Blue Swimmer Crab fisheries are provided in subsection 1.2.2.1. The sampling methodology and analytical techniques employed in this chapter are described in subsections 2.1.2.2 and 2.1.2.3 only for Black Bream and not Blue Swimmer Crabs.

2.2.3. Results

2.2.3.1. Demographics

Of the respondents that completed every question on the online survey 92% were male and 7% were females (Table S2.2.1). While this ratio of 13:1 (male:female) is almost identical to that recorded in online surveys of the social dimensions of Black Bream fishing (Sections 1.2, 1.4), is markedly different to the 1:1 ratio for the population of Western Australia (ABS, 2016). Thus, the overwhelming majority of fishers are male. Respondents for each of the age groups ranging from 18-24 to > 65 years old completed the survey, noting that people < 18 years old were not invited to partake in the survey as per our Human Ethics Permit. Among the respondents, ~67% belonged to the 18-24, 25-34 and 35-44 groups (19.5 to 26.8 % of respondents; Table S2.1.1). Over 94% of respondents were of working age.

The vast majority of respondents (96%) had their highest level of educational attainment as secondary school or above, with 34 and 32% completing technical or further educational institution and university (Table S2.1.1). Note that ~1% did not state any level. About 71% of the respondents were in full-time and part-time/casual employment, with only 7% identifying as unemployed which is similar to the ~6% of the population in the same situation across Western Australia in 2018 (ABS, 2018). The relatively high proportion of employment resulting in only 8% of respondents reporting a negative or no personal income, with annual gross salaries up to between AUD $286,000 and $337,999 (Table S2.1.1). Of those 88% of respondents who selected a personal income option, 69% ranged between AUD $20,800 and $142,999, with 42.4% reporting a salary in an income category greater than the 2021 median Western Australian value of $76,544 (ABS, 2022) and 40.4% below.

2.2.3.2. Fisher and fishing trip characteristics

Recreational Black Bream fishers had been fishing for between 1 and 60 years, with mean and median of 14.2 and 9.0, respectively. The most represented experience category was 1-5 years (31%), followed by 6-10 years (24%) and 16-20 (18%). Only 2% of respondents had fished for > 40 years (Table 2.2.1). Shore-based fishing was practised by 39% of fishers, with 22% fishing exclusively from a vessel (boat or kayak) and the remaining 39% fishing from both vessels and the shore depending on the trip.

Recreational Black Bream fishers utilised a wide range of estuarine and coastal waters in south-western Australia. Fishing activity was centred on the west coast with 69% of respondents saying they had fished in the Swan-Canning and 43% in other estuaries on this coast (likely the Peel-Harvey; Table 2.2.1). Around a third of respondents fished for Black Bream in the Blackwood River Estuary and 39% utilised other estuaries along the south coast (likely Beaufort and Stokes inlets). Despite being a recreational fishery only 25% of respondents fished in the Walpole-Nornalup Estuary. Fishers utilised between one and all six of the listed options (noting that some options contained multiple estuaries), with 36% of fishers fishing in one option, 22% in two or three, 10% in four and 6 and 4% in five and all six, respectively.

Table 2.2.1. Number and percentage of recreational Black Bream fishers with different years of fishing experience.

Years	n	%
0-5	39	30.7
6-10	31	24.4
11-15	12	9.5
16-20	23	18.1
21-25	6	4.7
26-30	5	3.9
31-35	2	1.6
36-40	6	4.7
41-45	2	1.6
46-50	0	0.0
51-55	0	0.0
56-60	1	0.8

Table 2.2.2. Number and percentage of recreational Black Bream fishers that visited each location over the last twelve months (annual visitation) and on their last crabbing trip (last visit). Note that fishers often visited more than a single location and so values to do not sum to 100.

Location	Coast	Annual visitation		Last visit	
		n	%	n	%
Swan-Canning Estuary	West	89	68.5	70	56.9
Other estuaries (e.g. Peel-Harvey)	West	56	43.1	25	20.3
Blackwood River Estuary	South	44	33.8	11	8.9
Walpole-Nornalup Estuary	South	33	25.4	4	3.3
Wilson Inlet	South	17	13.1	3	2.4
Other estuaries (e.g. Beaufort)	South	51	39.2	10	8.1

The next set of questions in the survey focused on the respondents most recent fishing trip. A similar spatial pattern of fishing effort was reported when asked '*Where did they most recently fish for Black Bream?'* compared to the last year. Over 77% of fishers conducted their most recent fishing trip on the west coast with 57% of those in the Swan-Canning (Table 2.2.2). In contrast, only 23% of respondents had utilised aquatic environments on the south coast on their last fishing trip, with most visiting the Blackwood River Estuary (9%), or estuaries other than Walpole-Nornalup or Wilson (8%).

On their most recent Black Bream fishing trip the vast majority of fishers (85%) used a car of some description, with 31% using either a four-wheel drive vehicle or a small car and 23% a ute (utility vehicle). Around 7% of fishers walked to their fishing site. Recreational fishers travelled between 1 and 900 km to go Black Bream fishing, producing a mean of 94 km and median of 25 km (95% confidence limits = 29.1 km). Trips were generally relatively long with 60% of respondents travelling > 50 km and 20% > 100 km. Despite the relatively log distances fishers travel the most commonly selected response when asked why they chose that particular site was *it is local/convenient* (57%; Table 2.1.4). The next most popular responses were about the level of congestion and the availability of large Black Bream (46 and 42%, respectively). Only 19% of respondents claimed to choose spots of the basis of the ease of catching fish (Table 2.2.4).

Table 2.2.3. Transport methods used by Black Bream fishers to get from their home to fishing location on their most recent fishing trip. Options ranked from most to least selected.

Transport method	n	%
Four-wheel drive vehicle	38	30.9
Small car	38	30.9
Ute	28	22.8
On foot (walking)	8	6.5
Boat	5	4.1
Bicycle	4	3.3
Other	2	1.6
Motorcycle	0	0.0

Table 2.2.4. Reasons recreational Black Bream fishers chose a fishing site on their most recent fishing trip. Options ranked from most to least selected. Note respondents were able to selection more than one option. Note that fishers often visited more than a single location and so values to do sum to 100.

Reason for choosing a fishing site	n	%
It is local/Convenient	91	57.2
Not crowded	73	45.9
Good size Black Bream available	67	42.1
Safe to fish for Black Bream there	57	35.8
Lots of Black Bream	54	34.0
Other	42	26.4
Easy to catch Black Bream	30	18.9

The primary motivation for fishing for Black Bream was *enjoyment/challenge,* with this option selected by 85% of respondents (Table 2.2.5). Important secondary motivations were to *be outdoors* (74%) and to *relax*

(70%). Spending time alone, or with family or friends were all selected by a similar number of respondents (~30%). Catching Black Bream to *eat* was only chosen by 10% of fishers. The sports rather than food-motivated nature of recreational Black Bream fishing is showcased by the fact that, on average, fishers caught 17 fish (± 8 95% confidence limit), but retained < 1 (i.e. 0.3 ± 0.2 95% confidence limit). Moreover, only 14% of fishers retained fish that they had caught on 75% of fishing trips, this equated to one or two fish.

When asked why they stopped fishing for Black Bream, the most common of the reasons provided was *ran out of time* (50%) followed by *that was all I could catch* (26%). *Poor weather* was a minor influence being selected by only 7% and only a single fisher (0.8%) stated that they *caught the bag limit*. It is noteworthy that 15% of respondents gave a different reason they entered into a text box (data not shown). The majority of respondents were satisfied with the number of Black Bream they caught (67%), kept (81%) and the time it took to catch them (69%). Half of fishers were happy with the size of the fish they caught (50%).

Table 2.1.5. Reasons recreational Black Bream fishers chose a fishing site on their most recent fishing trip. Options ranked from most to least selected. Note respondents were able to selection more than one option. Note that fishers often visited more than a single location and so values to do sum to 100.

Motivation for fishing	n	%
For the enjoyment or challenge of catching fish	135	84.9
To be outdoors	118	74.2
To relax	112	70.4
To spend time with other friends	56	35.2
To be on your own	54	34.0
To spend time with family	49	30.8
Participate in a competition	22	13.8
Catch Black Bream to eat	16	10.1
Other	7	4.4
Catch Black Bream to share with friends	6	3.8

2.2.3.3. Average costs of a Black Bream fishing trip

Among the Black Bream fishing trips conducted by the respondents in the previous 12 months from the survey date, the location that were most frequently visited by far was the Swan-Canning (1,977 trips year^{-1}; 64% of the total number), followed by other west coast estuaries (mainly the Peel-Harvey estuaries; 420 trips; Table 2.2.6a). The respondents fished aquatic environments on the south coast less frequently (685 trips year^{-1}; or 22% of the total number). The majority of trips focused around the Blackwood River Estuary and 'other estuaries' on the south coast (265 and 266 trips year^{-1}, respectively). The greater number of trips to the Swan-Canning compared to the other estuaries was due to the fact that this site was visited by the largest proportion of fishers (68%) and that they fished, on average, 15 times a year. By comparison, between 13 and 43% of fishers used the other locations and visited them < ~2 times per year except for the Peel-Harvey (3 times year^{-1}).

The respondents who completed all questions on the survey, together with their fishing companions, claimed to have caught 15,833 Black Bream but retained only 1,676 of them (~11%; Table 2.2.6b). The numbers of Black Bream caught on each fishing trip varied quite substantially, ranging from 38 and 34 in the Swan-Canning and 'other estuaries' on the south coast, respectively to between 9 and 15 fish in the other locations. Despite the marked difference in the number of Black Bream caught across the various locations in all except the Peel-Harvey (4.6) the number of retained fish was < 3 (Table 2.1.6c). The proportion of Black Bream released ranged from 64 to 98%, being least in the Peel-Harvey (64%) and most in the Walpole-Nornalup (87%), Blackwood and Swan-Canning (92%) and 'other estuaries' on the south coast (98%).

Catch and release fishing was undertaken by between 70 and 87% of fishers at the various locations and was more common at those sites on the south than west coasts (i.e. 81-87 vs 70-73%, respectively; Table 2.2.6). Of the limited number of Black Bream that were retained, on average, 82% of the catch was consumed by members of their household, with 12% given to another household and 3% used for other purposes (e.g. bait).

Table 2.2.6. (a) Total number of trips, average number of trips per fisher, standard deviation, range, and proportion of fishers that visited each location to catch Black Bream. Total number of crabs, average number of crabs per fisher, standard deviation, range, and proportion of fishers (F) that (b) caught and (c) kept Black Bream at each location.[23]

(a) Number of trips							
Location	**Total**	**%**	**Avg**	**SD**	**Range**	**#F**	**%F**
Swan-Canning Est.	1977	64.1	15.21	21.16	0-100	89	68.46
Other WC estuaries	420	13.6	3.23	10.75	0-100	56	43.08
Blackwood River Est.	265	8.6	2.04	4.81	0-30	44	33.85
Walpole-Nornalup Est.	100	3.24	0.77	2.07	0-12	33	25.38
Wilson Inlet	54	1.75	0.42	1.26	0-6	17	13.08
Other SC estuaries	266	8.63	2.05	4.50	0-30	51	39.23

(b) Black Bream caught							
Location	**Total**	**%**	**Avg**	**SD**	**Range**	**#F**	**%F**
Swan-Canning Est.	4883	31.2	37.56	73.26	0-500	85	65.38
Other WC estuaries	1664	10.6	12.80	31.36	0-200	47	36.15
Blackwood River Est.	1893	12.1	14.56	51.51	0-400	37	28.46
Walpole-Nornalup Est.	1717	11	13.21	48.57	0-400	29	22.31
Wilson Inlet	1210	7.73	9.31	37.81	0-250	16	12.31
Other SC estuaries	4466	28.5	34.35	121.46	0-1000	45	34.62

(c) Black Bream kept								**% fish**	**% Fishers that**
Location	**Total**	**%**	**Avg**	**SD**	**Range**	**#F**	**%F**	**released**	**release all fish**
Swan-Canning Est.	378	22.6	2.91	12.29	0-100	24	18.46	92.26	72.94
Other WC estuaries	601	35.9	4.62	24.50	0-250	19	14.62	63.88	70.21
Blackwood River Est.	139	8.29	1.07	8.99	0-100	6	4.62	92.66	86.49
Walpole-Nornalup Est.	210	12.5	1.62	13.83	0-150	6	4.62	87.77	82.76
Wilson Inlet	269	16.1	2.07	21.94	0-250	4	3.08	77.77	81.25
Other SC estuaries	79	4.71	0.61	3.19	0-20	7	5.38	98.23	86.67

The number of people partaking in a fishing trip ranged from 1 to 45, although 98% involved between 1 and 7 people. Solo trips (31%) and two person trips (44%) were by far the most common (Table 2.1.7). Events for > 10 people were fishing competitions. Members of the fishing party tended to be a friend of the respondent (54%) or their partner/spouse (30%).

Table 2.2.7. Number of recreational Black Bream fishers in the party for a fishing trip and their relationship to the respondent. Note respondents were able to selection more than one option if applicable for the relationship to the respondent (i.e. a friend and child) and so the percentages do not sum to 100.

Number of fishers	**n**	**%**	**Relationship to respondent**	**n**	**%**
1	38	31.7	Friend	67	54.9
2	53	44.2	Partner/spouse	36	29.5
3	10	8.3	Children	27	22.1
4	11	9.2	Extended family	18	14.8
5	1	0.8	Parent	8	6.6
6	3	2.5	Other	8	6.6
7	1	0.8			
10	1	0.8			
35	1	0.8			
45	1	0.8			

[23] The percentage number of Black Bream released by fishers utilising each location and the percentage of fishers that practice catch & release fishing is also provided. WC = West coast; SC = South coast; F = fishers.

The average total trip costs accrued by recreational Black Bream fishers on a single fishing trip in south-western Australia was $297.87. Fishers spent an average of $203 on fishing gear, $38 on bait and lures, $42 on other items, $13 on fuel and less than <$2 on ice (Table 2.2.7a). Incorporating an average trip of almost 6 hours with ~2 people fishing (some of which were children and so below working age) the opportunity cost of fishing for Black Bream was $233. The 'total cost' (i.e. trip cost and opportunity cost) of a fishing trip among the estuaries ranged from $289 to $1,112. Some market costs were fairly consistent across locations, with ice for example being < $5 in all estuaries except Walpole-Nornalup ($15), however, generally costs differed between locations. The biggest differences were seen in the cost of fishing gear ranging from an average of $100 in Wilson to $784 on other estuaries along that coast. The costs associated with boat fuel were less on the west ($4-14) compared to on the south-coast ($20-26), while more money was spent on bait and lures in particularly Walpole-Nornalup and 'other estuaries' on the south coast then in the other locations. The opportunity cost varied substantially, due to the trip length and number of participants. For example, values were lowest in the 'other estuaries' on the west coast (mainly Peel-Harvey) at $99, where fishing trips where the shortest at ~4 hours and two people went fishing. Conversely, they were six times greater in Blackwood and almost four times larger Walpole-Nornalup, likely due to longer travel distances, time spent fishing and the number of fishers.

On the basis of average market expenditure per fishing trip, divided by the number of fishers the cost, per person, of Black Bream fishing on the west coast is $102.48 in the Swan-Canning and $92.26 Peel-Harvey. Using the same process, average estimates of opportunity cost per person are as follows; Swan-Canning ($96.64) and Peel-Harvey ($43.09). On the south coast average market expenditure is $382.40, $140.67, $79.00 and $52.70 in 'other estuaries', Walpole-Nornalup, Wilson and the Blackwood, respectively, with associated opportunity costs of $80.93, $96.83, $94.58 and $103.42, respectively.

Finally, incorporating the above estimates, together with both the average of number of trips made by a fisher and the fisher population size for each estuary sums of the market and non-market expenditure for recreational Black Bream fishing in the Swan-Canning and Walpole-Nornalup are:

Swan-Canning Estuary = total trip cost $31,179,603 and total opportunity cost $29,401,814; total cost = $60,581,417.

Walpole-Nornalup Estuary = total trip cost $1,298,462 and total opportunity cost $893,871; total cost = $2,192,332.

Table 2.2.7. Average and standard deviation (SD) market and non-market costs (AUD$) associated with a Black Bream fishing trip in south-western Australia.

(a) Overall	Avg	SD
Boat fuel (AUD$)	13.87	13.77
Bait/lures (AUD$)	37.75	30.39
Ice (AUD$)	1.54	56.98
Fishing gear (AUD$)	203.28	4.33
Other costs (AUD$)	41.75	541.38
Total trip cost (AUD$)	*297.87*	*650.57*
Time spent fishing (h)	5.70	145.00
No people fishing	2.82	5.10
Opportunity cost (AUD$)	*233.29*	*729.45*
Total cost (AUD$)	**531.16**	

	Swan-Canning Estuary		**Peel-Harvey Estuary**	
(b) West coast	Avg	SD	Avg	SD
Boat fuel (AUD$)	14.03	17.94	4.16	2.56
Bait/lures (AUD$)	36.59	35.73	23.36	10.66
Ice (AUD$)	0.70	57.48	0.76	23.39
Fishing gear (AUD$)	179.63	2.24	150.12	1.79
Other costs (AUD$)	30.46	338.18	34.20	324.30
Total trip cost (AUD$)	*261.41*	*530.10*	*212.60*	*356.40*
Time spent fishing (h)	6.24	161.94	4.14	102.08
No people fishing	2.55	4.12	2.30	1.52
Opportunity cost (AUD$)	*246.50*	*762.57*	*99.31*	*141.25*
Total cost (AUD$)	**507.91**		**311.91**	

	Blackwood River Estuary		**Walpole-Nornalup Estuary**		**Wilson Inlet**		**Other estuaries**	
(b) South coast	Avg	SD	Avg	SD	Avg	SD	Avg	SD
Boat fuel (AUD$)	26.36	1.94	25.00	3.77	20.00	2.00	22.50	2.92
Bait/lures (AUD$)	45.45	30.83	87.50	28.87	35.00	26.46	80.75	25.74
Ice (AUD$)	4.36	28.76	15.00	75.00	0.00	13.23	2.40	109.49
Fishing gear (AUD$)	129.55	7.90	200.00	10.00	10.00	0.00	784.50	4.20
Other costs (AUD$)	105.91	302.66	200.00	227.30	66.67	17.32	27.50	1576.66
Total trip cost (AUD$)	*311.64*	*457.81*	*527.50*	*335.99*	*131.67*	*146.32*	*917.65*	*1654.97*
Time spent fishing (h)	5.18	177.13	7.25	187.08	6.00	115.47	5.17	62.68
No people fishing	5.91	13.01	3.75	4.19	1.67	0.58	2.40	1.43
Opportunity cost (AUD$)	*611.11*	*1564.78*	*363.14*	*435.55*	*157.64*	*39.01*	*194.24*	*228.03*
Total cost (AUD$)	**922.75**		**890.64**		**289.31**		**1111.89**	

2.2.3.4. Economic value of recreational Black Bream fishing

The results for the Poisson and Negative Binomial models are reported in Table 2.2.8. As also occurred with Blue Swimmer Crabs, due to over-dispersion problems with the Poisson models, negative binomial models were utilised to estimate consumer surpluses. Using the preferred negative binomial model the roundtrip travel cost variable was significant for the Swan-Canning and Walpole-Nornalup estuaries, but not Wilson Inlet and Blackwood River Estuary (Table 2.2.8). Therefore, the economic values of recreational fishing in those last two estuaries could not be estimated accurately.

In the Swan-Canning Estuary, the roundtrip travel cost variable had a negative coefficient, demonstrating that as the cost of fishing goes up, the number of fishing trips undertaken by recreational fishers declines. The opportunity cost of travel time is significant, albeit positive, indicating that fishers are not concerned with traveling to fish for Black Bream. The number of fish kept for food in this estuary was also significant, meaning that people who caught kept more fish fished more often. The rest of the variables in this model were not significant (Table 2.2.8). Using the negative binomial model the consumer surplus for recreational Black Bream fishing in the Swan-Canning Estuary is estimated to be $12.52 per trip, with fishers conducting an average of 15.21 trips per year. Therefore, the consumer surplus per fisher on an annual basis is expected to be $190.43, which after aggregating this to the estimated 20,000 recreational fishers using the estuary gives an estimated aggregated surplus value of $3,808,584.

In the Walpole-Nornalup Estuary on the south coast of the state, the round trip travel cost was significant with a negative sign, and while the opportunity cost of travel time, number of fish caught and fishers with very high incomes ($286,000-337,999) were also significant their sign was positive (Table 2.2.8). The consumer surplus for recreational Black Bream fishing in this estuary is estimated to be $28.90 per trip. With fishers conducting an average of 0.77 trips per year, the annual consumer surplus per recreational fisher per year is $22.25. Aggregating this for the estimated 12,000 recreational fishers that utilise this estuary gives an estimated aggregated surplus value of $267,036 per year.

Combining the total trip cost, total opportunity cost and the consumer surplus the annual values for the two estuaries are as follows; Swan-Canning is ~$64.4 million and Walpole-Nornalup is ~$2.5 million. At a per fisher basis this equates to $3,220 and $205, respectively.

Table 2.2.8. Results of Poisson and Negative Binomial (nbreg) models for recreational Black Bream fishing in four estuaries in south-western Australia.

	Swan-Canning		Walpole-Nornalup		Wilson		Blackwood	
Variable	Poisson	nbreg	Poisson	nbreg	Poisson	Nbreg	Poisson	nbreg
Round trip cost	-0.0490***	-0.0799***	-0.0425**	-0.0346*	-0.0192	-0.0192	-0.0234***	-0.0177
	(-20.99)	(-7.49)	(-2.96)	(-2.25)	(-0.86)	(-0.86)	(-4.59)	(-1.09)
Opportunity cost of travel time	0.182***	0.311***	0.175**	0.148**	0.0924	0.0924	0.100***	0.0912
	-22.74	-7.57	-3.27	-2.6	-1.09	-1.09	-5.37	-1.52
No. fish caught	-0.00263	0.0173	0.0118***	0.0122***	0.0169***	0.0169***	0.00535***	0.0102***
	(-0.77)	-1.07	-4.15	-3.78	-5.55	-5.55	-9.81	-3.7
No. fish kept	0.0212***	0.0277**	-0.0648	-0.0436	0.209**	0.209**	0.0447***	0.0588
	-14.52	-2.84	(-1.67)	(-1.02)	-3.28	-3.28	-4.21	-1.94
Female	0	0	0	0	0	0	0	0
	(.)	(.)	(.)	(.)	(.)	(.)	(.)	(.)
Male	0.870***	0.536	1.457	1.56	13.91	14.75	1.041*	1.185
	-4.74	-0.81	-1.94	-1.93	-0.01	-0.01	-2	-1.2
Other	-0.517	-0.735	2.494**	2.578*	14.49	15.34	1.252	1.314
	(-1.29)	(-0.64)	-2.6	-2.49	-0.01	-0.01	-1.51	-0.81
$20,800-$41,599	0.0125	0.071	-0.577	-0.602	16.54	15.47	1.599	0.666
	-0.13	-0.15	(-0.77)	(-0.73)	0	0	-1.53	-0.5
$234,000-$285,999	-0.16	-0.452	-19.83	-22.45	-0.157	-22.6	2.005	1.157
	(-0.81)	(-0.37)	(-0.00)	(-0.00)	(-0.00)	(-0.00)	-1.62	-0.64
$286,000-$337,999	-2.160**	-2.196	-3.830**	-3.963**	-0.157	-22.6	-15.63	-17.58
	(-3.04)	(-1.58)	(-3.00)	(-2.71)	(-0.00)	(-0.00)	(-0.00)	(-0.00)
$182,000-$233,999	-1.324***	-1.869	0.112	0.179	-0.157	-22.6	-15.63	-17.58
	(-4.10)	(-1.49)	-0.14	-0.19	(-0.00)	(-0.00)	(-0.00)	(-0.00)
$41,600-$62,399	0.101	0.3	-0.349	-0.278	15.79	14.72	3.086**	1.947
	-1.13	-0.67	(-0.50)	(-0.36)	0	0	-3.05	-1.54
$62,400-$83,199	-0.00742	0.347	-1.345	-1.257	16.04	14.96	1.844	1.157
	(-0.08)	-0.75	(-1.58)	(-1.39)	0	0	-1.75	-0.87
$84,000-$103,999	0.383***	0.502	0.921	1.051	18.15	17.07	2.329*	2.064
	-3.98	-1.02	-1.37	-1.41	0	0	-2.28	-1.64
Constant	0.472*	-0.784	-4.162***	-4.368***	-33.9	-33.67	-3.928***	-4.804**
	-2.35	(-0.97)	(-3.93)	(-3.74)	(-0.01)	(-0.01)	(-3.49)	(-3.08)
lnalpha								
Constant		0.267		-2.235		-17.24		0.178
		-1.57		(-1.83)		(-0.01)		-0.66
pr2	0.395	0.0943	0.6546	0.4539	0.7294	0.5448	0.4958	0.261
aic	1722.8	667.5	157.2	158.1	100.6	102.6	406	273.6
bic	1764.5	711.8	198.8	202.4	142.2	146.8	447.6	317.9

Note: t statistics in parentheses; significant terms shaded in grey * = $p < 0.05$, **= $p < 0.01$, ***= $p < 0.001$.

2.2.4. Discussion

Management of fish stocks in estuaries is complex and, as such, ecosystem-based fisheries management approaches using biological, social and economic data are increasingly being used to ensure sustainability and the best use of the resource (Essington and Punt, 2011; Link and Marshak, 2019). However historically, emphasis has been placed on determining and utilising biological dimensions, e.g. abundance and stock structure, to manage stocks and information on the human dimensions is typically lacking (Hobday et al., 2016a). For example, while there is limited data on the gross value of production estimates for the commercial Black Bream, information on recreational fishing is limited to a state-wide survey for Western Australia (McLeod and Lindner, 2018b) and so there are no species-specific estimates, even for iconic species in population fishing locations. Thus, the aim of this chapter is to collect information on the economic costs of a Black Bream fishing trip, the number of trips, and locations where such fishing occurs. These data were then used to estimate the non-market values of recreational Black Bream fishing in Western Australia.

2.2.4.1. Demographics and motivations

The vast majority of the recreational fishers surveyed were male (92%), with only 7% identifying as females. This is an even more skewed male:female ratio than for Blue Swimmer Crabs fishers surveyed in the same region of Western Australia using an online survey (Section 1.1) or from on-ground face-to-face interviews (Section 1.2), where 15% of fishers were female. This is not an isolated result with Copeland et al. (2017a) profiling the motivations of recreational fishers who participated in habitat management activities in Australia, the United States of America, the United Kingdom, and Ireland reporting their review that recreational fishing is generally male dominated. Women are more likely than men to face constraints that may reduce fishing participation and contribute to a gendered 'leisure gap,' for example, women have greater caregiving and housework responsibilities (Hochschild and Machung, 2012), smaller chunks of leisure time (Bittman and Wajcman, 2000; Beck and Arnold, 2009) that may be incompatible with fishing compared to other leisure forms, and feel less safe while participating in outdoor activities (Bialeschki and Huh, 1999). In this context, the higher dominance of male recreational Black Bream than Blue Swimmer Crab fishers could be related to the fact that Black Bream fishers are more likely to undertake solo fishing trips (i.e. 32 vs 18%) and fewer fish with their children (22 vs 43%).

About 71% of the respondents were in full-time and part-time/casual employment, which is slightly less than the 78% for Blue Swimmer Crab fishers and likely reflects the fact that 94% of respondents were of working age and the relatively low unemployment rate at the survey time, i.e. seasonally adjusted unemployment rate of 5.0 percent in December 2018. Recreational Black Bream fishers had been fishing for between 1 and 60 years, with a mean and median of 14.2 and 9.0 years, respectively. This reaffirms the fact that recreational fishing is an integral part of the way of life in Australia for many years (Arlinghaus et al., 2021). Such a view is supported by the high proportion of the population that partake in recreational fishing in Australia compared to other developed countries and, within Australia, in the State of Western Australia the proportion of recreational fishers is greater than in other states (Henry and Lyle, 2003; Young, Foale and Bellwood, 2016) (Ryan et al., 2015). For example, (McLeod and Lindner, 2018b) estimated that ~750,000 people in Western Australia fish recreationally, equating to at least one person in every third household.

Over three quarters of recreational Black Bream fishers conducted their most recent fishing trips on the west coast of the state, with most utilising the Swan-Canning Estuary. This reflects a number of factors, firstly that the abundance of Black Bream is greater in the Swan-Canning than Peel-Harvey estuaries (Tweedley, Krispyn and Hallett, 2021) and those could improve catch rates and that several well-published fish kills have occurred in the Peel-Harvey Estuary linked to poor-water quality, which may deter fishers (recfishwest, 2017). These systems are likely fished more than some of those on the south coast (e.g., Walpole-Nornalup) due to their distance from the capital city of Perth, where 80% of the Western Australia population resides (Australian Bureau of Statistics, 2022a). Furthermore, Perth boarders the Swan-Canning Estuary and is fairly close (< 80 km) to the Peel-Harvey Estuary, on which the City of Mandurah (80,000 people) is located. It should be noted that, on average, Black Bream fishers travelled (mean = 94 km) further than Blue Swimmer Crabs fishers (mean = 40 km), due to the fact that some fishers targeting the former species travelled to estuaries on the south coast (> 400 km from Perth). This showcases the willingness of fishers to travel long distances to catch Black Bream and is, in part, due in part to Black Bream being consistently abundant on the south coast, whereas the abundance of Blue Swimmer Crab is more variable due to the strength of the Leeuwin current and variable recruitment (Newman et al., 2021).

The primary motivation for fishing for Black Bream was enjoyment/challenge, which was selected by 85% of respondents compared to only 10% who stated that they caught Black Bream to eat. The trophy nature of this fishery is also reflected in the fact that in each estuary, between 64 and 98% of fish are released alive into the water and that 70 to 87% of fishers practice catch and release fishing. In contrast, for Blue Swimmer Crab recreational fishing, nearly three-quarters of fishers catch Blue Swimmer Crabs to eat (74%), with this being the most common motivation for fishing. Results from Section 1.2 also demonstrated that Crab fishers were strongly food motivated, with 92% fishing for food and were primarily motivated to '*catch big crabs*' and '*catch enough crabs to eat*'. Furthermore, 91% of fishers always consumed their legal-sized catch, with only 2% practicing catch and release fishing. In contrast to the food-motivated nature of the crab fishers, 81% of Black Bream fishers did so for the sport/challenge, with the strongest motivation being to catch a bream considerably above the minimum legal length, with '*food*' only selected as motivation by 15% of respondents. The marked differences between the two fisheries for the two species are likely driven by the accessible nature of the crab fishery, ease of catching crabs, the low cost of fishing equipment required to obtain them (< AU $25 for a scoop net or crab pot) and the delicacy of the meat. Fishing for Black Bream requires more expensive equipment, patience and a great skill level, particularly if using lures. Fishers considered crab fishing to have about the same importance as other fishing and outdoor activities, whereas Black Bream fishers considered bream fishing considerably more important, reflecting the trophy nature of this fishery.

2.2.4.2. Cost of a fishing trip (direct expenditure)

The average total trip cost by a recreational fisher on a single Black Bream fishing trip in south-western Australia was AU$298. This is considerably more than $87 spent by recreational Blue Swimmer Crabs fishers in the same region of Australia (Section 2.1). The major difference in expenditure between these two types of fishing was the gear cost. Black Bream fishers spent, on average, $203 on fishing gear (e.g. rods and reels) and $38 on bait and lures, whereas Blue Swimmer Crab fishers spent $30 and $11 on these items, respectively. Clearly, Black Bream fishers use more expensive gear compared to the relatively cheap scoop nets ($25) and drop nets/crab pots ($15-25) employed by crabbers. Although a relatively minor contribution to the direct expenditure, crab fishers reported spending $9 on ice compared to <$2 to Black Bream fishers. Ice is typically used to store retained catches to keep any individuals fresh and so it is not surprising that fishers utilising the food-motivated crab fishery purchase ice, whereas those in the sport-fishery (i.e. catch-and-release) for Black Bream do not. In comparison to studies on direct fishing expenditure elsewhere in Australia, the value of $298 per person per fishing trip for Black Bream is similar to those for other fish species. For example, in Victoria, the average direct cost of a fishing trip was $244 (Ernst & Young, 2020) and in NSW was $225 and $223, in freshwater and saltwater environments, respectively (McIlgorm and Pepperell, 2013).

Opportunity costs, i.e. the opportunity cost of travel time averaged across employed adults in the fishing party, was also calculated. The mean opportunity cost for a recreational Black Bream fisher was $233 and varied considerably across fisheries, ranging from $99 in the Peel-Harvey Estuary to $611 in the Blackwood Estuary. These numbers are ~2 to 15 times greater than the ~$42 opportunity cost estimated for the average Blue Swimmer Crab fisher (Section 2.1). While fishing parties contain a similar number of fishers (i.e. ~3), Black Bream fishers claimed to spend 5.7 h fishing compared to only 2.5 h for crabbers. Such a difference could be due to the types of fishery, with food-motivated crab fishers seeking to catch sufficient number of crab above the minimum legal size to consume, whereas the sport-motivated Black Bream fishers attempt to catch an elusive large individual, which would be considerably larger (e.g. > 40 cm total length) than the minimum legal length for retention of 25 cm total length (Section 1.2). Moreover, Black Bream are highly mobile, with individuals from the Vasse-Wonnerup Estuary, on the lower-west coast of Australia, moving on average 2.7 km (maximum 45 km) per day (Beatty et al., 2018) and so fishers may need to spend time locating spots where the fish are biting.

2.2.4.3. Consumer surplus and total economic value

Using the negative binomial model, the consumer surplus for recreational Black Bream fishing was estimated to be $12.52 and $28.90 per trip, in the Swan-Canning and Walpole-Nornalup estuaries, respectively. These marked differences in value between estuaries were also present for Blue Swimmer Crabs, ranging from $20.40 in the Swan-Canning Estuary to $3.30 in the Leschenault Inlet (Section 2.1). Negative binomial models showed that in the Swan-Canning and Walpole-Nornalup estuaries, the roundtrip travel cost variable had a negative coefficient, demonstrating that as the cost of fishing goes up, the number of fishing trips undertaken by recreational fishers declines following the law of demand. This finding is consistent with other recreational fishing studies (Rolfe and Prayaga, 2007; Ezzy, Scarborough and Wallis, 2012). Likely in both estuaries the opportunity cost of travel time is significant, albeit positive, indicating that fishers are not concerned with traveling to fish for Black Bream, which could be due to this species being one of the largest and best 'fighting' fish found in the upper reaches of estuaries (Department of Primary Industries and Regional Development, 2018b) and thus the travel time is worth the thrill of the catch. Although relatively few fishers retained bream for food, the number of fish kept for food in the Walpole-Nornalup and caught in the Swan-Canning was also significant, meaning that people who either caught or kept more fish, fished more often.

Like with the findings for Blue Swimmer Crabs, the that estimates of economic value for Black Bream recreational fishing varied greatly from estuary to estuary. This may be due to the expense involved with each fishing excursion as well as the attributes of the location where recreational fishing takes place. The findings of this chapter highlight the importance of species and ecosystem specific studies on recreational fishing activities. These findings corroborate the findings of previous research, which found that the motivations of recreational fishers and the economic value of the activity vary greatly depending on the target species and location of fishing. (Fedler and Ditton, 1994a; Cooke and Suski, 2005).

Combining the total trip cost, total opportunity cost and the consumer surplus, on a per recreational Black Bream fisher basis, equates to $3,220 in the Walpole Nornalup and $205 in the Swan Canning Estuary. Scaling up to account for the estimated number of bream fishers in each estuary, bream fishing is estimated to be valued at ~$64.4 and ~$2.5 million annually, respectively. For comparison, per fisher total economic values for Blue Swimmer Crabs ranged from $58 in Leschenault, to $189 in the Peel-Harvey and $334 in the Swan-Canning (Section 2.1). Generally, speaking the higher values for Black Bream reflect the greater cost of fishing gear (including lures), the longer time recreational fishers spent fishing and, in the case of the Swan-Canning, the far greater number of fishing trips conducted by bream than crab fishers.

Section 3. Estimated effects of aquaculture-based enhancement

This section details research relating to Objective 3: Investigate the benefits of release programs in contributing to the optimisation of biological, social and economic objectives for those fisheries. Four components were undertaken and presented in three chapters.

3.1. Optimising release strategies for the stock enhancement of Blue Swimmer Crabs in the Peel-Harvey Estuary

3.2. Biological effectiveness of different aquaculture-based enhancement options for Black Bream in the Blackwood River Estuary.

3.3. Economic estimates of stock enhancement of Blue Swimmer Crabs and Black Bream (PhD studies of Denis Abagna).

3.1. Optimizing release strategies for the stock enhancement of Blue Swimmer Crabs in the Peel-Harvey Estuary

3.1.0. Summary

Blue Swimmer Crabs (*Portunus armatus*) are the most popular recreational fish species in Western Australia, with the Peel-Harvey Estuary being a major hotspot for recreational and commercial crab fishing. While this stock is classified as sustainable, increasing fishing pressure and environmental factors that affect the early life stages could potentially negatively influence this population. Aquaculture-based enhancements are thus an appropriate approach for managers to consider applying to help ensure continued exploitation of crab stocks into the future. To explore the optimum stocking quantity on fishery production, four stock enhancement options (releases of 0, 1.6 million, 3.2 million and 6.4 million crabs at 40 mm carapace width) were simulated on three different natural population levels (low, medium and high). The simulation model first constructed each population and tracked their abundance and carapace widths through the 18 months of their residency in the estuary, while accounting for density-dependent effects. When the population had a low natural density (1 crab 100 m^{-2}), the total estimated catch ranged from 120 tonnes, with no stock enhancement to 230 tonnes under the medium stock enhancement option (3.2 million released crabs). Annual catches under a medium natural density population (2 crabs 100 m^{-2}) ranged from 77 tonnes under the high stocking option (release of 6.4 million crabs), to 291 tonnes under a low stocking option (release of 1.6 million crabs), with the no stocking option producing an annual catch of 240 tonnes. At the highest-density population (4 crabs 100 m^{-2}), due to the greater density dependence and the relationship between crab density and individual growth, the no stocking option produced the greatest catches of 173 tonnes greater than two times the catch of any of the enhancement options. Thus, the low stocking option produced 83 tonnes, the medium and high stocking options only produced 22 and 0.4 tonnes, respectively. The results of the simulation model thus emphasise the importance of exploring optimum stocking density through simulation prior to release of stock and the importance of consideration of other factors, such as density-dependent growth, that regulate fishery production. They clearly demonstrate that stocking can be beneficial but not under all circumstances, particularly when natural populations are at high densities.

3.1.1. Introduction

Overfishing exerts continuous pressure on fish stocks throughout the world, with over a third of global fisheries estimated to be overexploited (Jackson et al., 2001; FAO, 2020). Portunid crabs are heavily targeted by commercial, recreational and artisanal fishers around the world (Hungria et al., 2017; Prince et al., 2020). Aquaculture-based enhancements have become among the most popular tool by fisheries managers to alleviate such pressures, particularly for socio-economically important small-scale fisheries (Arlinghaus and Mehner, 2003; Bell et al., 2006; Cottingham et al., 2020; Obregón et al., 2020b). Such interventions thus facilitate continued exploitation of stocks and, in many cases, intend to increase fishery yields (Masuda and Tsukamoto, 1998; Okouchi et al., 2004; Kitada et al., 2019). However, the expected outcomes of different release options, e.g. optimum stocking quantity, are not often explored quantitatively prior to enhancement (Bell et al., 2006; Johnston et al., 2018).

Modelling and simulation provide an effective way to explore outcomes of different release options on a population and potential fishery yields. Such exploration may be particularly applicable for fisheries that are managed using size limits, as growth of cultured and wild stock can simultaneously become reduced when releases exceed carrying capacity and thus delay entry of individuals into the fishery (Kitada, 2018). Among the list of overexploited fisheries that have been successfully enhanced, portunids (crustaceans) are well represented (Fushimi, 1983; Ito, 2000; Young et al., 2008; Lebata et al., 2009; Hamasaki et al., 2011). A number of aquaculture-based enhancement programs designed to increase stocks of commercially important species have occurred, including for *Portunus trituberculatus* and *Scylla paramamosain* in Japan, *Callinectes sapidus* in the USA, *Portunus pelagicus* in Thailand and *Scylla* spp. in the Phillippines (Fushimi and Watanabe, 2000; Hines et al., 2008; Hamasaki et al., 2011; Arkronrat et al., 2013). In each case, successful hatchery techniques were developed to enable small-scale production (e.g. Zohar et al., 2008), however, only in the case of *P. trituberculatus* was production increased to a commercial scale of ~27-35 million juveniles per year (Hamasaki et al., 2011). Releases were found to be most successful when the hatchery-reared individuals were released as crablets rather than megalopae and where they are less vulnerable to predation by fish (Ariyama, 2000; Jenkins, Michael and Tweedley, 2017).

The Blue Swimmer Crab (*Portunus armatus*) is a highly valued recreational and commercial crab species that inhabits sub-tropical coastal waters and estuaries across Australia (Beckmann and Hooper, 2016; Harris et al., 2016). In Western Australia, Blue Swimmer Crab is the most popular recreational species, with, for example, an estimated 900,000 individuals caught by boat-based recreational fishers in 2013/14 (Ryan et al., 2019). Fishing pressure is typically concentrated in estuaries, particularly those located near population centres, such as the Peel-Harvey Estuary, which is located on the lower west coast of Australia (Malseed and Sumner, 2001a). Recreational catch from this system, for example, was estimated between 110–180 t in 2007/08, which was greater than the 50-100 t caught by the commercial sector (Johnston et al., 2014). Despite Blue Swimmer Crab stocks in the Peel-Harvey Estuary receiving Marine Stewardship Council Certification as sustainable, increasing fishing pressure and anthropogenic changes to the environment could potentially negatively influence the population. For example, the high variability in recruitment that occurs among years in this population may be related to inter-annual variations in spawning stock biomass and/or early life-history stages that are sensitive to brackish water (Ravi, Manisseri and Sanil, 2014).

To assess logistical constraints of aquaculture-based enhancement of Blue Swimmer Crab in the Peel-Harvey Estuary a small-scale pilot project was undertaken using eight berried females collected from the estuary during October and November of 2015 (Jenkins, Michael and Tweedley, 2017). Of those, one successfully produced 175,000 megalopa from 340,000 zoea, a survival rate of 52%. Mortality however increased following metamorphosis from megalopa to crablet (2.4%; i.e. 1.2% of the zoea), which took ~22 days post-hatch. The high mortality was largely attributed to the morphological development of claws and their highly aggressive and cannibalistic nature (Jenkins, Michael and Tweedley, 2017).

As populations of Blue Swimmer Crab are distributed throughout a wide range of environments, that differ markedly in their physico-chemical properties, the biological characteristics of Blue Swimmer Crab populations can vary considerably, even within relatively small spatial scales. For example, their diet in the Peel-Harvey Estuary was distinct from that of a nearby estuary and coastal embayment (Swan-Canning Estuary and Cockburn Sound) because of greater consumption of the bivalves *Arthritica semen* and *Spisula trigonella* (Campbell et al., 2021). Size (carapace width; CW) at maturity likewise differs among populations, for females, as low as 79.1 mm in Cockburn Sound to 98.8 in Shark Bay, ~900km to the north. While spawning in those latter warmer tropical waters is mostly during the austral winter (July-September), spawning in the cooler waters of the lower west coast is more restricted to warmer months (Potter and de Lestang, 2000; Johnston and Yeoh, 2021). Although de Lestang, Hall and Potter (2003b) did not find major differences in the growth of Blue Swimmer Crab among those populations, Marks et al. (2020) provided strong evidence that crab density in Cockburn Sound played a major role in growth. Density-dependent factors have also been found to affect the growth of other portunids, such as the Chesapeake Blue Crab *Callinectes sapidus* and European Green Crab *Carcinus maenus* (Pile et al., 1996; Moksnes, 2004b).

The aim of this research was to explore, through simulation, the impact of different stock enhancement release strategies for Blue Swimmer Crab on the population in the Peel-Harvey Estuary with particular focus on the number of legal-sized crabs (both wild and cultured stock) that enter its fisheries. As the abundance of Blue Swimmer Crabs in the Peel-Harvey Estuary can vary markedly among years, the effect of the four release quantities (0, 1.6, 3.2 and 6.4 million crabs) were explored at three different natural population densities; 1,2 and 4 crab 100 m^{-2} representing low, medium and high -density populations, respectively.

3.1.2. Methods

3.1.2.1. Study location

The Peel-Harvey Estuary, adjacent to the city of Mandurah (80,000 people), is located in microtidal, temperate south-western Australia about 25 and 50 km south from Cockburn Sound and the Swan-Canning Estuary. At 131 km^2 in area, the Peel-Harvey Estuary, is the largest in the region and consists of two large, shallow (mainly < 2 m deep) basins, which are permanently connected to the Indian Ocean by a natural (Mandurah Channel) and an artificial entrance channel (Dawesville Channel), and tidal portions of three rivers (Valesini et al., 2019). The estuary has a long history of crab fishing (Lenanton, 1984), supporting an estimated 100,000 recreational and, through recent government licence buy-backs, a diminishing number of commercial fishers (from 11 to currently 6 licenses).

3.1.2.2. Summary of the biology of the Blue Swimmer Crab in the Peel-Harvey Estuary

In the Peel-Harvey Estuary small Blue-Swimmer Crabs (<30 mm CW) can be found in early summer (de Lestang, Hall and Potter, 2003a). Carapace widths remain <80 mm between June and October and the minimum legal size for capture (127 mm CW) typically attained between December and February (Potter et al. 1983). Under current restrictions, the crab fishing season begins in December and few crabs remain by winter. While the maximum age of the Blue Swimmer Crabs is ~2.5 years, surviving individuals typically leave the estuary during winter in their second year of life and the estuary rarely contains individuals > 20 months old (Potter, Chrystal and Loneragan, 1983).

3.1.2.3. Simulation model overview

As the population of Blue Swimmer Crabs is highly dynamic in the Peel-Harvey Estuary, the stock enhancement release options were assessed under three different population densities, representing low, medium and high -density natural populations. These densities of 1, 2 and 4 crabs 100 m^{-2}, respectively, were selected based on field surveys of crabs in the Peel-Harvey Estuary (Potter, Chrystal and Loneragan, 1983; de Lestang, Hall and Potter, 2003c; Johnston et al., 2020a) and the Leschenault Estuary (Potter and de Lestang, 2000). For each of those population models, the progression of the numbers and carapace widths of individuals were tracked from the recruitment pulse in November at a size of 7-9 mm carapace width through to May in their second year of life, when the 1+ age class migrate from the estuary. For each of the three population densities, four stock enhancement options were then explored: no stock enhancement, low, medium and high stock enhancements. To simplify the model the following assumptions were employed:

1. Individuals are fully recruited into the estuary in November.
2. Individuals leave the estuary during May in their second year of life.
3. Annual recruitment among years is constant.
4. Natural mortality is age dependent.
5. Growth of all individuals follow the same trajectory regardless of sex and origin.
6. Carapace width is a function of annual average crab density.
7. Fishing removes 50% of legal-sized crabs each month between December and May.

3.1.2.4. Growth of Blue Swimmer Crabs

Average monthly carapace width was derived from the seasonal growth curve:

$$\widehat{CW}_t = CW_\infty \left\{1 - exp\left[-k\left(t - t_0 + \frac{C}{2\pi}[S(t) - S(t_0)]\right)\right]\right\},$$

where $\widehat{CW}_j$ is the expected carapace width at age t, CW_∞ is the asymptotic carapace width (mm), k is the von Bertalanffy growth coefficient, t_0 is the hypothetical age of a crab with zero length and C is the seasonality amplitude parameter. $S(t) = sin[2\pi(t - t_c)]$ and $S(t_0) = sin[2\pi(t_0 - t_c)]$, where t_c determines the time of year at which growth is at its maximum or minimum (Somers, 1988). The model parameters were broadly based on those reported previously for Blue Swimmer Crab

$(CW_\infty = 149 \text{ mm}, k = 1.3\ y^{-1}, t_0 = -0.02, C = 0.9, t_c = 1)$.

To account for density-dependence, the relationship between carapace width and crab density was defined as $\delta_{CW} = 100\left(\frac{0.5}{1+\exp\left(-(density-5)\right)}\right)$, where δ_{CW} is the percentage change in carapace width across all ages, 0.5 is the maximum proportion carapace width can be reduced, density is average annual density (crabs 100 m^{-2}) and 5 represents the midpoint of the curve, i.e. where 5 crabs 100 m^{-2} would result in a 25% reduction in carapace width.

3.1.2.5. Size structure of the three simulated natural populations

The size structure of each natural population in each month was then created using the number of individuals in each month and the assignment of a carapace width drawn randomly from a normal distribution for that corresponding month with a mean $\widehat{CW}_t$ and a standard deviation $\widehat{CW}_t/5$. This standard deviation was chosen as it produced monthly carapace width-frequency histograms with similar distributions as that shown in de Lestang, Hall and Potter (2003a) for this species in the Peel-Harvey Estuary. As recruitment of Blue Swimmer Crabs into the population to maintain stock densities ranged between 1.9 and 7.8 million, to simplify the simulation model it was assumed, the carapace width of one crab would represent that of 1000 crabs for the 0+ age class, whereas for the 1+ age class, in which numbers were less, the carapace width of one crab would represent that of 100 individuals. In the high-density population model this represented up to 7,800 estimates of carapace widths for the 0+ age class and 17,795 estimates for the 1+ age class.

3.1.2.6. Stock enhancement release strategies

Of the four stock enhancement options, three release strategies were explored. These were the release of 1.6, 3.2 and 6.4 million crabs, which represent an increase in the initial density of crabs of 1, 2 and 4 crabs 100 m^{-2} (accounting for an initial release mortality of 20% and an area of the estuary occupied by Blue Swimmer Crabs of 131 km^{-2}). Release size options were not explored as the average minimum size-at-release of 4 mm CW and age of about 22 days corresponds to the size attained immediately following the development of the periopods for swimming (Figure 3.1.1) and release at larger size would result in high mortality from cannibalism in the hatchery (Jenkins, Michael and Tweedley, 2017). This size at release is just after the crabs have metamorphosed from the last megalopal stage into a crablet.

Figure 3.1.1. Photo of 22-day old cultured Blue Swimmer Crab with developed the periopods for swimming. Photo courtesy of Jenkins et al. (2017).

3.1.2.7. *Annual crab catches*

Fishing was assumed to remove 50% of the available legal-sized Blue Swimmer Crab each month and that during the period of intense recreational and commercial fishing (December to May), the natural mortality of the 1+ age class was reduced by 50 %, i.e. half of the natural mortality was replaced by fishing morality. The annual weight of crab catches (tonnes) was then estimated by summing the weight (W) of individual crabs derived from their carapace width (CW) and the equation $\ln(W) = -10.4871 + 3.2390\ln(CW)$ (Johnston et al., 2020a).

3.1.3. Results

3.1.3.1. *Natural mortality*

The number of Blue Swimmer Crabs in the Peel-Harvey Estuary under the three different natural population densities (1, 2 and 4 crabs 100 m^{-2}) would require annual recruitment levels of ~1.9, 3.9 and 7.8 million crabs, respectively, to maintain those stock densities. Once recruited (in November) and following a natural mortality rate of 1.4 y^{-1} (Johnston et al., 2020a), ~0.5, 1.0 and 1.9 million crabs, respectively, would be expected to survive for one year. By May, without removals from fishing, an estimated ~0.2, 0.4 and 0.8 million individuals would have survived (Figure 3.1.2).

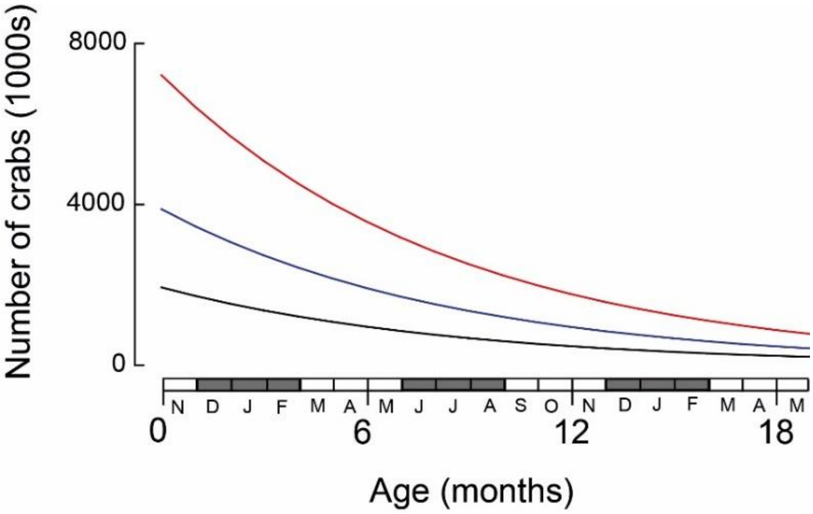

Figure 3.1.2. Numbers of Blue Swimmer Crabs over time in three simulated populations in the Peel-Harvey Estuary, representing low (black line), medium (blue line) and high (red line) annual average natural population densities of 1, 2 and 4 crabs 100 m^{-2}, based on a natural mortality of 1.4 y^{-1}.

3.1.3.2. *Density dependent growth*

The assumed relationship between average annual crab density and percentage change in carapace width would have resulted in a reduction in carapace width at age in the low, medium and high-density natural populations of <0.9, 2.4 and 13.4 %, respectively. Thus, for example, the carapace width of the same individual would range from 111 to 127 mm if subjected to high (4 crabs 100 m^{-2}) and low (1 crab 100 m^{-2}) -density populations, respectively (Figure 3.1.3).

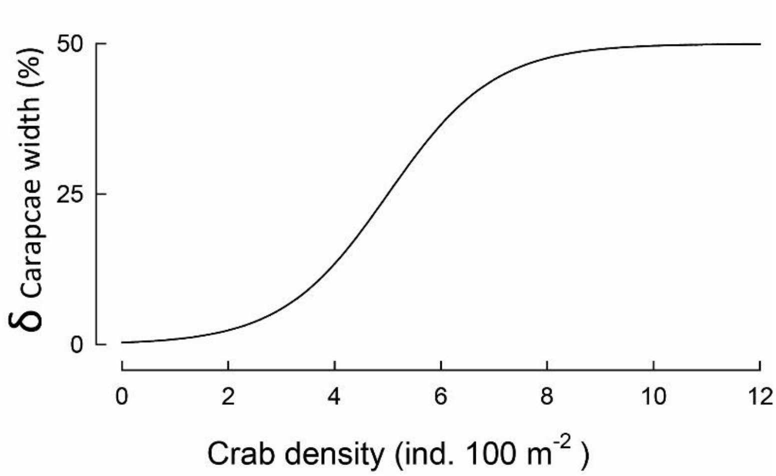

Figure 3.1.3. Assumed relationship between average annual density (crabs 100 m^{-2}) and percentage change in carapace width for Blue Swimmer Crabs in the Peel-Harvey Estuary.

Based on the above density-dependent relationship, the growth of the simulated low and medium densities followed similar growth trajectories and average carapace widths at the end of 12 and 18months only varied by <2 mm and attained maximum carapace widths of 130 and 128 mm, respectively. In contrast, growth simulated under high density population lay well below that generated by the low and medium population densities with carapace width at 10 and 20 months ~10 and 15 mm less that the corresponding values for medium density and an average maximum carapace width of 113 mm (Figure 3.1.4).

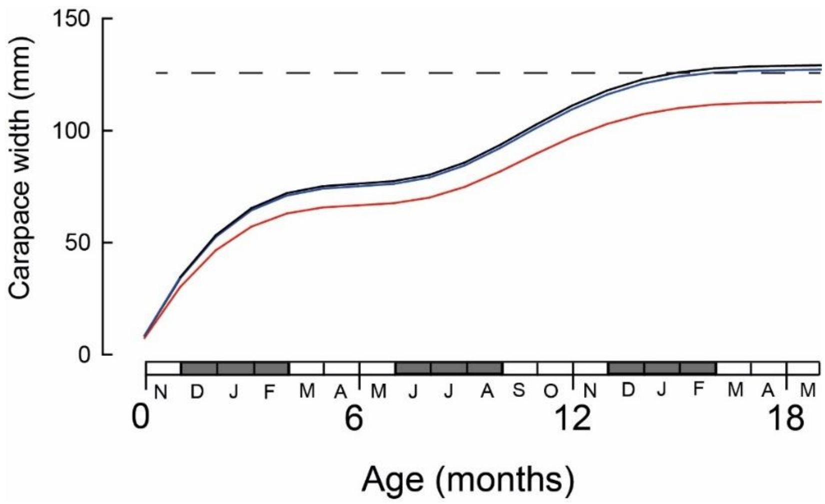

Figure 3.1.4. Seasonal von Bertalanffy growth curves for three simulated populations of Blue Swimmer Crabs in in the Peel-Harvey Estuary, representing low (black line), medium (blue line) and high (red line) densities of 1, 2 and 4 crabs 100 m^{-2} and accounting for density-dependent growth effects.[24]

3.1.3.3. Size structure of natural populations

The resultant simulated carapace width-frequency histograms for each population density illustrate the progressive monthly change in carapace width of the 0+ cohort, which are fully recruited in November, and the previous cohort, which become the 1+ age class in November (Figures 3.1.5-3.1.7). In the low-density simulated natural population, the modal carapace width of the 0+ age class increased from 0-10 mm in November to 70-80 mm in March, where it remained until July (Figure 3.1.5). By October, at the end of their first year, the 0+ age class attained a modal carapace width of 90-100 mm. The modal carapace width of the

[24] Dashed line represents minimum legal carapace width for retention by fishers of 127 mm.

1+ crabs increased from 110-120 mm in November to 130-140 mm in May. Many 1+ crabs had reached the legal minimum size for retention in January (Figure 3.1.5).

The modal carapace width of the 0+ crabs in the medium-density natural population model followed similar trends to that of the low-density population model, increasing from 0-10 mm in November to 70-80 mm in March through to July and attained 90-100 mm by the end of their first year (Figure 3.1.6). The modal length of 1+ crabs in the medium-density population increased from 100-110 mm in November to 120-130 mm in May (Figure 3.1.6).

The modal carapace width of the 0+ age class in the high-density simulated population show the greatest difference to the progression in the medium and low population densities – increasing from 0-10 mm in November to only 60-70 mm in March and remaining at this modal size until June (Figure 3.1.7). By the end of their first year, the 0+ age class attained a modal length of 90-100 mm and the modal length of the 1+ age class in that high-density population increased from 100-110 mm in November to 120-130 mm in May (Figure 3.1.7).

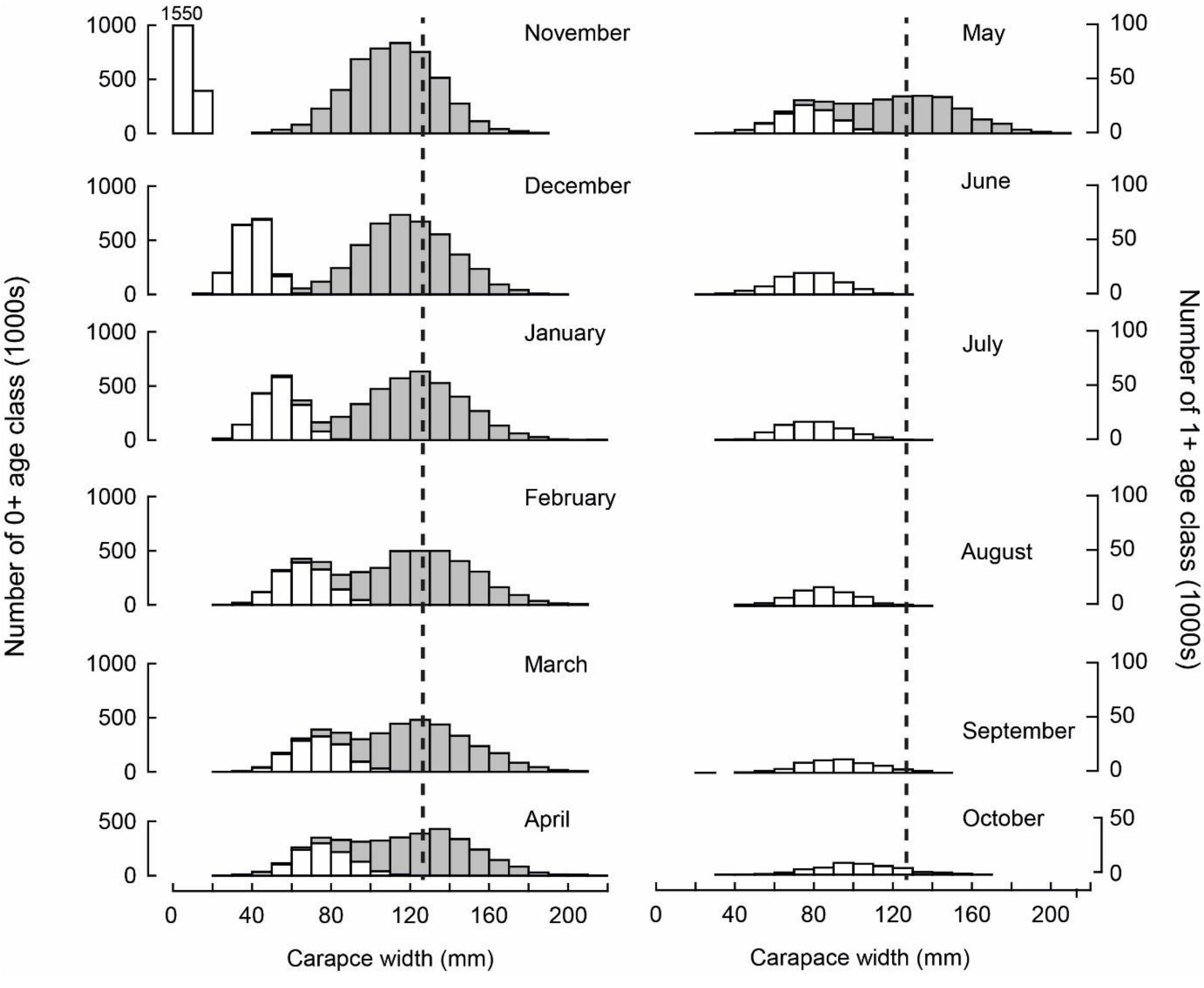

Figure 3.1.5. Simulated monthly carapace width-frequency histograms for Blue Swimmer Crabs in the Peel-Harvey Estuary assuming a low population density (1 crabs 100 m^{-2}).[25]

[25] Open bars: 0+ age class, grey bars: 1+ age class. Dashed vertical line represents the minimum legal size (127 mm carapace width) for retention by fishers.

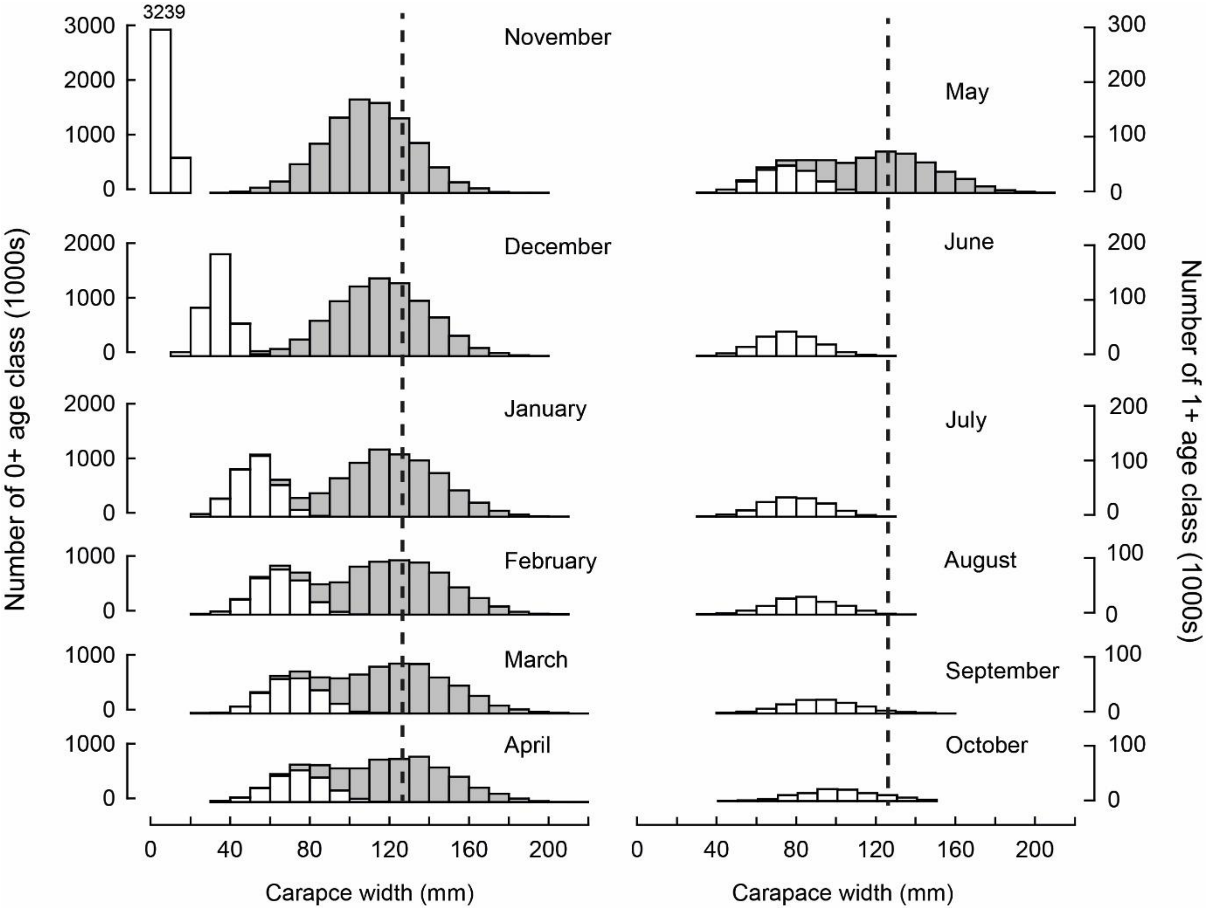

Figure 3.1.6. Simulated monthly carapace width-frequency histograms for Blue Swimmer Crabs in the Peel-Harvey Estuary assuming a medium population density (2 crabs 100 m^{-2}).[26]

[26] Open bars: 0+ age class, grey bars: 1+ age class. Dashed vertical line represents the minimum legal size (127 mm carapace width) for retention by fishers.

3.1.3.4. Stock size following stock enhancement options

In each simulated population, the low, medium and high stock enhancement options, which increased initial stock densities by 1, 2 and 4 crabs 100 m^{-2}, respectively, led to an increase in average annual densities of ~0.7, 1.35 and 2.7 crabs 100 m^{-2}, respectively. Thus, annual average crab densities in the low-density population increased from 1 (no enhancement) to a maximum of 3.7 crabs 100 m^{-2} (high stock enhancement). The corresponding values for the medium-density population was 2 to 4.7 crabs 100 m^{-2} and for the high-density population from 4 to 6.7 crabs 100 m^{-2}.

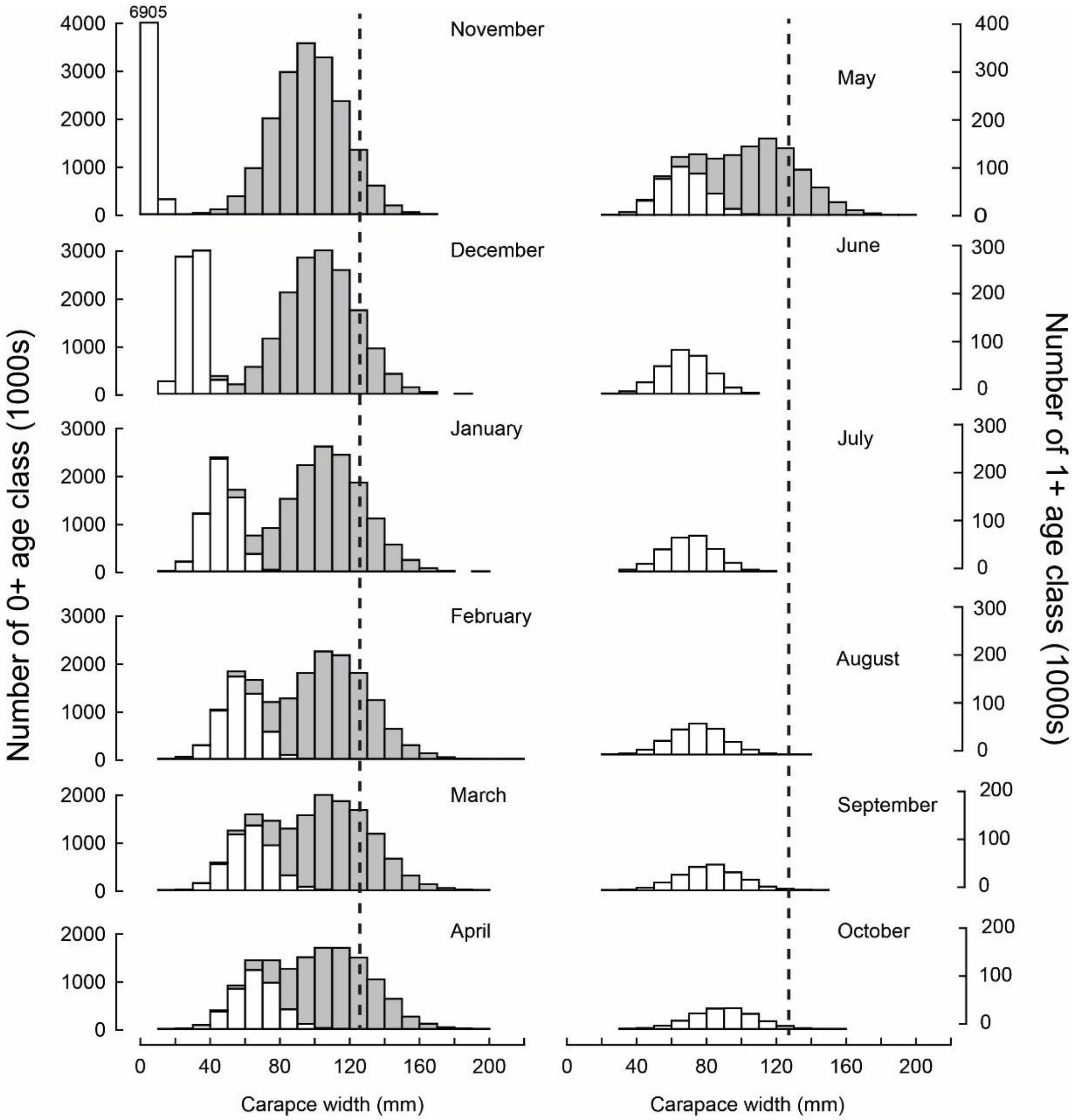

Figure 3.1.7. Simulated monthly carapace width-frequency histograms for Blue Swimmer Crabs in the Peel-Harvey Estuary assuming a high population density (4 crabs 100 m^{-2}).[27]

[27] Open bars: 0+ age class, grey bars: 1+ age class. Dashed vertical line represents the minimum legal size (127 mm carapace width) for retention by fishers.

Growth following stock enhancement

Growth of Blue Swimmer Crabs in the low-density population model did not change markedly from natural levels following the low and medium stock enhancement options, with average CW reduced from 111 mm to 108 mm by the end of their first year, i.e. October (Figure 3.1.8) which was accompanied by the average time taken to reach legal size increasing from ~15.5 to 16 months. This trend continued throughout the remainder of the time spent in the estuary, with CWs in the following May with no stock enhancement attaining 129 mm compared with 116 mm (10.1% smaller) under the high stock enhancement option. Thus, the average carapace width under the high stocking option was under legal size (Figure 3.1.8).

Growth of Blue Swimmer Crabs in the medium-density population declined sequentially with increasing levels of stock enhancement (Figure 3.1.8). While average CW at the end of the first year with no stock enhancement was 109 mm, the corresponding value under low, medium and high stock enhancement was 107, 103 and 88 mm, respectively. By the end of the following May, those values ranged from 127 mm under no stock enhancement to 102 mm under high stock enhancement (Figure 3.1.8). In the high-density population model, by the end of the first year, average carapace width without stock enhancement was 97 mm (Figure 3.1.8). Following stock enhancement, the corresponding values under the low, medium and high stock enhancement options were 89, 79 and 65 mm and by the end of the following May those values ranged between 113 and 75 mm (Figure 3.1.8).

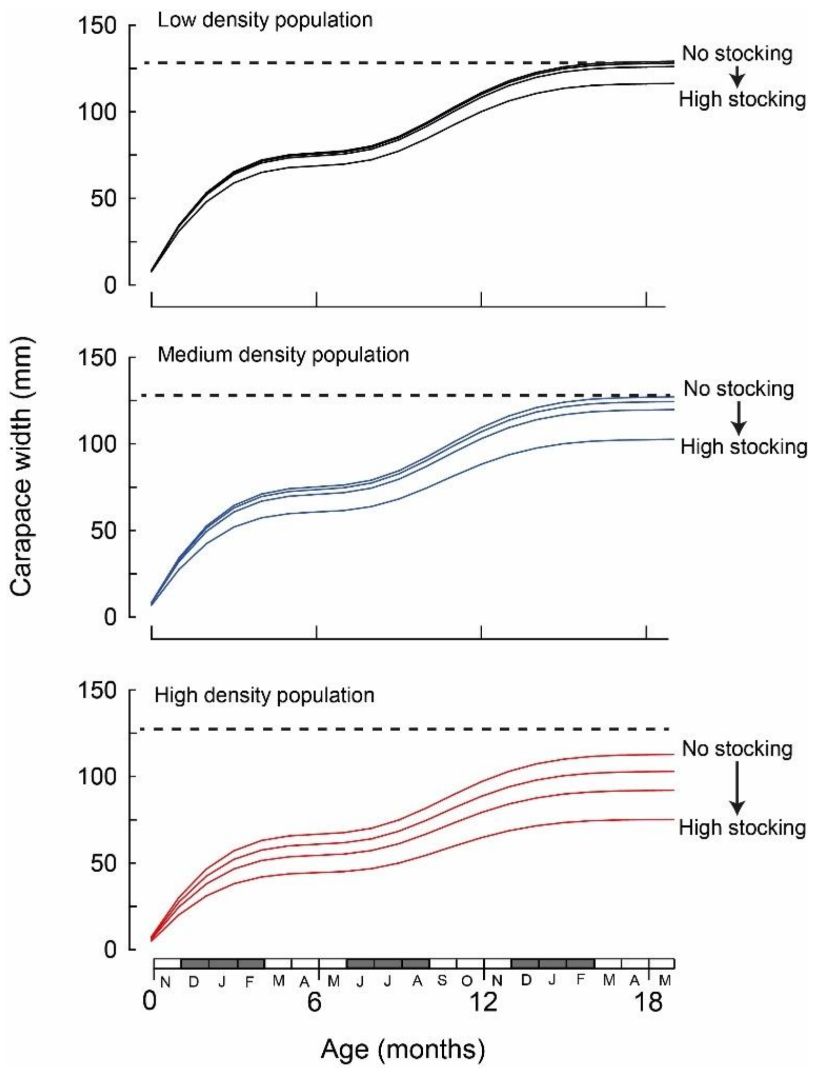

Figure 3.1.8. Simulated seasonal von Bertalanffy growth curves illustrating differences in carapace widths of Blue Swimmer Crabs under three different natural population densities (low (black lines), medium (blue lines) and high (red lines)) and subjected to four stock enhancement options: no stock enhancement and low, medium and high stock enhancements.[28]

[28] Horizontal dashed line represents the legal size (127 mm carapace width) for retention by fishers.

Size structure following stock enhancement

In the low-density population model, modal carapace width of the 1+ age class, under the low stock enhancement option, increased from 110-120 to 120-130 mm between November and May (Figure 3.1.9). For the medium stock enhancement option, modal carapace widths increased from 100-110 to 120-130 over that same period and, in the case of the high stock enhancement option, modal carapace widths increased from 90-100 to 110-120 (Figure 3.1.9).

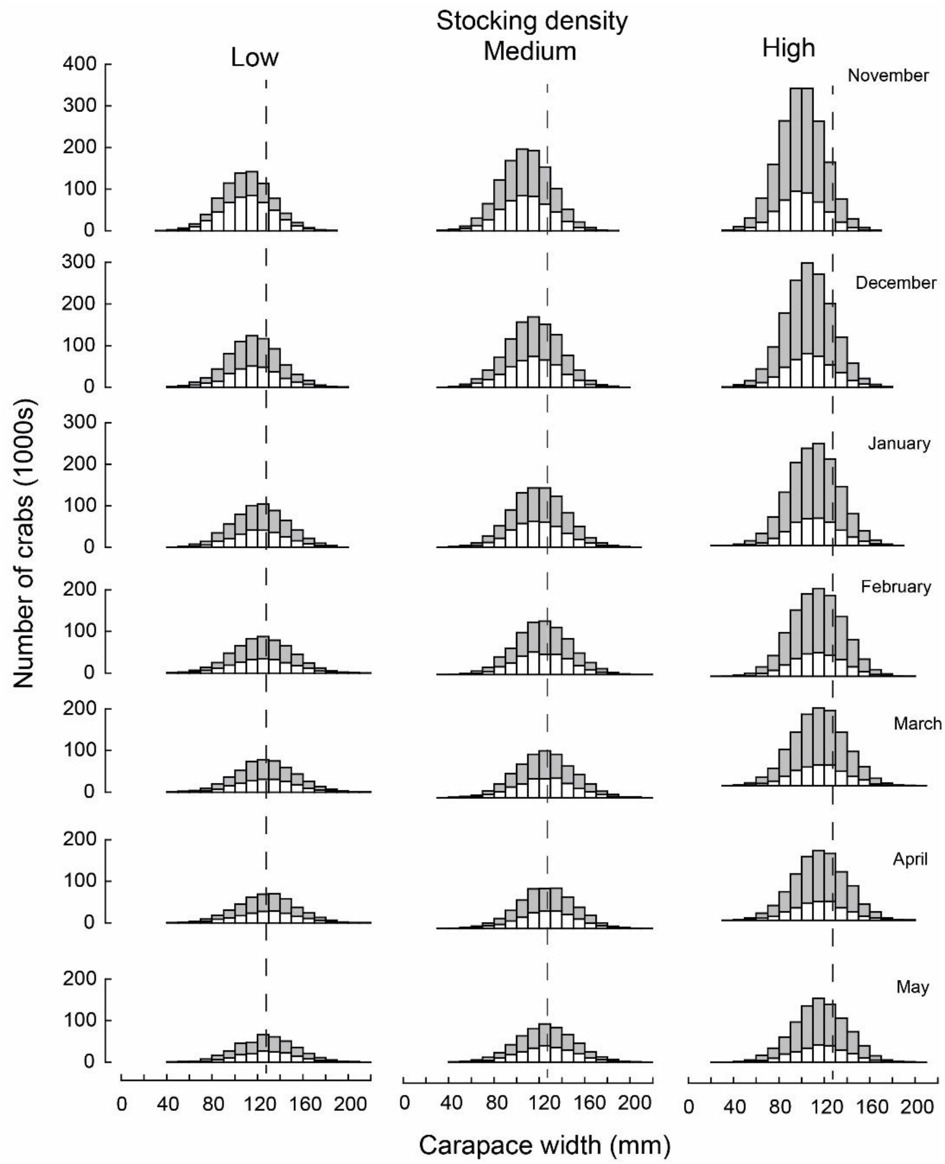

Figure 3.1.9. Model-generated carapace width-frequency histograms of the expected sizes of 1+ age class of Blue Swimmer Crabs in the Peel-Harvey Estuary for each month between November and May. Simulation is based on a low natural population of 1 crab 100 m^{-2} and low, medium and high numbers released.[29]

In the medium-density population model, modal carapace widths of the 1+ age class, under the medium stock enhancement option, increased from 100-110 to 120-130 mm between November and December (Figure 3.1.10). For the medium stock enhancement option, modal carapace widths from 100-110 mm in November to 110-120 in May and over that same period in the case of the high stock enhancement option, from 80-90 to 90-100 mm (Figure 3.1.10).

[29] Open bars represent the wild stock and grey bars the cultured stock.

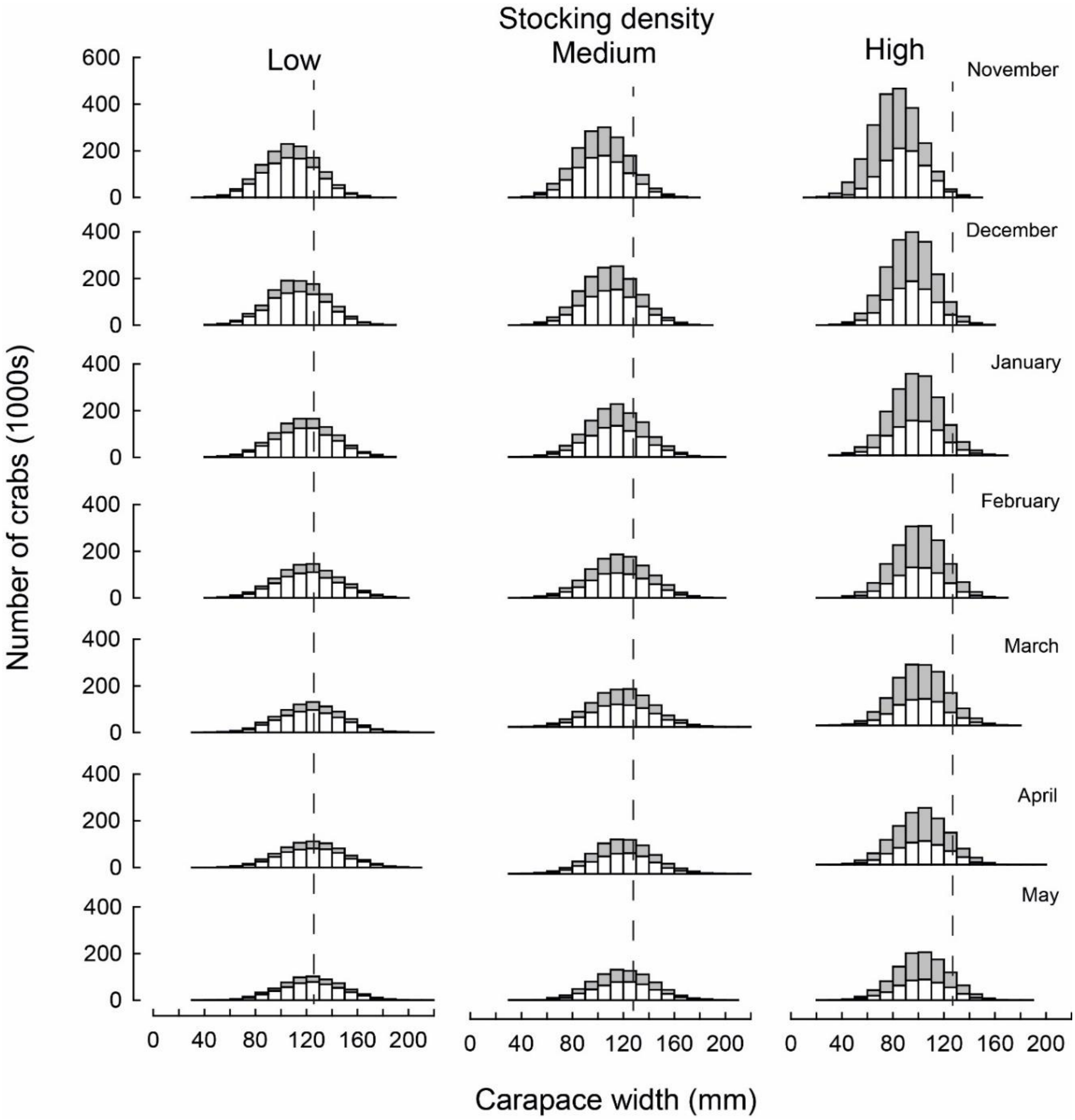

Figure 3.1.10. Model-generated carapace width-frequency histograms of the expected sizes of 1+ age class of Blue Swimmer Crabs in the Peel-Harvey Estuary for each month between November and May. Simulation is based on a medium natural population of 2 crab 100 m^{-2} and low, medium and high numbers released.[30]

In the high-density population model, under the low stock enhancement option, modal carapace width increased from 80-90 mm in November to 100-110 mm in May (Figure 3.1.11). Under the medium stock enhancement option, modal carapace widths were about 10 mm narrower than in the low enhancement in November and May, while they were 20 mm narrower in the high enhancement option (Figure 3.1.11).

[30] Open bars represent the wild stock and grey bars the cultured stock.

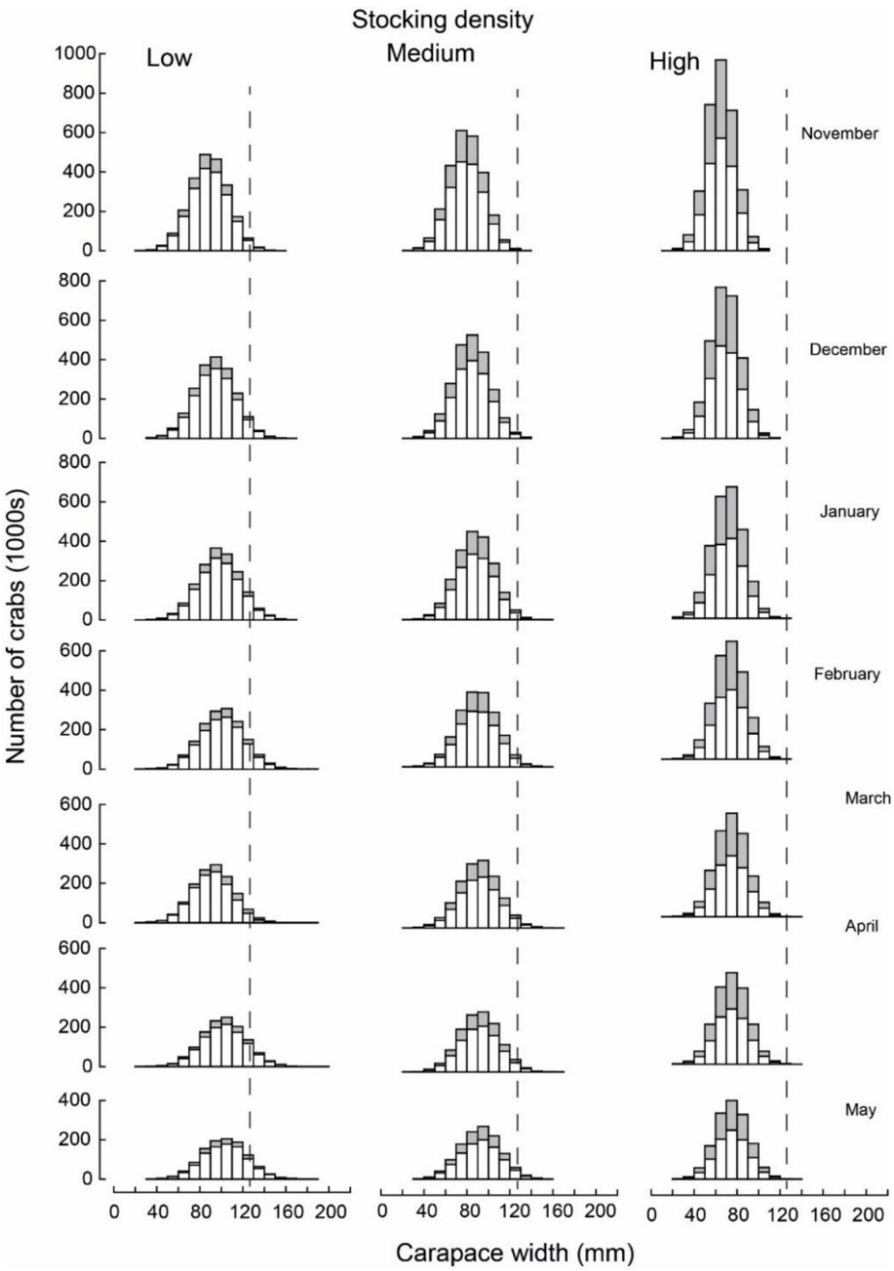

Figure 3.1.11. Model-generated carapace width-frequency histograms of the expected sizes of 1+ age class of Blue Swimmer Crabs in the Peel-Harvey Estuary for each month between November and May. Simulation is based on a high natural population of 4 crab 100 m^{-2} and low, medium and high numbers released.[31]

3.1.3.5. Number of legal-sized crabs without fishing pressure

In the low-density population model, without stock enhancement, the number of legal-sized crabs i.e. carapace width ≥127 mm, increased successively from 113,200 in November to their peak of 164,000 in January before declining to 125,800 in May (Figure 3.1.12). Under the low stock enhancement option, those numbers increased from 177,800 in November to 263,900 in February before declining to 203,900 in May. For the medium and high stock enhancement options, the numbers of legal-sized crabs were least in November of 220,800 and 158,300, respectively, and greatest in February of 345,700 and 345,500, respectively (Figure 3.1.12).

Under a medium-density population, without stock enhancement, the number of legal-sized crabs increased successively from 201,800 in November to 306,400 in February before declining to 237,500 in May (Figure 3.1.12). Under the low stock enhancement option, the corresponding values increased from 225,500 to

[31] Open bars represent the wild stock and grey bars the cultured stock.

370,200, declining to 290,000 and for the medium stock enhancement option, 196,500 to 376,400 down to 301,100 in May. In the case of the high stock enhancement option, 31,600 were available in November, 142,400 in February and 128,400 in May (Figure 3.1.12).

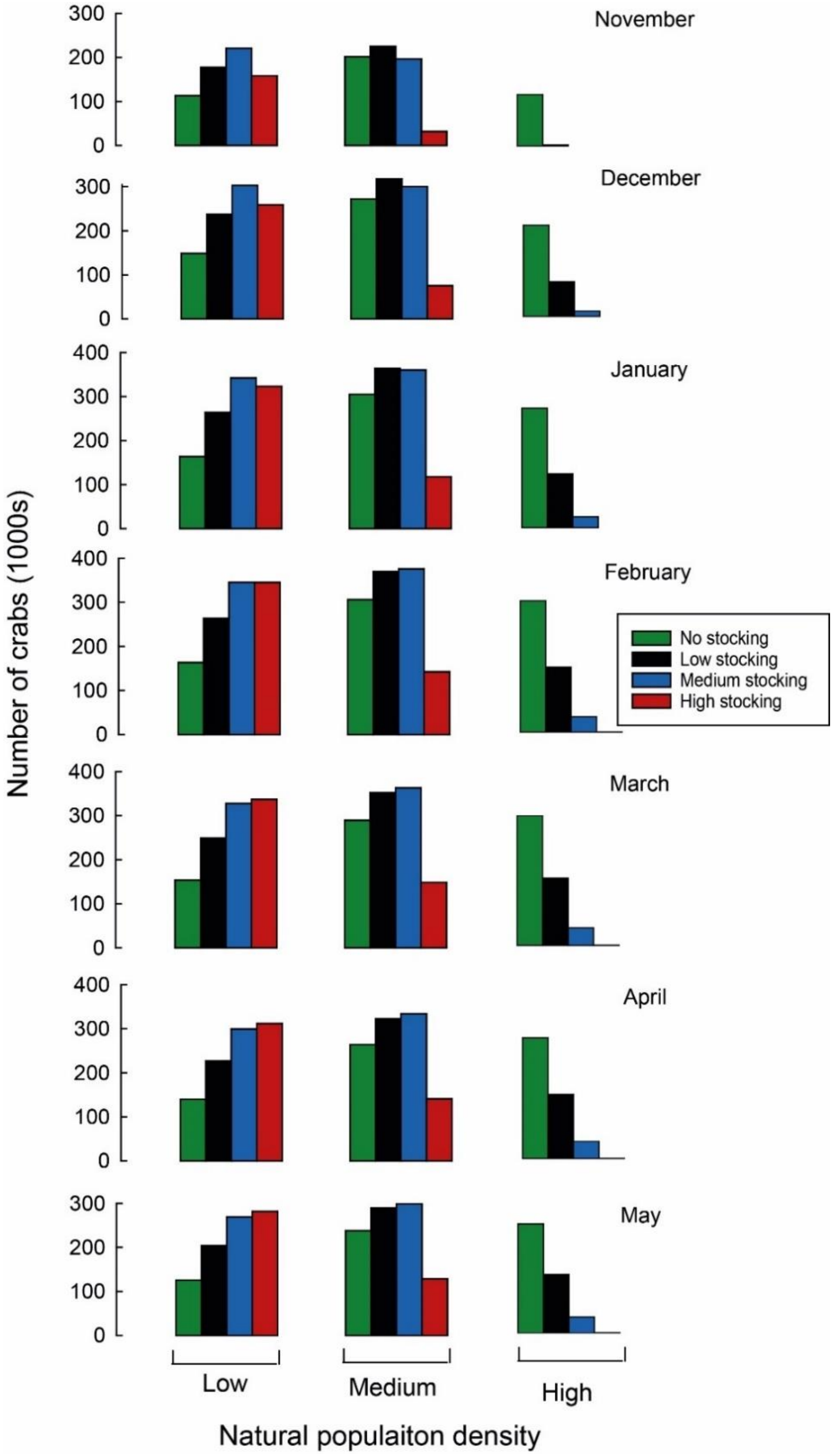

Figure 3.1.12. Estimated number of legal-size Blue Swimmer Crabs (≥127 mm) in the Peel-Harvey Estuary in each month under three different natural population densities; low, medium and high (1, 2 and 4 crabs 100 m^{-2}, respectively) and their corresponding numbers following four stock enhancement options (no stocking, low stocking, medium stocking and high stocking).

Under a high-density population, without stock enhancement, the number of legal-sized crabs increased from 116,700 in November to reach their peak of 297,600 in February before declining to 247,500 in May (Figure 3.1.12). Under the low stock enhancement option, 2,900 crabs would have attained legal size by November, attained a peak of 39,500 crabs in March and declined to 35,800 in May. For the medium stock enhancement option, 12,200 legal sized crabs appeared in December and their numbers peaked at 38,388 in

April. For the high stocking option, legal sized crabs did not appear until January and their numbers remained <500 throughout the remainder of the time spent in the estuary (Figure 3.1.12).

3.1.3.6. Number of removals by fishing

In the low-density population, the number of crabs removed by fishing (assuming a fishing mortality of 0.5 month^{-1}) was greatest in December and February and least in January and May (Figure 3.1.13). While the expected monthly removals ranged from 49,700–74,500 without stock enhancement, the corresponding values for low and medium stock enhancement were 79,900–124,800 and 98,300–151,300, respectively. In the case of the high stock enhancement, those values were 97,300–127,600 (Figure 3.1.13).

In the medium-density population, the number of crabs removed by fishing typically followed a similar monthly trend as that of the low-density population (Figure 3.1.13). While the expected removals without stock enhancement ranged from 99,000–144,400, those numbers increased with a low and medium stock enhancement to 120,600–170,300 and 118,400–156,800. In contrast, the numbers removed by fishing in the medium-density population under the high stock enhancement option was least in December of 25,300 crabs and greatest in April of 44,800 crabs (Figure 3.1.13).

In the high-density population, the numbers removed by fishing without stock enhancement ranged from 86,300 to 113,700 crabs (Figure 3.1.13). The number of crabs removed in the low stock enhancement option was least in December of 32,700 crabs and greatest in April of 53,600 crabs. Under the medium stock enhancement option, between 5,700 crabs would have been caught in December and 14,800 in April. Under a high stocking option, no crabs would have been caught in December and <300 crabs in each subsequent month (Figure 3.1.13).

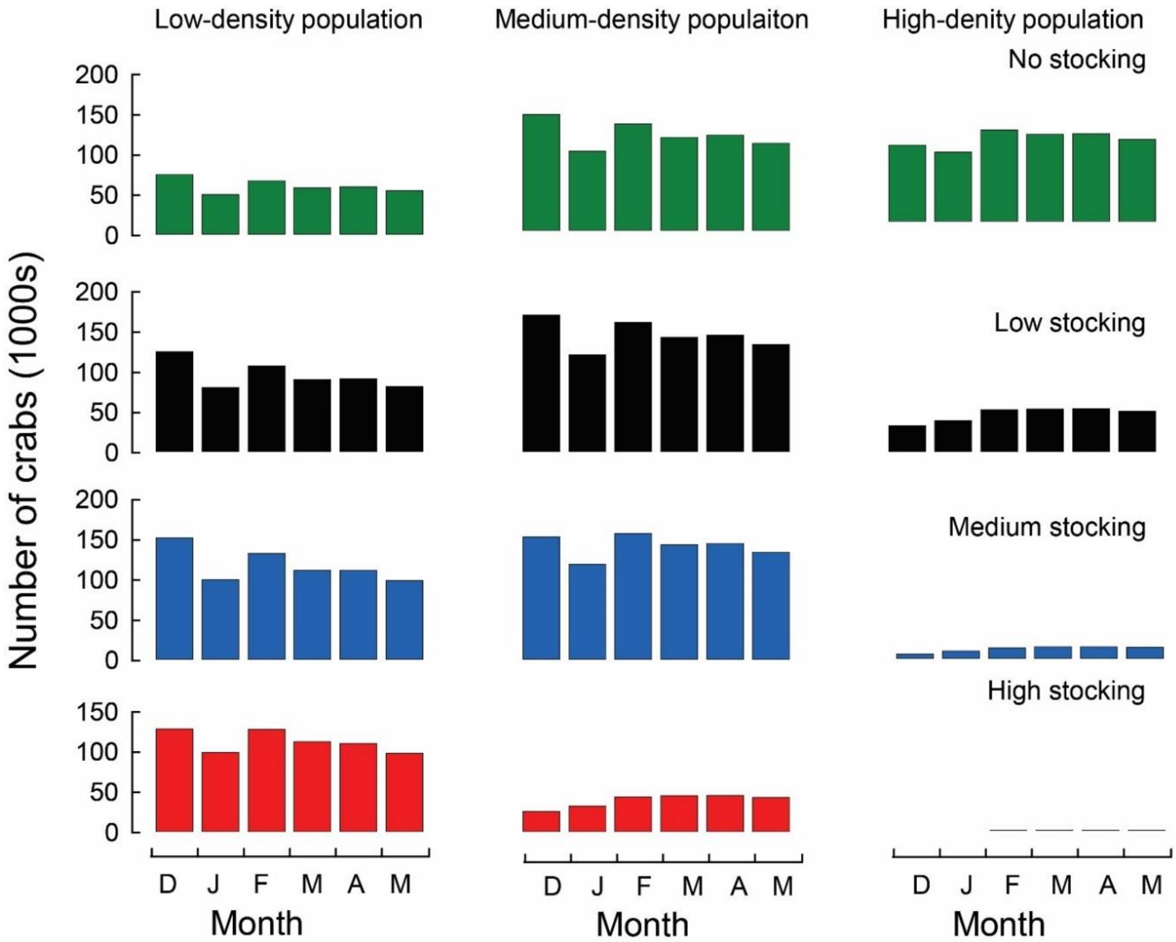

Figure 3.1.13. Estimated number of legal-sized Blue Swimmer Crabs (≥127 mm) removed by fishing in the Peel-Harvey Estuary in each month between December and May under three different natural population densities; low, medium and high (1, 2 and 4 crabs 100 m^{-2}, respectively) and their corresponding numbers following four stock enhancement options (no stocking, low stocking, medium stocking and high stocking).

3.1.3.7. *Annual catches*

The estimated annual catch of Blue Swimmer Crabs in the low-density population ranged from 121.7 tonnes without stock enhancement to 234.3 with a medium stock enhancement, with the high stock enhancement option producing a slightly lower catch (224.0 tonnes) than the medium enhancement (Figure 3.1.14). In the medium-density population scenario, the greatest estimated annual catch was in the low stocking option (240.1 t) and the least (77.4 t) in the high stocking option. In the high-density population scenario, the greatest catches occurred in the no stocking (173.2 t), with the low stocking option producing 82.9 t and the medium and high stocking options producing 22.2 and 0.4 t, respectively (Figure 3.1.14).

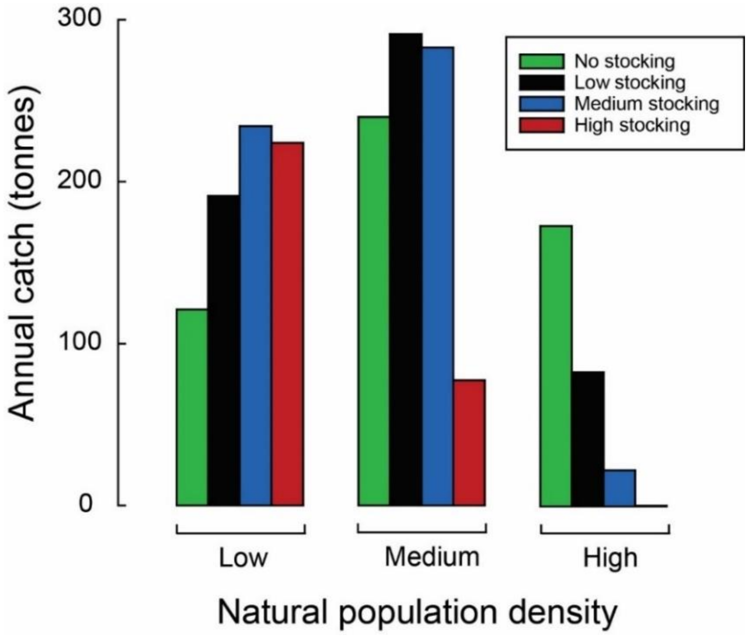

Figure 3.1.14. Estimated annual tonnes of Blue Swimmer Crabs removed by fishing in the Peel-Harvey Estuary under three different natural population densities; low, medium and high (1, 2 and 4 crabs 100 m^{-2}, respectively) and their corresponding numbers following four stock enhancement options (no stocking, low stocking, medium stocking and high stocking).

3.1.4. Discussion

The model developed in this chapter explored the effect of different releases options on the Blue Swimmer Crab fishery in the Peel-Harvey Estuary. As with many crab stocks, Blue Swimmer Crab is an excellent candidate for aquaculture-based enhancement, due to its high socio-economic value and its potential to become depleted due to recruitment limitations, e.g. from depleted spawning stock biomass and/or bottlenecks that occur during its early life-history stages (Ravi, Manisseri and Sanil, 2014; Daly, Eckert and Long, 2020). The simulation model also highlighted, however, the importance of the acquisition of sound data on natural population levels prior to stock enhancement as well as accounting for factors, such as density-dependent growth, that was shown to strongly regulate the numbers of individuals entering the fishery. Knowledge of such factors is not only essential for aquaculture-based enhancement and accurate simulation modelling, but also for successful fishery management in general (Lorenzen and Enberg, 2002; Lloyd-Jones et al., 2016; Punt, Haddon and McGarvey, 2016).

As the effects of crab density on growth of individuals in the Peel-Harvey Estuary has not been evaluated, assumptions were made on the scale of density-dependent growth effects in the model. While such relationships will vary among different environments, in Cockburn Sound (50 km north of the mouth of the Peel-Harvey Estuary), a linear relationship was established between the density of juvenile crabs and their growth as adults. This translated to an approximate 10% decline in carapace width of adults when densities of juvenile crab increased from ~0 to 1 crab 100 m^{-2} (Marks et al., 2020). In contrast, the current chapter assumed density-related reductions in carapace width could be described by a logistic equation, with a corresponding decline of 10% in carapace width occurring from an increase in annual average crab densities from ~0 to 3.7 crabs 100 m^{-2}. While the parameter estimates of this relationship were not derived empirically, the logistic equation applied in this chapter accounts for virtually no effect on growth at low crab densities and a maximum effect of a decline in carapace width of 50% once crab densities attained extremely high densities of >10 crabs 100 m^{-2}. The selected parameters for the simulation model also helped account for the far greater carrying capacity of estuaries, due to their higher productivity, than coastal embayments (Elliott and Whitfield, 2011).

Although estimates of crab densities that constitute low, medium and high densities are difficult to ascertain in the Peel-Harvey Estuary, densities derived from fishery-independent trawl surveys between 2016 and 2019 ranged from 0.4 to 1.3 juvenile crabs 100 m^{-2} (Johnston et al., 2020a). These densities differed from those derived by de Lestang, Hall and Potter (2003a), which (including adults) ranged from 0.5 crabs 100 m^{-2} in the Harvey Estuary to 2 crabs 100 m^{-2} in the Peel Inlet and to 4 crabs 100 m^{-2} in the Mandurah entrance channel. In the nearby Leschenault Estuary, 100 km south of the Peel-Harvey, crab densities varied markedly among seining and trawling data sets, with for example, average densities in November of ~2.5 to 15 crabs 100 m^{-2}, respectively (Potter and de Lestang, 2000). Thus, the selection of low, medium and high densities of 1, 2 and 4 crabs 100 m^{-2} in this chapter were within the boundaries of the data presented in previous publications. The assumption of these densities and also a fishing mortality rate of 50% $month^{-1}$ were also broadly consistent with the ~200 tonnes of Blue Swimmer Crabs caught annually by recreational and commercial fishers (Johnston et al., 2014). The fishing mortality rate was also consistent with previous studies that most Blue Swimmer Crabs die from natural and fishing mortality by the time they are 20 months (Potter, de Lestang and Melville Smith, 2001).

Based on the assumptions of the simulation model, only low and medium stocking numbers optimised fisheries catches. This would equate to the release of 1.6 and 3.2 million Blue Swimmer Crab each year, accounting for 20% initial mortality (see Cottingham et al., 2020). As a pilot study demonstrated that female Blue Swimmer Crab with a carapace width of 115 mm from the Peel-Harvey Estuary produces ~352,000 zoea, which have a 1.85% survival through to crablet, every 1 million crablets would require the collection of ~150 berried females, noting this number would be reduced to ~60 for berried females with 140 mm carapace width (Jenkins, Michael and Tweedley, 2017). Although berried females are removed from the estuary in which they would otherwise spawn, mortality in the wild is substantially greater than in the hatchery (Daly, Eckert and Long, 2020). For example, from hatching to settling, survival of the Red King Crab *Paralithodes camtschaticus* and Blue Crab *C. sapidus* was ~1 and 0.2% in the wild compared with 50 and 43%, respectively, in the hatchery (Shirley and Shirley, 1989; McConaugha, 1992; Zmora et al., 2005; Swingle, Daly and Hetrick, 2013).

While it is difficult to ascertain the costs associated with the aquaculture process, from collection of berried females to release could potentially be undertaken within a single month. Further to this, however, is the number of crablets released may be irrelevant if individuals are maladapted to the release environment (Daly, Eckert and Long, 2020). Thus, greater investment into the production of individuals that are ecologically competent to avoid predators and forage similar to their wild conspecifics may improve survival rates once released (Daly, Eckert and Long, 2020). It is also likely that such hatchery techniques would be improved over time and require less costs associated with research and development. It is noteworthy, however, that while successful hatchery techniques have been developed to enable small-scale production of several portunids, only of the production of *P. trituberculatus* has production increased to a commercial scale, producing ~27-35 million juveniles per year in Japan (Hamasaki et al., 2011).

Although the simulation model developed in this chapter has been simplified, increasing the complexity would only be appropriate following the acquisition of a greater understanding of the factors that regulate fishery production. Thus, for example, the current model assumed a constant natural age mortality rate, even although mortality is typically far higher at the juvenile stage and thus more dependent on size (Marshall et al., 2005). It also did not consider density-dependent cannibalism, which not only plays an important role in the hatchery, but also in regulating the population in the wild (Moksnes, 2004a; Møller et al., 2008; Jenkins, Michael and Tweedley, 2017). The results of the simulation model thus emphasise the importance of exploring optimum stocking density through simulation prior to release of stock and the importance of consideration of other factors, such as density-dependent growth, that regulate fishery production. This is particularly the case when the population is at a high density as stock enhancement could potentially lead to fewer crabs attaining the requires size for capture.

3.2. Biological effectiveness of different aquaculture-based enhancement options for Black Bream in the Blackwood River Estuary

3.2.0. Summary

Aquaculture-based enhancements are frequently used to support recreational and commercial fisheries. However, exploration of different release options, such as quantity and size at release, and long-term monitoring programs are often lacking, Thus, the effectiveness of such releases are rarely evaluated quantitatively. This chapter, initially funded by FRDC (FRDC 2000/180 – "Restocking of the Blackwood River Estuary with Black Bream") employs a ~20-year data set for an important recreational (and commercial) estuarine fish population (Black Bream *Acanthopagrus butcheri*) which had become depleted and subsequently enhanced. This chapter thus constitutes among the longest monitoring programs, in which the performance of 150,000 cultured juveniles were tracked from their release in 2003. These data were used to assess the efficacy of that enhancement program and to explore, through simulation, the expected outcome of alternative release options. The chapter also revealed a lot of valuable information about the natural population in the Blackwood River Estuary and showed that good levels of natural recruitment into this system occur infrequently – only in two years in the period from 1999 to 2020. To assess the relationship between biomass and growth of individuals the population was reconstructed over a ten-year period employing previously determined indices of recruitment strengths. A year-specific growth model with competition coefficients was then fitted to the simulated data to assess the effect of biomass on the growth parameters L_∞ and k. The resultant competition coefficients were used to evaluate the effect of different release sizes (20, 40 and 60 mm) and number of individuals (75,000, 150,000 and 300,000) released on the time taken for individuals to attain legal length for retention by fishers (250 mm total length) and the contribution of released fish to the population and the fishery. Simulations showed that cultured fish entered the fishery at ages between 4.60 (60 mm release size) and 5.05 years (20 mm release size) and that size-at-release did not have a major effect on biomass in the population. The simulation model also demonstrated that the 150,000 individual release option was projected to maintain biomass levels similar to that of the natural population. In the absence of natural recruitment for extended periods of time, however, releases of this scale are likely to be necessary every five years.

3.2.1. Introduction

Aquaculture-based enhancements are frequently used to maintain or enhance small-scale fisheries, particularly recreational fisheries which are often of high socio-economic importance (Arlinghaus and Mehner, 2003; Arlinghaus, 2006c; Bell et al., 2008; Taylor et al., 2017). While the specific objectives of such interventions are, in some cases, well-defined, i.e. 'restocking', to support regular harvests, or 'stock enhancement', to increase yields beyond natural levels, the outcomes of different release options, such as number of individuals, size-at-release and timing and frequency of releases and their effect on the target population, are rarely explored (Bell et al., 2006; Johnston et al., 2018). Furthermore, the absence of long-term monitoring programs following releases makes it difficult to evaluate the effectiveness of any release strategy (e.g. Johnston et al., 2018; Kitada, 2018; Cottingham et al., 2020).

In many well-managed fisheries, controls, such as daily bag and size limits, are used to prevent recruitment (and growth) overfishing, i.e. to maintain spawning stock biomass sufficient to sustain the population (FAO, 1996; Ben-Hasan et al., 2021). However, in many inland water bodies, such as estuaries, modifications to catchments and instream barriers can lead to reductions in water quality and area of habitat conducive to successful breeding (Rogers et al., 2010; Ziegler et al., 2017; Beatty et al., 2018; Williams et al., 2020). Consequently, habitat bottlenecks are among the most common explanations following recruitment failure (Cowx, 1994). Under such circumstances, aquaculture-based enhancements are particularly useful short-term solutions to maintain stocks or increase catch rates as the size at which the recruitment bottleneck occurs can be easily bypassed under hatchery conditions (Lorenzen, 2005; Potter et al., 2008; Johnston et al., 2018).

The introduction of cultured fish, however, can have detrimental effects on the wild population, thereby creating a trade-off between conservation issues and socio-economic importance of the release (Arlinghaus and Cooke, 2009; Loneragan, Jenkins and Taylor, 2013; Lorenzen et al., 2013; Camp et al., 2017). For example, although the release of large numbers of cultured fish can increase overall catches, intraspecific competition may increase and lead to density-dependent growth of the population resulting in increased (size-dependent) mortality (Lorenzen, 2005; Cottingham, Hall and Potter, 2015; 2020). Consequently, fewer wild fish will attain maturity and thus contribute to future generations, thereby potentially leading to a reduction in genetic diversity (Lorenzen, 2005; Frost, Evans and Jerry, 2006; Ward, 2006). This is particularly the case when large numbers of cultured fish are introduced which typically only contain a subset of the genetic variation of the population (Roodt-Wilding, 2007; Bell et al., 2008; Johnston et al., 2018).

The Black Bream *Acanthopagrus butcheri*, which is endemic to southern Australia, is among the most important recreational and commercial finfish species found in estuaries (Gomon, Bray and Kuiter, 2008; Jenkins, Conron and Morison, 2010; Beatty et al., 2018). This sparid, which can attain a relatively large size (> 600 mm total length) and old age (> 30 years), typically spawns over a relatively short (~3 months) period in the upper reaches of the estuary during the austral mid-spring to summer months, i.e. October-December (Morison, Coutin and Robertson, 1998; Potter et al., 2008; Sakabe and Lyle, 2010). In south-western Australia, this species is considered a solely estuarine species (sensu Potter et al., 2015a) and thus completes its life cycle within its natal estuary, which it seldom leaves (Chaplin et al., 1998; Cottingham, Hall and Potter, 2016; Williams et al., 2020). Thus, if a population becomes depleted within an estuary, it cannot be naturally replenished from outside sources.

Because individual Black Bream are also subjected to the condition of its natal estuary throughout their life-cycle, their biological characteristics e.g. growth, body condition, maturity schedules and diet vary markedly among estuaries and over relatively short time periods, particularly if the environment within a system deteriorates (Chuwen, Platell and Potter, 2007; Cottingham et al., 2014; Valesini et al., 2017; Potter et al., 2022). Thus, for example, the time taken to attain 250 mm, the minimum legal length (MLL) for retention by recreational and commercial fishers, in the Swan-Canning Estuary increased from 2.8 to 6.1 years over a 20-year period following marked declines in annual freshwater discharge (Cottingham et al., 2018b).

During the 1980s and 1990s the stock of Black Bream in the Blackwood River Estuary in south-western Australia, which hosts both an important recreational and a small commercial fishery, became depleted, with catch rates of recreational fishers in the early 2000s, one third of those in the 1970s (Caputi, 1976; Prior and Beckley, 2007). This marked decline was attributed to overfishing, environmental issues and the flushing of some individuals out of the estuary during an extreme flood event (Hodgkin and Hesp, 1998; Prior and Beckley, 2007). An aquaculture-based enhancement program (FRDC 2000/180) was subsequently implemented, which released 70,000 Black Bream in 2002 when they were 60 mm total length (TL), and a further 150,000 fish in 2003, when they were 40 mm TL (Jenkins et al., 2006; Cottingham et al., 2020). Prior to release, the otoliths of the cultured fish were stained with alizarin complexone, to distinguish them from the wild stock which enabled the use of aquaculture-based enhancement as a tool for replenishing the population to be assessed (Potter et al., 2008; Gardner et al., 2013; Cottingham, Hall and Potter, 2015). These marks have been retained in the otoliths for over 15 years (Cottingham et al., 2020).

The restocking program was deemed highly successful, as cultured fish represented up to 75 % to commercial catches and their potential contribution of ~50 % to egg production in some years (Cottingham, Hall and Potter, 2015). However, to date alternative release strategies such as size- and density- at-release have not been explored. With aquaculture-based enhancement as one of the most popular fisheries management tools for recreational fisheries (Bell et al., 2006; Johnston et al., 2018; Obregón et al., 2020b), such information is invaluable for informing future release strategies for this and other fish populations.

In order to assess the effects of different release strategies on this population, through simulation, this chapter first established the relationship between the annual biomass of Black Bream (kg ha^{-1}) and average annual growth using 20 years of data. A year-specific growth model with competition coefficients, to assess the effect of biomass on the growth parameters L_∞ and k, was then fitted to those data. The resultant competition coefficients were then employed to explore the effect of different release strategies, i.e. numbers of fish released and size-at-release, on the population and the fishery, including the time taken to attain legal-size and the biomass of both the wild and cultured Black Bream associated with each release option. The results of this chapter highlight important aspects to consider when designing future release strategies that maximise the benefits of aquaculture-based enhancements to both the fish population and its fisheries.

3.2.2. Methods

3.2.2.1. Study site

The Blackwood River Estuary is located on the microtidal southern coast of Western Australia. Located in a Mediterranean climate, the estuary receives highly seasonal freshwater flows (740,000 ML), with ~80 % occurring during the austral winter to early spring (June to September; Hallett et al., 2018; Williams et al., 2020). The estuarine section of the Blackwood River is ~42 km long and is characterised by steep banks and average maximum depths of ~5 m. It has one of the largest catchments of an estuary in south-western Australia, covering ~23,500 km^2 (Brearley, 2005). At its seaward end, the river opens into a relatively large (9 km^2) and shallow (<0.5 m) basin, which is connected by a permanently-open channel to the Southern Ocean. The area of the estuary inhabitable by Black Bream is assumed to cover 1000 hectares (10 km^2).

3.2.2.2. Sampling for Black Bream

Random Black Bream frames (with fillets removed) were provided annually between 2005 and 2020 by the only commercial fisher operating in the Blackwood River Estuary. Additional samples were obtained at different intervals between 2000 and 2007 and again between 2012 to 2014 by researchers using line fishing, seine netting and sunken composite gill nets. The seine net was 41.5 m long and contained a 1.5 m bunt made of 9 mm mesh and two 20 m long wings comprising 25 mm mesh. The gill net comprised six to eight panels, each 20 m long and 2 m high and with different mesh sizes, ranging in approximately equal intervals from 35 to 127 mm. In the laboratory, the total length of each Black Bream was measured to 1 mm and aged using the growth zones in the otoliths, which have been shown to form annually (Sarre and Potter, 2000). Further details of sampling and laboratory procedures are given in Gardner et al. (2013) and Cottingham, Hall and Potter (2015).

3.2.2.3. Overview of approach

To explore the effects of different release strategies for Black Bream in the Blackwood River Estuary the population was first simulated using the indices of year class strengths for both wild and cultured Black Bream and the knowledge that 150,000 cultured Black Bream were released in March 2003. The numbers of individuals surviving to the next year were then estimated using length-based mortality parameters, with their lengths derived using a modified year-specific growth model fitted to fishery-dependent and independent data (Figure 3.2.1). The resultant parameter estimates of the modified year-specific growth model were then employed to explore the effect of the different release strategies on the population (Figure 3.2.1). The data sources and information required for each step of the approach to evaluate the effectiveness of different release strategies are outlined in Figure 3.2.1.

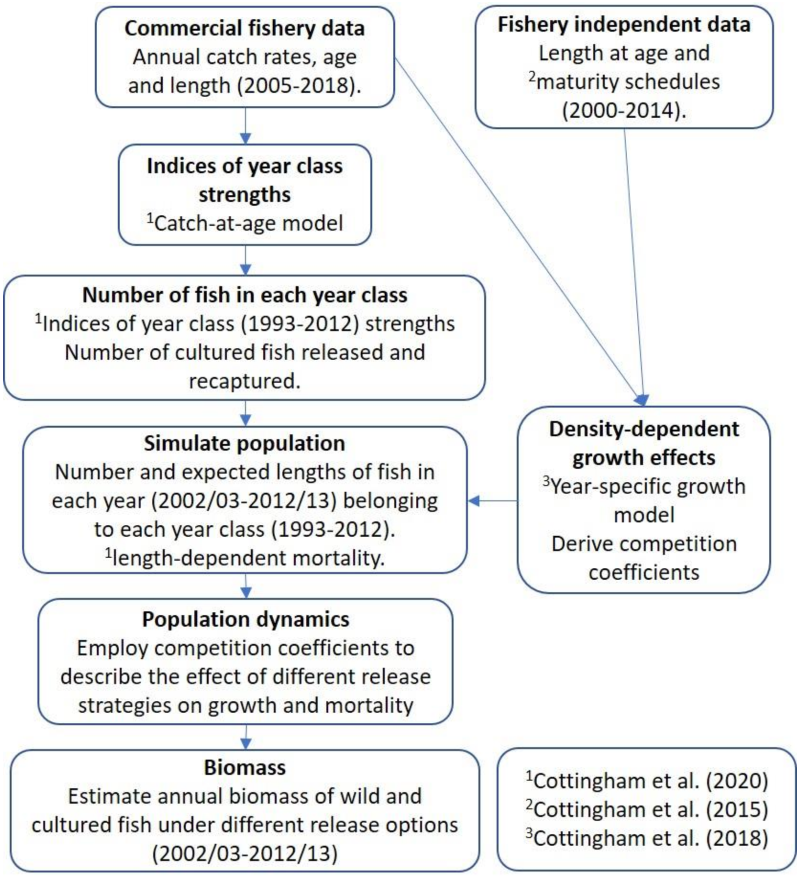

Figure 3.2.1. Flow chart of the approach, data and sources used to explore the effect of different release strategies on the population of Black Bream in the Blackwood River Estuary.

3.2.2.4. Annual biomass densities

To assess the growth responses of Black Bream to annual changes in biomass, the approximate numbers of the cultured and wild Black Bream in the estuary were determined for eleven years, between the austral spring of 2002 and winter 2013. Note that in the subsequent text, each of the 12 months between the spring of one year (September – when Black Bream spawns in this system; Williams et al., 2020) and the winter of the next year (August), is subsequently referred to as a 'year', e.g. spring 2002 to winter 2003 is referred to as 2002/03. The years (2002 to 2013) were chosen as they represent the years in which cultured fish were abundant and when sufficient data were available on the year classes present (1993 to 2012) to estimate their relative strengths (see Cottingham et al., 2020).

The numbers of individuals in each of those year classes were first derived using the point estimates of the indices of year class strengths from Cottingham et al. (2020), which were calculated using a statistical catch-at-age model fitted to annual commercial fishery data collected between 2005 and 2018. The point estimates for year class strengths for the wild year classes (and cultured fish) were used knowing the number of cultured fish released to derive estimates of the number of wild fish of the same age in each year class and calculated as follows:

1) $n_{yc} = n_{cultured} \cdot ind_{yc} / ind_{cultured},$

where n_{yc} is the initial number of 3 month old Black Bream in a year class *yc*, $n_{cultured}$ is the number of cultured Black Bream released (120,000 assuming an initial release mortality of 20 % for the 150,000 fish), ind_{yc} is the index of year class strength for the corresponding year class of the wild stock and $ind_{cultured}$ is the point estimate of the index of year class strength of the cultured fish. The above equation thus assumes a linear relationship between relative year class strength and total numbers of individuals in a year class.

The numbers of Black Bream in each year class and each subsequent year were then derived using previously derived length-dependent mortality parameters Cottingham et al. (2020).

2) $n_{y+1,yc} = n_{y,yc} - \left(n_{y,yc} \cdot M\left(\hat{L}_{t,yc}/\hat{L}_{50}\right)^{c}\right)$,

where $n_{y,yc}$ is the number of Black Bream at the start of each year *y* belonging to year class *yc*, *M* is the rate of natural mortality (0.211 y^{-1}), $\hat{L}_{50}$ is the average total length of females and males at maturity in this system (167.5 mm) and $\hat{L}_{t,yc}$ is the average length of Black Bream at age *t* belonging to year class *yc*, derived using the model described in the following section and *c* is the 'allometric exponent'. Note $n_{t,yc}$ for the first year of capture in the model, i.e. 2002/03, were estimated using $\hat{L}_t$s derived from the traditional von Bertalanffy growth model (see Cottingham et al., 2020). Based on analysis of data for 53 stocking events in seven experiments for three species (i.e. *Esox masquinongi*, *Oncorhynchus mykiss*, and *Stizostedion vitreum*), Lorenzen and Enberg (2002) concluded that a model with *c* = 1 provided the best performance and suggested using the allometric relationship with this value of *c* when assessing the optimal release size of fish in stocking programs.

3.2.2.5. Growth model

The values for the average length of Black Bream belonging to each year class *yc* (1993 to 2012) in each year *y* (2002/03 to 2012/13) were calculated using the following approach adapted from Cottingham, Hall and Potter (2016), which was developed to explore inter-annual variation in the growth of a population of Black Bream in the Swan-Canning Estuary. That model structure follows He and Bence (2007). For fish in each year between 2002/03 and 2012/13, the average length for a fish of age 0 years in year *y* was first determined using the von Bertalanffy growth equation

1) $\hat{L}_{t,y} = L_{\infty y}(1 - e^{-k_y(t_0)})$,

where 2002/03 ≤ *y* ≤ 2012/13, $L_{\infty y}$ (mm) is the asymptotic length in the year of birth, k_y (y^{-1}) is the growth coefficient in the year of birth and t_0 (y) is the hypothetical age a fish had zero length. While t_0 was assumed to be constant for all years of capture, $L_{\infty y}$ and k_y were allowed to vary in response to annual biomass densities (see later). The $\hat{L}_{t,yc}$ at the beginning of each subsequent year for each year class were then determined as

2) $\hat{L}_{y+1,yc} = r\left[\hat{L}_{y,yc} + (L_{\infty y} - \hat{L}_{y,yc})(1 - e^{k_y})\right]$,

where $\hat{L}_{y,yc}$ is the expected length of a fish belonging to year class *yc* (1992 to 2012) at the start of year y (2003/04 to 2012/13), with $\hat{L}_{2003/04,yc}$ for year classes 1992 to 2002 represented by parameters in the model, r set to 1 for wild fish and allowed to vary for cultured fish to account for the slightly slower growth that was observed in the cultured fish,

3) $L_{\infty y} = \hat{L}_{\infty} - (g \cdot B_y)$,

where *g* is the competition coefficients for response of asymptotic length ($L_{\infty y}$) to biomass, and

4) $k_y = k - (h \cdot B_y)$,

where *h* is the competition coefficients for the instantaneous growth coefficient (*k*) response to biomass (B_y mm ha^{-1} kg^{-1}), with B_y calculated using the number of individuals in each year of capture (and their expected weight) belonging to the previous 10 years classes. This approach was chosen to reduce the bias associated with, for example, the year 2002/03 comprising 10 year classes (1993 to 2002) compared with 20 year classes in 2012/13 (1993 to 2012).

5) $B_y = \sum n_{y,yc} \cdot \mathrm{a}\hat{L}_{y,yc}^{b}$,

where, a and b are the average of the female and male weight-length relationship, which were $e^{-11.384}$ and 3.058, respectively, for wild stock and $e^{-11.395}$and 3.077, respectively, for cultured stock (see Cottingham et al., 2020).

The model was thus fitted to the length at age data for the cultured and wild Black Bream belonging to the 1992 to 2012 year classes caught between 2002/03 and 2012/13. The expected length of fish *i*, from year class yc_i, caught with length L_i at decimal age a_i years in year $y = \lfloor yc_i + a_i \rfloor$, where $\lfloor x \rfloor$ represents the 'floor' function of *x*, *i.e*. the greatest integer less than or equal to *x*), the expected length,

6) $\hat{L}_i = \hat{L}_{\lfloor a_i + yc_i \rfloor, yc_i} + \left(L_{\infty \lfloor a_i + yc_i \rfloor} - \hat{L}_{\lfloor a_i + yc_i \rfloor, yc_i}\right)\left\{1 - \exp\left[-k_{\lfloor a_i + yc_i \rfloor}(a_i - \lfloor a_i \rfloor)\right]\right\}$.

The model also assumes that fish do not undergo negative growth. The base model included the parameters associated with the average lengths of each age class in 2003, the average lengths in the first year of the model, $\hat{L}_{\infty}$, k and t_0 (a 15 parameter model), i.e. without any effect of biomass on growth. When fitting the model, the log-likelihood (*LL*) was calculated assuming that the length at age of each individual at the time of capture was normally distributed with common variance, about the estimated length at age at that date. The *LL* was then recalculated including *g* and *h* both individually and together, i.e. three models, two with16 parameters and one with 17.

The above models were first compared to the traditional von Bertalanffy growth model, using only L_{∞}, k and t_0 and employing the Akaike Information Criterion (AIC), with the model with the smaller AIC value accepted as the best model. The AIC was calculated as $\text{AIC} = 2_{n_p} - 2LL$, where n_p is the number of parameters.

The resultant parameter values of the best fitting model were then used to explore the expected effect of releasing 20 and 60 mm juveniles, instead of 40 mm, and the expected effect of releasing 75,000 and 300,000, instead of 150,000, on three performance indicators. These were 1) the time taken for cultured and wild fish to enter the fishery, i.e. attain the MLL for capture; 2) the biomass. ha^{-1} of the cultured and wild fish over a 10 year period; and 3) the potential contributions, in terms of both biomass and number, to the fishery by cultured and wild fish under those different aquaculture-based enhancement options.

3.2.3. Results

3.2.3.1. Density of Black Bream in each year class

The estimates of density of (3-month-old) wild Black Bream typically ranged from 8.5 -12.2 fish ha^{-1} for the year classes between 1993 and 2012, except for 1999 (24.0 fish ha^{-1}) and 2008 (40.0 fish ha^{-1}; Figure 3.2.2) year classes.

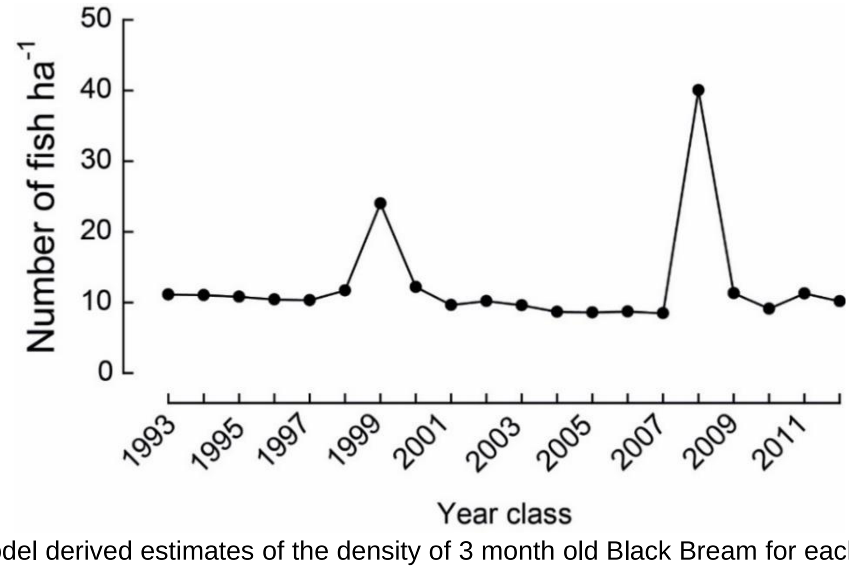

Figure 3.2.2. Model derived estimates of the density of 3 month old Black Bream for each year class 1993 to 2012 in the Blackwood River Estuary.

3.2.3.2. Model selection

The inclusion of year-specific von Bertalanffy growth parameters and the initial length of Black Bream in 2002/03 (15 parameter model) resulted in an improved fit to the traditional von Bertalanffy model, with the AIC decreasing from 27899 to 27409. The model that incorporated biomass ha^{-1} further improved to the model fit with the addition of the competition coefficient parameter *g* on L_{∞}(AIC = 27369) and to a lesser extent the competition coefficient parameter *h* on *k* (AIC = 27403), with the best model incorporating all parameters (AIC = 27337; Figure 3.2.3). The values for L_∞ and k when biomass was zero were 496 mm and 0.33 y^{-1}, with the corresponding values declining by 6.17 mm and 0.001 for each kg of biomass per hectare.

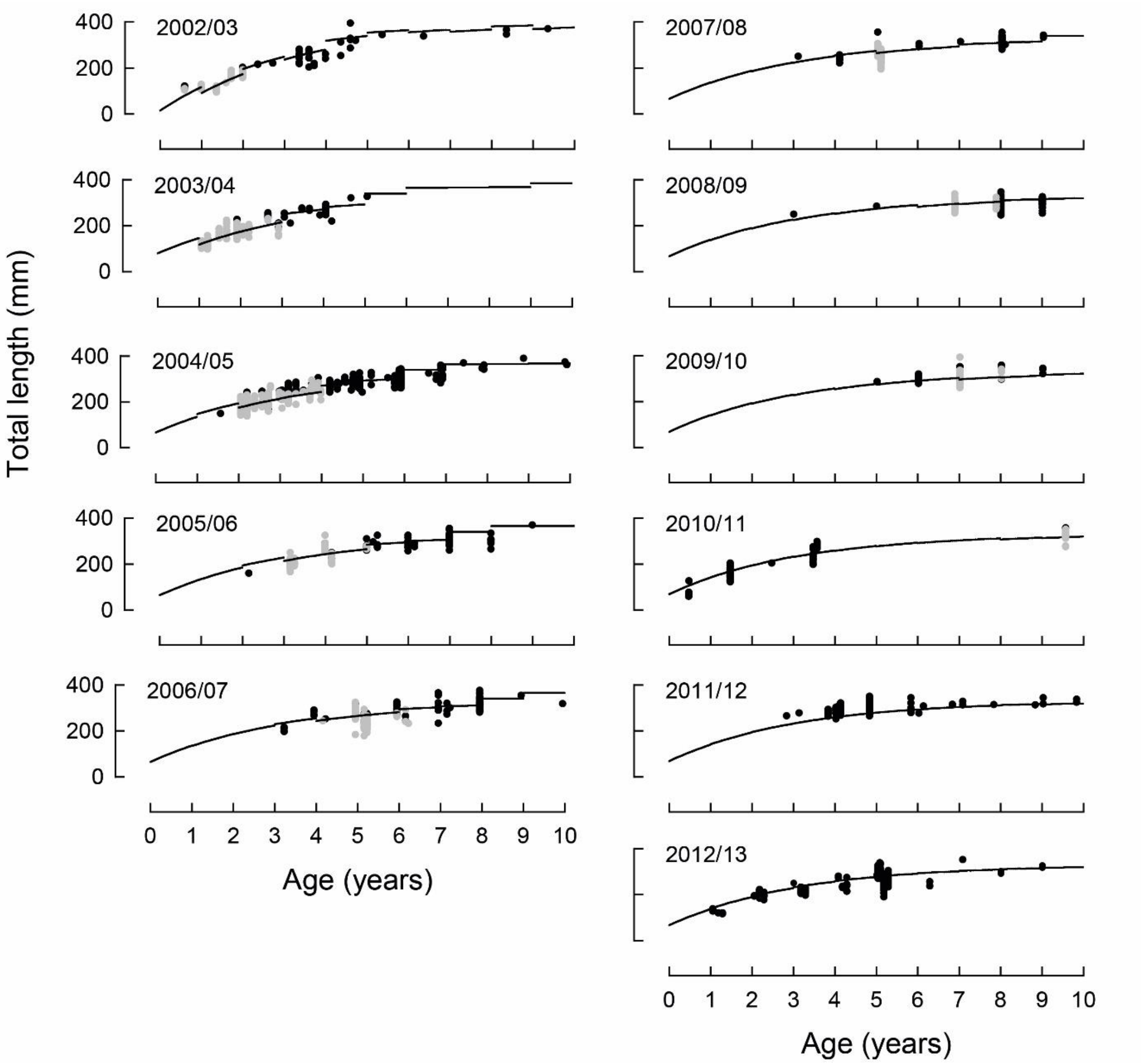

Figure 3.2.3. Lengths at age of wild (black) and cultured (grey) Black Bream caught in the Blackwood River Estuary between 2003 and 2013 and the lengths at age predicted by the fitted year-specific growth model that included competition coefficients to account for the effect of changes in annual biomass (kg h^{-1}) on L_∞ and k.

3.2.3.3. Biomass densities

The total biomass of cultured and wild Black Bream ranged from 19.8 kg ha^{-1} in 2008/09 to 23.1 kg ha^{-1} in 2003/04 (Figure 3.2.4). The biomass of cultured fish was greatest in 2009/10, when they contributed 9.8 kg ha^{-1} to the population, when the biomass of wild was 9.9 kg ha^{-1}. The greatest biomass-density of wild stock was 21.7 kg ha^{-1} in 2002/03 (Figure 3.2.4).

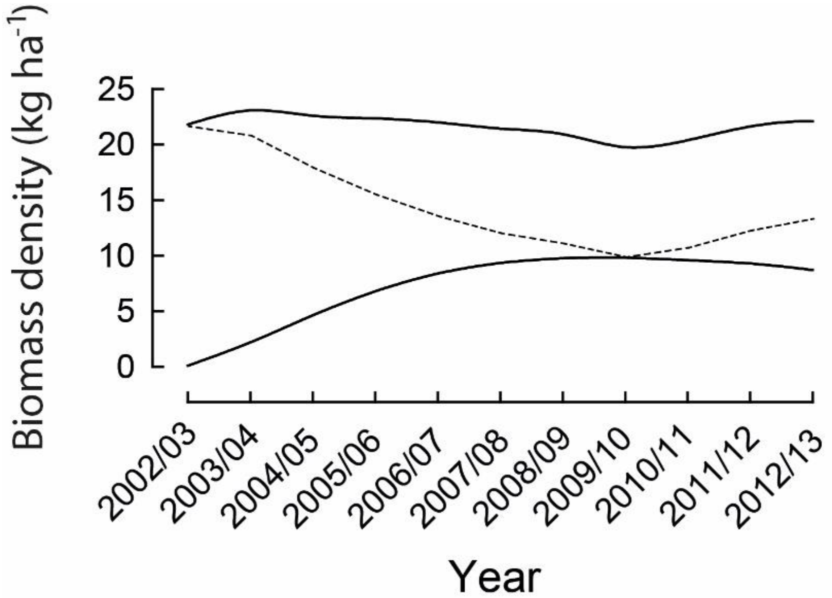

Figure 3.2.4. Model-derived biomass-densities (kg ha^{-1}) of cultured (lower line), wild fish (dashed line) and total (upper line, i.e. cultured and wild fish) of Black Bream in the Blackwood River Estuary between 2002/03 and 2012/13.

Population simulated densities of 0+ age class in each year typically ranged from 8.5 to 11.3 individuals ha^{-1}, except for the ~40.0 individuals ha^{-1} in 2008/09 (Figure 3.2.5). For wild stock 3 year old fish values typically ranged from 4.3 to 6.8 individuals ha^{-1}, but were as high as 13.3 and 20.6 in 2002/03 and 2011/12, respectively. Biomasses were typically dominated by older and thus larger fish ≥ 3 years of age (Figure 3.2.5).

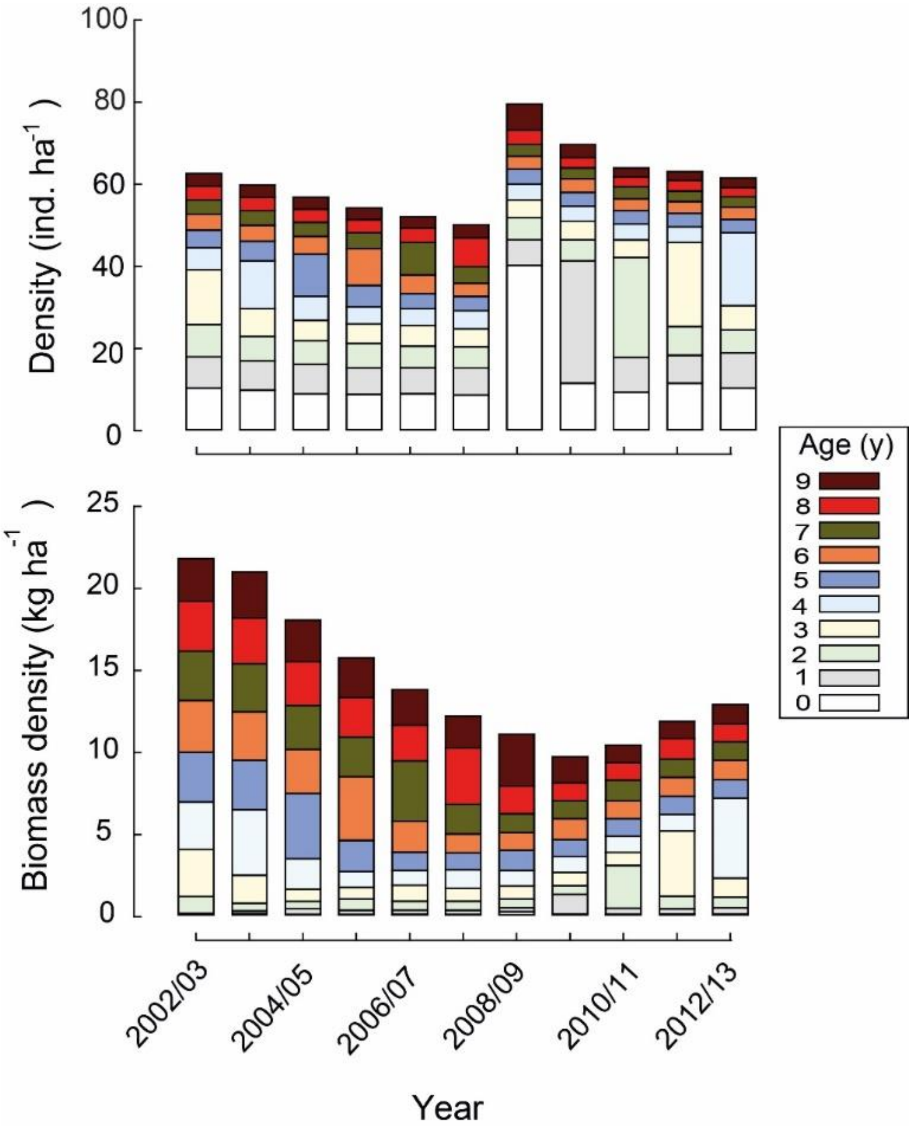

Figure 3.2.5. Density (top) and biomass (bottom) of the model-derived age structure of wild Black Bream in the Blackwood River Estuary in each year between 2002/03 and 2012/13.

Under the three different size-at-release options for 150,000 cultured Black Bream, biomass ha^{-1} of all three release options followed similar trends, with that of the 20 mm release producing the least biomass and that of the 60 mm, the greatest (Figure 3.2.6). Thus, the maximum contribution to biomass of cultured Black Bream was 8.9 kg ha^{-1} when fish were released at 20 mm and 10.6 kg ha^{-1} when they were released at 60 mm. The different sizes at release effected the biomass estimated for the wild stock, for example in 2009/10, when maximum biomass densities of cultured stock were reached, the estimated biomass densities of the wild stock were 10.5 kg ha^{-1} for a 20 mm release size and 9.5 kg ha^{-1} for a 60 mm release (Figure 3.2.6). After ~6 years the differences between the different sizes-at-release options on the total (wild and cultured fish) biomass became negligible, i.e. ~2% difference.

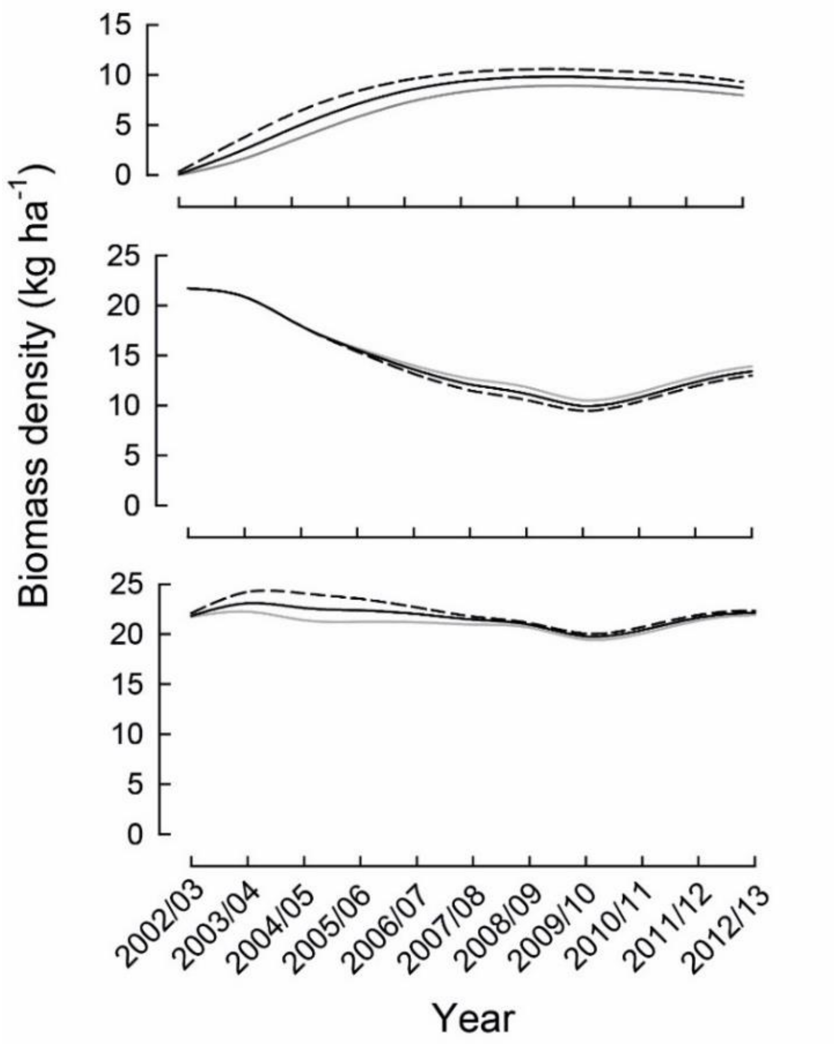

Figure 3.2.6. Biomass (kg ha^{-1}) of cultured (top graph), wild stock (middle graph) and total (bottom graph) of Black Bream in each year in the Blackwood River Estuary between 2002/03 and 2012/13.[32]

[32] Biomass densities at release size – Black line = 40 mm total length; grey line = 20 mm; dashed line = 60 mm.

3.2.3.4. Effect-of-size at release on recreational fishery

Following the release of the 150,000 (40 mm) cultured Black Bream into the estuary in 2003, ~38,050 were predicted to survive to attain the MLL of 250 mm at an age of 4.85 years (i.e. in 2008) and biomass of 10.2 kg ha^{-1} (Table 3.2.1). If those individuals were released at 20 mm, ~33,700 would have survived to attain the MLL, at which time they would be 5.05 years old (2009) and have a biomass density of 9.1 kg ha^{-1}, and if released at 60 mm, ~42,300 would have entered the fishery at age 4.60 years and a biomass of 11.4 kg ha^{-1} (Table 3.2.1). The average weights of individuals at the three different release sizes were 0.11 g (20 mm), 0.96 g (40 mm) and 3.33 g (60 mm). The predicted times taken for wild Black Bream to attain the MLL (for the 2002 year class) were 4.43 years if the cultured fish were released at 20 mm and 4.50 years if they were released at 60 mm (Table 3.2.1).

Table 3.2.1. Model-predicted values for the age ($A_{250\ mm}$, y), number surviving ($n_{250\ mm}$) and the biomass ($B_{250\ mm}$,kg ha^{-1}) for released Black Bream to attain the minimum legal length of capture (MLL = 250 mm), and the predicted age of wild fish at the MLL.

Length at release	Cultured fish			Wild fish
	$A_{250\ mm}$	n_{250mm}	B_{250mm}	A_{250mm}
20 mm	5.05	33,700	9.1	4.43
40 mm	4.85	38,050	10.2	4.46
60 mm	4.60	42,300	11.4	4.50

3.2.3.5. Effect of numbers of cultured fish released on biomass

The numbers of cultured Black Bream, of which 150,000 (40 mm) were released (and assuming an initial mortality of 20 %) were thus predicted to decline from 120,000 in 2002/03 to ~16,500 in 2012/13. The biomass-density of those 150,000 cultured fish increased from 0.11 kg ha^{-1} in 2002/03 to attain a peak of ~9.6 kg ha^{-1} in 2008/09, before declining to ~7.4 kg ha^{-1} in 2012/13 (Figure 3.2.7). For a release of 75,000 (40 mm) cultured Black Bream, their biomass would have increased from 0.05 kg ha^{-1} to 5.6 kg ha^{-1} in 2009/10, before declining to 4.3 kg ha^{-1} in 2012/13, and, for 300,000 (40 mm) cultured Black Bream were released, biomass would have increased from 0.22 kg ha^{-1} in 2002/03 to 14.9 kg ha^{-1} in 2007/08, before declining to 11.7 kg ha^{-1} in 2012/13 (Figure 3.2.7).

As trends in size-at-release, numbers-at-release among years had little effect on the predicted biomass of the wild stock for the first three years (Figure 3.2.7). However, 2009/10, the estimated wild stock biomass densities ranged from 7.4 kg to 10.0 ha^{-1} for releases of 300,000 and 75,000 cultured fish, respectfully. This difference in wild stock biomass of ~2.6 kg ha^{-1} was maintained until the end of 2012/13 (Figure 3.2.7).

The predicted total biomass (cultured and wild stock Black Bream) of the 150,000 Black Bream released remained fairly constant throughout the study period, declining from 21.7 kg ha^{-1} in 2002/03 to 19.5 kg ha^{-1} 2009/10 (Figure 8). This compares with predicted biomass-densities in 2009/10 of 17.5 kg ha^{-1} for a release of 75,000 fish and 21.8 kg ha^{-1} for a 300,000 fish release, ~12% higher than that of the 150,000 fish release (Figure 3.2.7).

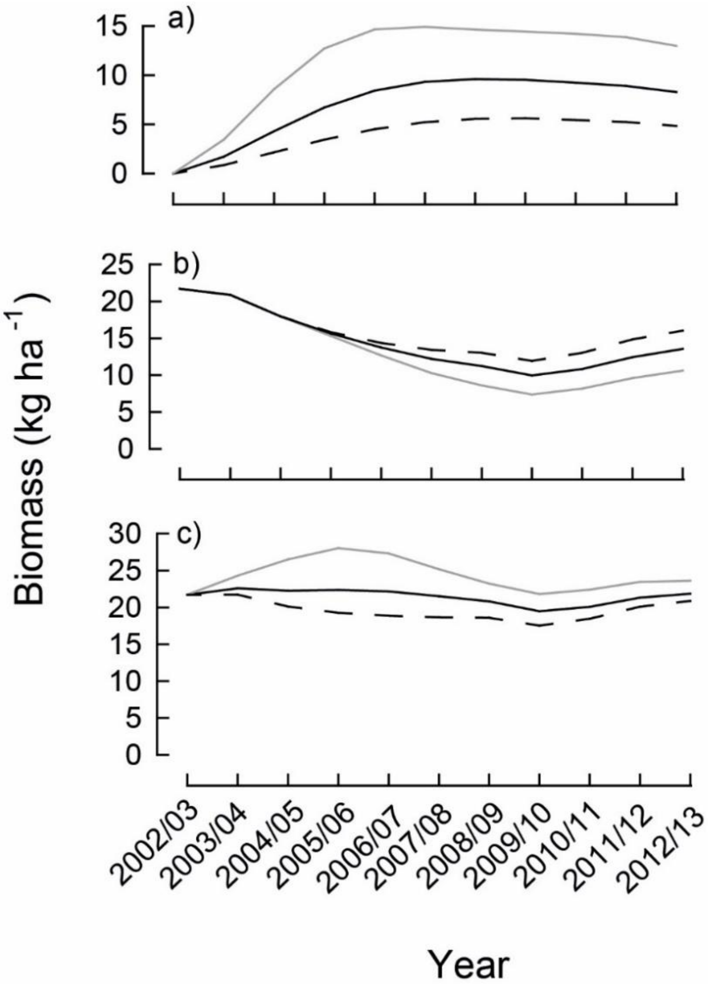

Figure 3.2.7. Biomass (kg ha^{-1}) of (a) cultured (top), (b) wild stock (middle) and (c) total (bottom) of Black Bream in each year in the Blackwood River Estuary between 2002/03 and 2012/13.[33]

3.2.3.6. Effect of numbers released on recreational fishery

Legal-sized cultured Black Bream, i.e. those ≥ 250 mm TL (of which 150,000 were released at 40 mm in length in 2002/03) began to enter the fishery in 2006/07, when they were 4.85 years old (Figure 3.2.8). For the 75,000 or 300,000 releases, the expected age at entry into the fishery varied from 4.4 to 5.5 years, respectively (Figure 3.2.8). The peak in biomass for cultured fish ranged from 5.6 kg ha^{-1} in 2007/08 for the release of 75,000 fish to 14.6 kg ha^{-1} in 2008/09 for the release of 300,000 cultured Black Bream and these values remained consistent (only declining slightly) in subsequent years (Figure 3.2.8).

Under all scenarios, the biomass of the cultured fish did not have a noticeable impact on the biomass densities of legal-sized wild Black Bream during the first ~3 years (Figure 3.2.8). The trends in biomass for the wild stock following releases of 75,000 and 150,000 cultured Black Bream were similar, with the biomass-densities of the wild stock being only slightly greater at the lower release number. In contrast, the release of 300,000 cultured Black Bream was predicted to result in marked differences in the biomass-density of the wild stock, particularly at the end of 2012/13, when biomass in that year was 4.5 kg ha^{-1}, compared to the estimated 11.2 and 13.3 kg ha^{-1} for the 75,000 and 150,000 releases, respectively. Note that the predicted low biomass-densities from the release of 300,000 cultured Black Bream were largely an artefact of slower growth delaying the entry of the particularly strong naturally recruited 2008 year class into the fishery. Thus, for example, if the model was extrapolated into 2013/14, the biomass densities of legal-sized wild stock would have more than doubled to 9.2 kg ha^{-1}.

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[33] Black line represents model-derived estimate following the release of 150,000 (40 mm) cultured fish and dashed and grey lines are those predicted through model simulation for the release of 75,000 and 300,000 cultured Black Bream, respectively.

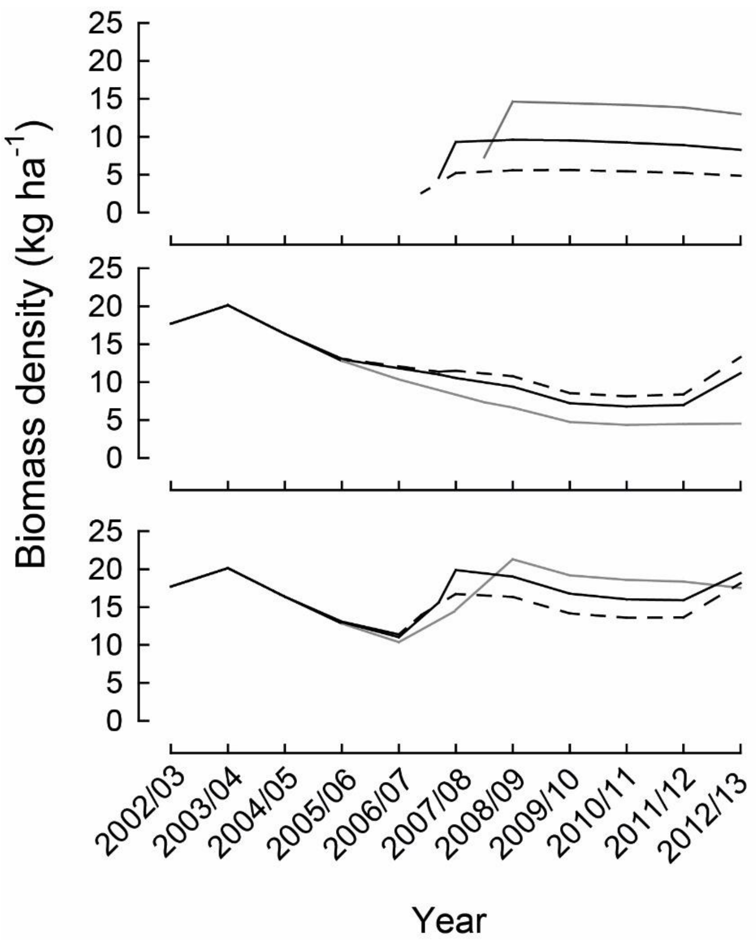


Figure 3.2.8. Biomass-densities (kg ha^{-1}) of cultured (top graph), wild stock (middle graph) and total (bottom graph) legal-sized Black Bream, i.e. those ≥ 250 mm, in each year in the Blackwood River Estuary between 2002/03 and 2012/13.[34]

3.2.4. Discussion

3.2.4.1. Overview of approach and key findings

Extensive data on recaptured and wild fish over a 10 year period allowed the development of a year-specific model to estimate the effects the effects of different sizes- and numbers-at-release on the wild, cultured and total biomass of Black Bream in the Blackwood River Estuary on the temperate south coast of Western Australia. It also allowed the effects of different release strategies on the number of fish attaining the minimum legal length of capture and the time taken to attain this size to be estimated.

3.2.4.2. Value of using a year-specific biomass growth model

The year-specific biomass growth model used in this chapter broadly resembled the structure of year-effects growth model developed by Cottingham, Hall and Potter (2016) for the population of Black Bream in the Swan-Canning Estuary ~260 km the north of the Blackwood River Estuary, with that model employed subsequently to explore annual changes in its standing biomass and production (Cottingham et al., 2018a). As with those previous studies, the year-specific model, along with the indices of year class strengths and length-based mortality parameters, derived previously by Cottingham et al. (2020) for this population, and through incorporation of density-dependent growth, facilitated a more comprehensive reconstruction of the population of Black Bream in this estuary over a 10 year period than would have been achieved using traditional approaches, such as those that employ the von Bertalanffy growth model and age-based mortality

[34] Black line represents model-derived estimate following the release of 150,000 cultured fish and dashed and grey lines are those predicted through model simulation for the release of 75,000 and 300,000 cultured Black Bream, respectively.

estimates. The resultant parameter estimates of the best fitting model demonstrated that biomass had a negative effect on $L_{\infty y}$ (the competition coefficient *g,* and to a lesser extent on k_y),- the competition coefficient (*h*), a finding that was consistent with the model developed by Lorenzen and Enberg (2002) for exploring density-dependent effects on fish populations. The resultant estimates of the biomass effect on L_{∞} of 6.17 mm ha^{-1} kg^{-1} (and *k*, 0.001 ha^{-1} kg^{-1}) in the current chapter, was well within the range recorded by Lorenzen and Enberg (2002), i.e. -3.5 to 38.9 mm ha^{-1} kg^{-1}, and thus enabled a more robust exploration of the effect of different release strategies on the population of Black Bream in the Blackwood River Estuary and its important recreational fishery.

3.2.4.3. Effect of size at release options

Of the three size at release options explored (20, 40 and 60 mm TL), the 60 mm release size produced the greatest biomass densities, which at their peak were 1.7 kg ha^{-1} greater than the 20 mm release option. However, the 60 mm TL release option also had the greatest effect on the wild stock, with the maximum difference in biomass densities between that and the 20 mm release option of ~1.0 kg ha^{-1}. The difference in biomass between any of the size-at-release options appeared negligible after ~6 years, i.e. <2%.

While it is often hypothesised that larger size-at-release is a better strategy (Halverson, 2008; Askey, Parkinson and Post, 2013; Camp et al., 2014; Garlock, Camp and Lorenzen, 2017), the optimal size-at-release will depend on the factors contributing to the recruitment bottleneck, with only the fish with lengths greater than the length at the bottleneck likely to perform well (Lorenzen, 2005). Studies of the ecology of the eggs and larvae of Black Bream in the Blackwood River Estuary concluded that the recruitment bottleneck occurred at the larval stages, which was attributed to low dissolved oxygen conditions that are now prevalent in the deeper waters following declines in freshwater discharge in recent decades due to climate change (Cottingham et al., 2020; Williams et al., 2020). This conclusion was supported by the contribution to commercial catches and research samples of the cultured fish released at 40 mm in 2002 (Cottingham et al., 2020) and was consistent with findings on the survival of Black Bream larvae in different oxygen conditions, with no larvae surviving past two days when subjected to hypoxic conditions, <2 mg/L^{-1} (Hassell, Coutin and Nugegoda, 2008). Thus, any size-at-release past the larval bream stage would probably overcome the recruitment bottleneck for Black Bream in the Blackwood Estuary.

When also considering the time taken by the individuals in the respective size at release options to attain the MLL, those at the largest size-at-release (60 mm) would have entered the fishery ~six months earlier (after 4.60 years) than those from the smallest size at release (20 mm; 5.05 years), which represents in the available biomass of 2.3 kg ha^{-1} (11.4 *vs* 9.1 kg ha^{-1}) at those times. However, these differences could be overcome through regular stocking, e.g. ~ every 5 years if natural recruitment had not occurred during that period.

3.2.4.4. Effect of numbers released

Of the three different number of individuals released (75,000, 150,000 and 300,000), the 150,000 release option provided the most constant population biomass. Thus, for example, the total population biomass of ~21.7 kg ha^{-1} in 2002/03 (irrespective of numbers released due to the small biomass of the cultured fish), ranged from 19.5 to 22.4 kg ha^{-1} under the 150,000 cultured fish release option, compared with 17.5 to 21.7 kg ha^{-1} and 21.7 to 28.1 under the 75,000 and 300,000 individuals release options, respectively. Thus, the release of the 150,000 cultured Black Bream appeared to be the best release strategy to maintain constant population biomass of the three number released options explored in this chapter.

In all the release strategies explored, the biomass densities of legal sized Black Bream in the estuary declined markedly from their peak of 20.1 kg ha^{-1} in 2003/04 to ~10.4 kg ha^{-1}, i.e. four years after the cultured fish were released and prior to those individuals contributing to catches. In the following years catches had attained levels close to that predicted in 2003/04, but for the 300,000 release option, the slower growth resulted in a delay in reaching the MLL and entering the fishery, as well as delaying the entry of the naturally recruited stock into the fishery. Similar reductions in density-related growth has been demonstrated in other Black Bream populations. For example, in the Moore River Estuary, ~400 km to the north, in which densities of Black Bream are among the highest of any estuary, it took between 7.0 and 12.4 years to attain the MLL (Sarre and Potter, 2000; Cottingham et al., 2018b).

3.2.4.5. Effect of release strategies on other biological characteristics

Although it was not explored in the model, changes in the growth of fish also likely effect reproductive schedules, with slower growing fish often postponing maturation, due to the trade-off that exists between allocating energy into maintenance and growth to improve lifetime fitness (Morita and Fukuwaka, 2007). This trade-off between growth and reproduction has been demonstrated for Black Bream throughout south-western Australia and among decades, with individuals delaying maturation under poor growing conditions (Cottingham et al., 2018b). Such delays would thus also be likely when stock densities are increased, as would be consistent with the 10 month delay of Black Bream attaining 250 mm when 300,000 were released compared with a release of 150,000. Furthermore, in many cases the slower growth not only resulted in a delay in maturation, but also individuals spawn at a smaller size, a phenomenon that is consistent with ecological theory, e.g. probabilistic maturation reaction norm models and developmental thresholds (Day and Rowe, 2002; Heino, Dieckmann and GODØ, 2002). This was evident in three of the four Black Bream populations studied by Cottingham et al. (2018b).

3.2.4.6. How often to release and release time

From the model, it would appear the frequency of release of cultured fish would be ~every 5 years, which is the time taken for released fish to attain the lengths that they can be retained by fishers and is also the approximate time taken for the biomass to decline following a release. The time of year of release is also of great importance. For example, past studies (and the current chapter) could not evaluate any of the data collected on the 70,000 Black Bream released (at ~60 mm TL) in the austral winter of 2001, as very few of those cultured fish were recaptured (Potter et al., 2008; Gardner et al., 2013; Cottingham, Hall and Potter, 2015). It is likely that those individuals did not settle before strong winter river flows, which are assumed to have flushed those individuals from the estuary (Cottingham, Hall and Potter, 2015; 2020). In contrast, the fish released in 2003 were released in early autumn and thus flows were much lower, allowing the fish to acclimatise and adapt to the natural environment.

3.2.4.7. Other considerations

The cost of production of cultured fish also must be considered in release strategies. Under the options explored it is relevant that the biomass of released fish, for example, at release of 300,000 20 mm fish (~33 kg) is far less than the biomass of 75,000 fish at 60 mm (250 kg). Thus, smaller size-at-releases have the potential to be far more cost effective than larger sizes-at-release. The cost of production of the Black Bream released into the Blackwood was $0.70 per fish (based on figures derived from Jenkins et al., 2006 and accounting for inflation). However, as the sizes-at-release explored during this chapter did not appear to have a major impact on the biomass densities of the population, smaller size at release could be an appropriate strategy. An alternative to standard intensive aquaculture approach is a semi-intensive larviculture techniques, in which phytoplankton and rotifers proliferate within the larval rearing tank (Palmer, 1991). This approach is far more efficient with the cost of production for 40-day Black Bream larvae ~ half that of traditional intensive aquaculture approach (Partridge et al., 1998).

The smaller size-at-release also reduces the effects of hatchery acclimation and potentially increases the speed with which released fish adapt to the natural environment when released. It must also be considered that aquaculture-based enhancements due to habitat loss are often considered bandage solutions rather than addressing the underlying issues (Sass, Rypel and Stafford, 2017). While such remediation of habitat is difficult in the case of estuaries in south-western Australia, in which reductions in freshwater flows are the main drivers of habitat loss, other factors, such as reducing nutrient input, can be addressed. Thus, while aquaculture-based enhancements can be an appropriate intervention to achieve short-term goals they should be used in conjunction with a longer-term vision that considers enhancements such as habitat restoration, which includes improving water quality and restoring habitat in those systems (Creighton et al., 2015; Taylor et al., 2019a).

3.3. Economic estimates of stock enhancement of Blue Swimmer Crabs and Black Bream

3.3.0. Summary

Aquaculture-based enhancement, i.e. the production of juveniles of a species in a hatchery and their release into the environment, is being increasingly utilised as a management measure to improve or restore fisheries. Due to past failures in marine stocking, a set of guidelines on the responsible approach was developed which include an assessment of the economic costs and benefits of enhancement. Benefits to commercial fishers can be inferred through catch records and income, however, there is limited information about the potential effect on recreational fisheries. Although stocks of Blue Swimmer Crabs (*Portunus armatus*) in Western Australian estuaries are classified as "sustainable" by fishery managers, those in the nearby marine embayment of Cockburn Sound are low and the fishery has been predominantly closed since 2006 and fully closed since 2014. With no increase in abundance, stocking has been suggested as a potential management intervention. Stocks of Black Bream (*Acanthopagrus butcheri*) have been successfully increased following stocking in south-western Australia. This chapter builds on earlier work estimating the economic value of recreational Blue Swimmer Crab (Section 2.1) and Black Bream (Section 2.2) fishing and estimates the effect a hypothetical stocking project where abundances and fisher catch rates are increased by 50%, on the economic value of the fishery. Recreational Blue Swimmer Crab fishers elicited that their fishing frequency would increase post stocking. Using existing information on their direct expenditure and opportunity cost per trip, there would be an increase in annual value by 159 and 109% in the Swan-Canning and Peel-Harvey estuaries, to give estimated values of ~$16.5 million and ~$19.7 million, respectively. Although the estimated values for consumer surplus derived from a negative binomial model declined slightly, the increase in the number of trips conducted resulted in increased estimates for the aggregate consumer surplus by 135% in the Swan-Canning (~$1.7million to ~$4.2 million) and by 57% in the Peel-Harvey (~$2.0 million to ~$3.2 million). Based on the estimated changes in economic value, the stock enhancement scenario proposed would result in a substantial increase in the economic value of recreational crab fishing. Recreational Black Bream fishers stated that their fishing frequency would increase post stocking and thus there would be an increase in annual value by between 31 and 176% in a range of estuaries. Estimated values for consumer surplus were able to be derived from a negative binomial model for the Swan-Canning and Walpole-Nornalup estuaries. Values in the Swan-Canning increased slightly from $12.52 (pre-enhancement) to $14.75 (after hypothetical enhancement), with a much more marked increase estimated for the Walpole-Nornalup, i.e. $28.90 to $55.25 (an estimated 91.2% increase vs 17.8% in the former estuary). Moreover, the number of fishing trips recreational fishers said they would conduct would also increase. These changes were estimated to increase the aggregate consumer surplus by 166% in the Swan-Canning (~$3.8 million to ~$6.3 million) and by 426% in the Walpole-Nornalup (~$267,000 to ~$1.4 million). Based on the estimated changes in economic value, the stock enhancement scenario proposed would result in a substantial increase in the economic value of recreational crab and bream fishing. While any enhancement program would require funds and around half of recreational fishers were willing to pay an annual fee to contribute to the cost the enhancement, with the majority offering a maximum fee of ≤ $20.

3.3.1. Introduction

Stocks of many fishery species are under pressure from a range of influences, including commercial and recreational fishing, climate change and habitat degradation (Roessig et al., 2004; Deegan and Buchsbaum, 2005; Edgar, Ward and Stuart-Smith, 2018), with (Halpern et al., 2008) estimating that no parts of the oceans were unaffected by human influences. Many of these threats occur in coastal areas, with temperate estuaries regarded as the most degraded of all aquatic ecosystems (Jackson et al., 2001). Furthermore, those located in microtidal (tidal range < 2 m) regions of the world, such as south-western Australia, are increasingly recognized as being particularly vulnerable to anthropogenic perturbations (Tweedley, Warwick and Potter, 2016; Warwick, Tweedley and Potter, 2018; Cowley, Tweedley and Whitfield, 2022), which can impact their fish and crustacean populations and fisheries. For example, overexploitation and changes in environmental conditions led to marked declines in the stocks of the Western School Prawn (*Metapenaeus dalli*) in the Swan-Canning Estuary and the cessation of most recreational fishing due to low catch rates (Broadley, Tweedley and Loneragan, 2017; Tweedley et al., 2017c). Moreover, overfishing that coincided with a period of severe habitat degradation, including flow reduction, eutrophication, benthic habitat loss and hypoxia resulted in declined in the abundance the plotosid catfish Cobbler (*Cnidoglanis macrocephalus*) in several estuaries on the lower west coast of Australia (Smith and Lenanton, 2021).

Fish stocks and therefore fisheries productivity can be constrained by several factors, including recruitment, habitat, trophic and genetic bottlenecks (Becker et al., 2018). Fisheries enhancement, which includes aquaculture-based and habitat-based enhancements if used appropriately can alleviate these constraints (Taylor et al., 2017; Ramm et al., 2021). Aquaculture-based enhancement, comprising stock enhancement, restocking and sea ranching, involves the release of hatchery-reared fish and can mitigate poor recruitment and potentially also low genetic diversity (Crisp et al., 2018; Kitada, 2018). However, the aquaculture of target species can be expensive and thus the cost and benefits of the program should be determined (Adams, Lindberg and Stevely, 2006; Ammar, 2009; Lorenzen, Leber and Blankenship, 2010). To date, there has been limited research on the economic effect of the fisheries subject to aquaculture-based enhancement and particularly those utilised by the recreational sector (Rutledge et al., 1990; Palmer and Snowball, 2009; Taylor, 2017b). The benefits generated by such projects are generally non-market values and reflect the recreational utility fishers derive from fishing. The utility cannot be observed in the market transaction but represents the economic surplus that recreational fishers derive from fishing when aquaculture-based enhancements are implemented. The economic or consumer surplus that recreational fishers derive from any enhancement is the value they derive from fishing over and above the cost they incur. These values can be estimated indirectly using econometric recreational demand models.

One study that investigated the cost-effectiveness of an aquaculture-based enhancement was that of Hunt et al. (2017) for a put and take recreational fishery for non-native salmonid species in Lake Purrumbete, Victoria, Australia. The observed economic expenditure (market value) associated with the stocking program was estimated to be $351,741 with a 1:4 cost-benefit ratio return on the cost of stocking. The additional willingness to pay (non-market recreational value of the stocked fishery), estimated using the travel cost method, was an additional $84 − $291 per person per day with a 1:5 to 1:16 cost-benefit ratio return on stocking investment (Hunt et al., 2017). While in this case stocking provided substantial economic benefits, this is not always the case. For example, only one of the nine stocking programs investigated by Hilborn (1998) was economically successful. It is situations such as this that led to assessing the economic and social benefits and costs of enhancement and alternatives (e.g. habitat restoration) at all stages of program development being a component of the responsible approach to aquaculture-based enhancements (Lorenzen, Leber and Blankenship, 2010). Rather than conducting the cost-benefit after the release of cultured-individuals there is value in estimating this prior to committing to any enhancement project.

In Western Australia, the Blue Swimmer Crab (*Portunus armatus*) is one of the most targeted and commonly caught species by boat-based fishers (Ryan et al., 2019). Stocks in the Swan-Canning and Peel-Harvey estuaries are regarded by local fisheries managers as “sustainable” and the latter fishery was Marine Stewardship Council certified in 2016 (Morison et al., 2016). However, in the nearby marine embayment of Cockburn Sound, commercial catches reached 300t in the late 1990s but began to drop in the early 2000s until 2006 when the fishery was closed (Johnston et al., 2011). The collapse of this fishery is thought to largely be due to lower water temperatures prior to the breeding season from 2002 to 2005, reducing the length or breeding season, and the number of batches of eggs that females were able to produce and, as a consequence, greatly reducing the population fecundity, combined with continued fishing pressure on mated pre-spawning females during winter (Johnston et al., 2011). Stock enhancement was suggested by these authors in 2011 as a potential management measure to increase stocks if they did not fully recover following revised management measures and, as of 2022, this fishery remains closed to commercial and recreational fishing. A number of aquaculture-based enhancement programs designed to increase stocks of commercially important portunid species have occurred, including for Gazami Crabs in Japan, Blue Crab in the USA, Blue Swimmer Crabs in Thailand, the Mud Crab *Scylla paramamosain* in Japan and several species of Mud Crab in the Philippines (Nghia et al., 2007; Tweedley et al., 2017a). In each case, successful hatchery techniques were developed to enable small-scale production (Zmora et al., 2005), however, only in the case of the Gazami

Crab was production increased to a commercial scale of ~27-35 million juveniles per year (Hamasaki et al., 2011).

The Black Bream (*Acanthopagrus butcheri*) is a relatively long-lived and large sparid endemic to estuaries in Southern Australia (Sarre and Potter, 2000). This species completes its life cycle within its natal estuary and the strength of recruitment varies markedly within and among estuaries (Sarre and Potter, 1999; Jenkins et al., 2015). Due to this life history strategy of remaining in estuaries, if a population becomes depleted, it cannot be naturally replenished from outside sources. In the Blackwood River Estuary, concerns from the sole commercial fisher and declining catch rates of recreational fishers determined from creel surveys and a comparison of two fishery-independent surveys suggested that the abundance of Black Bream had declined (Jenkins et al., 2006; Prior and Beckley, 2007). To increase stocks, an aquaculture-based enhancement program (FRDC 2000/180) was subsequently developed (Jenkins et al., 2006). During that project 220,000 juvenile Black Bream were introduced at a cost of ~$0.50 (2001 $AUD) per released fish. Due to high rate of survival (i.e. 35% over 12 months and 16% to minimum legal length of 250 mm, the cost of each stocked fish that survived to reach legal size was estimated to be $1.60, exclusive of the cost of monitoring. Monitoring and chemical tagging increased the cost to $2.19 per fish for each recruit entering the fishery (WAFF, 2007). Due to the effects of climate change, i.e. reduced freshwater discharge, growth rates and the body condition of Black Bream have declined and recent mass mortality events have occurred in a number of estuaries (Krispyn et al., 2021; Cottingham et al., 2022). Aquaculture-based enhancement having proved successful in the Blackwood River Estuary suggests that such a program could be used in other estuaries. Moreover, the results of Section 3.2 indicate that in the absence of natural recruitment, however, releases of 150,000 juveniles are likely to be necessary in the Blackwood River Estuary every five years to mitigate the recruitment bottleneck and maintain productive stocks. Such a program will have an economic cost and a mechanism is needed to provide funds (WAFF, 2007).

In light of the above, the first aim of this chapter is to expand on an economic valuation of the recreational fishery for Blue Swimmer Crabs and Black Bream (Sections 2.1 and 2.2) and estimate how a hypothetical successful aquaculture-based enhancement project that increased catch rates would influence recreational fishers fishing frequency and economic expenditure and use these to estimate how this would affect the economic value of the fisheries in the various estuaries. Although enhancement of crabs is not required currently (Section 3.1), the results of the chapter could be transferable to Cockburn Sound and to aid in future decision making. The second aim of this chapter is to estimate the willingness of recreational fishers to fund any future aquaculture-based enhancement project.

3.3.2. Methods

Information on the study estuaries and their Blue Swimmer Crab and Black Bream fisheries are provided in subsection 1.2.2.1.

The survey was the same as that used in Section 2.1 and comprised three major sections, i.e. revealed preference, stated preference and demographic information. Note that the methodology and results of the revealed preference and demographic components are given in Section 2.1 and this chapter only used the results generated from the stated preference section of the survey. In this part of the survey, respondents were given the following scenario. "*Stock enhancement could be introduced in the estuary to fish in, which increases the number of Blue Swimmer Crabs available to be taken by recreational fishers by 50% and their catch rate by 50%. This means that you could catch more crabs within a shorter time frame".* They were asked how many times they would fish in each of the estuaries after the enhancement (to compare to the without enhancement value they provided in the revealed preference part of the survey). Follow-up questions focused on would fishers be satisfied by the number of Blue Swimmer Crabs they would catch, that they would keep and about the time taken to obtain that catch if this scenario occurred.

The reported willingness of recreational fishers to pay for enhancement was determined by their answer to the following set of questions. The initial question stated that the hypothetical stock enhancement would require an annual recreational fishing licence fee. Current regulations state that a licence costing AUD $40 is only required if a fisher is operating from a boat, there is no licence required for shore-based fishing (DPIRD, 2022). This enhancement fee would be $10 and be paid in addition to any boat-based fishing licence (i.e. fishers would pay either $10 or $50). The resultant fees would solely be used to fund the enhancement. If respondents selected '*yes*' they were then asked to state the maximum amount of money they would be willing to pay annually. If a respondent said '*no*' they were not willing to pay the initial $10 enhancement fee, they were provided the range of options including a $5 fee and a suite of other options to select from to explain their decision and the text box to enter their own explanation.

Full details of the methodology and rationale are provided in Section 2.1.2. The major differences between the data in Section 2.1.2 and the current chapter is the number of trips here are the estimated number that could be conducted after enhancement rather than the number undertaken in the last 12 months as in Section 2.1.2.

3.3.3. Results

3.3.3.1. Satisfaction and change in economic value of recreational Blue Swimmer Crab fishery

Recreational Blue Swimmer Crab fishers were asked if they were happy with the number of crabs they currently caught and kept and the time taken to catch those individuals. These questions were answered again after the respondent was provided with the hypothetical stock enhancement scenario. In all cases, the percentage of fishers that stated they would be satisfied after crab stocks were enhanced increased by between 20 and 25% (Figure 3.3.1).

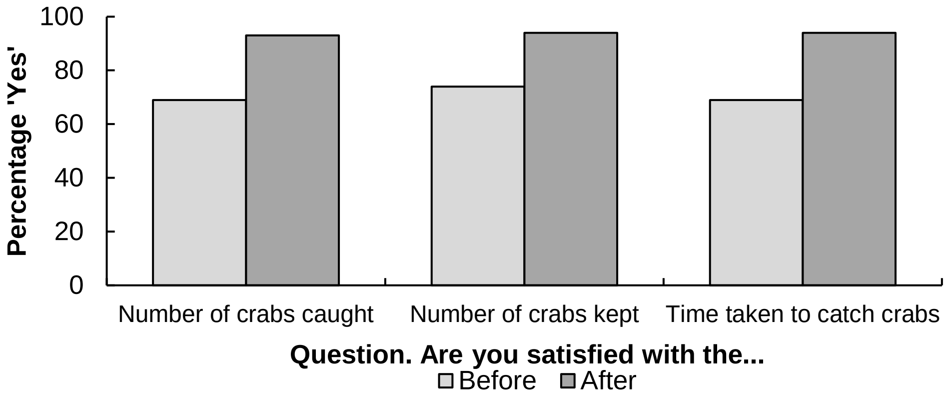


Figure 3.3.1. Percentage of recreational Blue Swimmer Crab fishers that agreed (selected yes) when asked if they were satisfied with the number of crabs they caught and kept, and the time taken to catch then and then asked the same question again having been provided with a stock enhancement scenario.

When considering the impact that increased numbers of Blue Swimmer Crabs would have on their fishing frequency, recreational fishers stated that, in all three main estuaries, there would be increased visitation. This was estimated to increase from 3.57 to 9.23 trips in the Swan-Canning Estuary, from 3.49 to 7.30 in the Peel-Harvey Estuary and from 1.67 to 3.42 in Leschenault Estuary (Table. 3.3.3). Assuming that the direct expenditure and opportunity cost per trip previously calculated (Section 2.1) remain the same and, being conservative, that the number of fishers is also unchanged the magnitude of recreational fisher expenses increases by 105% in the Leschenault, 109% in the Peel-Harvey and 159% in the Swan-Canning (Table. 3.3.1).

Table 3.3.1. Per trip direct expenditure and opportunity cost before and after the stock enhancement scenario for Blue Swimmer Crabs is initiated. Green shading indicates an increase in value.

	Swan-Canning	Peel-Harvey	Leschenault
Before enhancement			
Per trip direct expenditure	$114.39	$85.77	$57.40
Per trip opportunity cost	$48.27	$43.31	$42.23
No Trips	3.57	3.49	1.67
Total	$6,362,432	$9,442,963	$452,676
After enhancement			
No Trips	9.23	7.3	3.42
Total	$16,465,023	$19,742,329	$928,892
Change (value)	$10,102,591	$10,299,366	$476,216
Change (%)	159	109	105

The consumer surplus generated from recreational fishing after the hypothetical case of stock enhancement was calculated using a negative binominal model, which was preferred over the Poisson model due to over-dispersion (Table 3.3.2). These tests generated similar results to those in the real-world scenario, i.e. without stock enhancement (see Table 2.1.8), in that the round trip cost was significant and negative and that the opportunity cost of travel time was also significant but positive in both the Swan-Canning and Peel-Harvey estuaries (Table 3.3.2).

Using this model, the consumer surplus per fishing trip in the Swan-Canning Estuary decreased slightly from $20.49 to $18.62 (Table 3.3.3). However, given fishers stated that the average number of crabbing trips they would undertake post stock enhancement increased markedly, the aggregate surplus value for recreational Blue Swimmer Crab fishing increased by 135% from ~$1.7million to ~$4.2 million. A similar situation is estimated for the Peel-Harvey Estuary, where once again there was a decrease in the per trip consumer surplus from $7.30 to $9.71 but a commensurate increase in the frequency of fishing trips. Therefore, the aggregate surplus value was estimated to be 57% larger at ~$3.2 million, up from ~$2.0 million without stock enhancement.

In both estuaries, the stock enhancement scenario proposed was estimated to result in an increase to the economic value of recreational crab fishing substantially.

Table 3.3.2. Results of Poisson and Negative Binomial models for the economic value of recreational Blue Swimmer Crab fishing following stock enhancement. Note Leschenault Estuary was excluded from this due to the model failing to converge.

Variable	**Swan-Canning**		**Peel-Harvey**	
	Poisson	**Nbreg**	**Poisson**	**nbreg**
Round trip cost	-0.0666***	-0.0537**	-0.0342***	-0.137**
	(-7.60)	(-3.06)	(-3.60)	(-3.10)
Opportunity cost of travel	0.197***	0.252***	0.152***	0.559***
	-10.04	-4.09	-4.58	-3.59
Opportunity cost of fishing	-0.00154	-0.00636	0.0000762	-0.000237
	(-1.57)	(-1.00)	-0.62	(-0.55)
Fuel cost	-0.0720***	-0.0586	0.0258	0.0277
	(-4.50)	(-0.94)	-1.66	-0.54
Bait cost	0.0211	-0.055	-0.0278*	-0.0489
	-1.86	(-0.94)	(-1.99)	(-1.09)
Ice cost	-0.0566***	-0.083	-0.018	-0.011
	(-4.23)	(-1.20)	(-1.12)	(-0.20)
Year of experience	-0.0148**	-0.0287	0.000641***	0.00077
	(-3.21)	(-1.31)	-4.14	-0.7
No. of crabs caught	0.00516	0.00511	0.0150***	0.0190**
	-1.36	-0.28	-14.54	-2.96
No. of crabs kept	0.00549	0.00601	0	0
	-1.21	-0.28	(.)	(.)
Female	0	0	0.435**	1.497*
	(.)	(.)	-2.65	-2.18
Male	2.097***	3.860**	0	0
	-6.12	-3.08	(.)	(.)
18 to 24 years	0	0	-1.066***	-0.524
	(.)	(.)	(-5.99)	(-0.73)
25 to 34 years	-0.379	-0.137	-0.193	0.204
	(-1.88)	(-0.16)	(-1.08)	-0.25
35 to 44 years	0.0886	-0.0566	-0.614***	0.284
	-0.4	(-0.06)	(-3.62)	-0.35
45 to 54 years	-0.113	-0.972	0.0495	0.946
	(-0.56)	(-1.00)	-0.24	-1.03
55 to 64 years	-0.503	1.013	-1.972***	-1.685
	(-1.56)	-0.67	(-4.73)	(-1.36)
65+ years	-0.813	-1.388	0	0
	(-1.12)	(-0.43)	(.)	(.)
$1-$20,799	0	0	-1.444***	-2.388*
	(.)	(.)	(-6.64)	(-2.47)
$104,000-$142,999	1.544***	3.281**	-2.683***	-5.108***
	-3.88	-2.79	(-10.88)	(-4.23)
$143,000-181,999	1.440***	1.757	-2.007***	-3.801***
	-3.4	-1.28	(-8.42)	(-3.52)
$182,000-$233,999	1.620***	3.265*	-1.292***	-1.897*
	-3.98	-2.52	(-5.79)	(-2.18)
$20,800-$41,599	1.109**	1.211	-15.24	-19.3
	-2.69	-1.04	(-0.02)	(-0.00)
$286,000-$337,999	2.013***	4.110*	-3.021***	-6.203**
	-3.64	-2.18	(-9.42)	(-3.16)
$234,000-$285,999	1.571*	3.967	-0.835***	-1.615
	-2.26	-1.13	(-4.25)	(-1.72)
$41,600-$62,399	0.761	0.67	-0.611***	-1.987*
	-1.75	-0.53	(-3.51)	(-2.32)
$62,400-$83,199	2.450***	3.484**	-0.727***	-0.592
	-6.09	-3.1	(-3.98)	(-0.69)
$84,000-$103,999	0.876*	1.487	-0.744**	-1.294
	-2.08	-1.4	(-2.92)	(-1.33)
No income ($0)	1.184**	3.465*		-0.00102
	-2.71	-1.96		(-0.07)
Constant	-1.128*	-3.321	1.642***	-0.386
	(-2.13)	(-1.92)	-5.89	(-0.35)
Lnalpha				
Constant		0.593**		0.181
		-2.82		-0.8
AIC	1083.6	486.7	786.4	461.9
BIC	1149.2	554.8	849.7	530

Note: t statistics in parentheses; significant terms shaded in grey * = $p < 0.05$, **= $p < 0.01$, ***= $p < 0.001$.

Table 3.3.3. Per trip direct expenditure before and after the stock enhancement scenario for Blue Swimmer Crabs is initiated. Green shading indicates an increase in value.

	Swan-Canning	Peel-Harvey
Before enhancement		
Consumer surplus	$20.49	$9.71
No Trips	3.57	3.49
Total	$1,776,161	$2,060,046
After enhancement		
Consumer surplus	$18.62	$7.30
No Trips	9.23	7.3
Total	$4,176,949	$3,237,954
Change (value)	$2,400,788	$1,177,908
Change (%)	135	57

3.3.3.2. Satisfaction and change in economic value of recreational Black Bream fishery

Recreational fishers were asked if they were happy with the number of Black Bream they currently caught and kept and the time taken to catch those individuals and then the same suite of questions after being provided with the hypothetical stock enhancement scenario. In all cases, the percentage of fishers that stated they would be satisfied after stocks were enhanced increased by 20 and 22% for time taken to catch fish and the number of fish caught, respectively, but by a lower amount (8%) when referring to the number of fish kept as the initial proportion of fishers satisfied was greater (e.g. 81% vs 69% for the other questions; Figure 3.3.2).

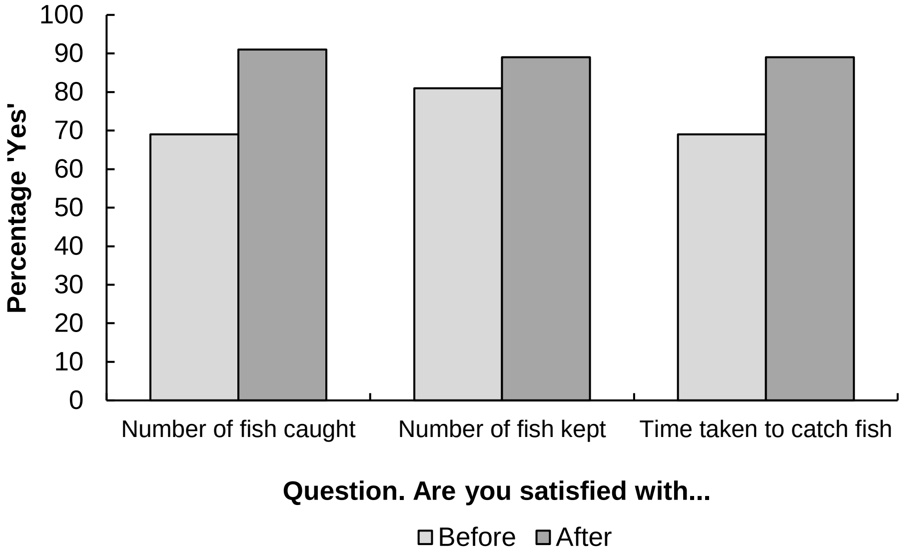


Figure 3.3.2. Percentage of recreational Black Bream fishers that agreed (selected yes) when asked if they were satisfied with the number of fish they caught and kept, and the time taken to catch then and then asked the same question again having been provided with a stock enhancement scenario.

When considering the impact that increased numbers of Black Bream would have on their fishing frequency recreational fishers stated that in all three systems (Swan-Canning, Peel-Harvey and Blackwood), there would be increased visitation. Fishers utilising the Swan-Canning stated they would fish, on average, 31.4 times a year following the stock enhancement scenario compared to 15.2 currently; an almost doubling of the number of trips. A proportional increase of a similar magnitude was recorded for the other estuaries ranging from 1.3 and 1.4 times more trips in the Peel-Harvey and Blackwood River estuaries to 2.8 times in the Walpole-Nornalup, albeit the overall number of trips to these estuaries located further away from Perth is less than that for the Swan-Canning Estuary (Table 3.3.4).

Assuming that the direct expenditure and opportunity cost per trip previously calculated (Section 2.2) remain the same and, being conservative and that the number of fishers is unchanged the magnitude of these expenses increases by between 31 and 176% (Table 3.3.4). Increases in expenditure are least in the Peel-Harvey, Blackwood and 'other' estuaries on the south coast at 31%, 47% and 63%, respectively, and largest in the Swan-Canning (106%) and Walpole-Nornalup (176%).

Table 3.3.4. Per trip direct expenditure before and after the stock enhancement scenario for Black Bream is initiated. Green shading indicates an increase in value.

	Swan-Canning	Peel-Harvey	Blackwood
Before enhancement			
Per trip direct expenditure	$261.41	$212.60	$311.64
Per trip opportunity cost	$246.50	$99.31	$611.11
No Trips	15.21	3.23	2.04
Total	$60,581,417	$2,190,695	$4,777,676
After enhancement			
No Trips	31.4	4.23	3
Total	$125,085,152	$2,868,245	$7,025,994
Change (value)	$64,503,735	$677,551	$2,248,318
Change (%)	106	31	47

	Walpole-Nornalup	Wilson	Other south coast estuaries
Before enhancement			
Per trip direct expenditure	$527.50	$131.67	$917.65
Per trip opportunity cost	$363.14	$157.64	$194.24
No Trips	0.77	0.42	2.05
Total	$2,192,332	$363,799	$18,994,702
After enhancement			
No Trips	2.12	0.8	3.35
Total	$6,042,068	$692,950	$31,040,123
Change (value)	$3,849,736	$329,151	$12,045,421
Change (%)	176	90	63

The consumer surplus generated from recreational Black Bream fishing after the hypothetical case of stock enhancement was calculated using a negative binominal model, preferred over the Poisson model (Table 3.3.5). These tests generated similar results to those in the real-world scenario, i.e. without stock enhancement (see Table 2.2.8), in that the round trip cost was significant and negative and that the opportunity cost of travel time was also significant but positive in both the Swan-Canning and Walpole-Nornalup estuaries and for the number of fish caught in the latter estuary.

Using this model, the consumer surplus per fishing trip in the Swan-Canning estuary increase slightly from $12.52 to $14.75 (Table 3.3.6). This, combined with fishers stating that the average number of fish trips they would undertake for Black Bream post stock enhancement increased markedly, the aggregate surplus value for recreational Black Bream fishing increased by 166% from ~$3.8 million to ~$6.3 million. A similar situation is estimated for the Walpole-Nornalup Estuary, where once again there was an increase in the per trip consumer surplus, but this time far more markedly from $28.90 to $55.25 and also in the frequency of fishing trips. Therefore, the aggregate surplus value was estimated to be 426% larger at ~$1.4 million, up from only ~267,000 without stock enhancement.

In both estuaries, the stock enhancement scenario proposed was estimated to increase the economic value of recreational Black Bream fishing substantially.

Table 3.3.5. Results of Poisson and Negative Binomial models for the economic value of recreational Black Bream fishing following stock enhancement.

	Swan-Canning		Walpole-Nornalup		Wilson		Blackwood	
Variable	**Poisson**	**Nbreg**	**Poisson**	**nbreg**	**Poisson**	**nbreg**	**Poisson**	**nbreg**
Round trip cost	-0.0595***	-0.0678***	-0.0224***	-0.0181*	-0.00237	-0.0372	-0.0139***	-0.00853
	(-22.39)	(-6.40)	(-3.43)	(-2.03)	(-0.14)	(-1.20)	(-4.46)	(-0.46)
Opportunity cost of travel time	0.191***	0.259***	0.0995***	0.0855*	0.0225	0.157	0.0642***	0.0526
	-27.1	-6.4	-4.12	-2.54	-0.35	-1.35	-5.63	-0.76
No. fish caught	0.00916***	0.0189	0.0123***	0.0139**	0.0153***	0.0145**	0.00516***	0.0109**
	-4.12	-1.15	-6.1	-2.81	-8.74	-2.88	-13.82	-2.65
No. fish kept	0.0189***	0.0179	-0.0279	-0.0312	0.0922*	0.0454	0.0313***	0.028
	-14.86	-1.84	(-1.48)	(-0.90)	-2.57	-0.39	-4.35	-0.84
Female	0	0	0	0	0	0	0	0
	(.)	(.)	(.)	(.)	(.)	(.)	(.)	(.)
Male	0.863***	0.413	1.316***	-0.592	-0.909	-1.647	1.388***	-1.143
	-7.52	-0.6	-3.55	(-0.71)	(-1.83)	(-1.85)	-4.23	(-1.06)
Other	0.0318	-0.358	2.156***	-0.119	-0.877	-1.884	1.623**	-1.1
	-0.15	(-0.32)	-4.29	(-0.09)	(-1.38)	(-1.30)	-3.06	(-0.67)
$20,800-$41,599	0.162**	-0.471	-0.691	-0.214	2.179*	1.709	0.545	0.611
	-2.73	(-0.95)	(-1.91)	(-0.30)	-2.11	-1.44	-1.43	-0.73
$234,000-$285,999	-0.398**	-1.149	-12.16	-14.91	-12.41	-19.5	-0.244	-0.753
	(-2.85)	(-0.89)	(-0.02)	(-0.01)	(-0.01)	(-0.00)	(-0.31)	(-0.42)
$286,000-$337,999	-1.295***	-1.86	-4.662***	-5.604**	-12.41	-19.5	-12.72	-16.06
	(-4.78)	(-1.45)	(-5.49)	(-2.60)	(-0.01)	(-0.00)	(-0.02)	(-0.00)
$182,000-$233,999	-1.184***	-2.132	-0.182	-0.473	-12.41	-19.5	-12.72	-16.06
	(-6.29)	(-1.64)	(-0.42)	(-0.37)	(-0.01)	(-0.00)	(-0.02)	(-0.00)
$41,600-$62,399	-0.0794	-0.606	-0.812*	-0.747	0.734	1.639	1.558***	0.851
	(-1.36)	(-1.27)	(-2.31)	(-1.06)	-0.69	-1.39	-4.43	-1.06
$62,400-$83,199	-0.226***	-0.527	-1.581***	-1.932*	1.05	0.818	0.441	-0.11
	(-3.62)	(-1.12)	(-3.63)	(-2.34)	-1	-0.65	-1.11	(-0.13)
$84,000-$103,999	0.434***	-0.309	1.066***	0.255	2.531*	1.711	1.860***	1.097
	-7.34	(-0.63)	-3.49	-0.37	-2.48	-1.46	-5.33	-1.3
Constant	1.581***	1.436	-2.148***	-0.156	-1.764	-1.127	-1.988***	-0.0468
	-12.77	-1.84	(-4.40)	(-0.21)	(-1.63)	(-0.88)	(-4.27)	(-0.05)
lnalpha								
Constant		0.341*		-0.0258		0.167		0.699**
		-2.13		(-0.07)		-0.36		-3.21
pr2	0.4411	0.0613	0.6638	0.231	0.6316	0.2168	0.4533	0.1347
AIC	3169.4	853.6	354.7	290	264	226.2	959.6	417.6
BIC	3211.1	897.8	396.4	334.3	305.7	270.5	1001.3	461.9

Note: t statistics in parentheses; significant terms shaded in grey * = $p < 0.05$, **= $p < 0.01$, ***= $p < 0.001$.

Table 3.3.6. Per trip direct expenditure before and after the stock enhancement scenario for Black Bream is initiated. Green shading indicates an increase in value.

	Swan-Canning	Walpole-Nornalup
Before enhancement		
Consumer surplus	$12.52	28.90
No Trips	15.21	0.77
Total	$3,808,584	$267,036
After enhancement		
Consumer surplus	$14.75	$55.25
No Trips	34.3	2.12
Total	$10,118,500	$1,405,560
Change (value)	$6,309,916	$1,138,524
Change (%)	166	426

3.3.3.3. Willingness to pay for stock enhancement

Recreational fishers were initially asked whether they would be willing to pay a $10 fee to allow stock enhancement of Blue Swimmer Crabs or Black Bream to be undertaken in the estuary they fish in. This would be additional to a recreational fishing from a boat licence ($40) if they had one (i.e. they were a boat- rather than shore-based fisher). In the case of crab fishers, a total of 66.4% of respondents stated they would be willing to pay for this. Those who agreed were asked to state the maximum amount they would be willing to contribute to stock enhancement through a licence payment. Almost two-thirds of fishers indicated that the $10 fee suggested earlier was their maximum limit, with the largest value they would pay being $100 (Table 3.3.8). Relatively large percentages of fishers were willing to pay $15 and $20, but only 12% listed values ≥ $25.

Among recreational Black Bream fishers, 59.9% they would be willing to pay for the enhancement. Of those who agreed, just over half (54%) of Black Bream fishers indicated that the $10 fee suggested earlier was their maximum limit, with the largest value listed being $105 (Table 3.3.8). On average, the maximum amount fishers willing to pay $10 for stock enhancement was $20.25.

Table 3.3.7. Maximum amount recreational Blue Swimmer Crab and Black Bream fishers stated they would be willing to pay annually to support a stock enhancement program.

	Blue Swimmer Crab		Black Bream	
Amount ($)	**%**	**Cumulative %**	**%**	**Cumulative %**
10	64.10	64.94	53.85	53.85
15	8.97	74.03	5.13	58.97
20	12.82	87.01	16.67	75.64
25	3.85	90.91	5.13	80.77
30	2.56	93.51	6.41	87.18
35	0.00	93.51	1.28	88.46
40	1.28	94.81	0.00	88.46
50	1.28	96.10	8.97	97.44
55	1.28	97.40	0.00	97.44
100	3.85	100.00	1.28	98.72
105	**0.00**	**100.00**	**1.28**	**100.00**

Those respondents who said they were unwilling to pay a $10 fee for stock enhancement, were provided with a list of alternative options. Almost 40% of those Blue Swimmer Crab fishers that would not pay $10 would be happy to pay a $5 fee. Another 59% we not willing to pay any fee, among which, over half felt did not support the proposed fee as they felt they should not have to pay to utilise the Blue Swimmer Crab fishery, the next most elicited reason was that people were happy with their catch and so did not want a stock enhancement project to occur. Only 7% of recreational fishers claimed a financial hardship as a reason not to pay a stock enhancement fee.

Among the Black Bream fishers who said they were unwilling to pay a $10 fee for stock enhancement, almost 40% would be happy to pay a $5 fee. Another 48% we not willing to pay any fee, among which, over 40% felt did not support the proposed fee as they felt they should not have to pay to utilise the Black Bream fishery, the next most elicited reason was that people were happy with their catch and so did not want a stock enhancement project. Only 8.5% of recreational Black Bream fishers claimed a financial hardship as a reason not to pay a stock enhancement fee.

Table 3.3.8. Percentage of recreational Blue Swimmer Crab and Black Bream fishers who would not pay a $10 fee for the hypothetical stock enhancement program and instead chose an alternative option in the survey.

Option	% Crabs	% Bream
$ 5	37.60	39.40
$ 0 "*I do not think I should pay to catch Crabs/Bream*"	29.40	20.20
$ 0 "*I am happy with my current catch and do not want to catch more Crabs/Bream*"	22.50	19.10
$ 0 "*I cannot afford to pay more to catch Crabs/Bream*"	7.10	8.50
Other	3.50	12.80

3.3.4. Discussion

This chapter investigated whether recreational fishers were i) satisfied with their catches of Blue Swimmer Crabs and Black Bream in south-western Australian estuaries and how they thought stock enhancement may influence their views, ii) how the economic value of these fisheries may change if stock enhancement occurred and iii) whether recreational fishers would be willing to contribute to the associated costs of this management strategy. The results indicate that fishers supported the hypothetical stock enhancement program and were willing to pay a small annual fee to implement it. Finally, it was estimated that a successful enhancement program would increase the total economic value of both recreational Blue Swimmer Crab and Black Bream fishing.

3.3.4.1. Views on stock enhancement as a management strategy

The percentage of fishers claiming they would be satisfied with the number of Blue Swimmer Crabs they caught, kept and the time taken to catch following a successful enhancement increased greatly from 69-74% to ~94%. This is not surprising as it is a popular perception among recreational fishers that stock enhancement can increase stocks and catches of target species, while also reducing fishing time (Poorten et al., 2011; Garlock and Lorenzen, 2017). It thus fits that the biggest issues identified facing the Blue Swimmer Crab fisheries in Western Australia were i) the retention of undersized crabs, ii) overfishing, iii) exceeding the bag limit and iv) recreational fishing (Sections 1.4). In that same section, recreational fishers were found to strongly supported stocking as a management tool, with 81% stating it was acceptable, 14% being neutral and only 6% saying that it was unacceptable. A two-phase approach was employed to elicit and measure recreational crab fisher beliefs about stock enhancement. Almost all fishers (97%) expressed beliefs associated with positive outcomes of crab stock enhancement. The two most common beliefs were that stock enhancement would increase the number of crabs in the estuary and result in more legal-sized crabs available to be caught (Section 1.1). In addition, a smaller proportion of fishers had negative beliefs but they perceived these as less likely to happen than their positive beliefs on enhancement (Obregón et al., 2020b). Thus not only is stocking supported but fishers believe it will help compensate for the perceived issues with the fishery.

Given that fishers in this and other studies (Poorten et al., 2011; Garlock and Lorenzen, 2017) are supportive of stock enhancement and consider that it would increase catches, it is unsurprising that, following the implementation of such a management strategy, fishers stated they would increase their number of fishing trips by ~200 to 250% depending on the estuary. Such a result is in keeping with the food-motivated nature of the crab fishery where many fishers consider a fishing trip to be successful if they obtain enough individuals for dinner and, in some case, reach the bag limit of 10 crabs (Section 1.2). Although creel surveys of fishing participants are rarely done before and after stocking events, anecdotal evidence from the stock enhancement of the Western School Prawn (*Metapenaeus dalli*) in the Swan-Canning Estuary suggested that following promotion of the releases of hatchery-reared individuals through broadcast media, fishing effort increased (Tweedley et al., 2017c). From talking to recreational fishers during that project, some were avid users of the fishery who were fishing more frequently due to the restocking, while others had fished previously but were driven to re-engage with the fishery because of the stocking and its associated media campaign (James Tweedley, Murdoch University, pers. comm.). The latter type of fisher was not captured in the current survey of 'active' Blue Swimmer Crab fishers, which could indicate that the estimates generated in this chapter are lower than may be expected following a successful crab stocking.

The percentage of recreational Black Bream fishers that stated they would be satisfied after stocking increased by 20 and 22% for time taken to catch fish and the number of fish caught, respectively, a similar proportional increase as that for Blue Swimmer Crabs. This is likely due to the general support for stocking (see references above) and fisher's opinions that the size and abundance of Black Bream had declined, that they were unhappy with the current stocks and that stocking was the second most 'acceptable' management tool after minimum size limits (Section 1.4). While Blue Swimmer Crab fishers also felt stocks had declined, stocking was ranked fifth of nine options, although highly acceptable. The relatively greater support for Black Bream stocking could be related to the fact that a successful stocking of Black Bream has occurred in the Blackwood Estuary around 15 years prior to the current survey being conducted (Jenkins et al., 2006), i.e. sufficient time for the news to spread amongst the fishing community. Although only published in the scientific literature and thus not readily available to recreational fishers, monitoring of commercial catches, showed that the hatchery-reared fish contributed between 61 and 73 % to the total number of fish between 2007 and 2010. However, ad hoc analysis of videos posted on YouTube indicated that recreational fishers also caught these fish (James Tweedley, Murdoch University, pers. comm.) and hatchery-reared fish were readily able to be distinguished from wild-spawned stock due to their lack of a lateral line. Thus, given the success of the stocking in this system, it is likely that this view has increased the support for stocking. This trend was also present among commercial fishers, with those targeting Blue Swimmer Crabs being less supportive than those fishing for Black Bream and particularly those utilising the Blackwood (Section 1.4).

3.3.4.2. Effect of stock enhancement of economic value

Increases in visitation by recreational Blue Swimmer Crab fishers after a successful stock enhancement were estimated to increase the magnitude of direct expenses by ~105% in the Leschenault, and Peel-Harvey estuaries and 159% in the Swan-Canning Estuary. In the case of the latter two estuaries, based on estimates of the number of fishers, the value of each fishery, based on direct expenditure, would increase by ~AU $10,000,000. Similar increases in the frequency of fishing were elicited by recreational Black Bream fishers, with visitation rates estimated to increase by up to a factor of 2.8. However, increase the magnitude of these direct expenses varied markedly among estuaries from 31 and 176% and with the largest increases in the Swan-Canning (106%) and Walpole-Nornalup (176%) estuaries. Moreover, due to estimates in the number of fishers that utilise each fishery and the visitation rates, the increase in direct expenditure above the level before stock enhancement range from ~AU $300,000 to $64,000,000. These findings are similar to those from a study in British Columbia which suggested that stocking leads to an increase in participation and license sales (Dabrowska et al., 2014).

It is not surprising that stock enhancement would lead to increased visitation as the primary reason for fishing for both species was catch-orientated, i.e. for food (Blue Swimmer Crabs) or as a trophy (Black Bream), particularly when recreational fishers believe stocking will lead to more individuals to catch (see above and Section 1.1). In the case of Blue Swimmer Crabs, simulation modelling suggested that given the high density of crabs in the Peel-Harvey Estuary, and the strong density dependent-effects no stocking is recommended at this time (Section 3.1) and so there is little point attempting to estimate a benefit-cost ratio particularly when experimental scale stock enhancement have yet to be scaled up in order to produce sufficient numbers for a full-scale release and thus cost data are not available (Jenkins, Michael and Tweedley, 2017; 2018). However, such data are available for Black Bream.

Simulations based on an existing stocking program (Section 3.2), estimated that releases of 150,000 juveniles of 20 mm are recommended every five years providing natural recruitment remains poor. These are condescendingly, the same number but 20 mm smaller than the Black Bream that were released as part of FRDC 2000/180 (Jenkins et al., 2006). Moreover, in addition to these authors providing costs, the infrastructure required to produce this number of hatchery-reared juveniles exists in the DPIRD Fremantle Hatchery. When the costs of purely hatching, rearing and releasing the juveniles (AU $1.60 per fish) are adjusted for inflation and multiplied for 150,000 individuals (Section 3.2), the cost of a stocking program for the Blackwood Estuary would be ~AU $350,000. Note that this value does not include the cost of an associated monitoring program which is required as part of the State's policy on restocking and stock enhancement (Department of Fisheries, 2013). The estimated cost is less than the predicted $2.2 million increase in direct expenditure from recreational fishers in this estuary. Moreover, in addition to providing fish for fishers once they reach the minimum legal length, these fish can also increase egg production thus helping to increase future recruitment and boost stocks. For example, as greater numbers of hatchery-reared Black Bream attained the minimum length for retention in the Blackwood Estuary, their contribution to the commercial fishery increased from 6% in 2005 to 74% in 2010 (Cottingham, Hall and Potter, 2015). While that contribution subsequently declined to 39% in 2012 and 10% in 2014, it was due predominantly to the introduction of the very strong 2008 year class in the commercial catches with stocked fish estimated to have contributed ∼55% to the eggs produced in that year (Cottingham, Hall and Potter, 2015). It is worth noting that the parameters of the proposed stocking were designed to maintain biomass levels similar to that of the natural population, however, if such a model was incorrect and density-dependent effects were greater than modelled grow rates would slow and potentially reduce the trophy-nature of the fishery.

In addition to the direct expenditure on recreational fishing (see above), this spending also stimulates flow-on economic impacts through the economy, referred to as the multiplier effect or indirect value (Scheufele and Pascoe, 2022). These flow on effects include additional expenditure on wages paid to those who work in tackle shops, fishing businesses, boat repair, fuel, bait, and ice suppliers. This may be a critical source of income for small regional towns outside of the Perth Metropolitan Area.

3.3.4.3. Fisher's willingness to pay for stock enhancement

Recreational fishers were initially asked whether they would be willing to pay a $10 fee to allow stock enhancement of Blue Swimmer Crabs to be undertaken in the estuary where they fish. This would be additional to a recreational fishing from a boat licence (AU $40) if they had one. Two-thirds of respondents stated they would be willing to pay a $10 fee for stocking. Among those who agreed to paying a fee two-thirds of indicated that the $10 fee was their maximum limit, with the largest value they would pay, in addition to their current fishing license for fishery management, being $100. In the case of Black Bream fishers, similar results were obtained with ~60% of respondents stated they would be willing to pay for the enhancement among which a slightly small amount (54%) indicated that the $10 fee was their maximum limit, with the largest value listed being $105. These results are in line with recent trends of fishers being willing to pay a fee to support enhancement of their fisheries (Cantrell et al., 2004; Rhodes et al., 2018). For example, a study conducted to investigate perspectives on developing a recreational saltwater fishing license program in Hawaii suggested that fishers would support fishing license programs, but only if the funds generated from the license fees are used to improve the fishery including stocking and compliance (TuckerWilliams, Lepczyk and Hawkins, 2018).

In the current chapter, the average reported willingness to pay was AU $17 for Blue Swimmer Crabs and AU $20 for Black Bream. The slight disparity between the two groups of fishers may reflect the fact that the Black Bream fishers are utilising a trophy-orientated fishery and thus are willing to pay for the chance to catch a big fish. Furthermore, the higher willingness to pay could also possibly be higher for Black Bream given that they are aware that stocking has been conducted in the Blackwood and, to some extent in the Swan-Canning (Dibden et al., 2000; Jenkins et al., 2006), and so is a proven technology and therefore less of an economic risk. In both cases, however, the cost of any additional licences was within the bounds of previous work around the world, with, for example, 81% of survey respondents in Hawaii accepting a license fee of AU $16-28 (US$11-US$19) to fish in saltwater compliance (TuckerWilliams, Lepczyk and Hawkins, 2018) and in South Africa 50% of recreational fishers in 2009 were willing to pay R100 (now R170 or AU$ 14) to target Mulloway, *Argyrosomus japonicus* (Palmer and Snowball, 2009). It is noteworthy that a mandatory fee where there was not one (e.g. for shore-based catching of Blue Swimmer Crabs or Black Bream) may result in the displacement of fishers from the fishery and thus a reduction in their economic contribution. For example, a fee increase of US $2.70 to a licence of US$ 12 was estimated to displace 11% of fishers from a fishery in Texas (Sutton, Stoll and Ditton, 2001).

An effectively implemented fishing licencing system to target species in particular estuaries where stocking occurred would have an additional benefit of allowing the recreational catch to be more reliably estimated based on the number of licences issued each year, and independent fishery assessment of the catches from the recreational sector (Lowry and Murphy, 2003). It is noteworthy that the implementation of a shore-based recreational crabbing licence was suggested as a potential solution by commercial crab fishers (Section 1.3). Each year, the Western Australia government generates about $8 million in revenue from issuing recreational fishing licenses (State of Western Australia, 2022). These funds come from the recreational fishing from a boat licence (AU $40) and more specific licenses, e.g. Rock Lobster, Abalone, Marron, freshwater angling, and net fishing (AU $50). Thus, a system is already in place to issue licences potentially reducing administrative burdens and associated costs.

It should be noted that the current study used reported willingness-to-pay and reported anticipated increase in fishing trips. However, the most serious problem related to this approach may be the fact that the method provides hypothetical answers to hypothetical questions, which means that no real payment or trips are undertaken (Tao, Youcai and Atta Nyankson, 2023). This may induce respondents to overlook their budget constraints, consequently overestimating their stated willingness-to-pay and trips. In addition, it is difficult to know for sure that individuals would behave in the same way in a real situation as they do in a hypothetical exercise (Butterfield et al., 2016). These well recognised limitations of stated preference methods are the reason that researchers employ discrete choice models and other methods that better reveal fishers' real preferences (Wattage, Mardle and Pascoe, 2005). Nevertheless, the use of reported willingness to pay has resulted in effective 'good-practice' protocols and manuals based on empirical experiences (Johnston et al., 2017).

Section 4. Training and engagement

This idea for this project stemmed from a trip made by Dr James Tweedley to attend the 2014 Annual Symposium of the Fisheries Society of the British Isles entitled '*Integrated perspectives on fish stock enhancement*' to present some of the findings of FRDC 2013/221 (Tweedley et al., 2017c). At this Symposium, it became clear that while we excel at understanding the biological aspects of aquaculture-based enhancement in Australia, we have limited knowledge of the social and economic dimensions and limited research capacity in these disciplines applied to fisheries in Western Australia. Thus, in addition to furthering our knowledge, a goal of this project was to increase the capacity to conduct studies in the future by training young researchers and educating stakeholders.

4.1. Researcher training and opportunities

As part of Murdoch University's support for this project, two international PhD scholarships (~$95,000 each) were provided, one focusing on social dimensions and the other on economic aspects. An advertisement promoting both PhD scholarships was circulated globally, using mailing lists, scholarship and job websites and a targeted mail drop of staff (academic chairs and course coordinators) at 24 universities with a recognised strength in agricultural and/or resource economics. Over 70 applicants applied from around the world, including people from UK, Italy, Germany, India, Singapore, Sri Lanka, Ghana and Nigeria. Very few applicants were received from potential Australian candidates reflecting the lack of skills that we were trying to develop. The two appointments made were Clara Obregón and Denis Abagna. Clara completed a BSc Hons. in Biology and MSc in Ecology at the University of Salamanca (Spain), during which she spent a year abroad at the University of Melbourne where she studied marine science and fisheries. She then undertook a second MSc degree, this time in Marine Resources Development and Protection at Heriot-Watt University (UK), where her thesis investigated the socioeconomics and quality of life and economic profit made by Red Grouper fishers in Mexico. Denis completed a BSc in Agriculture Economics at the University for Development Studies in Ghana, before moving to Perth to complete a MSc in Agricultural Economics at the University of Western Australia. These PhD students were joined by Sarah Beukes (née Poulton) who was enrolled as an Honours student. The titles of their respective theses are as follows.

Clara Obregón: *The social-ecological dimensions of small-scale crab fisheries in Western Australia.*

Denis Abagna: *Evaluating the economic value of recreational fishing and aquaculture-based enhancement in south-western Australia estuaries.*

Sarah Buekes: *Beyond biology: social dimensions of Blue Swimmer Crab fishing, restocking and other management options.*

Clara's PhD was conferred in 2021, with her graduation in early 2022. At the time of writing, Denis' PhD is drafted and due for submission in July 2022 and Sarah completed her Honours thesis in 2018 and was awarded 1st class.

Throughout their candidatures all three students were supported and encouraged to develop their skills through workshops and attending conferences to promote their work on the project and meet experts in their research areas. In terms of workshops, Clara attended the *Ocean Conservation Master Class* taught by Professor Daniel Pauly at the University of Western Australia. This week-long course covered global fisheries catches, effects of climate change on fish and fisheries and fisheries management and governance. She also participated in the IMBeR conference in Brest, France and attended a workshop on "*Visioning Global Ocean Futures*" convened by, amongst others, Dr Beth Fulton and Dr Ingrid van Putten from CSIRO. In preparation for building the social network analysis of the Blue Swimmer Crab fishery in the Peel-Harvey we sought out opportunities for Clara to increase her knowledge on network and statistical analysis. She has attended a short Course on *Social-Ecological Modelling and Agent-based Simulation* held in Perth, the València International Bayesian Analysis Summer School (http://vabar.es/events/vibass3/) while at home in Spain. In

2020 she travelled to Tasmania to attend a free summer school in Interdisciplinary Skills for Equitable Climate Adaptation in Socioecological Systems that involved Prof. Gretta Pecl, Dr Fulton, Dr Emily Ogier and Dr van Putten (Figure 4.1). To facilitate Denis' development, he attended a lecture by globally renowned fisheries economist, Professor Rashid Sumaila (University of British Columbia) and partook in a two-day Masterclass in Fisheries Economics (http://www.ias.uwa.edu.au/masterclass/sumaila) covering the role and impact of fishing and overfishing on the economy and the environment, bioeconomic modelling and cost benefit analysis. Denis also presented his research on the economic contribution made by recreational crab fishers to the West Australian Agricultural and Resource Economics Conference in Perth in 2019. his conference also functioned as a workshop for students they were required to deliver an oral presentation and submit a full manuscript for academic peer review and discussion at a feedback session.

Figure 4.1. Photograph of participants, including Clara Obregón (front row, 6th from left), at the Interdisciplinary Skills for Equitable Climate Adaptation in Socioecological Systems summer school in Tasmania (Hobart, 2020).

After completing her Honours degree Sarah obtained a short-term position in the recreational fishing surveys teams at the Department of Primary Industries and Regional Development in Western Australia and conducted creel surveys of Blue Swimmer Crab fishers in the Peel-Harvey. Having graduated from her PhD in 2021, Dr Obregón was recognised as *distinguished talent* and awarded permanent residency in Australia. She currently has a number of roles including being the Marine Stewardship Council (MSC) Program Support Officer for Bio.Inspecta, a company that provides inspection and certification services for the MSC, the Aquaculture Stewardship Council and the MSC Chain of Custody. Clara still maintains a research position at the Centre for Sustainable Aquatic Ecosystems, Harry Butler Institute at Murdoch University and is the joint chief investigator on a two year grant to investigate opportunities and impacts for recreational fishing from the proposed Westport development in Cockburn Sound. Thus, both Sarah and Clara are utilising the skills and experience they gained from this project.

In addition to providing training and opportunities for students, this project provided financial support and opportunities to early career researchers. In the initial stages of this project, salary was used to fund a part-time post-doctoral position for Dr James Tweedley. He subsequently obtained a senior lecturer position at Murdoch University. The salary savings were used to appoint another post-doctoral staff member, Dr Alan Cottingham, to undertake studies looking at the biological aspects of stock enhancement using simulations of different stocking scenarios (Sections 3.1 and 3.2).

Over the course of the project, staff and students attended 16 conferences giving one conference paper, 20 oral presentation and 6 posters (see Project materials developed for full details). Furthermore, of the 27 conference-related publications, all contained student authors and except for four, had Clara, Denis or Sarah as lead author. Note that no project funds were used to attend these events as these were provided by Murdoch University and many were local to Western Australia and those during the COVID-19 pandemic were hosted online. Among the events students and staff attended were the World Fisheries Congress (online), International Symposium on Stock Enhancement and Sea Ranching (Florida, USA), Fisheries Society of the British Isles Symposium (Norwich, UK), Estuarine & Coastal Sciences Association (Perth, Australia) and multiple events organised by the Australian Marine Sciences Association (Perth, Australia; Figure 4.2).

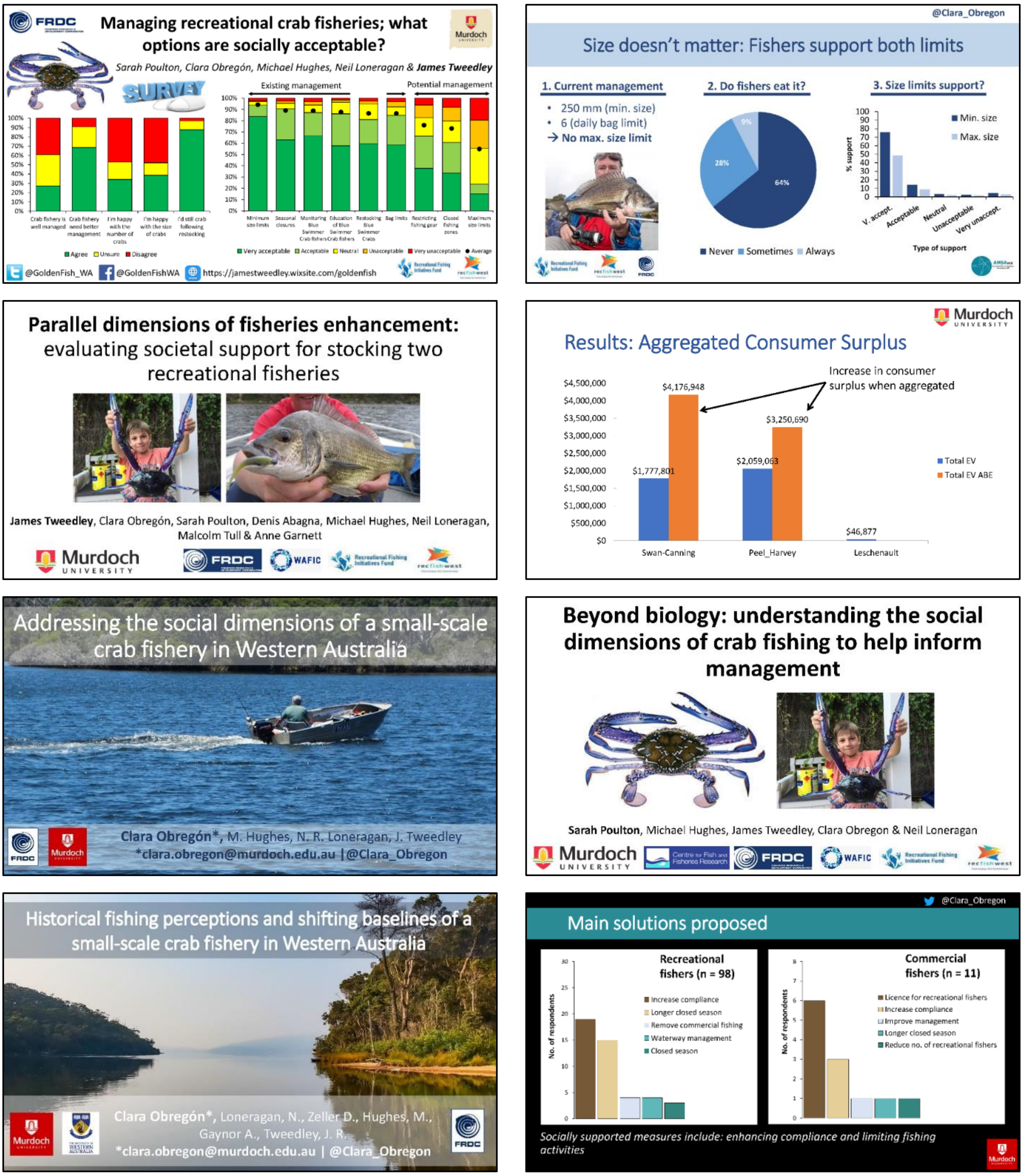
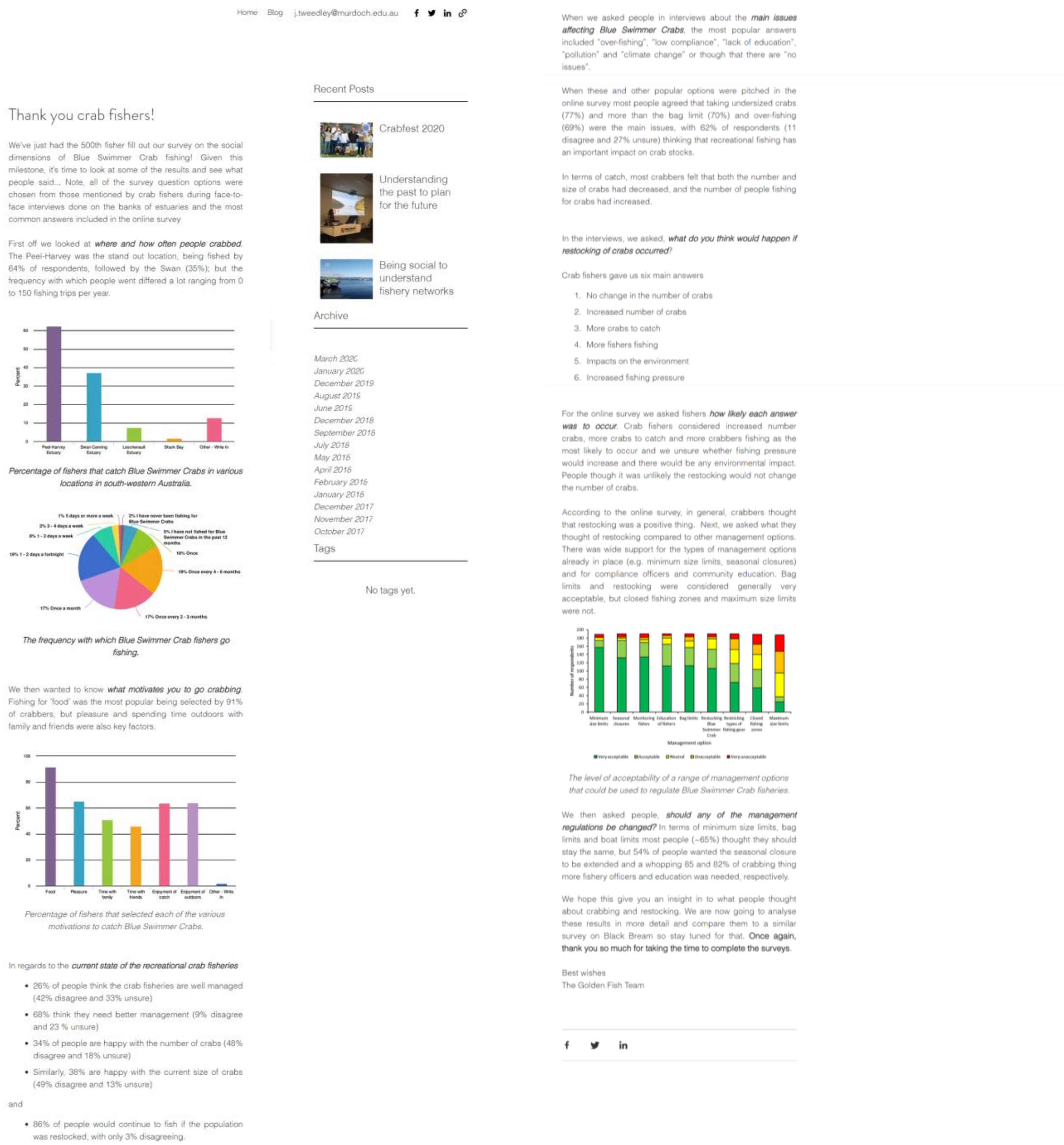


Figure 4.2. A selection of slides taken from conference presentations where the findings of FRDC 2016/034 were presented.

4.2. Engagement

This project sought to engage with a wide range of people including (i) users of the Blue Swimmer Crab and Black Bream fisheries (i.e. recreational and commercial fishers), (ii) the general public including those who use these systems for alternative motivations and thus resource-share at the ecosystem level and (iii) the broader scientific community (including staff in government departments and universities). The primary method of project communication was the project website. This included details about the project aims, the staff involved (including contact details) and a blog, where 24 project updates were posted (Figure 4.3). Social media accounts were also established on Facebook and Twitter where updates were written and other relevant content about the fisheries studied were shared (Figure 4.4). These pages, and those of project funders and partners (e.g. FRDC, Recfishwest), shared information on the project and promoted the release of the surveys and their results (Figure 4.5). Finally, to target a more scientific audience, particularly researchers from outside Western Australia, a project page was made on ResearchGate, which included versions of published papers and conference presentations.



Home Blog j.tweedley@murdoch.edu.au

Thank you crab fishers!

We've just had the 500th fisher fill out our survey on the social dimensions of Blue Swimmer Crab fishing! Given this milestone, it's time to look at some of the results and see what people said... Note, all of the survey question options were chosen from those mentioned by crab fishers during face-to-face interviews done on the banks of estuaries and the most common answers included in the online survey

First off we looked at ***where and how often people crabbed***. The Peel-Harvey was the stand out location, being fished by 64% of respondents, followed by the Swan (35%); but the frequency with which people went differed a lot ranging from 0 to 150 fishing trips per year.

Percentage of fishers that catch Blue Swimmer Crabs in various locations in south-western Australia.

The frequency with which Blue Swimmer Crab fishers go fishing.

We then wanted to know ***what motivates you to go crabbing***. Fishing for 'food' was the most popular being selected by 91% of crabbers, but pleasure and spending time outdoors with family and friends were also key factors.

Percentage of fishers that selected each of the various motivations to catch Blue Swimmer Crabs.

In regards to the ***current state of the recreational crab fisheries***

- 26% of people think the crab fisheries are well managed (42% disagree and 33% unsure)
- 68% think they need better management (9% disagree and 23 % unsure)
- 34% of people are happy with the number of crabs (48% disagree and 18% unsure)
- Similarly, 38% are happy with the current size of crabs (49% disagree and 13% unsure)

and

- 86% of people would continue to fish if the population was restocked, with only 3% disagreeing.

Recent Posts

Crabfest 2020

Understanding the past to plan for the future

Being social to understand fishery networks

Archive

March 2020
January 2020
December 2019
August 2018
June 2018
December 2018
September 2018
July 2018
May 2018
April 2018
February 2018
January 2018
December 2017
November 2017
October 2017

Tags

No tags yet.

When we asked people in interviews about the ***main issues affecting Blue Swimmer Crabs***, the most popular answers included "over-fishing", "low compliance", "lack of education", "pollution" and "climate change" or though that there are "no issues".

When these and other popular options were pitched in the online survey most people agreed that taking undersized crabs (77%) and more than the bag limit (70%) and over-fishing (69%) were the main issues, with 62% of respondents (11 disagree and 27% unsure) thinking that recreational fishing has an important impact on crab stocks.

In terms of catch, most crabbers felt that both the number and size of crabs had decreased, and the number of people fishing for crabs had increased.

In the interviews, we asked, ***what do you think would happen if restocking of crabs occurred***?

Crab fishers gave us six main answers

1. No change in the number of crabs
2. Increased number of crabs
3. More crabs to catch
4. More fishers fishing
5. Impacts on the environment
6. Increased fishing pressure

For the online survey we asked fishers ***how likely each answer was to occur***. Crab fishers considered increased number crabs, more crabs to catch and more crabbers fishing as the most likely to occur and we unsure whether fishing pressure would increase and there would be any environmental impact. People though it was unlikely the restocking would not change the number of crabs.

According to the online survey, in general, crabbers thought that restocking was a positive thing. Next, we asked what they thought of restocking compared to other management options. There was wide support for the types of management options already in place (e.g. minimum size limits, seasonal closures) and for compliance officers and community education. Bag limits and restocking were considered generally very acceptable, but closed fishing zones and maximum size limits were not.

The level of acceptability of a range of management options that could be used to regulate Blue Swimmer Crab fisheries.

We then asked people, ***should any of the management regulations be changed?*** In terms of minimum size limits, bag limits and boat limits most people (~65%) thought they should stay the same, but 54% of people wanted the seasonal closure to be extended and a whopping 85 and 82% of crabbing thing more fishery officers and education was needed, respectively.

We hope this give you an insight in to what people thought about crabbing and restocking. We are now going to analyse these results in more detail and compare them to a similar survey on Black Bream so stay tuned for that. **Once again, thank you so much for taking the time to complete the surveys.**

Best wishes
The Golden Fish Team

Figure 4.3. Examples of a blog post from the project website.

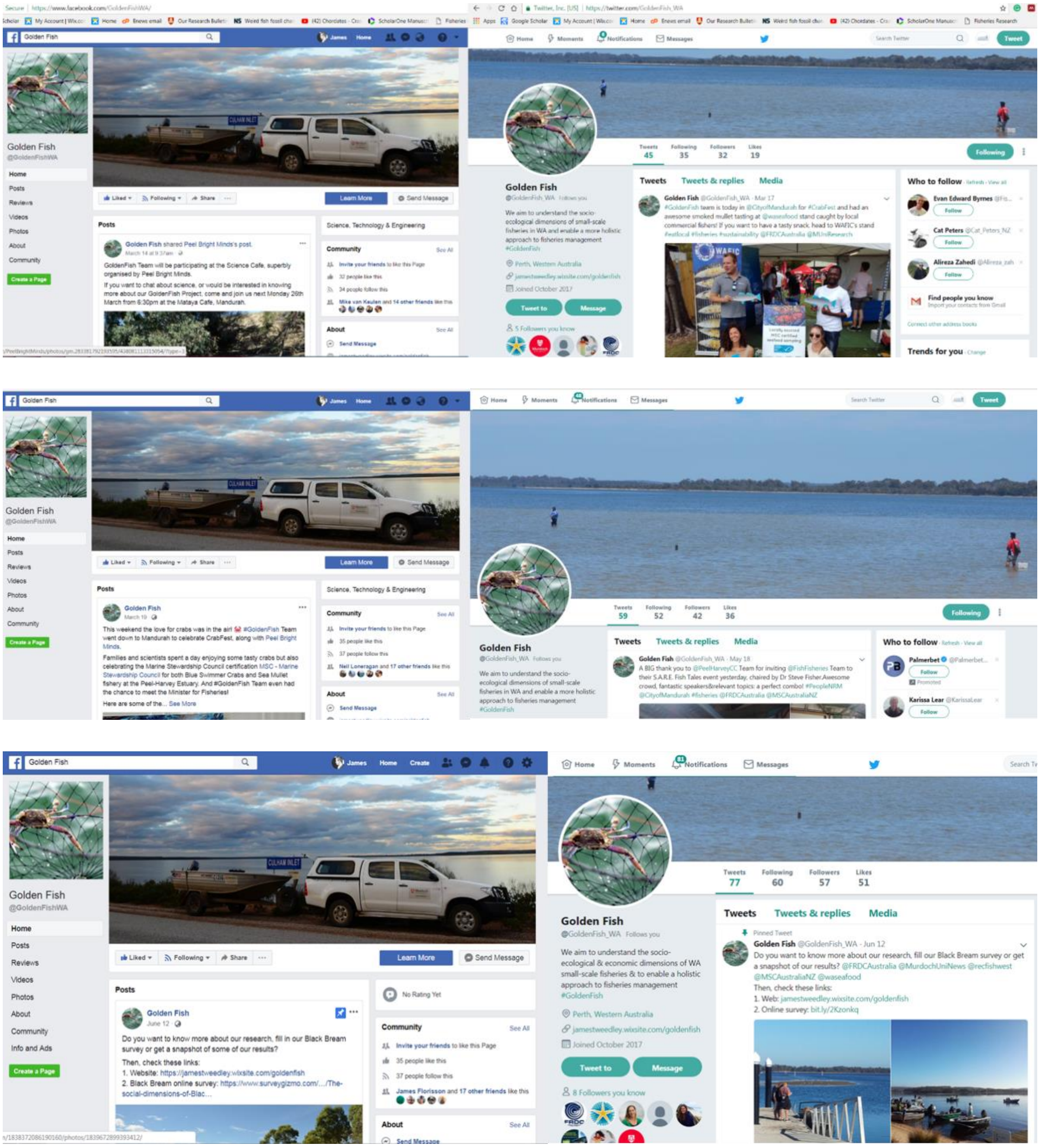


Figure 4.4. Examples of a social media posts about project activities.

Efforts were also made to engage with the commercial and recreational fishers and their representative peak bodies (Western Australian Fishing Industry Council; WAFIC and Recfishwest). Open-lines of communication were kept with the commercial fishers, particularly those in the Peel-Harvey, and with the various presidents of the Mandurah Licenced Fishermans Association (MLFA) through face-to-face meetings, fishing trips and phone conservations. Feedback from the commercial fishers was sought and provided for the surveys, as was that of project partners and the Human Dimensions Research Coordination Program at the FRDC. Moreover, on completion of the social survey the findings were discussed with the current president of the MLFA and during meetings with WAFIC's senior resource access and communications officers. During the analyses, it became clear that some recreational fishers had misguided opinions of aspects of commercial fishing, particularly for Blue Swimmer Crabs, thus a short report was prepared: Obregón et al. (2019) *A missing link? Views from the recreational sector on the blue swimmer crab fishing industry in south-western Australia*. This highlighted some of their views including some that were contradictory, i.e. recreational fishers wanting a supply of locally-sourced seafood, but not supporting commercial fishing. Project staff also attended multiple 'Crab Fest' events in Mandurah helping to support sustainable fishing (MSC and WAFIC) and promoting this concept and the current project to the then Western Australian Minister of Fisheries Hon. Dave Kelly (Figure 4.6). The project was featured in FISH Magazine (September 2019 edition Vol 27, No.3, page 9) and resulted in other commercial fishers contacting the project team and stimulating good discussions.

Figure 4.4. Examples of a social media posts about surveys for FRDC 2016/034.

Additional engagement with recreational fishers was undertaken during interviews as fishers were often keen to share their views and then discuss the fishery more generally and ask questions. Infographics (e.g. Figure 4.7) were produced and handed out as fishing competitions and when conducting surveys to share project results. Note these were also available on the project website.

Figure 4.6. Photographs of project staff conducting 'on-ground' activities.[35]

Information was also disseminated to recreational fishers and members of the public at community seminars run in conjunction with catchment councils, e.g. the Peel-Harvey Catchment Council's Share in a Shed series and *ad-hoc* talks hosted by these organisations. This provided a good forum to showcase the value of the fisheries to people who were not always active participants and, in some cases, would be advocating for the alternative use of the estuaries.

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[35] (top row) social and economic surveys in the Blackwood River and Peel-Harvey estuaries, respectively, (top middle row) promoting sustainable seafood to members of the public and the then Fisheries Minister Hon Dave Kelly (BA MLA), (bottom middle row) Clara giving a community talk at the Peel-Harvey catchment council and project staff attending a fishing competition in the Swan-Canning Estuary, (bottom row), James and Clara presenting at conferences held by the Australian Marine Sciences Association WA Branch and Fisheries Society of the British Isles, respectively.

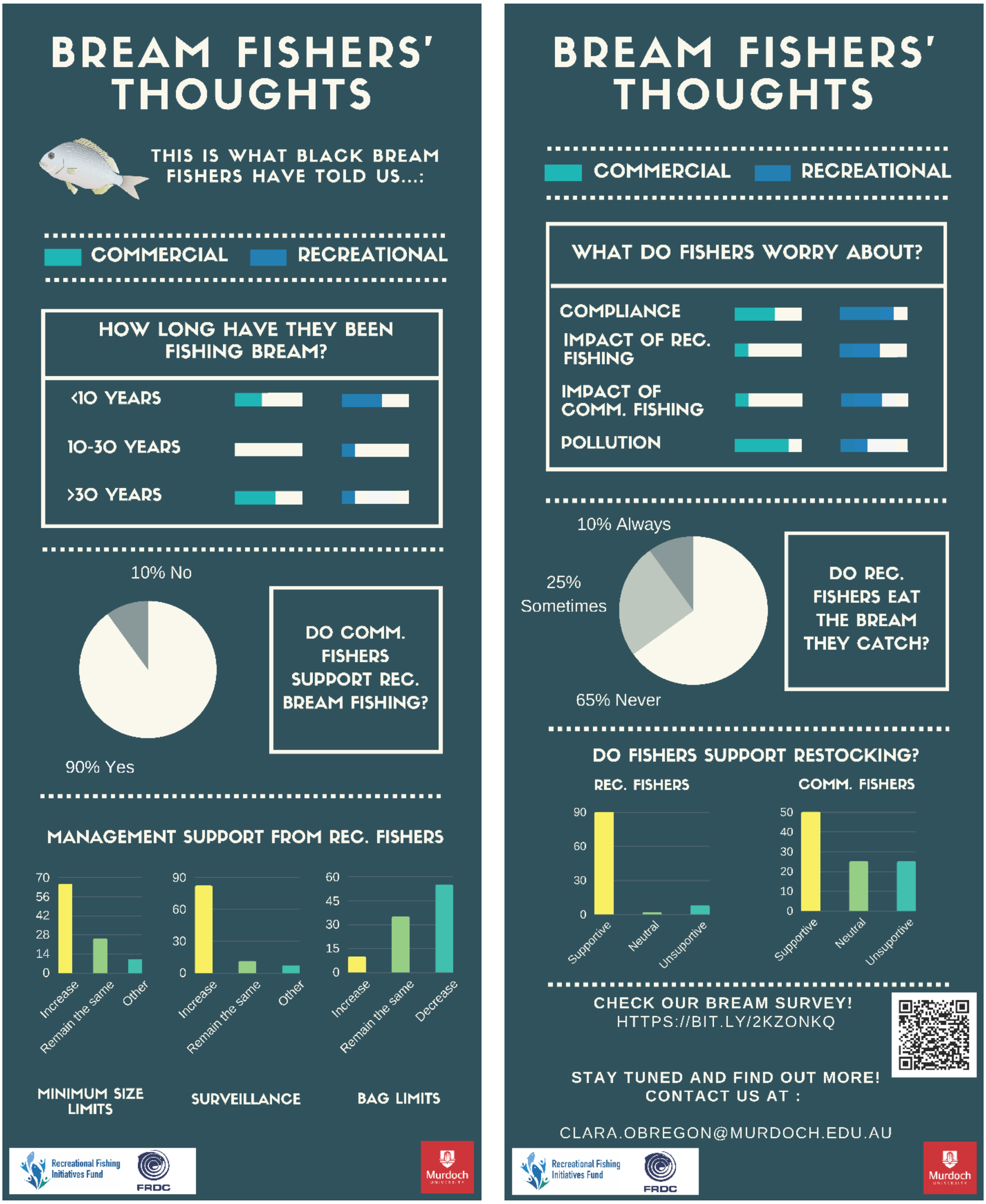

Figure 4.7. An infographic produced using the data collected from the survey on the social dimensions of Black Bream fishing, which was handed out to bream fishers doing subsequent sampling and surveys.

Finally, we actively sought to engage with government agencies and other scientists. This was done by providing six-monthly emails to a steering committee and presenting results to peak bodies and government agencies through seminars held at Murdoch University but also at their premises too to increase participation and engagement. Furthermore, over the course of the project staff and students attended 16 conferences and gave 20 oral and 6 poster presentations, showcasing the results, receiving feedback and discussing the implications. Four papers have also been published in Q1-ranking journals (Ambio, ICES Journal of Marine Science, Frontiers in Marine Science and Marine Policy), which increases the profile and visibility of project findings internationally.

Conclusion

This project investigated the potential effects of stock enhancement of Blue Swimmer Crab (*Portunus armatus*) and Black Bream (*Acanthopagrus butcheri*) on the human, economic and biological dimensions in a range of estuaries in south-western Australia.

Recreational Blue Swimmer Crab and Black Bream fishers have strong and universal catch-related motivations, albeit for different purposes, i.e. consumption- and trophy-orientated, respectively. The majority of these fishers stated that their catches had declined over the time since they started fishing and strongly supported stock enhancement (together with a suite of existing management measures e.g. minimum size limits). Recreational fishers believed stock enhancement could have strong positive outcomes for the abundances of their target species and increase their subsequent catches. While they also recognised that this management strategy could lead to some negative outcomes, such as increasing fishing pressure and environmental issues, they considered them unlikely to occur. Commercial crab fishers considered stocks adequate, albeit the abundance of crabs fluctuates inter-annually. These fishers did not support stocking as it was not considered needed and that it may have negative impacts. Although, some commercial Black Bream fishers were also not supportive, again due to sufficient stocks, those utilising the Blackwood River Estuary supported stocking because of the demonstrated very beneficial effects of stocking in 2002 (FRDC 2000/180).

From an economic perspective, the total economic value (incorporating direct expenditure on fishing-related items, the opportunity cost and consumer surplus) over a year of a single recreational Blue Swimmer Crab fisher was estimated at \$334, \$189 and \$58 in the Swan-Canning, Peel-Harvey and Leschenault estuaries, respectively. Using identical methods, the economic value of recreational Black Bream fishing (per fisher annually) was estimated as \$3,200 in the Swan-Canning and \$205 in the Walpole-Nornalup. This reflects large differences in the number of trips respondents took to each system. The per fisher economic value of Black Bream was significantly larger than that for Blue Swimmer Crabs, due to the greater cost of fishing gear (including bait/lures) and opportunity costs resulting from longer travel and fishing times. In response to a hypothetical aquaculture-based enhancement project that resulted in recreational catches increased by 50%, fishers suggested that their frequency of fishing would increase. For both Blue Swimmer Crabs and Black Bream this would substantially increase their direct expenditure on fishing and the aggregate consumer surplus, although not infinitely due to scarcity constraints of fisher's income and time. Most fishers would be willing to pay an annual license fee of to support aquaculture-based enhancement if it was ≤ \$20.

Using a simulation approach the effectiveness of stocking Blue Swimmer Crabs in the Peel-Harvey was found to be highly dependent on stocking density and the natural density of crabs in the estuary. For example, when numbers of the natural population the estuary are high, density-dependent effects are strong and stocking is likely to lead to a decrease in the biomass of the catch. Thus, no stocking is recommended at this time. However, in systems like Cockburn Sound, where stock are low (and the recreational and commercial fisheries are closed), the strength of density-dependent effects are greatly reduced. In the Blackwood Estuary recruitment of Black Bream is episodic (twice in the last 20 years). The simulation model demonstrated that the 150,000 individual release option was projected to maintain biomass levels similar to that of the natural population. In the absence of natural recruitment for extended periods of time, however, releases of this scale are likely to be necessary every five years.

Implications

This study was the first in Western Australia to attempt to understand the human dimensions of multisector fisheries. It revealed strong homogenous motivations for recreational and commercial fishers to partake in fishing, and in the case of recreational fishers, their views on a range of existing and potential management options. With the exceptions of minimum size limits and stock enhancement, views of management options were more heterogenous among the diverse recreational fisher population. For the crab fishery, some common views were expressed between recreational and commercial fishers, albeit there were some differences too. Given the highly engaged nature of fishers from both sectors, there would be value in utilising a co-management approach in the future should management arrangements need to be changed. Social network analysis that identified several individuals (including commercial fishers) were identified as key for sharing information and should be involved in any stakeholder groups. Moreover, different modes of communication were used by the various stakeholders, particularly between government departments and recreational fishers. Given the relatively-high-levels of non-compliance of recreational fishers in the Peel-Harvey these findings could be used to devise effective methods of reducing illegal fishing. Finally, the survey instruments developed here could be used for other species and other recreational fisheries, helping to address the knowledge gap in human dimensions of fisheries and provide comparison and more context to the data derived in the current study.

Stocking of several species is regularly conducted in Western Australia, but the economic and biological implications are typically not investigated and thus cost-effectiveness has not been determined. The data on recreational fishing expenditure and changes in those expenses as the result of a successful stocking program could be used to developed cost-benefit models for Blue Swimmer Crab, Black Bream and potentially other species with similar biological and behavioural characteristics. Finally, the different simulation approaches developed in this project were designed to utilise existing data held by government departments and the university-sector and thus not require expensive and time-consuming bespoke sampling. The results from these studies demonstrate the value of such work in informing the parameters of any future stocking programs.

Recommendations

Recreational fishers elicited strong and consistent motivations for fishing and view on management options. As non-compliance from members of this sector is an issue in some fisheries and that management of these fishers is reliant, in part, on encouraging voluntary compliance there is value in engaging with both recreational and commercial fishers in a co-management approach. There is some common ground between the views of fishers from both sectors, but also some marked differences including around beliefs on the need and effectiveness of stock enhancement. Thus, any co-management would need to address the expectations of both fishery sectors while counterbalancing these with the biological impact of hatchery-reared individuals on wild stock and increased in fishing pressure. If any stocking program was to be initiated the expectations of the recreational sector need to be managed.

In terms of stocking, while there is evidence of a significant economic contribution made by recreational fishers, which is likely to increase after any stocking, a responsible and conservative approach to stock enhancement should be adopted (Lorenzen, Leber and Blankenship, 2010). As demonstrated, the cost-effectiveness of stocking Blue Swimmer Crabs in the Peel-Harvey is highly dependent on stocking density and the natural density of crabs in the estuary. Based on current estimates, any stocking in this system is likely to lead to a decrease in the biomass of the catch. Thus, no stocking is recommended unless the population declines in abundance, although such a program may work in the nearby marine embayment of Cockburn Sound, and if successful and the fishery was reopened would reduce fishing pressure in the Swan-Canning and Peel-Harvey estuaries. Furthermore if stocking of crabs is seen as a future desire, research and development needs to be done to develop cost-effective hatchery and grow out methods, which is also likely to require capital expenditure to expand aquaculture facilities in Western Australia.

In the absence of natural recruitment of Black Bream in the Blackwood, which is episodic, stocking would be required on a regular basis (every five years) to maintain catches. Releases of 150,000 juveniles of 20 mm are recommended for future stocking events. This is the same number but 20 mm smaller than the Black Bream that were released in 2002 (FRDC 2000/180) and thus effective hatchery methods have been developed and infrastructure is available. In fact, the proponents of this project, have established been working with high schools in the Mandurah region undertake small scale releases to boost populations of Black Bream in the Murray River (Peel-Harvey Estuary) and engage students with aquaculture, fisheries management and the environment.

Further development

This project estimated economic value of recreational Blue Swimmer Crab and Black Bream fishers on per fisher per year scale for individual estuaries. To develop a full-economic model of the implications of any stocking program reliable estimates on the number of fishers utilising the estuaries and embayments along the extensive Western Australian coastline need to be derived. In addition, due to the cannibalistic nature of crabs, any large-scale stocking program with the capacity to release millions of crablets would require an investment to develop cost-effective hatchery methods and in grow-out facilities. Inland saline aquaculture could provide a cost-effective option for producing aquaculture reared crablets, as a trial has demonstrated previously for Black Bream.

Extension and Adoption

This is covered in Section 4.2 as part of Objective 4 of the project with media coverage provided in Appendix 4.

Project materials developed

A wide range of publications have been produced from this project, including 6 papers in international journals, 1 conference paper, 2 thesis (1 PhD and 1 Honours) and 21 oral and 6 poster presentation. Full citation details are provided below.

Papers

Tweedley, J.R., Obregón, C., Beukes, S., Loneragan, N.R. & Hughes, M. (2023). Selecting from the fisheries managers' tool-box: recreational fishers' views of stock enhancement and other management options. Fishes 8(9): 460. DOI: 10.3390/fishes8090460.

Tweedley, J.R., Obregón, C., Beukes, S.J., Loneragan, N.R. & Hughes, M. (2023). Differences in recreational fishers' motivations for utilising two estuarine fisheries. Fishes 8(6): 292. DOI: 10.3390/fishes8060292.

Obregón, C., Christensen, J., Zeller, D., Hughes, M., Tweedley, J.R., Gaynor, A. & Loneragan, N.R. (2022). Local fisher knowledge reveals changes in size of blue swimmer crabs in small-scale fisheries. *Marine Policy* 143: 105144. DOI: 10.1016/j.marpol.2022.105144.

Obregón, C., Admiraal, R., van Putten, I., Hughes, M., Tweedley, J.R. & Loneragan, N.R. (2020) Who you speak to matters: social network analysis on information sharing to inform the management of a small-scale fishery. *Frontiers in Marine Science*. October 2020 (7): 578-14. DOI: 10.3389/fmars.2020.578014.

Obregón, C., Tweedley, J.R., Loneragan, N.R., & Hughes, M. (2020). Different but not opposed: perceptions between fishing sectors on the status and management of a crab fishery. *ICES Journal of Marine Science* 77 (6): 2354–2368. DOI: 10.1093/icesjms/fsz225.

Obregón, C., Hughes, M., Loneragan, N.R., Poulton, S.J. & Tweedley, J.R. (2020). A two-phase approach to elicit and measure beliefs on management strategies: fishers supportive and aware of trade-offs associated with stock enhancement. *Ambio* 49(2): 640-649. DOI: 10.1007/s13280-019-01212-y.

Through the connections Clara established though this project she was also involved in another paper on Marine Stewardship Council fisheries in Western Australia.

van Putten, I., Longo, K., Arton, A., Watson, M., Anderson, C.M., Himes-Cornell, A., Obregón, C., Robinson, L. & van Steveninck, T. (2020). Shifting focus: The impacts of sustainable seafood certification. PLOS One 15(6): e0235602. DOI: 10.1371/journal.pone.0235602.

Conference papers

Abagna, D., Tweedley, J.R. Garnett, A.M. (2019). Small in scale, but not small in value. Economic valuation of recreational crab fishing in south-western Australian estuaries. West Australian Agricultural and Resource Economics Conference. Perth, Australia. 1-26.

Theses

Obregón, C. (2021) The social-ecological dimensions of small-scale crab fisheries in Western Australia. PhD thesis, Murdoch University. https://researchrepository.murdoch.edu.au/id/eprint/62281/.

Poulton, Sarah, J. (2018) Beyond biology: social dimensions of Blue Swimmer Crab fishing, restocking and other management options. Honours thesis, Murdoch University. https://researchrepository.murdoch.edu.au/id/eprint/45239/.

Other written documents

Obregón, C., Hughes, M., Loneragan, N. & Tweedley, J. (2019) A missing link? Views from the recreational sector on the blue swimmer crab fishing industry in south-western Australia. 6 pp.

Obregón, C. (2018). The socio-ecological dimensions of two small-scale fisheries in WA: Towards a sustainable future. Project proposal for confirmation of candidature. 21 pp.

Obregón, C. (2018). Building bridges towards sustainability: understanding the socio-ecological dimensions of small-scale fisheries in Western Australia. Literature review for confirmation of candidature. 29 pp.

Abgana, D. (2018). Evaluating the cost and benefits of aquaculture-based enhancement in small-scale commercial recreational fisheries in south-western Australia. Project proposal for confirmation of candidature. 20 pp.

Oral presentations

Obregón, C., Christensen, J., Zeller, D., Hughes, M., Tweedley, J.R., Gaynor, A., & Loneragan, N.R. (2023). Historical records and local fisher knowledge reveal changes in size and abundance of crab catches in Western Australia. 2023 MARE People & the Sea Conference. Amsterdam, Netherlands.

Obregón, C., Hughes, M., Loneragan, N.R. & Tweedley, J.R. (2021). The value of understanding fishers for enhancing small-scale fisheries management? YOUMARES 12. Hamburg, Germany & online.

Obregón, C., Admiraal, R., van Putten, I., Hughes, M., Tweedley, J.R. & Loneragan, N.R. (2021) Understanding information-sharing behaviour in a crab fishery using social network analysis. World Fisheries Congress. Adelaide, Australia & online.

Obregón, C., Hughes, M., Loneragan, N.R. & Tweedley, J.R. (2021). Can fisher perceptions be used as information to detect biological change? Australian Marine Science Association (AMSA) Marine Snapchat. Perth, Australia.

Obregón, C., Loneragan, N.R., Zeller D., Hughes, M., Gaynor A. & Tweedley, J.R. (2019). Historical fishing perceptions and shifting baselines of a small-scale crab fishery in Western Australia. Applied marine environmental history in the indo-pacific: problems, sources and opportunities. Perth, Australia.

Tweedley, J.R., Obregón, C., Poulton, S.J., Abagna, D., Hughes, M., Loneragan, N.R., Tull, M., Garnett A. & Pascoe, S. (2019). The parallel dimensions of fisheries enhancement: evaluating societal support for stocking small-scale recreational estuarine fisheries. 10th Florida State University-Mote International Symposium on Fisheries Ecology and 6th International Symposium on Stock Enhancement and Sea Ranching. Florida, United States of America.

Loneragan, N., Obregón, C. Taylor, M., Tweedley, JR., Wu, Z & Ye, Y. (2019). Evaluating trends in research on marine release programs (aquaculture-based enhancement) in western countries compared with China and Japan. 10th Florida State University-Mote International Symposium on Fisheries Ecology and 6th International Symposium on Stock Enhancement and Sea Ranching. Florida, United States of America.

Abagna, D., Tweedley, J.R. Garnett, A.M. (2019). Small in scale, but not small in value. Economic valuation of recreational crab fishing in south-western Australian estuaries. West Australian Agricultural and Resource Economics Conference. Perth, Australia.

Obregón, C., Hughes, M., Tweedley, J.R. & Loneragan, N.R. (2019). Commercial and recreational fishers' views on the status and management of the blue swimmer crab fisheries in south-western Australia. Australian Marine Science Association (AMSA): Marine Science for a Blue Economy Conference. Fremantle, Australia.

Loneragan, N., Obregón, C. Taylor, M., Tweedley, J.R., Wu, Z & Ye, Y. (2019). The status of marine release programs (aquaculture-based enhancement) in western countries; comparisons with China and Japan. Australian Marine Science Association (AMSA): Marine Science for a Blue Economy Conference. Fremantle, Australia.

Poulton, S., Hughes, M., Tweedley, J.R., Obregón, C., & Loneragan, N.R. (2019). Beyond biology: understanding the social dimensions of Blue Swimmer Crab fishing to help inform management. Australian Marine Science Association Western Australia Honours Prize Night. **This talk won the best presentation award at the event.*

Loneragan, N.R., Obregón, C., Tweedley, J.R., Taylor, M.D. & Ye, Y. (2018). Marine release programs and research in North America, Europe, Oceania and southern Asia. 2nd International Symposium on Modern Marine (Freshwater) Ranching. Chifeng, China.

Obregón, C., Poulton, S. Hughes, M., Tweedley, J.R. & Loneragan, N.R. (2018). Social dimensions of a small-scale crab fishery in Western Australia. 3rd World Small-Scale Fisheries Congress. Chiang Mai, Thailand.

Poulton, S., Obregón, C., Hughes, M., Loneragan, N.R. & Tweedley, J.R. (2018). Managing recreational crab fisheries; what options are socially acceptable? Australian Marine Science Association (AMSA) Marine Snapchat. Perth, Australia.

Obregón, C., Hughes, M., Loneragan, N.R., & Tweedley, J.R. (2018). Size doesn't matter: Fishers support both limits Australian Marine Science Association (AMSA) Marine Snapchat. Perth, Australia.

Poulton, S., Hughes, M., Tweedley, J.R., Obregón, C., & Loneragan, N.R. (2018). Beyond biology: understanding the social dimensions of Blue Swimmer Crab fishing to help inform management. Estuarine & Coastal Sciences Association (ECSA) 57: Changing estuaries, coasts and shelf systems - Diverse threats and opportunities. Perth, Western Australia.

Obregón, C., Hughes, M., Tweedley, J.R., & Loneragan, N.R. (2018). Unravelling the importance of social dimensions in a small-scale finfish fishery in Western Australia to help improve management. Estuarine & Coastal Sciences Association (ECSA) 57: Changing estuaries, coasts and shelf systems - Diverse threats and opportunities. Perth, Western Australia.

Obregón, C., Hughes, M., Loneragan, N.R. & Tweedley, J.R. (2018). Unravelling the importance of social dimensions in a small-scale finfish fishery in Western Australia to help improve management. Fisheries Society of the British Isles Symposium - The Sustainable Use and Exploitation of Fishes. Norwich, United Kingdom.

Obregón, C., Hughes, M., Tweedley, J.R. & Loneragan, N.R. (2018). An elephant in the room: addressing the social-dimensions of a small scale estuarine fishery in Western Australia. 16th Australian Marine Science Association (AMSA) Marine Science Student Workshop 2017. Rottnest Island, Australia.

Poulton, S., Hughes, M. & Tweedley, J.R. (2017). Beyond biology: determining the social dimensions of crabbing and support for different management options to sustain crab stocks. 15th Australian Marine Science Association (AMSA) Marine Science Student Workshop 2017. Rottnest Island, Australia.

Tweedley, J.R., Loneragan, N.R., Hughes, M., Tull, M., Obregón, C. & Poulton, S.J. (2017). Golden Fish: evaluating and optimising the biological, social and economic returns of small-scale fisheries. Australian Marine Science Association (AMSA) Marine Snapchat. Perth, Australia.

Presentations were also given by project staff to people at Peel-Harvey Catchment Council (including fishers from the Mandurah Licenced Fisherman's Association), Peel Bright Minds, Department of Primary Industries and Regional Development, Murdoch University and University of Tasmania.

Poster presentations

Obregón, C., Hughes, M. Loneragan, N., Tweedley, J.R., & van Putten, I. (2019). Network structure and information flow between fishery stakeholders: an interdisciplinary approach towards assessing communication pathways for management. Integrated Marine Biosphere Research (IMBeR) Future Oceans 2 Conference. Brest, France.

Obregón, C., Tweedley, J.R., Loneragan, N.R, Hughes, M., & Tull, M. (2018). Golden Fish: evaluating and optimising the biological, social and economic returns of small scale fisheries in Western Australia. 3rd World Small-Scale Fisheries Congress. Chiang Mai, Thailand.

Obregón, C., Hughes, M., Tweedley, J.R., & Loneragan, N.R. (2018). Understanding socio-ecological systems: A case study protocol for two small-scale estuarine fisheries in Western Australia. Estuarine & Coastal Sciences Association (ECSA) 57: Changing estuaries, coasts and shelf systems - Diverse threats and opportunities. Perth, Western Australia.

Abagna, D., Tweedley, J.R., Tull, M., Garnett, A. & Loneragan, N.R. (2018). Evaluating the costs and benefits of aquaculture-based enhancement in small-scale commercial and recreational fisheries. Estuarine & Coastal Sciences Association (ECSA) 57: Changing estuaries, coasts and shelf systems - Diverse threats and opportunities. Perth, Western Australia.

Obregón, C., Tweedley, J.R., Loneragan, N.R, Hughes, M., & Tull, M. (2018). Golden Fish: assessing and increasing the biological, social and economic returns of small scale fisheries in Western Australia. Fisheries Society of the British Isles Symposium - The Sustainable Use and Exploitation of Fishes. Norwich, United Kingdom.

Obregón, C., Poulton, S. Hughes, M., Tweedley, J.R. & Loneragan, N.R. (2018). Understanding the social dimensions of a small-scale estuarine crab fishery in Australia. Fisheries Society of the British Isles Symposium - The Sustainable Use and Exploitation of Fishes. Norwich, United Kingdom.

Appendices

Appendix 1. Project staff and students

Murdoch University

Dr Alan Cottingham; post-doctoral research fellow

Dr Anne Garnett; senior lecturer

Dr Clara Obregón; former PhD student

Mr Denis Abagna; PhD student

Dr James Tweedley; senior lecturer

Mr Kurt Krispyn; research assistant

Professor Malcolm Tull; professor

Dr Michael Hughes; senior lecturer

Professor Neil Loneragan; professor

Ms Sarah Beukes (née Poulton); honours student

Authors from other institutions involved in publications

Associate Professor Andrea Gaynor; associate professor, University of Western Australia

Dr Danielle Johnston; senior research scientist, Department of Primary Industries and Regional Development

Dr Daniel Yeoh; research scientist, Department of Primary Industries and Regional Development

Dr Ingrid van Putten; senior research scientist, CSIRO

Dr Joseph Christensen; lecturer, University of Western Australia

Dr Ryan Admiraal; senior lecturer, Victoria University of Wellington

Professor Dirk Zeller; professor University of Western Australia and Director Sea Around Us

Appendix 2. Intellectual property

The information produced in this study is not suited to commercialisation.

Appendix 3. Social dimensions of Blue Swimmer Crab recreational fishing in the Peel-Harvey Estuary

This chapter has been published in an Honours thesis from Murdoch University.

Poulton, Sarah, J. (2018) Beyond biology: social dimensions of Blue Swimmer Crab fishing, restocking and other management options. Honours thesis, Murdoch University. *https://researchrepository.murdoch.edu.au/id/eprint/45239/*.

To reduce duplication with other chapters in this report, sections of this thesis have been deleted and reference made to where that information can be sourced elsewhere in the report. Note also that this survey employed a subset of that used in Sections 1.2 and 1.3, i.e. only those recreational fishers that targeted Blue Swimmer Crabs in the Peel-Harvey Estuary. Thus this chapters provides a more detailed investigation of recreational fisher views in this system.

A3.0. Summary

Blue Swimmer Crabs (*Portunus armatus*) are the most popular recreational fishery in Western Australia, with the Peel-Harvey Estuary being a major hotspot for crab fishing. With fishing pressure and climate change having affected Blue Swimmer Crab stocks in the nearby embayment of Cockburn Sound, stock enhancement/restocking (i.e. the release of aquacultured individuals) has been suggested as a potential fisheries management tool. Semi-structured interviews and an online survey were used to determine the primary motivations of recreational fishers using the Peel-Harvey Estuary, their strongest beliefs and attitudes associated with restocking and their perceptions of fishery management. The responses collected from the 41 interviews informed the design of the online survey, which was based on the most common responses. Of the 236 fishers surveyed online, 94% fished for food, and were primarily motivated to 'catch big crabs' and 'enough crabs to eat', likely reflecting the ease of catching crabs, the low cost of fishing equipment and the delicacy of the meat. Overall, 71% thought the fishery could be better managed, while were not happy with the number and size of crabs available i.e. they did not catch enough crabs and they caught too many small crabs. Fishers supported current management regulations, i.e. minimum size limits, seasonal closures and fishery surveillance, and wanted a longer closed season and more enforcement officers and community education. While the fisher acceptability of current regulations may be explained by their familiarity with them, it also emphasises that if stricter controls are to be enforced, the tightening of existing regulations would be more socially acceptable than the implementation of new management measures. Analysis of the belief strength × belief evaluation demonstrated that fishers thought that restocking would be very likely to 'increase crab numbers' and provide 'more crabs to catch'. Most fishers (85%) considered restocking beneficial, due to their preference for a higher abundance of crabs, larger crabs and the increased chance of a successful catch. However, they did not seem aware, or chose not to express the views that restocking could have negative impacts on the "wild" population through density-dependent effects (e.g. slower growth), genetic effects and a risk of introducing disease. Understanding the social dimensions of fishers will improve the decision-making abilities of fishery and environmental managers, enabling them to manage both the 'fish' and the 'fisher' to ensure a biologically and socially sustainable fishery.

A3.1. Introduction

Fishing has been practised for over 90,000 years, but commercial fishing effort and participation in recreational fishing has grown rapidly since the 1950s, leading to an annual wild capture fisheries production of ~90 million tonnes and an estimated 850 million recreational fishers, respectively (Kennelly and Broadhurst, 2002; Cooke and Cowx, 2004; Bell, Watson and Ye, 2017). During the last 20 years the world's population has increased almost 30% from 5.7 to 7.3 billion leading to a 35% increase in overall aquatic food production (FAO, 2014). Increased demand for fish, combined with environmental perturbations and climate change, have augmented pressure on global fish stocks, with 80% of commercial stocks being fully or overexploited (Mora et al., 2009). Recreational fishing, despite providing multiple social and economic benefits, exacerbates the pressures on many fishery resources, particularly when both sectors target the same species (Ihde et al., 2011; Jordan, Fairfull and Creese, 2016). Most fishery management interventions involve input, output and access controls, which are intended to limit the fishing effort and landings (Hatcher et al., 2000; Morison, 2004). However, such interventions have the potential to place significant hardship on individuals and communities by limiting access to fish stocks (Britton, 2014).

An alternative intervention that is becoming increasingly popular is aquaculture- based enhancement, including restocking, *i.e.* the release of hatchery-reared juveniles into the wild population to increase the spawning biomass to a level that is considered sustainable (Bell et al., 2005). Restocking can enhance the social dimension of recreational fisheries by improving fishing experiences, increasing fishers' catches and supporting the local fishing/tackle stores (Pinkerton, 1994; Aprahamian et al., 2003). The scale of aquaculture-based enhancement is comparatively small in Australia compared to Japan, China and the USA (Loneragan, Jenkins and Taylor, 2013), however, numerous restocking projects for finfish (Russel et al., 2004; Potter et al., 2008) and crustaceans have occurred (Ochwada-Doyle et al., 2010; Crisp et al., 2018). Typically, these projects have been popular with recreational fishers, particularly those that place high importance on catch-related aspects of fishing (Arlinghaus and Mehner, 2005; Garlock and Lorenzen, 2017).

That being said, while a large portion of recreational catch is used for human consumption, food is often, and increasingly, not the primary objective for a recreational fisher (Kearney, 2002). Non-catch related motivations such as the enjoyment of the outdoors, thrill of the catch and time spent with family and friends can also be important (Holland and Ditton, 1992; Pollnac et al., 2006; Young, Foale and Bellwood, 2016). This showcases the importance of understanding the social dimensions of recreational fishing, yet few studies have determined fisher motivations, or the social values associated with fishery management plans, particularly for restocking programs. This latter lack of knowledge is surprising as the success of management measures are dependent on (1) the willingness of fishers to comply with the regulations (Fedler and Ditton, 1994b) and (2) fisher participation in the system, which is vital when designing and implementing new policies (Dimech et al., 2009). Without this engagement, conflict can occur between the fishers and management authorities, resulting in amongst other things, poor regulatory compliance. Such conflict can be avoided by understanding the motivations, behaviour and perceptions of fishers and incorporating them into the regulatory system through social surveys (Fedler and Ditton, 1994b; Dimech et al., 2009).

The Blue Swimmer Crab *Portunus armatus*, formerly known as *Portunus pelagicus*, is an iconic crustacean species that is highly-valued among recreational and commercial fishers (Harris et al., 2016). This sub-tropical portunid inhabits coastal waters and estuaries and is widely distributed across Australia, extending northwards from the south coast of Western Australia to the New South Wales–Victoria border, while also occurring in the South Australian gulfs (Beckmann and Hooper, 2016). Despite stocks in the Peel-Harvey Estuary receiving Marine Stewardship Council Certification as sustainable, increased fishing pressure and anthropogenic changes to the environment could negatively influence the Blue Swimmer Crab population, as occurred in the nearby marine embayment of Cockburn Sound (Johnston et al., 2014). Restocking has been suggested as a potential fisheries management tool to help increase stocks in Cockburn Sound (Johnston et al., 2011).

Although aquaculture-based enhancement of several portunid fisheries have been implemented, their successes and failures have typically been quantified using biological and economic data, with the social dimensions receiving comparatively little attention (Hamasaki et al., 2011; Nitiratsuwan, Panwanitdumrong and Ngamphongsai, 2014; Tweedley et al., 2017a). In order to maximise their success, any aquaculture-based enhancement should be complimented with traditional fisheries input, output or access controls (Lorenzen et al., 2013; Crisp et al., 2018). The process of involving fishers in the development of such management plans will enhance fishers understanding, lead to the development of socially acceptable rules, and in turn, result in greater compliance (Fulton et al., 2011; Yates, 2014; Barclay et al., 2017).

Thus, the overall aim of this chapter is to determine the social dimensions of the recreational Blue Swimmer Crab fishery in the Peel-Harvey Estuary. Specifically, this involved achieving the following goals.

1. Determine the key motivations of recreational Blue Swimmer Crab fishers in the Peel-Harvey Estuary (face-to-face interviews and closed-question online survey).

2. Ascertain the main beliefs fishers associate with potential Blue Swimmer Crab restocking in the Peel-Harvey Estuary (face-to-face interviews and closed-question online survey).

3. Illicit the attitudes of fishers towards potential Blue Swimmer Crab restocking (closed-question online survey).

4. Investigate whether there is a relationship between the motivations of Blue Swimmer Crab fishing, and the beliefs and attitudes associated with restocking (closed-question online survey).

5. Determine how the opinions of restocking compare to other existing and potential management options (closed-question online survey).

Understanding the social dimensions of recreational Blue Swimmer Crab fishers in the Peel-Harvey Estuary will improve the decision-making abilities of fishery and environmental managers to ensure a biologically and socially sustainable fishery. While this chapter is focussed on a single fishery in a defined area, the implications of the resultant data could be translated and used in other similar fisheries. Moreover, as no social measures of fishery performance have been incorporated into the management plan for this, or any other fishery in Western Australia (Hobday et al., 2016b), these data may be useful in developing social indicators for use in the future.

A3.2. Methods

A3.2.1. Study location

The Peel-Harvey Estuary is located ~80 km south of the City of Perth in south- western Australia. This microtidal estuary is permanently open to the ocean via the natural Mandurah Channel and artificial Dawesville Cut, comprised of two adjoining basins (Peel Inlet and Harvey Estuary) and covers a surface area of 131 km^2 (Figure A3.1). The basins receive fluvial discharge from three rivers, *i.e.* Murray, Serpentine and Harvey, which drain a 12,000 km^2 catchment (Valesini et al., 2014). Maximum depths in the estuary reach 2.5 m, but the average depth is only 0.9 m (McComb and Lukatelich, 1995; Valesini et al., 2019). The estuary is adjacent to the City of Mandurah, the largest regional city in Western Australia (City of Mandurah Council, 2016). The city is undergoing rapid urbamnisdation and has one of the fastest growing populations in Australia (Department of the Environment and Heritage, 2006). Moreover, between 2016 to 2036, the population of Mandurah is forecasted to increase by 44%, reaching a total of 119,877 people (City of Mandurah Council, 2016; Australian Bureau of Statistics, 2017). The popularity of this city is related, in part, to the variety of water-based attractions, particularly fishing. The Peel-Harvey Estuary supports commercial and recreational fisheries for a number of species including teleosts, such as the Sea Mullet *Mugil cephalus* and various species of sillaginid, and crustaceans like Blue Swimmer Crab and the Western School Prawn *Metapeanaeus dalli*. Among them that of the portunid Blue Swimmer Crab is the most iconic (Ryan et al., 2015).

A3.2.2. Surveys

The chapter used two sequential data collection methods; (1) a face-to-face open- question interview, which produced qualitative data and (2) an online closed-question survey, which generated quantitative data. The initial open-question survey, *i.e.* one without a list of choices, was conducted in the form of highly-structured interviews undertaken at nine sites around the banks of the Peel-Harvey Estuary (Figure A3.1). The most commonly recorded responses from this survey were used to develop a subsequent closed-question online survey, *i.e.* questions with a definite answer or a list of choices, using an online survey tool, Surveygizmo. Full details of these surveys are provided in subsections 1.2.2.2 (open-question survey and motivations for fishing) and 1.3.2.1 (view on stock enhancement and other management options).

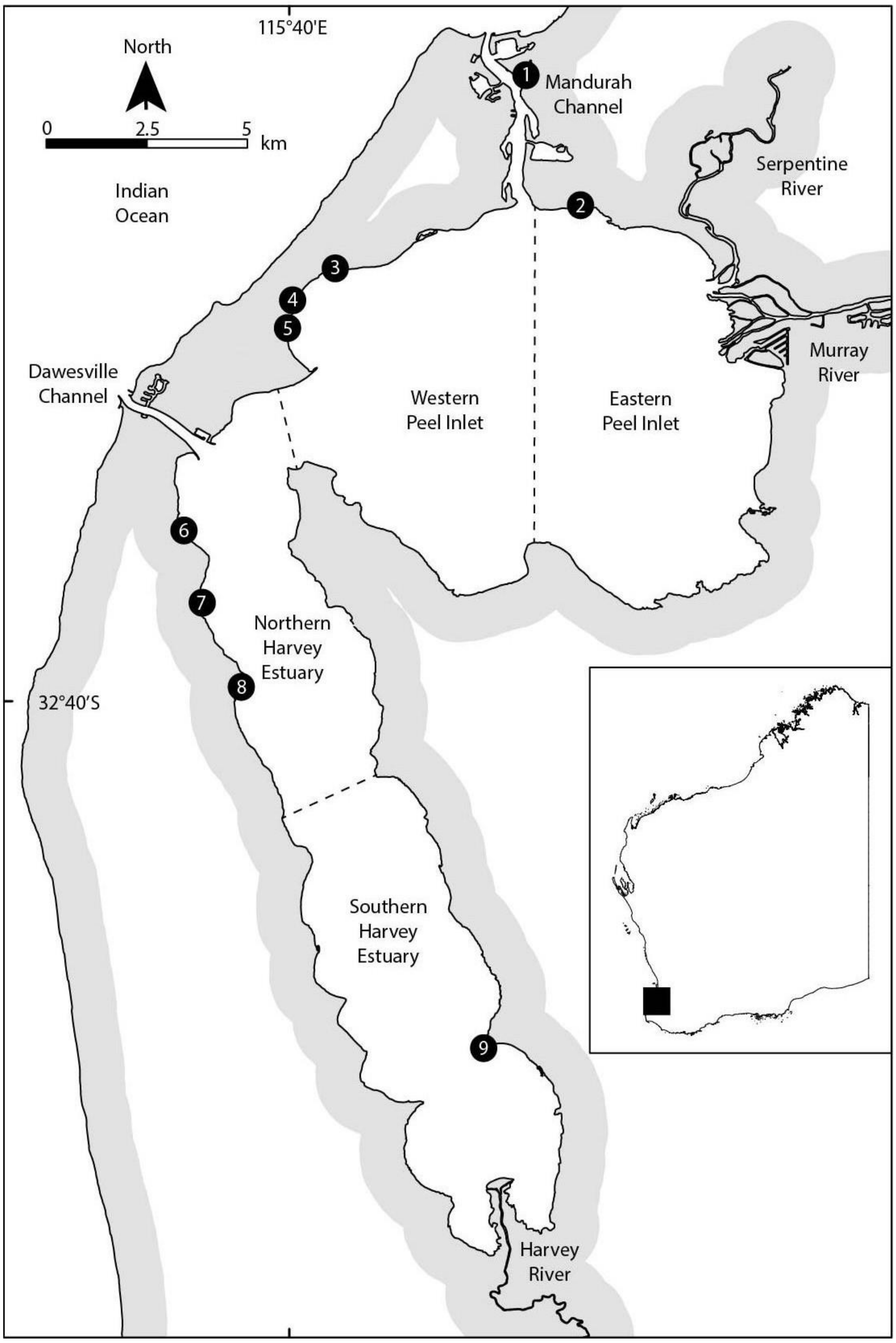

Figure A3.1. Map of the Peel-Harvey Estuary and its location in south-western Australia, showing the main regions, rivers and entrance channels. Black circles denote the nine survey sites where face-to-face interviews were conducted with recreational fishers.

Quantitative identification of fisher groups

A preliminary analysis was undertaken using Primer v7 (Clarke and Gorley, 2015) to quantitatively group fishers that had similar fisher characteristics. Note that this analysis was conducted using only the 163 respondents who had completed every question in the survey. Respondent's answers to the following four questions *i.e.* (1) how often have you fished for Blue Swimmer Crabs over the last 12 months, (2) how long have you been fishing for Blue Swimmer Crabs (years), (3) how do you fish for Blue Swimmer Crabs and (4) what is your self-assessed fishing expertise, were each assigned to a numeric value. In the case of fishing frequency, each category was converted to a number of times per year and the lowest value in the range selected, e.g. a fisher who fishes 1-2 days a week, would be recorded as fishing 52 times a year. The length of time the respondent has fished for Blue Swimmer Crabs was taken as the lowest number of years from each category (*e.g.* 11-20 years = 11). For the method of fishing, an index was created; *i.e.* 1 = shore only, 2 = both boat and shore, but mainly shore, 3 = both boat and shore equally, 4 = both boat and shore, but mainly boat and 5 =

boat only. Self-assessed fisher expert level was assigned a scale of 1 = beginner, 2 = intermediate and 3 = expert.

The numeric values for each of the fisher characteristics examined using pairwise Draftsman plots and Pearson's correlations to visually assess the extent to which the distribution of values for each the four variables were skewed and thus the type of transformation required to ameliorate any such effect and determine whether any pair of variables were highly correlated. As this plot demonstrated that no transformations were required and that none of the variables were correlated (r = 0.054 – 0.413), the 'raw' data was normalised to place all variables on a common scale and used to construct a Euclidean distance matrix. Euclidean rather than Manhattan distance was employed as the former resemblance coefficient operates with squared rather than the absolute differences and thus reflects the greatest variation in analysis outcomes (Clarke et al., 2006).

To identify groups of fishers who did not differ significantly in their fishing characteristics and thus represent distinct 'fisher groups' the above Euclidean distance matrix was subjected to hierarchical agglomerative clustering with group-average linking (CLUSTER) and an associated Similarity Profile (SIMPROF) test (Tweedley et al., 2013). This SIMPROF test was performed at each node of the dendrogram to determine whether the group of fishers being subdivided contains significant internal structure. The null hypothesis of no significant difference among fishers was rejected if $P < 0.05$. The same resemblance matrix was used to construct a non-metric MultiDimensional Scaling (nMDS) ordination plot (Clarke, 1993) to visually display the level of dissimilarity between individual respondents coded for fisher groups. A plot of the means and 95% confidence intervals were constructed for each fisher characteristics to explain the differences in fisher groups.

CLUSTER-SIMPROF identified five groups of fishers, termed 'fisher groups', *i.e. a* to *e* (Figure A3.2). Those in group *a* were the most distinct, being well separated from the other groups on the nMDS plot (Figure A3.3). Fishers in this fisher group were distinguished by their far greater frequency of fishing (*i.e.* 156 *vs* < 20 days in the other groups; Figure A3.4; Table A3.1). Of the remaining groups *b* and *c* contained boat-based fisher, while those in *d* and *e* fisher from the shore. Among those boat-based fishers, those in *b* had been fishing, on average, for 40 years compared to 12 in *c,* and likewise deemed themselves to be 'expert' rather than 'intermediate'. Similarly, shore-based fishers in *d* were proficient than those in *e* (Figure A3.4).

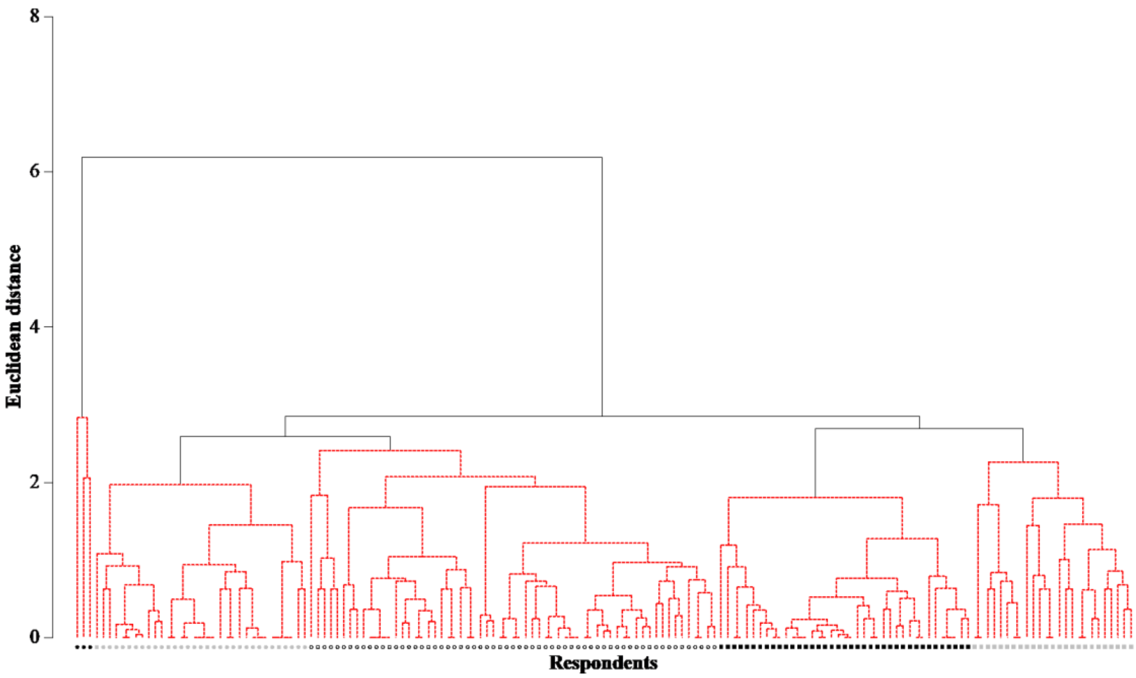

Figure A3.2. Dendrogram derived CLUSTER analysis of the four fisher characteristics of 163 Blue Swimmer Crab fishers from the Peel-Harvey Estuary that answered every question in the survey.[36]

[36] The clusters under each dashed vertical red line represent fishers that were shown by SIMPROF to have statistically similar fisher characteristics ($P > 0.05$), but to be significantly different from all those fishers in other fisher groups ($P < 0.05$).

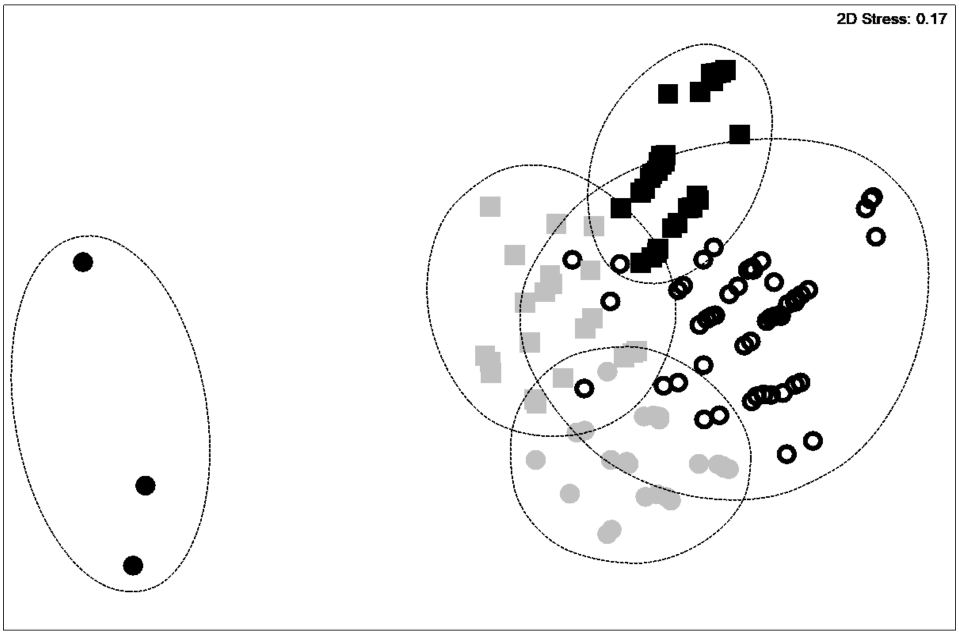

Figure A3.3. nMDS ordination plot constructed from a Euclidean distance matrix of the fisher characteristics from the 163 Blue Swimmer Crab fishers that use the Peel-Harvey Estuary and answered every question in the survey.[37]

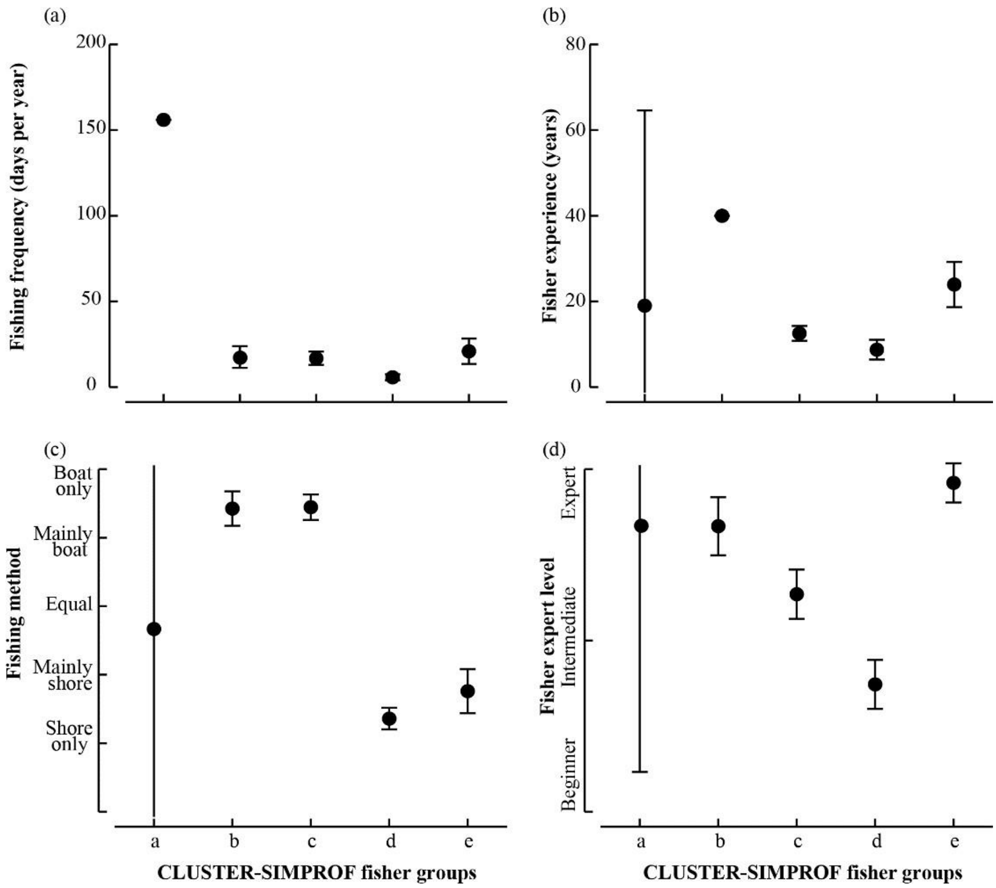

Figure A3.4. The mean and ± 95% confidence intervals for each fisher group for (a) frequent fishers, (b) boat-based fishers, (c) boat-based fishers, (d) shore-based fishers, (e) shore-based fishers.

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[37] Fishers coded according to the fisher group they belong to as determined by CLUSTER-SIMPROF (Figure A3.2). Dashed ellipses have been superimposed to highlight the spatial distribution of the various groups. Fisher groups; a = ● frequent fishers, b = ● boat-based fishers, c = O boat-based fishers, d = ■ shore-based fishers, e = ■ shore-based fishers.

Table A3.1. Description of the typical characteristics exhibited by members of each group of fishers identified by CLUSTER-SIMPROF.

Fisher group	Description
a) Frequent fishers	Fishers that fish >150 days a year
b) Boat-based older, experienced fishers	Predominately boat-based fishers who have been fishing for > 40 years and regard themselves as experts
c) Boat-based, inexperienced fishers of intermediate skill	Predominately boat-based fishers who have been fishing for ~10 years and assess themselves as of intermediate skill
d) Shore-based beginner fishers	Predominately shore-based fishers, who assess themselves as beginners
e) Shore-based experienced fishers	Predominately shore-based fishers, who assess themselves as experts

Univariate statistical analyses

All univariate analysis were conducted in Minitab v18 (Ryan, Joiner and Cryer, 2013) using those respondents that had partially and entirely completed the survey. The question '*what is your main motivation to fish for Blue Swimmer Crabs*' was analysed to determine which of the motivations selected from the open-question face-to-face interviews were the most popular among fishers. This was determined by calculating the number of respondents that selected each motivation and the overall percentage.

Responses to the question '*what makes your fishing trip successful*', were analysed using a Kruskal-Wallis test, to determine if the mean ratings for the six motivations differed ($p < 0.05$ in this and all tests that followed), and, if so, pairwise combinations of the motivations were subjected to *post hoc* Mann-Whitney test to determine which motivations were responsible for the overall differences, *e.g.* catching enough crabs to eat *vs* catching big crabs. The mean rating for each motivation was separately tested among a suite of demographics, *i.e.* age, gender, residency, fisher characteristics, *i.e.* fishing frequency, length of practice, fishing method and self-assessed level of expertise, and the fisher groups identified by CLUSTER-SIMPROF, using the same combination of Kruskal-Wallis and Mann-Whitney test(s) described above. The same testing procedure was also employed to test for overall and pairwise differences in the mean response rating for the salient belief strengths, evaluation and their cross-product and within each belief across demographics and fisher characteristic variables and fisher groups.

Next, the relationship between the motivations for Blue Swimmer Crab fishing and the beliefs and attitudes associated with restocking were investigated. This involved using Mann-Whitney tests to determine whether each of the belief ratings (for belief strength and belief evaluation) and cross-product values differed significantly between respondents who selected a particular motivation, *e.g.* food *vs* those who did not. It should be noted, however, that as this question was presented as a checkbox question, which allowed respondents to select more than one option, there were vast differences in the number of respondents between groups. Despite using a non-parametric test to help compensate for the unbalanced design, the sometimes-small samples size for one motivation (or group of motivations) should be taken into consideration when interpreting the results.

Two-tailed Spearman's rank correlations were used to determine whether there was a significant positive or negative relationship between the perceived success of a fishing trip (identified in the question '*What makes your fishing trip successful*'), and the belief strength values for restocking. Note that, due to the data for both variables being on the Likert scale, rather than continuous data, the strength of the *r* values is diminished.

The final suite of analysis investigated the opinions of current and potential management options for the Blue Swimmer Crab fishery. The mean response rating and ±95% confidence interval was calculated for each of the nine management options compared using Kruskal-Wallis and *post hoc* Mann-Whitney tests, to determine which were the most socially acceptable. Those same tests were also used to determine whether the overall attitude towards restocking differed among respondents who chose different levels of acceptability for each of the nine management options, for example, was restocking more or less popular amongst fishers who considered minimum size limits acceptable *vs* those who did not? The same testing procedures was also employed to test for overall and pairwise differences in the mean response rating for the management options and overall attitude towards restocking within each belief across demographics and fisher characteristic variables and fisher groups.

A3.3. Results

A3.3.1. Initial face-to-face interview

Recreational Blue Swimmer Crab fisher characteristics

A total of 41 face-to-face interviews were completed with recreational Blue Swimmer Crab fishers at locations on the banks of the Peel-Harvey Estuary. The response rate, *i.e.* proportion of fishers approached who agreed to complete the interview was 82%, with this high response rate indicating that the subsequent analyses and reporting of the results is appropriate (Babbie, 2014). Of the interviewees, 76% were male and 24% were female. Respondents ranged from '*18-24*' to '*65+*' with the majority of people belonging to the '65+' (29%), '55-64' (22%) and '25-34' (20%) categories (Table A3S1). More than 70% of those interviewed were residents, *i.e.* living within a 20 km radius of the estuary, all had completed high school, with 47% also completing some form of further education and/or training. The experience of interviewees varied markedly, with 14% having only fished for crabs for '1 year or less' and 34% having fished for 'more than 40 years' (Table A3S1). Approximately equal numbers of respondents fished from the shore and boats, one third of respondents said that Blue Swimmer Crabs were key to their identity and 83% claimed they had an understanding of what restocking is (Table A3S1).

The main motivations of recreational Blue Swimmer Crab fishers

Five salient motivations for fishing for Blue Swimmer Crabs were identified during the face-to-face interviews, of which the most common was food (chosen by 61% of participants). This motivation was stated almost three times more than the next most prevalent motivations of pleasure (22%), enjoyment of the catch (20%) and spending time with family and friends (17%; Table A3.2).

Table A3.2. Number of responses (n) and percentage number of times (%) a salient motivation for Blue Swimmer Crab fishing was identified during the 41 face-to-face interviews with Blue Swimmer Crabs fishers on the Peel-Harvey Estuary.[38]

Salient motivation	n	%*
Food (*e.g.* eating, tastes good, delicious)	25	61
Pleasure (*e.g.* fun)	9	22
Enjoyment of catch (*e.g.* exciting, fun to catch)	8	20
Time with family/friend(s) (*e.g.* fun with grandkids/kids, time for bonding)	7	17
Being outdoors (*e.g.* outdoor activity, exercise)	4	10

The beliefs and attitudes associated with restocking

From the open question face-to-face interviews, six salient beliefs associated with restocking were identified. The most prevalent beliefs were positive with, for example, 56% of respondents believing that restocking will enhance the number of crabs in the estuary and 46% believing that this will enhance the number of crabs that they can catch. Only 15% of people associated restocking with an increase in fishing pressure, while 59% thought that restocking would not influence the abundance of crabs in the Peel-Harvey Estuary (Table A3.3).

Table A3.3. Number of responses (n) and percentage number of times (%) a salient restocking belief for Blue Swimmer Crab fishing was identified through the 41 face-to-face interviews with Blue Swimmer Crabs fishers on the Peel-Harvey Estuary.[39]

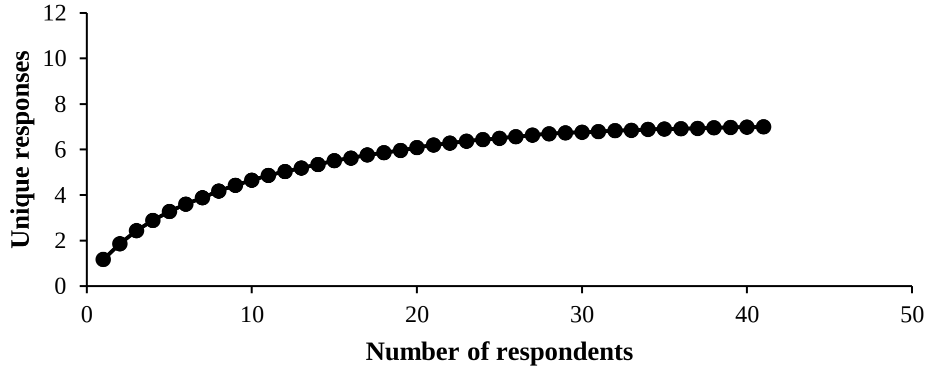
Salient beliefs that restocking will result in	n	%*
No change in the abundance of crabs	24	59
Increase the number of crabs	23	56
More crabs to catch	19	46
More fishers fishing for Blue Swimmer Crab	9	22
Impact on the environment and other species	8	20
Increase the fishing pressure on the crabs	6	15

[38] Examples of the types of responses categorised into motivations are provided in parentheses. * Does not sum to 100% because some respondents provided more than one response.

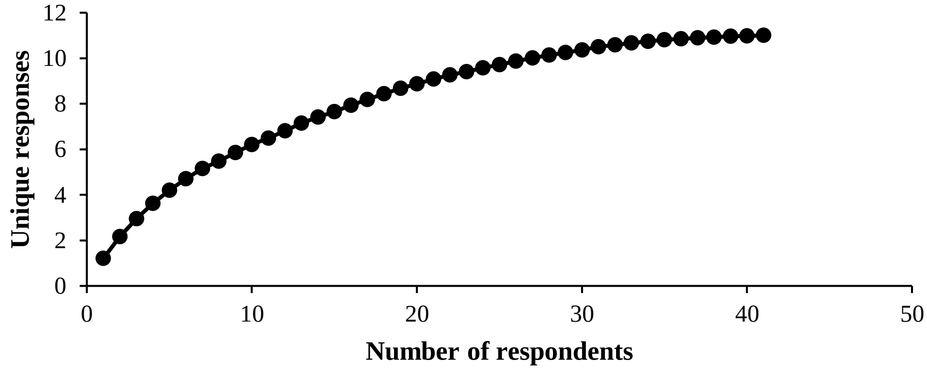
[39] * Does not sum to 100% because some respondents provided more than one response.

Visual analysis of response-accumulation curves constructed for three questions that sought to identify the main fisher motivations and the advantages and disadvantages relating to restocking demonstrated that the number of unique responses decreased rapidly after 20 respondents (Figure A3.5). For example, seven unique responses were recorded for the question '*what is your main motivation to fish for Blue Swimmer Crabs*' and 96% saturation was achieved after 29 fishers had been interviewed. While eleven and seven beliefs were identified about the advantages and disadvantages of restocking, respectively, they also reached 98 and 97% saturation at 34 and 32 fishers, respectively. Thus, regardless of the question, the sample size of 41 face-to-face interviews was sufficient to detect the main responses provided by fishers and inform the closed question online survey.

(a)



(b)



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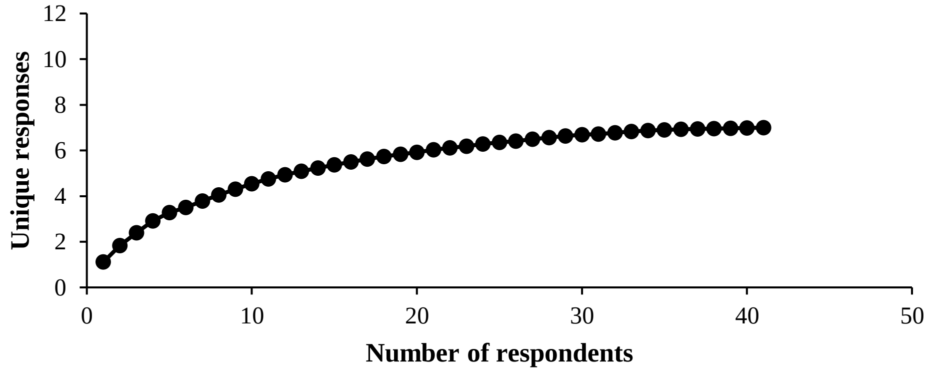

Figure A3.5. Response-accumulation curves showing the number of different responses provided by an increasing number of respondents.[40]

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[40] Questions (a) *What is your main motivation to fish for Blue Swimmer Crabs?* (b) *What do you think are the advantages or good things that could occur if restocking is used to manage the Blue Swimmer Crab fishery in the Peel-Harvey Estuary?* and (c) *What do you think are the disadvantages or bad things that could occur if restocking is used to manage the Blue Swimmer Crab fishery in the Peel-Harvey Estuary?* n=41.

A3.3.2. Online survey

Blue Swimmer Crab fisher characteristics

A total of 424 fishers accessed the closed question online survey and answered questions, of which 236 (56%) stated that they used the Peel-Harvey Estuary to catch Blue Swimmer Crabs. Among those fishers, 163 completed every question within the survey; a 70% survey completion rate.

Of the 236 fishers that use the Peel-Harvey Estuary, 80% were male and 20% were female, with the majority of respondents being fairly equally represented among the '*25- 34*', '*35-44*', '*45-54*' and '*55-64*' categories (*i.e.* 17-24%; Table A3S2) and split between Mandurah residents (49%) and those that live > 20 km from the Peel-Harvey Estuary (51%). Although fishers ranged in experience from *'≤ 1 year*' to '*more than 40 years*', 69% of respondents said they had practiced Blue Swimmer Crab fishing for over 11 years. The frequency of fishing over the previous 12 months ranged from '*never*' to '*5 days or more a week*'. The vast majority of respondents had fished within the last year (97%), typically ranging between '*once every 4-6 months'* to '*1-2 days a fortnight*' (all 17-20%). Some respondents, however, fished very frequently, *i.e.* '*3-4*' and '*≥ 5 days per week*'; 2 and 1%, respectively). Fishing from a '*boat only*' was the most common method, followed by '*shore only*'. In terms of self-assessed fishing level, over half of respondents classified themselves as intermediate fishers, with 39% considered experts (Table A3S2).

The key motivations of recreational Blue Swimmer Crab fishers in the Peel- Harvey Estuary

When asked '*what is your main motivation to fish for Blue Swimmer Crabs*' 94% of respondents selected food, making this by far the most common driver of fishing (Table A3.4). Enjoyment of the outdoors, enjoyment of catch, and fishing for pleasure were the next most prevalent motivations, each selected by 66 to 70% of respondents.

Table A3.4. Number of responses (n) and the frequency of occurrence (%) a motivation for Blue Swimmer Crab fishing was identified through the online survey. * Does not sum to 100% because some respondents provided more than one response. n = 222.

Motivation	n	% of respondents*
Food	209	94
Enjoyment of outdoors	155	70
Enjoyment of catch	152	68
Pleasure	146	66
Time with family	124	56
Time with friends	105	47

When asked '*what makes your fishing trip successful?*' the means for the suite of six perceived success metrics for a fishing trip ranged from +1.97 to -0.62 on a scale of -3 to +3, with all being positive, *i.e.* agree, except for '*some crabs, despite number or size'* (Figure A3.6). A Kruskal-Wallis test indicated that these means were statistically different (H = 194.71, $p < 0.01$), with pairwise Mann-Whitney tests demonstrating that the six motivational factors fell into one of four groups (Figure A3.6). The first of these comprised catching '*enough crabs to eat*' and '*big crabs*', which had the highest mean rating (> 1.87) and are regarded as being the most important aspects of a successful fishing trip. The next strongest motivation was '*being with friends/family is enough*' and '*being outdoors is enough*'. While these were not significantly different from one another ($p = 0.644$; mean rating ~1.5), they were from all other motivations ($p < 0.036$). Although catching enough crabs to eat and larger individuals were clearly important and had the highest mean rating, '*catching as many crabs as legal*', was less important overall (0.67), but more so than catching '*some crabs*' (-0.62); with these last two motivations being different from all others ($p < 0.01$). Thus, catching a sufficient number of crabs to eat, and preferably larger ones, are the most important factors for crab fishers, relative to the other factors. While they need not catch enough to meet the bag-limit, fishers had a negative response towards catching only a limited number or small-sized crabs and therefore, disagree with this factor. The secondary motivation was spending time with friends and family and enjoying the time spent outdoors.

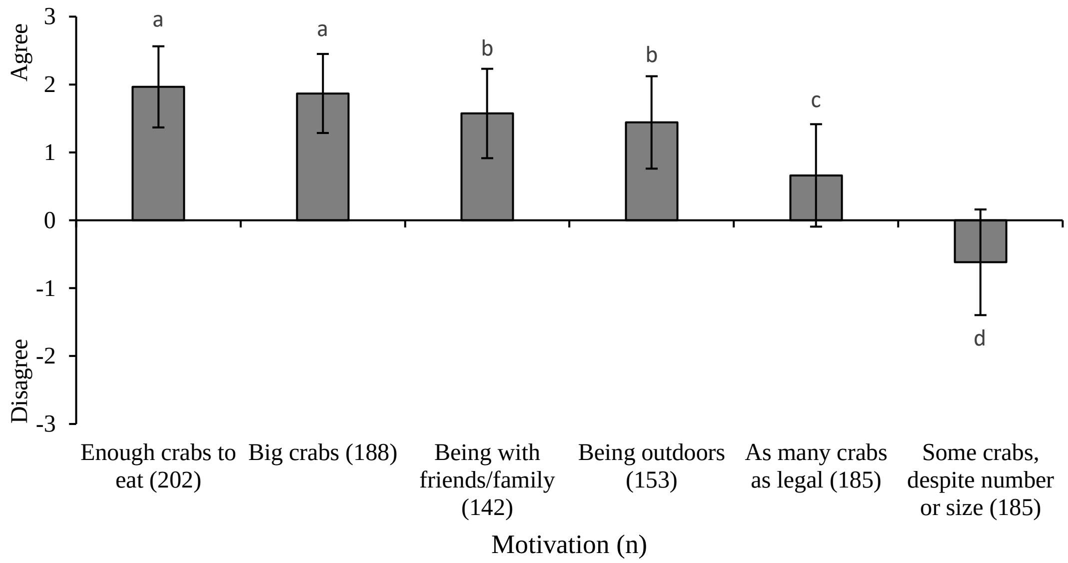


Figure A3.6. Mean ratings (± 95% confidence interval) per motivational factor in the online survey question '*Thinking about when you go fishing for Blue Swimmer Crabs, in your opinion, what makes your fishing trip successful?*'.[41]

When the rating of various motivational factors for crabbing were compared against the various demographics (age, gender and residency), fisher characteristics (fishing frequency, length of practice, method and expertise) and the CLUSTER-SIMPROF groups, Kruskal-Wallis tests showed 42 of the 48 comparisons did not differ significantly (p = 0.065 – 0.953; Table A3S3). Among those where significant differences were detected, two comparisons involved residency; with the median rating for '*being outdoors is enough*' and '*catching enough crabs to eat*' greater for residents than non-residents (*i.e.* 2 *vs* 1, respectively; p = 0.042 and 3 *vs* 2, respectively; p = 0.024). The ratings for the motivation to '*catch some crabs, despite number or size*' differed among ages (p = 0.035). Fishers in the 25-34 group scored this motivation as positive (*i.e.* 1) and were thus significantly different from people in the three groups between 35 and 64 (p = 0.002 –0.020) who scored this as negative (*i.e.* between -1 and -3). The '*frequency of fishing over the last 12 months*' was shown by a Kruskal-Wallis test to influence the rating for the motivation to '*catch enough crabs to eat*' (p = 0.029; Appendix 1.1). Fishers that fished once every 4-6 months considered catching crabs less important (median = 2) to those that fish more regularly, *i.e.* 1-2 days a week (p = 0.005) and once a month (p = 0.005 and 0.017, respectively; median = 3 in both cases). The mean ratings for '*being outdoors is enough*' differed with the '*length of fishing practice*' (p = 0.038). Fishers who had been crabbing for ≤ 1 year considered being outdoors more important (median = 3) than those who have been fishing for 11-20, 21-39 and 40+ years (p = 0.003 – 0.031; median 1-2) and those crabbing for ≥ 40 assigning a higher rating than those practicing for 11-20 years (p = 0.049; median 2 *vs* 1, respectively). Finally, the importance of '*catching as many crabs as legally allowed*' differed for fishers using different fishing methods (p = 0.026). Thus, those that crabbed from a boat and the shore equally thought this motivation was more important (*i.e.* 2) than those that used a boat or shore more often (*i.e.* both 1; p = 0.008 and 0.038, respectively).

The main beliefs fishers associate with potential Blue Swimmer Crab release programs

The mean strength for each of the six behavioural beliefs identified in the face-to- face interviews, *i.e.* the likelihood of each belief to occur if restocking is implemented, ranged from +1.76 to -0.77 (on a scale of +3 to -3) and were shown by a Kruskal-Wallis test to differ significantly (H = 256.48; KW $p < 0.01$). Multiple Mann-Whitney tests demonstrated that the beliefs fell into three groups that were each significantly different form one another (all $p < 0.05$; Figure A3.7a). Namely, (1) outcomes that were considered highly likely, i.e. that

[41] The number of respondents for each motivation is given in parenthesis. Letters above or below a graph indicate significant differences between groups as determined by a suite of Mann-Whitney tests.

restocking would '*increase in the number of crabs*' (1.70), result in '*more crabs to catch*' and also '*more fishers fishing*' for the Blue Swimmer Crabs (all ~1.70), (2) outcomes where fishers were unsure what would happen *i.e*. an '*increase in fishing pressure*' (0.17) and (3) those that were slightly unlikely following restocking, *i.e.* '*impact on the environment and other species*' and '*no change in the abundance of crabs*' (0.58 and 0.77, respectively).

In only two cases did the strength of the behavioural belief, across the various demographic, fisher characteristics and CLUSTER-SIMPROF fisher groups, differ significantly (Table A3S4). First, the belief that restocking will '*increase the fishing pressure*' differed with gender (MW p = 0.036), with females believing this was slightly more likely than males (median = 1 vs 0, respectively). Second, for the belief that restocking will '*impact the environment and other species*' among fishers in the CLUSTER-SIMPROF fisher groups (MW p = 0.031), with old, experienced boating crabbers (group b) thought that this was moderately unlikely (median = -2) *vs* shore-based beginner fishers (group d) who considered this was likely, albeit not strongly (median = 1).

The main attitudes fishers associate with potential Blue Swimmer Crab release programs

A Kruskal-Wallis test demonstrated that the mean evaluation for each behavioural belief, *i.e.* whether the outcome from the restocking program is good or bad, ranged from +2.15 to -1.57 (Figure A3.7b) and differed significantly (H = 457.61; KW p < 0.01). Only two of the outcomes were associated with a positive judgement, *i.e.* '*increased number of crabs*' and '*more crabs to catch*' (2.14), which were significantly different from the other beliefs (KW p < 0.01). The '*impact on the environment and other species*' (-1.57) and an '*increase in fishing pressure*' (-1.55) were considered to be the worst outcomes from restocking and different from all other beliefs (all KW p < 0.01) except for '*no change in crab abundance*' (KW p = 0.185 and 0.181, respectively). The views of fishers were consistent among *a priori* groups in each demographic, fisher characteristics and the CLUSTER-SIMPROF fisher groups (KW p = 0.061 – 0.941; Table A3S5).

The cross-product data from potential Blue Swimmer Crab release programs

The mean cross-product, *i.e.* the belief strength × belief evaluation, for the six behavioural beliefs ranged from +11.40 to -4.84 (on a scale of +18 to -18) and were found to differ significantly (H = 396.21; KW p < 0.01). As with the belief evaluation, only an '*increase in crab number*' (11.39) and '*more crabs to catch*' (11.40) were positive (and different to all other beliefs; KW p < 0.01) (Figure A3.7c). The beliefs that there will be '*no change in crab abundance*', an '*impact on the environment and other species*' and '*increase in fishing pressure*', were all negative going from bad, but unlikely (-1.10), to likely and somewhat bad (-2.23), and to somewhat likely and bad (-4.84). Each of these beliefs were different to all other except for '*more fishers fishing*', which while having a mean of -2.22 exhibited more variability than the other beliefs.

The cross-products for only two of the six beliefs were shown by Kruskal-Wallis tests to differ among variables (Table A3S6). The belief that restocking will '*impact the environment and other species*' differed between self-assessed fishing expertise (MW p = 0.022), with intermediate skilled fishers having a relatively more negative attitude than expert fishers (median = -4 *vs* -2; MW p = 0.006). There was also a significant difference between the '*length of time*' fishers have been fishing for Blue Swimmer Crabs and the belief that restocking will result in '*more fishers fishing*' (MW p = 0.038). The median cross-product for respondents who have been fishing for 21-39 years (-6) was significantly different from all other groups; those medians ranged from -3 to 0; MW p = 0.01 – 0.027).

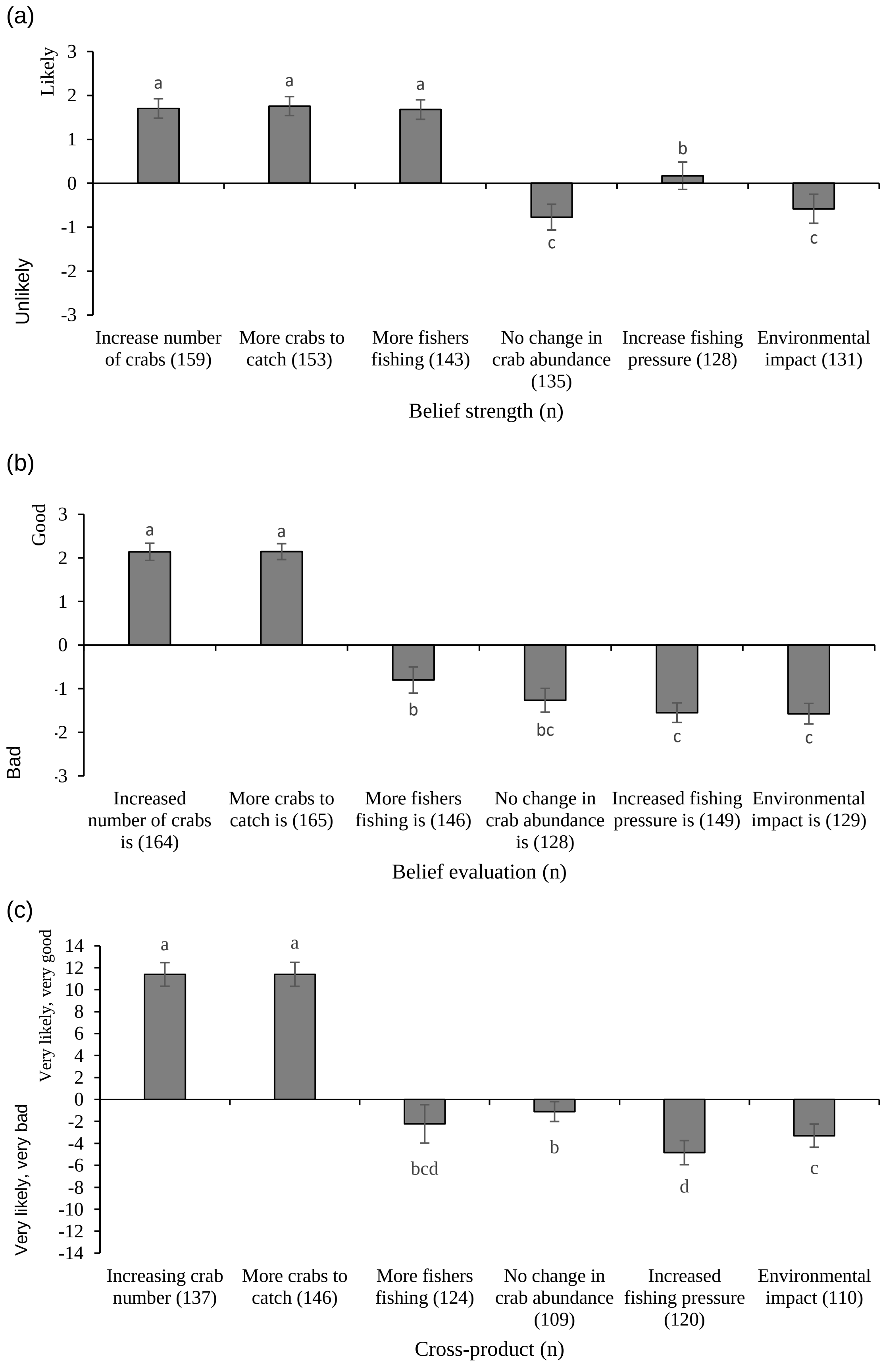


Figure A3.7. Mean ratings (± 95% confidence interval) for each restocking belief across (a) belief strength, (b) belief evaluation and (c) cross-products for restocking Blue Swimmer Crabs in the Peel-Harvey Estuary. The number of respondents for each belief or cross-product is given in parenthesis. Letters above or below a bar indicate significant differences between groups as determined by a suite of Mann-Whitney tests.

The relationship between the motivations of Blue Swimmer Crab fishing and the beliefs and attitudes associated with restocking

As respondents could select more than one motivation, a series of presence/absence pairwise comparative tests were used to determine whether the belief ratings for belief strength and belief evaluation and cross-product values between fishers who selected a certain motivation were different from those that did not select that same motivation. In the case of the belief strength, no significant differences were detected by a suite of Mann- Whitney tests between the restocking beliefs (p = 0.065 – 0.957; Table A3.5). There were, however, two tests that were close to significant (*e.g. p* = 0.065 and 0.072; Table 1.4.10). People who crab to spend '*time with friends*' believe it is more likely that restocking will result in more fishers fishing, than those who did not select the motivation. Additionally, people who crab for '*food*' believe it is less likely that restocking will result in environmental changes, than those who did select the motivation.

Table A3.5. W-values from Mann-Whitney test of the presence/absence comparison of restocking belief strength for each motivation to fish for Blue Swimmer Crabs.[42]

		Motivation					
		Food	Pleasure	Time with family	Time with friends	Enjoyment of catch	Enjoyment of outdoors
Belief strength	Increase number of crabs	11,812	7,927	6,811	6,096	8,561	8,694
	More crabs to catch	11,237	7,484	6,467	5,557	7,954	8,001
	More fishers fishing	9,650	6,471	5,295	4,064	6,992	7,035
	No change	8,599	6,196	5,021	3,762	6,272	5,881
	Increase fishing pressure	7,627	5,920	4,396	3,569	5,271	5,636
	Environmental impact	7,854	5,886	4,774	3,884	5,782	5,936

Four significant differences between respondents' motivations for fishing and the six belief evaluations were detected by a series of Mann-Whitney tests (Table A3.6), two of which were related to the belief evaluation that restocking would lead to an '*increase in the number of crabs*'. Fishers that selected the motivations '*enjoyment of the catch*' and '*enjoying the outdoors*' had a more positive belief that the restocking outcome would be relatively better (median of 3 with selected motivation *vs* 2 for those who did not select the motivation both cases; p = 0.032 and 0.024, respectively). Fishers who selected spending '*time with family*' rated the outcome that restocking will result in '*no change in crab abundance*' more negatively (median = -2 *vs* -1; p = 0.034) than those who did not select this motivation, while those that selected '*food*' rated the belief that restocking will impact the '*environment and other species*' more negatively than those that did not selected this motivation (median = -2 *vs* -1; p = 0.016).

[42] Shaded cells indicate a p- value between 0.051-0.100. Pale green cells indicate that the median was greater among the group that chose the motivation, while pale red cells indicate that the median was greater among those that did not choose the motivation. No shading indicates no significant difference.

Table A3.6. W-values from Mann-Whitney test of the presence/absence comparison of restocking belief evaluation for each motivation to fish for Blue Swimmer Crabs.[43]

		Motivation					
		Food	Pleasure	Time with family	Time with friends	Enjoyment of catch	Enjoyment of outdoors
Belief evaluation	Increase number of crabs	12,772	8,691	7,440	6,674	9,610	9,719
	More crabs to catch	13,074	9,120	7,855	7,162	9,601	9,711
	More fishers fishing	10,043	7,026	5,844	4,616	7,324	7,284
	No change	7,595	5,552	4,138	3,596	5,508	5,381
	Increase fishing pressure	10,351	7,303	6,953	4,704	7,281	7,793
	Environmental impact	7,461	5,553	4,684	3,382	5,844	5,767

When comparing the cross-product values among the presence/absence of a motivation, three significant differences were identified (Table A3.7), two of which were related to the motivation '*time with family*'. Fishers that selected this motivation rated the outcome that restocking will result in '*no change in crab abundance*' more negatively (median = -2 *vs* 0; $p = 0.049$) than those that did not select this motivation. These fishers rated the outcome that restocking will result in an '*increase in fishing pressure*' more positively (median = -4 *vs* -5; $p = 0.044$). Fishers who selected '*enjoyment of catch*' rated the outcome that restocking will '*increase the number of crabs*' more positively (median = 15 *vs* 10; $p = 0.043$) than those who did not select this motivation.

Table A3.7. W-values from Mann-Whitney tests of the presence/absence comparison of restocking cross-products for each motivation to fish for Blue Swimmer Crabs.[44]

		Motivation					
		Food	Pleasure	Time with family	Time with friends	Enjoyment of catch	Enjoyment of outdoors
Cross-product	Increase number of crabs	10,091	6,679	5,803	5,205	7,476	7,384
	More crabs to catch	10,304	7,041	5,889	5,425	7,520	7,401
	More fishers fishing	7,221	4,963	4,263	3,348	5,256	5,328
	No change	5,565	3,838	2,977	2,785	3,957	3,875
	Increase fishing pressure	6,801	4,927	4,615	3,133	4,785	4,907
	Environmental impact	5,764	4,236	3,494	3,005	4,357	4,345

Two-tailed Spearman's rank correlations were used to determine whether there was a significant positive or negative relationship between the perceived success of a fishing trip, and the belief strength values for

[43] Dark and light shading indicate significant results ($p < 0.050$) and those with a *p*-value between 0.051-0.100, respectively. Dark and pale green cells indicate that the median was greater among the group that chose the motivation, while dark and pale red cells indicate that the median was greater among those that did not choose the motivation. No shading indicates no significant difference.

[44] Shaded cells indicate a significant result ($p < 0.050$). Dark green cells indicate that the median was greater among the group that chose the motivation, while dark red cells indicate that the median was greater among those that did not choose the motivation. No shading indicates no significant difference.

restocking. Although most correlations were not significant (*p* = 0.058 – 0.967), four significant differences were detected, three of which were associated with the belief that restocking will '*increase the number of crabs*' (Table A3.8). In these cases, there was a positive association between the belief that restocking will '*increase the number of crabs*' and the motivation to '*catch as many crabs as legal*', '*catch big crabs*', and catch '*enough crabs to eat*', (*r* = 0.168 – 0.275; *p* = 0.001 – 0.041; Table A3.8). This indicates that those respondents who agree that these motivational factors are important for a successful fishing trip also believe that restocking will '*increase the number of crabs*'. There was also a positive association between the belief that restocking will result in '*more crabs to catch*' and the motivation to '*catch as many crabs as legal*', (*r* = 0.197; *p* = 0.027).

Table A3.8. *r* values from two-tailed Spearman's rank correlation tests of the relationship between restocking belief strength and the motivational factors for fishing for Blue Swimmer Crabs.[45]

		Strength					
		Increased crabs	More crabs	More fishers	No change	Increase fishing pressure	Environment impact
Motivational factors	Catching as many crabs as legal	0.275	0.196	0.020	-0.010	0.046	-0.099
	Catching crabs despite number or size	0.056	0.005	0.004	-0.071	0.065	0.075
	Enough crabs to eat	0.168	0.101	0.037	-0.024	0.022	-0.131
	Catching big crabs	0.211	0.091	0.143	-0.039	-0.040	-0.066
	Being outdoors is enough	0.090	0.114	0.139	0.078	0.114	0.183
	Being with friends/ family is enough	0.082	0.138	0.116	-0.012	0.049	0.197

Six significant differences were detected between the motivational factors for fishing and the belief evaluations associated with restocking, three of which were associated with the motivation to '*catch as many crabs as legal*' (Table A3.9). In these cases, there was a positive association between this motivation and the belief that restocking will '*increase the number of crabs*', result in '*more fishers fishing*' and '*increase the fishing pressure*' (*r* = 0.184 – 0.211; *p* = 0.021 – 0.034). There were also two positive relationships associated with the motivational factor to '*catch big crabs*' and the belief that restocking will '*increase the number of crabs*' and have '*more crabs to catch*' (*r* = 0.183 – 0.256; *p* = 0.002 – 0.031). A positive association was detected between '*catch enough crabs to eat*' and '*more crabs to catch*', (*r* = 0.207, *p* = 0.010). In summary, respondents who agree that these motivational factors are important for a successful fishing trip also believe these corresponding restocking outcomes will be good.

[45] Dark and light shading indicate significant results (*p* < 0.050) and those with a *p*-value between 0.051- 0.100, respectively. Dark and pale green cells indicate that there was a positive relationship between the motivation factors and the restocking behavioural beliefs. No shading indicates no significant difference.

Table A3.9. *r* values from two-tailed Spearman's rank correlation tests of the relationship between restocking belief evaluation and the motivational factors for fishing for Blue Swimmer Crabs.[46]

		Evaluation					
		Increase crabs	More crabs	More fishers	No change	Increase fishing pressure	Environment impact
Motivational factors	Catching as many crabs as legal	0.184	0.126	0.211	-0.106	0.198	0.164
	Catching crabs despite number or size	0.152	0.145	-0.052	-0.054	-0.080	-0.181
	Enough crabs to eat	0.133	0.207	-0.050	-0.066	-0.046	-0.011
	Catching big crabs	0.256	0.183	0.036	-1.06	-0.145	0.128
	Being outdoors is enough	0.158	0.020	0.061	0.145	-0.035	-0.042
	Being with friends/ family is enough	0.101	0.028	0.032	0.168	0.004	-0.065

When comparing the cross-product values among the motivational factors, four significant differences were detected, two of which were associated with the motivation to '*catch as many crabs as legal*', whilst the other two were associated with the motivation to '*catch big crabs*' (Table A3.10). In these cases, there was a positive association between the motivation to '*catch as many crabs as legal*' and the restocking belief that there will be an '*increase in the number of crabs*' and '*increase in fishing pressure*' (r = 0.209 – 0.245; p = 0.014 – 0.022). Additionally, there was a positive association between the motivation to '*catch big crabs*' and the restocking belief that there will be an '*increase in the number of crabs*' and '*more fishers fishing*' (r = 0.191 – 0.206, p = 0.022 – 0.049).

Table A3.10. *r* values from two-tailed Spearman's rank correlation tests of the relationship between restocking cross-products and the motivational factors for fishing for Blue Swimmer Crabs.[47]

		Cross-product					
		Increase crabs	More crabs	More fishers	No change	Increase fishing pressure	Environment impact
Motivational factors	Catching as many crabs as legal	0.209	0.158	0.183	0.026	0.245	0.129
	Catching crabs despite number or size	0.065	0.060	-0.061	-0.035	-0.023	-0.123
	Enough crabs to eat	0.098	0.092	0.015	0.010	0.050	-0.055
	Catching big crabs	0.206	0.027	0.191	0.027	-0.022	0.043
	Being outdoors is enough	0.083	0.072	0.031	0.145	0.123	0.159
	Being with friends/ family is enough	0.035	0.027	-0.020	0.092	0.086	0.141

[46] Dark and light shading indicate significant results (p < 0.050) and those with a p-value between 0.051-0.100, respectively. Dark and pale green cells indicate that there was a positive relationship between the motivation factors and the restocking behavioural beliefs, while pale red cells indicate that there was a negative relationship. No shading indicates no significant difference.

[47] Dark and light shading indicate significant results (p < 0.050) and those with a p-value between 0.051- 0.100, respectively. Dark and pale green cells indicate that there was a positive relationship between the motivation factors and the restocking behavioural beliefs. No shading indicates no significant difference.

Opinions of restocking and comparisons to other existing and potential management options

Among the 193 respondents, only 22% of fishers thought the Blue Swimmer Crab fishery in the Peel-Harvey Estuary is well-managed, with 49% disagreeing and 29% unsure (Table A3.11). Moreover, 71% of fishers stated that the crab population needs to be better managed. In terms of catching crabs, 32% of fishers are happy with both the number and size of Blue Swimmer Crabs they are catching, with 49% and 56% of respondents, respectively, expressing their dissatisfaction with the remainder unsure. Only 3% of respondents said they would stop fishing if Blue Swimmer Crabs were restocked, with 86% stating they would continue and 11% unsure (Table A3.11).

Table A3.11. Number (n) and percentage (%) of respondents that agree, disagree or are unsure about a suite of statements about the management of the Blue Swimmer Crab fishery in the Peel-Harvey Estuary.[48]

	Agree		Disagree		Unsure	
Statement	**n**	**%**	**n**	**%**	**n**	**%**
The fishery is well managed (193)	42	22	94	49	43	29
The fishery needs to be better managed (194)	137	71	18	9	39	20
I am happy with the number of crabs (194)	63	32	96	49	35	18
I am happy with the size of crabs (193)	62	32	109	56	22	11
I would continue to fish if crabs are restocked (194)	167	86	6	3	21	11

With regard to the suite of management options that could be used to regulate the recreational catch of Blue Swimmer Crabs in the Peel-Harvey Estuary, those measures that are currently being employed were deemed, on average, very acceptable, whereas those that have not yet been implemented are less popular. Means for the acceptability of the nine management options, on a scale of 0 (very unacceptable) to 5 (very acceptable), ranged from 4.7 to 2.6. A Kruskal-Wallis test demonstrated that there was a significant difference among the options (H = 345.8, $p < 0.01$), with *post-hoc* Mann-Whitney tests identifying five groups of options that differed in their acceptability (p = < 0.001 – 0.028; Figure A3.6). Eighty three percent of respondents considered '*minimum size limits*' to be very acceptable and had the highest mean score of 4.7, which was significantly greater than that for all other options (p = 0.001 – 0.028). The next most acceptable groups were those containing '*seasonal closures*' and '*monitoring fishers*' (both 4.5 and considered very acceptable by 70% of respondents) and another comprising *'education of fishers'*, *'bag limits'* and *'restocking'* (all 4.3 and considered very acceptable by 56%-59% of respondents). However, '*fishing gear restrictions*' (3.7), '*closed fishing zones*' (3.5) and '*maximum size limits*' (2.6), were all considered relatively unacceptable, with the last having a significantly lower acceptability than all other options ($p < 0.01$). Only 13% of people considered '*maximum size limits*' to be very acceptable (Figure A3.8).

[48] The total number of respondents that answered each question are given in parentheses.

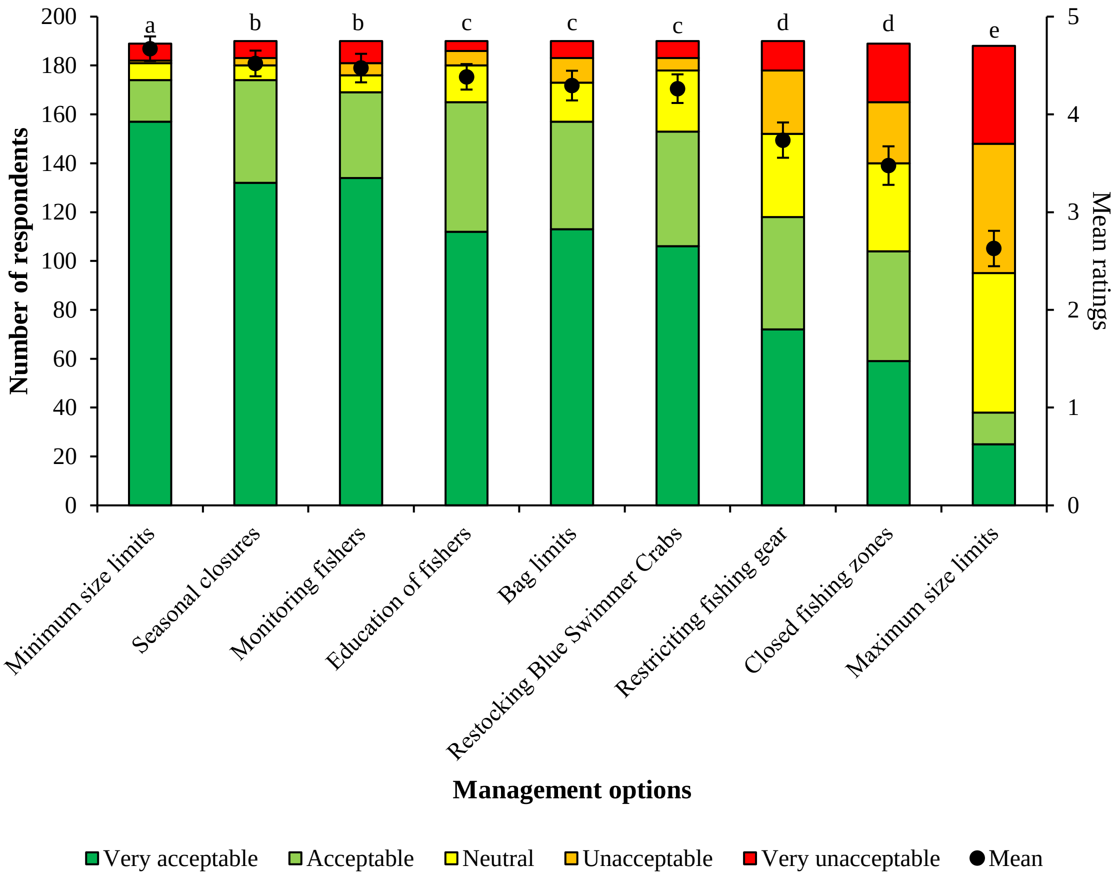


Figure A3.8. The mean ratings (± 95% confidence intervals) and a stacked bar graph of the number of respondents that chose a management acceptability option for each of the nine management options that currently are or could potentially be used to manage Blue Swimmer Crabs in the Peel- Harvey Estuary.[49]

When the management interventions were compared against the basic demographics, fisher characteristics and the CLUSTER-SIMPROF fisher groups, Kruskal-Wallis tests showed that 66 of the 72 comparisons did not significantly differ (p = 0.055 – 0.999; Table A3S7). Among those that were significantly different, two comparisons involved fisher expertise. The median rating for '*closed fishing zones*' and '*restricting fishing gear*' was greater among beginner and intermediate fishers than those that are self-assessed expert fishers, which indicates that expert fishers consider these interventions less acceptable (*i.e.* 4 – 4.5 *vs* 3, respectively; p = 0.016 and 0.001 and 4 *vs* 3.5, respectively; p = 0.015 and 0.021). The management intervention '*maximum size limits*' differed among genders (p = 0.023), where females have a greater acceptance than males (median = 3 *vs* 2). The acceptability of '*maximum size limits*' also differs for fishers using different fishing methods (p = 0.005), thus, those that crabbed from the shore only thought this management was more acceptable, albeit neutral (*i.e.* 3) than those that used a boat only, used a boat more often, or those that go crabbing from the shore and boat equally (*i.e.* all 2; p = 0.001 – 0.008). The frequency of fishing over the last 12 months was found to influence the acceptability of '*closed fishing zones*' (p = 0.025). Fishers that fished once a month considered the management intervention to be more acceptable (median = 4) to those that fish less regularly, *i.e.* once a year (median = 3; p = 0.049). Finally, a significant difference was detected among the CLUSTER-SIMPROF fisher groups with '*closed fishing zones*' (p = 0.042). Shore-based beginner fishers (group d) believe that this is acceptable (median = 4), while old, experienced boaters (group b), intermediate, inexperienced boaters (group c) and shore-based experienced fishers (group e) have a more neutral opinion (median = 3 – 3.5; p = 0.007 – 0.019; Table A3S7).

[49] Letters above or below a bar indicate significant differences between groups as determined by a suite of Mann-Whitney tests.

Fisher attitude towards restocking

More than 85% of respondents agree that restocking Blue Swimmer Crabs is a good thing to do, with 40% stating that it will be very good. In contrast only 9.3% of fishers through that restocking will be a bad thing to do (Figure A3.9). The views of fishers were consistent among *a priori* groups in each demographic, fisher characteristics variable, and the CLUSTER-SIMPROF fisher groups (p = 0.076 – 0.941; Table A3.12).

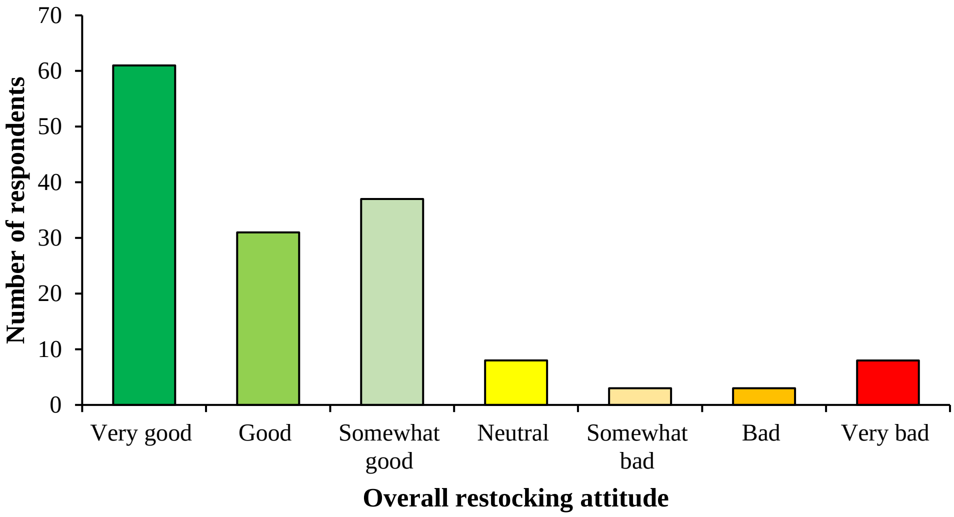


Figure A3.9. The number of respondents that selected each attitude category for the question '*Overall, I think using restocking as a management option for Blue Swimmer Crabs in the Peel-Harvey Estuary is…*' n = 151.

Table A3.12. H-values from the Kruskal-Wallis test between the basic fisher demographics, fisher characteristics and CLUSTER-SIMPROF fisher groups and the overall attitude fishers have towards restocking.[50]

	Overall attitude towards restocking
Demographics	
Age	9.88
Gender	0.56
Residency	3.14
Fisher characteristics	
Fishing frequency	7.04
Length of practice	1.76
Fishing method	4.93
Expertise	1.17
Fisher groups	4.86

Each management option was analysed against fishers '*overall attitude*' towards a restocking program, using a Kruskal-Wallis test. All produced non-significant results (KW p = 0.107 – 0.916), except for one, *i.e.* the acceptability of using a restocking program in the Peel-Harvey Estuary, which was significantly different from the '*overall attitudes towards restocking*' (p < 0.001). Multiple Mann-Whitney tests identified that those fishers who stated that restocking Blue Swimmer Crabs in the estuary would be very acceptable (5), had a stronger, albeit neutral, attitude than those who stated it would be very unacceptable (1), neutral (3) and acceptable (4) (median 3 *vs* 0 – 1; MW p = 0.001 – 0.005). While the mean restocking attitudes generally increased as the acceptability of restocking increased, those respondents that considered restocking to be an unacceptable management intervention still had a relatively strong belief that restocking will produce a good outcome (mean attitude = 1.4; Figure A3.10).

[50] Dark and light shading indicate significant results (p < 0.050) and those with a p-value between 0.051-0.100, respectively.

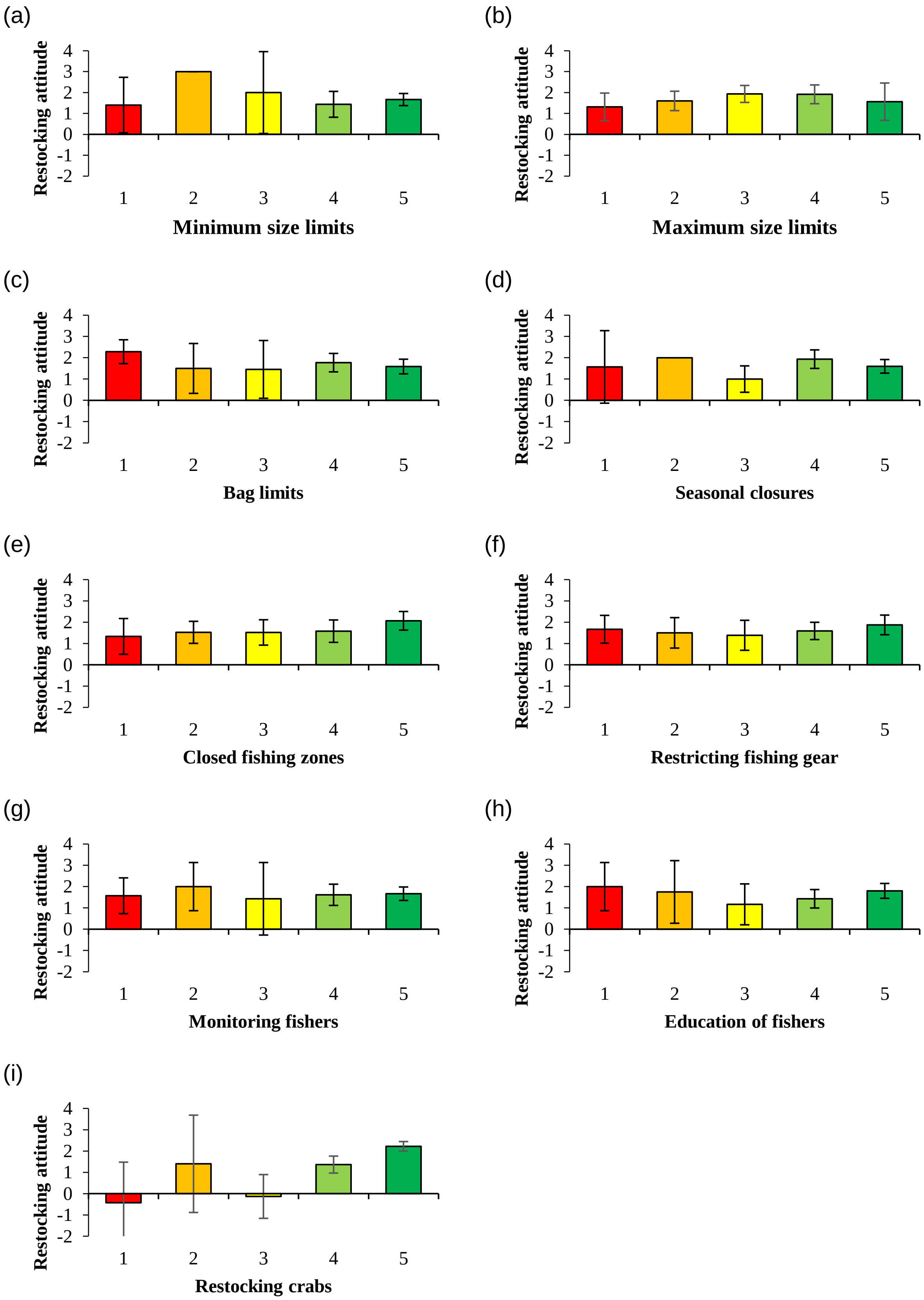


Figure A3.10. The mean (± 95% confidence intervals) of the overall attitude towards restocking (*y* axis) for each of the 'acceptability' responses across each management option (*x* axis). The scale of acceptability: (1) very unacceptable, (2) unacceptable, (3) neutral, (4) acceptable, (5) very acceptable.

A.3.4. Discussion

This chapter employed structured face-to-face interviews (n=41) and online questionnaire (n=236), to identify the social dimensions of Blue Swimmer Crab fishing in the Peel-Harvey Estuary. Based on the demographics of fishers, most respondents were male (80%), though were spread across a wide range of ages 18 to > 65 (most 25-64), with an equal split between Mandurah residents (49%) and those that live > 20 km from the estuary (51%). Based on the characteristics of fishers, most have been practicing this activity for > 11 years (69%), though the frequency of fishing over the previous 12 months varied between 'never' and '5 days or more a week'. Fishers were identified to fish from both a boat and the shore (43%), and most frequently identified themselves as intermediate fishers (52%).

However, despite the differing demographic and characteristics, the motivations of fishers, their beliefs and attitudes towards restocking and their perceptions about the management of the fishery are remarkably consistent. Acquisition of food is the primary motivation for fishing, with restocking heavily supported and considered very likely to '*increase crab numbers*' and result in '*more crabs to catch*', both positive outcomes, but would probably be accompanied by an increase in fishing pressure, a negative outcome. Interviewees strongly support some of the existing management regulations, notably the existing minimum size limit and seasonal closure, but felt that more enforcement officers, community education and a longer closed season were required.

The key motivations of recreational Blue Swimmer Crab fishers

Motivations for Blue Swimmer Crab fishing

Six salient motivations were identified through face-to-face interviews, with the acquisition of food the most prevalent, followed by several non-catch aspects, including the enjoyment of the outdoors, pleasure and the time spent with family/friends. The online survey yielded similar results but highlighted catching '*enough crabs to eat*' and '*big crabs*' as measures of a successful fishing trip. The motivations and experiences sought by recreational fishers are regarded as either (1) activity-specific, *i.e.* unique to the activity (*e.g.* target species, size and number of the fish) or (2) activity-general, *i.e.* elements that are common to all outdoor recreation activities (*e.g.* relaxation, socialization and spending time outdoors) (Fedler and Ditton, 1994b; Arlinghaus, 2006a). The results on the motivations of recreational Blue Swimmer Crab fishers in the Peel-Harvey Estuary, show that participants seek both elements, but are predominately pursuing a catch-related, activity specific outcome.

The importance of food as the primary motivation for fishing can be explained by the fact that the crabs are iconic locally and known for their edibility (Keenan, 2004; City of Mandurah, 2017; Santhanam, 2018). Moreover, the crabs are readily accessible using inexpensive equipment by people of all ages and experience levels. For example, the Peel-Harvey Estuary is a relatively large (131 km^2), with extensive shallow margins, average depth 0.9 m (McComb and Lukatelich, 1995; Valesini et al., 2014), which are easily accessible by waders using hand or scoop nets. Moreover, drop nets, which are baited and left unattended, can be used in the deeper parts (maximum depth 2.5 m), accessible from a boat using one of the 18 boat ramps that provide access to the estuary (DOT, 2011). Thus, in addition to be highly valued for their flavour, catching crabs is relatively easy compared to, for example, finfish species such as sillaginids (Whiting) using rod and line. The fact that the fishery can be exploited by a wide range of people with varying skills levels could explain why the motivations for recreational Blue Swimmer Crab fishing are relatively consistent across demographics and fisher characteristics, which the opposite to that found in many other studies where fishers require more specialised equipment and/or skill levels to catch fish (e.g. Schroeder et al., 2006; Arlinghaus, Tillner and Bork, 2015; Brinson and Wallmo, 2017).

In addition to being motivated by food, catching substantial numbers of crabs and large crabs were perceived measures of a successful fishing trip. This mirrors the findings of Arlinghaus et al. (2014), who identified that catching large fish and more fish relative to effort were important factors in determining success across various freshwater fisheries in Germany, for species including the Common Carp *Cyprinus carpio,* Zander *Sander* *lucioperca* and Pike *Esox Lucius*. Furthermore, Beardmore et al. (2011) found that fisher satisfaction increased as fish size and catch rates also increased, reflecting that the desire to catch big fish is inherent in human nature (Holland and Ditton, 1992; Zhou et al., 2010) and that catching 'trophy size' fish creates a sense of masculinity for the fisher (Bull, 2009). Moreover, in a more practical sense, removing the carapace of a crab to access the flesh is time consuming and more difficult on smaller individuals, thus a larger crab represents a bigger reward in terms of quantity of flesh and this is obtained faster and more readily than for small crabs.

The non-catch aspects, *i.e.* time spent with family/friends, pleasure and the enjoyment of outdoors, were also selected as motivations for Blue Swimmer Crab fishing, albeit secondary to obtaining food. Eight face-to-face interviewees also stated that they love taking their kids/grandkids out for the day and showing them what crabbing is all about. The selection of these motivations may also reflect the close proximity of fishing locations to local attractions and amenities (cafés, parks etc) and the fact that crab fishing in the Peel-Harvey Estuary is predominately a summer activity (Johnston et al., 2014), when average maximum temperatures are ~30 °C (BOM, 2018) and thus a cool off in the estuary may be appealing. The non-catch benefits of recreational fishing have been highlighted in numerous studies (Kearney, 2002; Britton and Coulthard, 2013; Acott and Urquhart, 2014; Young, Foale and Bellwood, 2016) and additional motivations have also commonly been recorded, such as stress release and physical fitness. For example, Young, Foale and Bellwood (2016) identified that fishers value the social interactions that the activity supports and these improve human wellbeing, as well as the functioning and management of the community. Participation in such activities runs contrary to the general view that modern society is becoming disconnected from nature and a sense of community, which is recognised as having detrimental impacts on human happiness and health (Nisbet, Zelenski and Murphy, 2011).

The selection, by recreational fishers, of catch and non-catch motivations clearly indicates that Blue Swimmer Crab fishing provides a heterogenous experience. The catch related aspects are the greatest motivator, which has been evidently seen in previous studies, though this can be related back to the fishery and the target species. The type of fish, the surrounding environment, and the management interventions can all influence the desires sought by the fishers (Wilde and Ditton, 1991; Arlinghaus et al., 2014).

Management implications

The primary motivations for fishing were catching enough crabs to eat, particularly larger crabs. The minimum legal-size limit for crabs (*i.e.* 127 mm carapace width) is thus an important management regulation. While minimum size limits are used widely in managing recreational fisheries, releasing undersized animals (*e.g.* soft-shell crabs) it does not prevent larger individuals being caught, discarded and potentially suffering from fishing-related mortality (Coggins Jr et al., 2007). The release rate of Blue Swimmer Crabs in Western Australia increased substantially from 51% in 2011/12 to 68% in 2013/14 (Ryan et al., 2015). This trend most likely reflects the fact that many undersize crabs were captured and subsequently released, although could also be caused by fishers catching enough crabs to eat (but not reaching their bag limit) and continuing to fish to attempt to catch larger (trophy) individuals. To increase the chance of crabs reaching the legal limit, the closed season could possibly be lengthened from 1 September to 31 October, to 1 September to 31 December/January, which would coincide with their growth moult (Stoner, 2012; Johnston et al., 2014). This, however, would reduce the social amenity of the fishery as these months constitute the peak in recreational effort (Malseed and Sumner, 2001a). In a suite of recently proposed management options, it has been suggested by the Department of Primary Industries and Regional Development (DPIRD, 2018) to extend the closure between 1 June to 31 October. The purpose of this is to enable better protection for the mated pre-spawning females which increase in numbers during this period (Johnston et al., 2011; Jenkins et al., 2018). However, this primarily applies to the commercial fishery, since the recreational fishers typically do not fish during the winter months. Alternatively, a maximum size limit could be employed, but such a regulation was shown to be socially unacceptable and would facilitate the capture of large crabs, but not allow them to be consumed. It is perhaps for these reasons that such a regulation is rarely used in crab fisheries.

Those fishers who partake in the fishery primarily to spend time outdoors and with family/friends would be less affected by any changes to fishing restrictions, than fishers motivated by catch-related aspects (Aas and

Kaltenborn, 1995; Arlinghaus, 2006a). Nevertheless, as Blue Swimmer Crab fishers are predominately motivated by these catch-related aspects and wanted to catch more crabs, they are more likely to benefit from regulations that increase stocks, such as restocking (Arlinghaus, 2006a; Tweedley et al., 2017c). It should be noted, however, that while greater emphasis needs to be placed on collecting and understanding fisher motivations (Grafton et al., 2006), implementing a management intervention on such data alone, can be misleading (Arlinghaus, 2006a). Therefore, in addition to this information, there is also value in understanding fisher perceptions towards the suggested regulations (Holland and Ditton, 1992; Fedler and Ditton, 1994b; Salas and Gaertner, 2004; Young, Foale and Bellwood, 2016). This can increase the success of new management schemes.

Main beliefs and attitudes associated with potential Blue Swimmer Crab restocking

Six salient beliefs associated with restocking were identified from face-to-face interviews and included both positive (2) and negative (3) and neutral responses (1). From the online survey, increased numbers of crabs and more crabs caught were identified as good, likely outcomes of restocking. Thus, both surveys suggest that Blue Swimmer Crab fishers in the Peel-Harvey Estuary have positive beliefs towards restocking, *i.e.* increased abundances leading to increased catches, but fishers seem largely unaware of the potential negative impacts and trade-offs of restocking, *e.g.* competition with wild stock, slower growth due to increased density-dependence and genetic and disease implications (Ward, 2006; Taylor, 2017a).

Similar results on fisher perceptions have been obtained from other studies, with fishers supporting restocking as they believe it will only influence the fishery in a positive way, believing it will improve the abundance of the target species and thus catches, *e.g.* Striped Bass *Morone saxatilis* and Largemouth Bass *Micropterus salmoides*, (Wilde and Ditton, 1991) and Red Drum *Sciaenops ocellatus*, Spotted Seatrout *Cynoscion nebulosus* and Common Snook *Centropomus undecimalis,* (Garlock and Lorenzen, 2017). These beliefs reflect a lack of understanding of the ecological and physiological processes that are potentially affected by restocking and thus the full range of benefits and costs involved (Hunt, Gonder and Haider, 2010; Garlock and Lorenzen, 2017). It highlights the need for good communication of the science of restocking between fishery managers, researchers and the fishers and their advocacy groups and a need for engagement and consultation in evaluating the potential application of restocking as part of the management process. To circumvent such issues, Arlinghaus and Mehner (2005) suggest that fishers should be involved in the planning and implementation of management interventions to facilitate their understanding and knowledge about the potential outcomes and risks. It is also worth noting that fishers may be selecting only the positive beliefs and outcomes, as they would like a restocking program to be implemented as they see this as a mechanism for increasing catches, whilst allowing normal fishing practices to continue, *i.e.* preventing the implementation of stricter fishery controls (Lipcius et al., 2008). This bias towards positive beliefs and outcomes on Blue Swimmer Crabs restocking may have occurred as fishers identified that negative environmental impacts and increases in fishing pressure may follow restocking, although they did not believe that they were likely to occur.

Recreational Blue Swimmer Crab fishers whose motivations were catch-related, believed that restocking will both increase the number of crabs and ensure that there are more crabs in the estuary to catch. This is indicative of the perceptions towards restocking that more fish in will result in more fish out (Loneragan, Taylor and Tweedley, 2018), yet, more often than not, restocking has failed to deliver increased fishery yields and economics benefits (Bell et al., 2005; Lorenzen, 2005). Such economic failures have occurred for the Pink Salmon *Oncorhynchus gorbuscha* in Alaska, the Chinook Salmon *Oncorhynchus tshawytscha* in the U.S, and the Clawed Lobster *Metanephrops* spp. in the United Kingdom (Hilborn, 1998). That being said, numerous restocking and stock enhancement projects have been successful, including some for portunids (Zohar et al., 2008; Jenkins et al., 2018). Thus, the results of the current chapter could reflect the fact that fishers may only being aware of successful restocking projects, like that for the Western School Prawn *Metapenaeus dalli* in the nearby Swan-Canning Estuary (Tweedley et al., 2017c; Crisp et al., 2018) that received substantial local news coverage and had a community engagement program (Jenkins, Tweedley and Trayler, 2016; Tweedley et al., 2017b).

While many fishers have also stated that they want to catch big crabs, due to density-dependent growth effects, the addition of more individuals to the waterbody increases competition and typically slows the growth of the wild population, resulting in more individuals, but of a smaller size (Ruzzante, 1994; Pile et al., 1996; Lorenzen and Enberg, 2002; Loneragan, Taylor and Tweedley, 2018). Therefore, unless the current size of the Blue Swimmer Crab population is substantially under the carrying capacity of the Peel-Harvey Estuary, restocking may fail to meet the motivation of catching more crabs. Unless the trade-offs of restocking are explained to fishers through science communication or community education, this could potentially reduce the perceived success of a fishing trip.

Fishers considered that restocking would increase the number of fishers fishing, increasing fishing pressure. Thus, any restocking should perhaps not be publicised to reduce pressure on the stocks and allow the hatchery-reared individuals to breed before suffering direct (catch) or indirect mortality (*e.g.* trampling) from the predicted additional fishing effort. Alternatively, any restocking could be accompanied by changes to fishery regulations, either temporally or permanently, to mitigate the effect of additional fishers and/or fishers fishing more frequently. For the Western School Prawn population in the Swan-Canning Estuary, various management interventions were suggested to help rebuild the stocks. These included a reduction in the catch limit by ~50%, as well as an extension of the closed fishing season to reduce fishing pressure in the shallows during the breeding season, which covers some of the peak period for the recreational fishing period (Crisp et al., 2018).

Restocking and other existing and potential management options

Perceptions of current management

Fishers expressed their concerns for the long-term sustainability of the Blue Swimmer Crab fishery in the Peel-Harvey Estuary, also stating that they were unhappy with the number and size of crabs available, which is consistent with the findings Johnston et al. (2014), who stated that recreational fishers have reported catch declines. This can be attributed, in part, to the large human population growth rate of Mandurah which, between 1996 and 2006, experienced a growth rate of 45%, three times the Western Australian average, which may have increased fishing pressure (Johnston et al., 2014). Urbanisation along the shorelines of this system and in the region as a whole, was highlighted by (Wildsmith et al., 2009) as a potential cause in the decline of the benthic macroinvertebrate fauna of this estuary. As these invertebrates are the major prey for Blue Swimmer Crab (Williams, 1982; de Lestang, Platell and Potter, 2000) these changes in faunal composition (Tweedley et al., 2014b) are likely responsible for the change in diet of this crab species between the 1990s and 2010s (Campbell et al., 2021). Such a change in prey availability has the potential to reduce the growth, fitness and survival of Blue Swimmer Crabs. The levels of unhappiness associated with catch rate could have been influenced by the timing of the surveys, which occurred in October (face-to-face interviews) and December/January (online survey) and thus before and at the beginning of their highly seasonal period of growth, respectively, meaning many crabs would be below the minimum legal size for capture (Potter, Chrystal and Loneragan, 1983; de Lestang, Hall and Potter, 2003a).

While the commercial and recreational Blue Swimmer Crab fisheries in the Peel- Harvey Estuary were certified as sustainable by the Marine Stewardship Council (Johnston et al., 2015), fishers are not happy with current management as a whole. Twenty-six of the forty-one respondents interviewed commented on the need for stricter management. For example, one fisher stated that: *"Education and good enforcement is crucial, most people don't understand management and people who are using the fishery need advice" (Respondent 1).* In addition, the collapse and subsequent closure of the Cockburn Sound fishery in 2006 and again in 2014 (Johnston et al., 2011) was believed to cause a shift in the recreational fishing pressure, from Cockburn Sound to the Peel. One fisher supported this belief and stated: *"This Estuary (Peel-Harvey Estuary) has been over crabbed since the closure of Cockburn Sound a few years ago" (Respondent 26).* This is reflected by the 57% of fishers in the online survey who when asked "*If the Blue Swimmer Crab fishery was not available, what would you do instead*" chose the option "*Fish for Blue Swimmers Crabs elsewhere*" (S. Poulton, unpublished data). Thus, given the fishers are willing to travel between fisheries to obtain a catch of a particular species (Camp et al., 2018), the connectivity of the fishers and the stock should be assessed when devising management regulations and anticipating the flow on effects to nearby fisheries. A co-management approach of involving recreational fisheries in the management process could also be useful, as Salas and Gaertner (2004) state that ignoring issues that are relevant to fishers limits the ability to anticipate their responses to changes in resource management and in turn, reduces the probability of management success.

While this illustrates that fishers think the management needs improving, they have also identified that the current fishery regulation are socially acceptable, *i.e.* they support the way the fishery is managed, but think it needs to be better managed. Minimum size limits, seasonal closures and fisheries enforcement very acceptable and received greater support than restocking. These results are consistent with Garlock and Lorenzen (2017), who found that fishers showed more support for various restrictive strategies, such as bag limits and minimum size limits, compared to restocking. Similarly, Rubio, Brinson and Wallmo (2014) found that minimum size limits, along with habitat related management strategies, were the most preferred interventions for managing coastal recreational fisheries in the USA. This trend may be explained by the familiarity that fishers have with the management policies, with fishers potentially preferring those regulations that they currently comply with and understand (Wilde and Ditton, 1991). For example, when fishers were offered a list of alternative fishery regulations, they commonly selected those that were most similar to those that were currently in place (Renyard and Hilborn, 1986; Helfrich, Chipman and Kauffman, 1987). These studies thus explain why Blue Swimmer Crab fishers considered maximum size limits, closed fishing zones and fishing gear restrictions unacceptable. Moreover, whilst they are already unfamiliar management methods, *i.e.* they are not current methods, they also seek to further limit fishers through location of catch, method of catch, and remove the potential to catch and keep a trophy fish.

Management implications

While recreational fishers can accept that not all fishing trips will be successful, participation may decrease, or even cease, if catch rates and/or size of the target species are consistently poor (Finn and Loomis, 2001). Blue Swimmer Crab fishers have a clear preference for current, rather than novel, management regulations and thus, fisheries managers should consider tightening existing regulations over implementing new schemes altogether, such as increasing the length of the closed season and the number of fishery officers patrolling the estuary, both of which were highly supported by the fishers.

Restocking, which can increase the abundance of the target species (Bell et al., 2008; Taylor et al., 2017), was among the most socially acceptable of all management interventions, as has been shown in several other studies (Wilde and Ditton, 1991; Aas, 1995; Aas and Kaltenborn, 1995; Arlinghaus and Mehner, 2003). This popularity reflects fishers' preferences for greater abundances of fish, larger fish and a greater chance of a catch (Arlinghaus et al., 2014), as was the case in the current chapter . These results are also supported by those of Garlock and Lorenzen (2017), who found that Red Drum fishers in Florida, with a high consumptive orientation, were more likely to support restocking than fishers with other motivations for fishing this species.

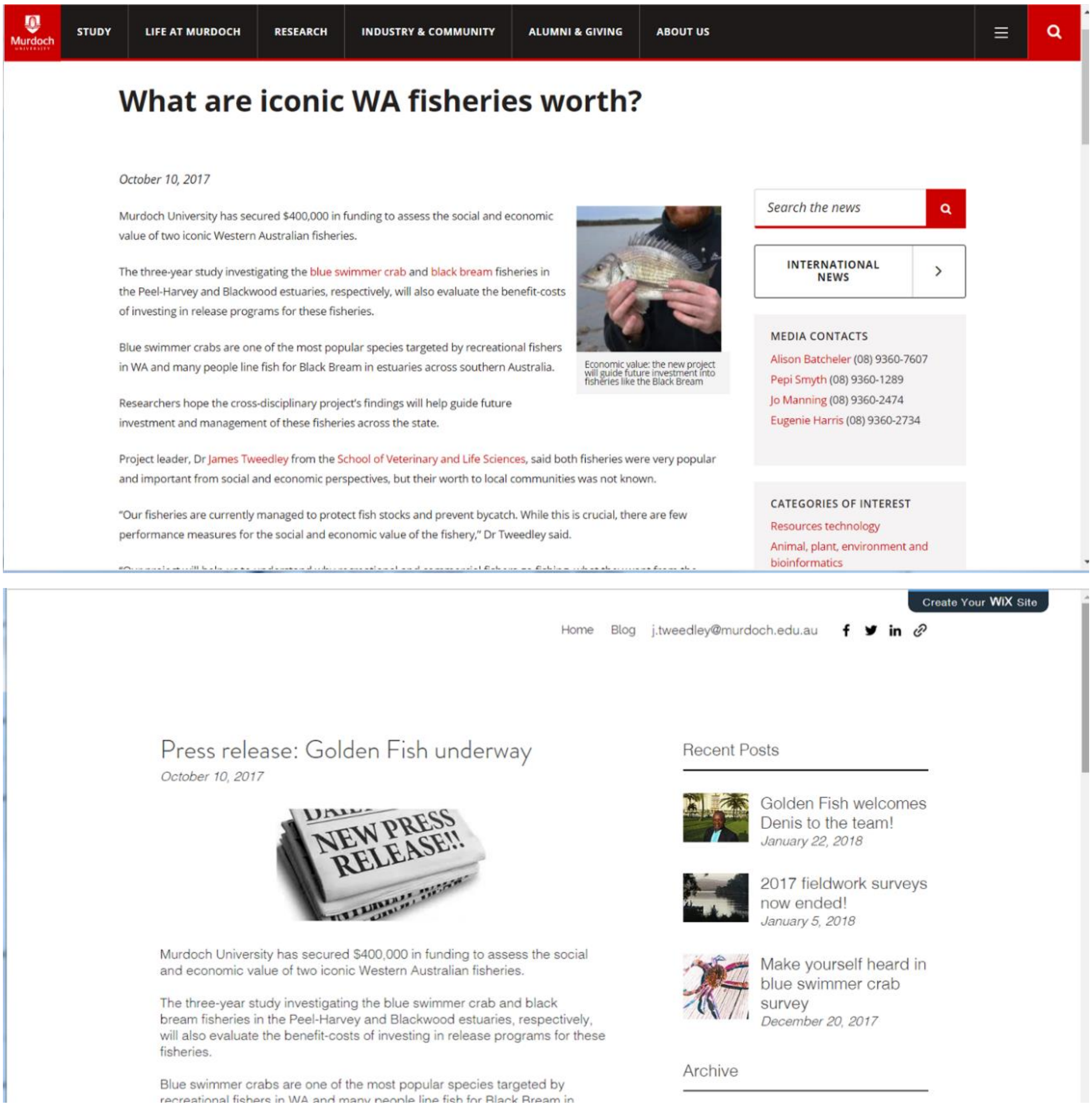
While numerous small and one large scale aquaculture-based enhancement for portunids have occurred, those employing fast-growing species with a limited home range and high economic and/or social values have been the most successful (Tweedley et al., 2017a). Fujaya et al. (2015) considered that Blue Swimmer Crabs have 'high potential' for restocking due to its wide environmental tolerances. Furthermore, Jenkins et al. (2018), successfully cultured juvenile Blue Swimmer Crabs from berried broodstock collected from the Peel-Harvey Estuary and released a small number of crablets back into that system. Given the success of that preliminary study, and the strong support from the fisher community, there is the potential for at least a small-scale restocking program to be implemented, if required, in the future. It should be noted, however, that any restocking would only be effective if the release environment (*e.g.* Peel-Harvey) could sustain and support the cultured individuals (Hines et al., 2008; Seitz et al., 2008). Furthermore, the most successful restocking programs are integrated with current and/or new management schemes, including fisheries input, output and access controls and habitat restoration/enhancement, that will adequately protect wild and released individuals (Zohar et al., 2008; Lorenzen et al., 2013).

A.3.5. Conclusion

Surveys, such as those employed in the current study of Blue Swimmer Crab recreational fishing, can serve as a tool to understand fishers' preferences for regulation (Renyard and Hilborn, 1986). The results from the current surveys have clearly identified the primary motivations of the fishers and their views on the management of the fishery, including the option of restocking. These views were very consistent across the different demographic groups of fisheries and intensity of fishing and suggests that there is a sense of community among the fishers in the Peel-Harvey Estuary, with their motivations relating to the internal themes of membership, influence and reinforcement, and the common responses indicate the shared emotional connection. As the success of fishery management is partially dependent on the support of the fishing community, studies like this, which is the first of its kind in Western Australia, will contribute valuable information and improve the decision-making abilities of fishery managers. The information from this survey and social surveys of other recreational fisheries will improve the decision-making abilities of fishery and environmental managers and potentially contribute to co-management. Understanding fisher views and regulatory preferences reduces criticism and complaints from fishers and increases compliance with regulations (Pomeroy et al., 2007). After all, it is better to empower communities rather than command them (Clark, 1998; Salm, Clark and Siirila, 2000).

Appendix 4. Project coverage

This project was features nine times in local print media (Figure EA1-9) and Dr James Tweedley was invited to speak on Stan Shaw's Breakfast Show on ABC South West. The equivalent advertising rate of the print media coverage was estimated at $10,252 and reached a total of 433,630 people, over five times to the population of City of Mandurah where much of the research was carried out. These media articles followed three press-releases from Murdoch University, written in conjunction with the FRDC, about the project, the launch of the surveys for Blue Swimmer crabs and another about the survey for Black Bream. These releases were also promoted on the projects, social media pages and websites and shared by groups like the FRDC and Recfishwest (see Section 4.2 for more details).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What are iconic WA fisheries worth?

October 10, 2017

Murdoch University has secured $400,000 in funding to assess the social and economic value of two iconic Western Australian fisheries.

The three-year study investigating the blue swimmer crab and black bream fisheries in the Peel-Harvey and Blackwood estuaries, respectively, will also evaluate the benefit-costs of investing in release programs for these fisheries.

Blue swimmer crabs are one of the most popular species targeted by recreational fishers in WA and many people line fish for Black Bream in estuaries across southern Australia.

Researchers hope the cross-disciplinary project's findings will help guide future investment and management of these fisheries across the state.

Project leader, Dr James Tweedley from the School of Veterinary and Life Sciences, said both fisheries were very popular and important from social and economic perspectives, but their worth to local communities was not known.

"Our fisheries are currently managed to protect fish stocks and prevent bycatch. While this is crucial, there are few performance measures for the social and economic value of the fishery," Dr Tweedley said.

Economic value: the new project will guide future investment into fisheries like the Black Bream

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Home Blog j.tweedley@murdoch.edu.au

Press release: Golden Fish underway

October 10, 2017

Murdoch University has secured $400,000 in funding to assess the social and economic value of two iconic Western Australian fisheries.

The three-year study investigating the blue swimmer crab and black bream fisheries in the Peel-Harvey and Blackwood estuaries, respectively, will also evaluate the benefit-costs of investing in release programs for these fisheries.

Blue swimmer crabs are one of the most popular species targeted by

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January 22, 2018

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Make yourself heard in blue swimmer crab survey
December 20, 2017

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Figure EA1. Screenshots of the initial project press release on the Murdoch University and project-specific website.

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Peel Harvey estuary to be studied as part of Murdoch Uni research into WA fisheries

October 10th, 2017, 10:30AM | Written by Vanessa Schmitt | Mandurah Coastal Times NEWS

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OCTOBER 13 2017 - 8:02AM

Murdoch University to launch massive blue swimmer crab study in Peel-Harvey Estuary

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Survey into fisheries

MURDOCH University has secured $400,000 in funding to assess the social and economic value of two iconic WA fisheries – the Peel Harvey and Blackwood estuaries.

The three-year study investigating the blue swimmer crab and black bream fisheries in the Peel-Harvey and Blackwood estuaries, respectively, will also evaluate the benefit-costs of investing in release programs for these fisheries.

Blue swimmer crabs are one of the most popular species targeted by recreational fishers in WA and many people line fish for black bream in estuaries across southern Australia.

Researchers hope the project's findings will help guide future investment and management of these fisheries across WA.

Project leader James Tweedley, from the School of Veterinary and Life Sciences, said both fisheries were popular and important from social and economic perspectives, but their worth to communities was not known.

"Our fisheries are currently managed to protect fish stocks and prevent bycatch. While this is crucial, there are few performance measures for the social and economic value of the fishery," Dr Tweedly said.

"Our project will help us to understand why recreational and commercial fishers go fishing, what they want from the fisheries, and estimate the economic contribution they make to these communities."

Dr Tweedley and the project team will survey recreational and commercial fishers and the wider community about their attitudes to fishing, their motivations for using the fisheries and their thoughts on release programs.

The surveys will be done at boat ramps, fishing events and online. Researchers will also produce a benefit-cost analysis of the economic value of the fisheries from a recreational and commercial perspective.

"We want to understand whether it would be cost effective to make a dollar investment in a fishery by spending money on growing a species in aquaculture, then releasing them into the fishery," Dr Tweedley said.

Uni on Peel crab quest

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Dr Tweedley and the project team would survey recreational and commercial fishers and the wider community about their attitudes to fishing, their motivations for using the specific fisheries and their thoughts on release programs.

The surveys would be done at boat ramps, fishing events and online.

The researchers will also produce a benefit-cost analysis of the economic value of the fisheries - from both a recreational and commercial perspective.

"We want to understand whether it would be cost effective to make a dollar investment in a fishery by spending money on growing a species in aquaculture, then releasing them into the fishery," Dr Tweedley said.

"Is this going to enhance the fishing experience for recreational fishers and increase profits for commercial fishers, leading to an economic boost for the local community, while at the same time ensuring the sustainability of the fishery? We don't yet know."

CRAB STUDY: Murdoch University's School of Veterinary and Life Sciences is on a mission to learn about the economic and social value of the region's popular crab fishery. Photo: Marta Pascual Juanola.

Figure EA2. Screenshots associated website and newspaper articles following the initial project press release.

Peel Harvey estuary to be studied as part of Murdoch Uni research into ...

Vanessa Schmitt at Communitynews.com.au on 10 Oct 2017 11:01 AM.

ASR: 500 AUD **Audience:** N/A unique visitors per day / N/A average story audience

Item Details:
- Item ID: 857192028
- Words: 415

Murdoch University to launch massive blue swimmer crab study in Peel-Harvey Est...

Sam Wood, Snezana Markoski at Mandurah Mail on 13 Oct 2017 9:03 AM.

ASR: 815 AUD **Audience:** N/A unique visitors per day / N/A average story audience

Item Details:
- Item ID: 858813837
- Words: 629
- Location: Online

Survey into fisheries

Mandurah Coastal Times(page 16) on 18 Oct 2017.

ASR: 273 AUD **Audience:** 31,465

View Original **View Full Text**

Item Details:
- Item ID: 861052929
- Section: General News
- Location: Mandurah WA, Australia
- Market: WA
- Classification: Regional
- Format: 146 cm² News Item

Uni on Peel crab quest

Mandurah Mail(page 37) on 19 Oct 2017.

ASR: 940 AUD **Audience:** 37,400

View Original **View Full Text**

Item Details:
- Item ID: 861604725
- Section: General News
- Location: Mandurah WA, Australia
- Market: WA
- Classification: Regional
- Format: 442 cm² News Item
- Words: 369

Figure EA3. Extract from media portal reports on media coverage resulting from the initial project press release.

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Make yourself heard in blue swimmer crab survey

December 20, 2017

If you love to fish for blue swimmer crabs, your views are wanted by Murdoch University researchers.

Blue swimmer crab: A new online survey will guide future management of the fishery (Pic: Recfishwest)

Novice fishers and seasoned veterans alike are being urged to respond to an online survey. The answers will help guide future management of the blue swimmer crab fisheries in key locations such as the Swan River in Perth and the Peel Harvey estuary in Mandurah.

"Fishing for delicious blue swimmer crabs is considered a staple of the Western Australian summer by many enthusiasts, and we want to help keep it that way," lead researcher Dr James Tweedley said.

"We want to understand more about what people want from their fishing trips, as well as their motivations for fishing, concerns about the fishery and opinion on management options."

Fellow Murdoch researcher Dr Michael Hughes added that restocking programs had been used to increase numbers of animals in other fisheries.

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CATEGORIES OF INTEREST

Recreational crabbing feedback sought

SCOTT COGHLAN

RESEARCHERS want to hear from keen recreational crabbers around WA.

Catching blue swimmers is one of the most popular recreational fishing activities for local anglers and it is an iconic summer pastime in the bottom half of the State.

It is currently peak time for catching these succulent crustaceans in the Swan and Canning rivers, and also in the Peel-Harvey Estuary in Mandurah,.

Murdoch University researchers want anyone who fishes for blue swimmer crabs to undertake an online survey, the results of which will help guide future management of crab fisheries in key locations such as the Swan River and Peel-Harvey.

Crab survey: Steve Anderson crabbing in the Peel-Harvey.

"We want to understand more about what people want from their fishing trips, as well as their motivations for fishing, concerns about the fishery and opinion on management options," lead researcher Dr James Tweedley said.

The research team has already spoken to anglers in the region about their opinions of the fishery, with their responses helping shape the questions.

The questionnaire is part of a study investigating the social and economic aspects of blue swimmer crab and black bream fisheries, entitled *Golden Fish*.

The survey can be accessed at http://www.surveygizmo.com/s3/4067539/The-social-dimension-of-Blue-Swimmer-Crab-fishing, and only takes 10-15 minutes to complete.

PERTH

On your marks for sports boost

USAIN Bolt, the fastest man on Earth, has a message for Aussie kids.

He wants them to believe "anything is possible" and make sure they have lots of fun trying out different sports to find out what they are good at.

The Jamaican sprinter – who set the world 100m record at 9.58s in 2009 – has joined Australia's world champion hurdler Sally Pearson to support the Coles Sports For Schools program this month.

As part of the program, schools can register for a chance to share in millions of dollars' worth of sports gear.

The Olympic great said sport should start off being something children enjoyed with friends as "that way it's fun".

"And if at first you don't succeed, try again. Don't put too much pressure on yourself. You'll be much better at things you enjoy," he said.

Bolt encouraged kids to keep their options open.

"I live by the motto anything is possible," he said.

"Find out what you're good at. At first I played cricket but then my teacher noticed I was a great sprinter.

"It was the best thing I did and I will always be grateful to the people who supported me."

More than 800 types of sports gear are up for grabs, including cricket and softball bats, footballs, basketballs, javelins, hockey sticks, skipping ropes, badminton racquets and first-aid kits as part of the Sports For Schools program.

Sally Pearson and Usain Bolt unite for Coles Sports for Schools.

The program has supplied more than $20 million worth of sports gear to more than 7500 schools across Australia since 2010.

For every $10 spent at Coles supermarkets from February 7, customers will receive one Sports For Schools voucher which can be placed in collection bins at Coles stores as well as at registered schools.

Once the vouchers are tallied by the participating schools at the end of the program they will be able to order from the range of more than 800 items of premium sporting equipment.

■ Schools can register at coles.com.au/sfs.

MURDOCH

Fishing for help

MURDOCH University researchers have called on fishers to take an online survey that will help guide future management of blue swimmer crab fisheries.

The survey will touch on what people want from their fishing trips, their motivation for fishing, concerns and opinion on management options.

Lead researcher James Tweedley said this kind of social survey had never been done before in WA.

The survey is completely anonymous and takes about 15 minutes to complete.

It is part of a three-year study investigating the social and economic aspects of blue swimmer crab and black bream fisheries.

Visit www.surveygizmo.com/s3/4067539/The-social-dimension-of-Blue-Swimmer-Crab-fishing.

Figure EA4. Screenshots press release from Murdoch University about the Black Bream survey and associated newspaper articles. Note the article from the Cockburn Gazette (bottom) was also repeated in the Fremantle Gazette.

31 Dec 2017
Sunday Times, Perth

Author: Scott Coghlan • Section: ReadersMart • Article Type: News Item
Audience : 183,828 • Page: 3 • Printed size: 146.00cm² • Market: WA
Country: Australia • ASR: AUD 2,655 • words: 209 • Item ID: 893461013

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06 Feb 2018
Cockburn Gazette Community, Perth

Section: General News • Article Type: News Item • Audience : 13,739 • Page: 15
Printed size: 54.00cm² • Market: WA • Country: Australia • ASR: AUD 158 • words: 101
Item ID: 908479494

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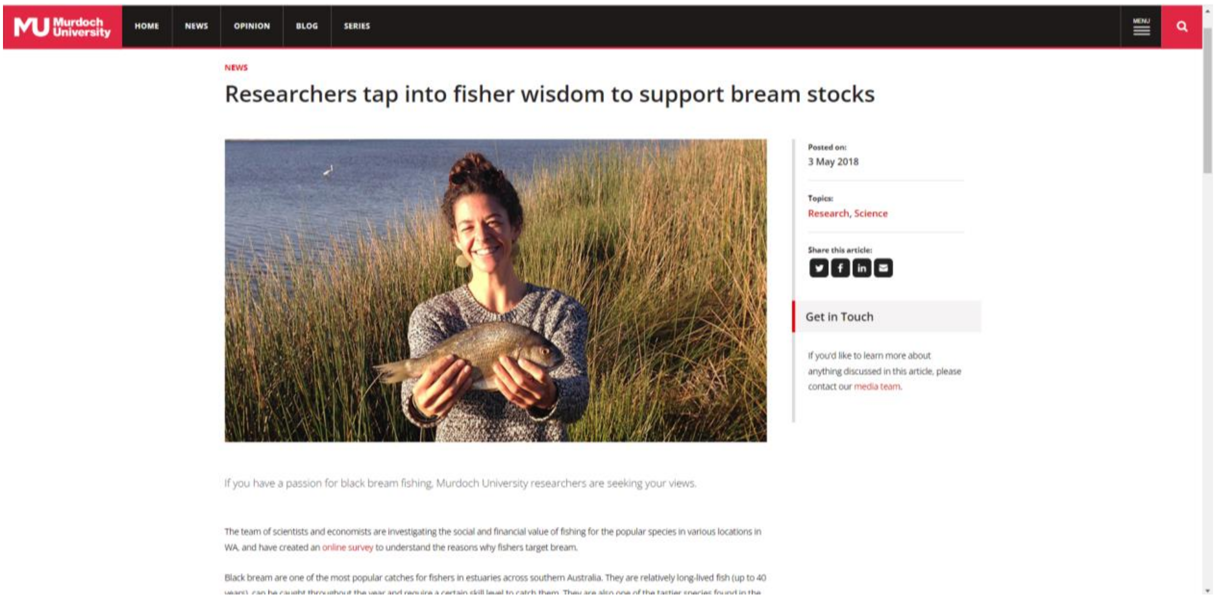
Figure EA5. Extract from media portal reports on media coverage resulting from the Blue Swimmer Crab survey press release.



Murdoch University HOME NEWS OPINION BLOG SERIES MENU

NEWS

Researchers tap into fisher wisdom to support bream stocks

Posted on:
3 May 2018

Topics:
Research, Science

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If you'd like to learn more about anything discussed in this article, please contact our media team.

If you have a passion for black bream fishing, Murdoch University researchers are seeking your views.

The team of scientists and economists are investigating the social and financial value of fishing for the popular species in various locations in WA, and have created an online survey to understand the reasons why fishers target bream.

Black bream are one of the most popular catches for fishers in estuaries across southern Australia. They are relatively long-lived fish (up to 40

INSIDE COVER

Ben O'Shea

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FISH FOR ANSWERS

When we heard WA anglers were being grilled we thought the fish were finally fighting back but the grilling turned out to be of the verbal kind.

The black bream is a feature of the Swan-Canning river system and is a popular target for anglers in the metro area and elsewhere in the State.

As well as being a great table fish, it presents a challenge to those who like to wet a line and often requires quite a degree of skill to catch.

These beautiful fish can live up to 40 years and preserving their numbers is good for anglers and the ecosystem, so Murdoch University is investigating why we love to catch them so much.

Murdoch researchers plan on doing this with an online questionnaire that has been developed from information gained by interviewing more than 100 fishers at popular bream-fishing spots, such as the Peel-Harvey Estuary in Mandurah, the Blackwood Estuary in Augusta and the Swan-Canning Riverpark.

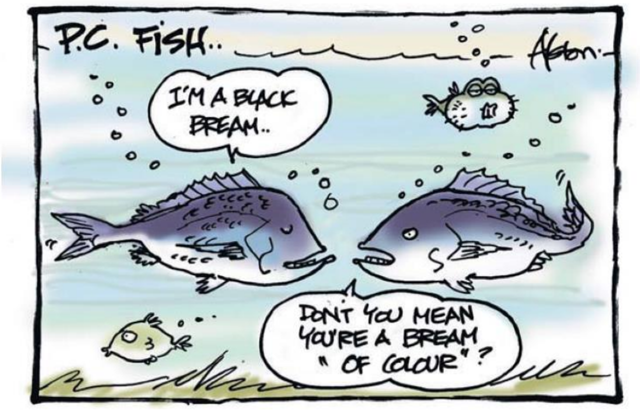
Murdoch environmental management expert Michael Hughes said the researchers wanted to find out what constituted a good fishing trip.

"Understanding the expectations of fishers is valuable for managing the future of black bream fisheries in WA and ensuring the social values are maintained as an important part of the fisheries," he said.

It's worth noting this study will also include the tourism impact of bream fishing on towns such as Augusta.

You can take the survey by finding the "research" tab on the university's website.

Anglers love catching a bream.



Survey calls on black bream fans

Murdoch study seeks anglers

SOUTH West residents with a passion for black bream fishing are being encouraged to take part in a Murdoch University study. A team of scientists and economists are investigating the social and financial value of fishing for the popular species in various locations in WA, and have created an online survey to understand the reasons why fishers target bream. Black bream are one of the most popular catches for fishers in estuaries across southern Australia.

They are relatively long-lived fish (up to 40 years), can be caught throughout the year and require a certain skill level to catch them. They are also one of the tastier species found in the South-West.

The questionnaire was developed using information given in more than 100 detailed interviews with fishers at popular bream fishing spots, including the Blackwood Estuary in Augusta.

Environmental management expert Dr Michael Hughes said the researchers wanted to know what makes a fishing trip successful for fishers.

"Understanding the expectations of fishers is valuable for managing the future of black bream fisheries in WA and ensuring the social values are maintained as an important part of the fisheries."

Project lead Dr James Tweedley said the fish was a popular catch for visitors to the South West.

"Bream are a strong drawcard to towns like Augusta and are part of what makes them popular tourist destinations. The survey results will help us understand what bream fishing is worth to those communities, and guide their future management."

PhD candidate Clara Obregón said the team also wanted to know what fishers think of restocking fish populations.

"Murdoch researchers collaborated with the South Metropolitan TAFE to culture 220,000 black bream which were then released as small juveniles into Blackwood Estuary in 2002-03," she said. "These restocked fish are still being caught today. We want to know what fishers think are the benefits of restocking."

The survey is completely anonymous and can be accessed at **www.surveygizmo.com/s3/4340334/The-social-dimensions-of-Black-Bream-fishing**

Initial results from a survey of blue swimmer crab fishers conducted earlier this year have indicated the activity is socially orientated, with fishers revealing the activity gives them the opportunity to spend time with friends and family. The survey results also showed that people were motivated by eating their catch.

The surveys are part of a three year study investigating the social and economic aspects of Blue Swimmer Crab and black bream fisheries, entitled Golden Fish.

Figure EA6. Screenshots press release from Murdoch University about the Black Bream survey and associated newspaper articles.

04 May 2018
West Australian, Perth

Author: Ben O'shea • Section: General News • Article Type: News Item
Audience : 147,676 • Page: 2 • Printed size: 290.00cm² • Market: WA
Country: Australia • ASR: AUD 5,084 • words: 251 • Item ID: 948922388

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23 May 2018
Augusta Margaret River Mail, Augusta WA

Section: General News • Article Type: News Item • Audience : 5,783 • Page: 7
Printed size: 461.00cm² • Market: WA • Country: Australia • ASR: AUD 984 • words: 427
Item ID: 958312960

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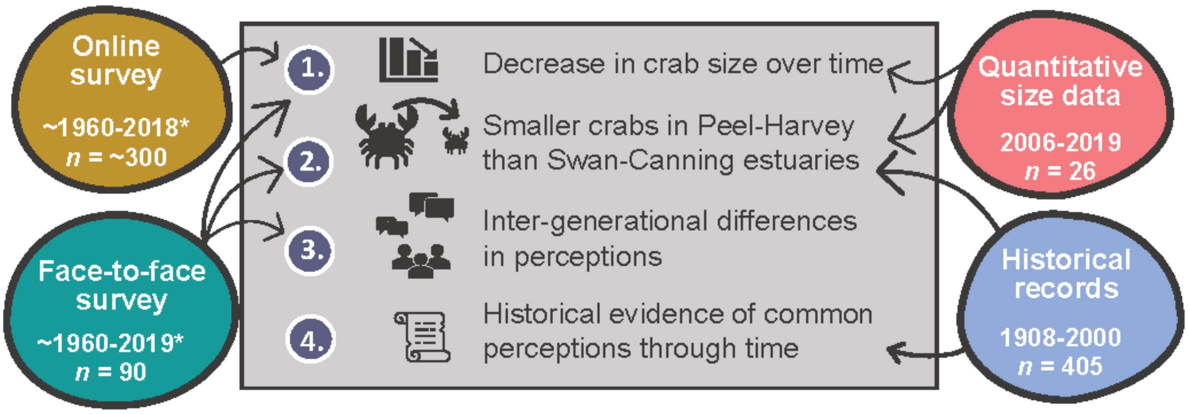
Figure EA7. Extract from media portal reports on media coverage resulting from the Black Bream survey press release.

Appendix 5. Local fisher knowledge reveals changes in size of blue swimmer crabs in small-scale fisheries

Obregón, C., Christensen, J., Zeller, D., Hughes, M., Tweedley, J.R., Gaynor, A. & Loneragan, N.R. (2022). Local fisher knowledge reveals changes in size of blue swimmer crabs in small-scale fisheries. Marine Policy 143: 105144. DOI: 10.1016/j.marpol.2022.105144.

Abstract

Fisheries stock status is generally based on time series catch and effort data sourced from independent surveys and the fishery. These methods are often expensive and can be limited in temporal and spatial scales. Alternative methods include the use of local fisher knowledge (LFK) to identify observed changes in catch. The Blue Swimmer Crab (*Portunus armatus*) supports a small-scale commercial fishery and one of the most popular recreational fisheries in south-western Australia. Previous studies identified concerns from recreational fishers over its long-term sustainability. To understand if fishers' perceptions of change provide useful information on actual changes in the fisheries, a triangulation approach was used to assess changes in size and abundance of crabs in two estuaries (Peel-Harvey and Swan-Canning). Three types of data were used: i) fisher recollections over time, including face-to-face interviews and online surveys; ii) historical records from newspaper articles from 1900 to 2000; iii) quantitative data on size between 2006/07-2018/19. Results identified: i) crabs were smaller in the Peel-Harvey-a consistent difference identified in all data sources; ii) crab size was perceived to have decreased in the Peel-Harvey; iii) inter-generational differences in fishers' perceptions regarding size changes over time; and iv) historical evidence of persistent fishers' concerns and perceptions of changes in the fishery and wider environment. These findings are evidence of a likely decline in the crabs' average size in south-western Australia over the last century, particularly in the Peel-Harvey and demonstrate that LFK may be a valuable source of information when other data sources are lacking.



Note that * shows data as "years of fishing experience", rather than years covered by quantitative records. n = 90.

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