The social-ecological dimensions of small-scale crab fisheries in Western Australia

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Declaration

I declare that this thesis is my own account of my research and contains as its main content work which has not been submitted for a degree at any tertiary education institution.

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Abstract

The pivotal role of humans in social-ecological systems has been globally recognised, particularly for fisheries, yet human dimensions are often overlooked. The blue swimmer crab (*Portunus armatus*) is the most popular recreational fishery in south-western Australia and also supports a small-scale commercial fishery. This study analysed the human dimensions of this fishery using qualitative and quantitative data, including those extracted from interviews with commercial and recreational fishers, newspaper records and the literature. Social network analysis was used to define the fishery network structure and communication patterns between stakeholders. Government agencies and the commercial sector were identified as key groups for information sharing within the network. The results also revealed potential logistical and institutional barriers to effective communication between different groups. Additionally, historical records and fisher surveys were used to understand fishers' perceptions of changes in crab stocks' through time and revealed a perceived decrease in the average size of the crabs in the Peel-Harvey Estuary, which paralleled trends evident in the literature. Non-parametric analyses of interview data on the beliefs and attitudes of recreational and commercial fishers towards stock enhancement found that fishers understand the benefits and drawbacks of this approach but considered that the benefits were more likely to occur. Further investigation identified some differences (*e.g.,* length of the seasonal closure) and commonalities (*e.g.*, reducing fishing and increasing compliance) between recreational and commercial fishers' concerns and the management approaches they supported. Finally, commercial fishers voiced a feeling of marginalisation influenced by new management measures implemented in 2019. They perceived the buyout of commercial licenses as limiting their access to the resource, while the lack of a shore-based recreational fishing license was seen to support the recreational sector. These new insights into commercial and recreational fishers' views and understanding of the resource could be utilised to provide direction for future research and management of blue swimmer crab fisheries in south-western Australia. This is the first baseline study of the human dimensions of a fishery in Western Australia and provides an important contribution to understanding fisheries' human dimensions in Australia and elsewhere.

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Publications during Candidature

Chapters 2 – 6 have been written as co-authored manuscripts. The contributions for each of these are indicated at the beginning of each chapter. Three of these chapters have been accepted for publication, resulting in the following publications:

Peer-reviewed articles included in this thesis:

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Book Chapter:

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Statement of Contributions

Chapter 1 - General Introduction

Contributor	*Contribution*
Clara Obregón	Developed chapter structure Wrote chapter
Neil R. Loneragan	Reviewed structure and provided editorial input
James R. Tweedley	Reviewed structure and provided editorial input
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Chapter 2 - Who you speak to matters: Information sharing and the management of a small-scale fishery

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Chapter 3 - Historical records and fisher perceptions reveal changes in size and abundance of crab catches in temperate Western Australian estuaries.

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Chapter 4 - Different but not opposed: perceptions between fishing sectors on the status and management of a crab fishery.

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Chapter 5 - Feeling the pinch: perceived marginalization of small-scale commercial crab fishers by an expanding recreational sector.

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Chapter 6 - A two-phase approach to elicit and measure beliefs on management strategies: Fishers supportive and aware of trade-offs associated with stock enhancement.

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When I started my PhD, I was convinced I would not have time for anything but the research. As I landed in Perth, I was mentally prepared to have nothing else in my life but my PhD project. Now, looking back, the most important things I take from these years, besides a deep understanding on my research topic, is spectacular adventures with inspiring people.

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Para mi familia menorquina, mallorquina, madrileña y malagueña. Sin vosotros, tampoco.

Dedication

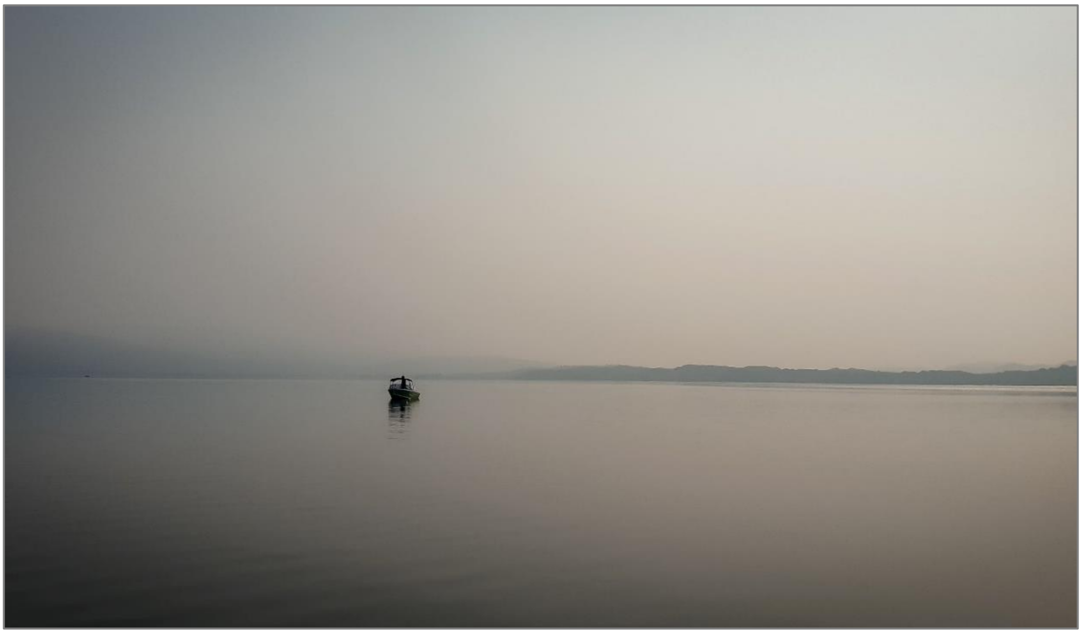
La ciencia nos enseña, en efecto, a someter nuestra razón a la verdad y a conocer y juzgar las cosas tal como son, es decir, como ellas mismas eligen ser y no como quisiéramos que fueran.

Miguel de Unamuno (1864 – 1936)

Chaque fois que j'utilise la raison, chaque fois que j'utilise la logique, je suis très pessimiste. Quand j'écoute mon coeur, quand j'écoute ma foi - et j'ai la foi en l'humanité - alors je deviens très optimiste.

Jacques-Yves Cousteau (1910 – 1997)

Chapter 1
General introduction



Two recreational fishers setting their gear at dawn in the Nornalup Inlet, Walpole, south-western Australia.

Chapter 1
General Introduction

1.1. Background and rationale

Globally, fisheries support the livelihood of millions of people through the provision of food and employment (FAO 2018a). Traditionally fisheries have been managed using predominantly biological indicators, which do not always match with conservation objectives and human uses of fishery resources. Instead, fisheries should be considered social-ecological systems (SES), which are complex and dynamic, and have interactive social (*i.e.,* human) and biophysical elements (Berkes & Folke 2000). Research on SES requires scientific and non-scientific knowledge, is inherently divided among various disciplines (e.g., social sciences; ecology; economics) and requires collaboration among these (Hertz & Schlüter 2015). Some countries, like Australia, have called for a holistic method to manage their fisheries, including the social (hereafter human), economic and biological elements of fisheries management (UN, 1987). Yet, the human component of this approach has been largely overlooked. Brooks and colleagues (2015) suggest that this is due to: firstly, a lack of information regarding the human impacts associated with fishing and fishing industries; and secondly, no practical methodology is available yet to describe how to integrate such information into a national management framework (Brooks et al. 2015). In Australia, only a few fisheries have indicators of the human elements. In some states, including Western Australia, no indicators or objectives were found for any of the fisheries studied (Hobday et al. 2016).

Overall, this thesis aims to contribute to understanding the human dimensions of the small-scale, multisector fishery for blue swimmer crabs (*Portunus armatus*) in south-western Australia. This General Introduction provides an overview of global fisheries and some of the current management challenges faced. I introduce the concept of SES and describe how this concept has helped transform the research and management of fisheries globally. It follows with an outline on the use of interdisciplinary approaches for fisheries research, and its value for current Australian fisheries management. Finally, I introduce the *P. armatus* fishery in south-western Australia and outline the structure of the thesis.

1.2. Status of the world's fisheries

Fisheries are the main source of food and income for millions of people (Cohen et al. 2019), and fish are arguably one of the most important natural resources in the world (FAO 2018a). Population growth, increasing food demand and increasing popularity of seafood globally results in greater pressures on natural resources, at local, regional and national scales. This results in an increasing demand for seafood, as seen in various developed countries, which leads to an increase in seafood consumption and results in a greater fishing pressure of wild stocks (FAO 2018a). In fact, seafood consumption has increased steadily by 3.1% each year since 1960s, outpacing the population growth and meat consumption globally (1.6% and 1.1% respectively; FAO 2020). This growth is the major driver of overfished fisheries, which nowadays reaches 33% of global wild fish stocks (Ritchie & Roser 2020). It is worth noting that the growth in aquaculture also contributes to satisfying this demand and increases are outstripping wild fisheries (Jennings et al. 2016).

In fact, the demand in regions like the United States of America (USA), the European Union (EU), China and Japan is so high that it exceeds catches within their Exclusive Economic Zones (EEZ; Pauly & Zeller, 2016a; Ritchie & Roser, 2020). To compensate, these markets are supplemented with imported seafood caught by industrial fleets elsewhere, often in developing countries (Pauly & Zeller 2016a, Cohen et al. 2019). As such, local fisheries, particularly small-scale fisheries (SSF), are often marginalised and pressured to compete with export-oriented fleets, generally with little support from their local government (Pauly & Zeller 2016a). As a result, the ability for these local small-scale fleets to supply seafood has been consistently squeezed due to two main reasons: industrial fisheries leading the seafood market, a reduction in catch caused by an increase in fishing pressure from industrial fisheries, or a combination of these reasons. Additionally, traditional fishing methods, which generally have lower impact on stocks and the environment, may be jeopardised and the local market negatively affected by the expansion of industrial fishing (Pauly & Zeller 2016a).

Increased pressure on the production and supply of fisheries products has resulted in a global fishing crisis in many regions. Numerous studies have demonstrated that, despite effective management leading to recovering stocks in many developed countries (Jackson & Moran, 2012; Kloser et al., 2015, Hilborn et al 2020), this is not always the case. In fact, in the last decades an increasing number of fisheries have been classified as overfished (Ritchie & Roser 2020). Moreover, the number of fisheries that are regarded as having collapsed is also increasing (Pauly & Zeller 2016b). Along with the dramatic decline of global catches, there are also grave impacts on the environment where these fisheries operate, affecting marine food webs, reducing the oceans' capacity to maintain its productivity, and overall hindering natural ecosystem functions (Smith et al., 2011; Worm et al., 2006). Consequently, there is a growing realisation that traditional catch-based approaches or traditional equilibrium-based models are not enough anymore to manage fishery systems and that, among other elements, a transition towards more fluid, and dynamic non-equilibrium based analysis is needed (Schoon & Van Der Leeuw 2015).

1.3. Fisheries as social-ecological systems

The concept of SES is commonly used by researchers to describe marine systems in a more holistic and complete manner (Máñez et al. 2014). This concept is based on the assumption that societies and nature are fundamentally interconnected, constantly changing and therefore co-evolving via interactions with users, resources and the institutions governing these (Ostrom 2009, Bodin & Tengö 2012). As part of managing such diverse elements of global fisheries (*i.e.,* livelihoods, market, sustainability of stocks), it is now widely accepted that there is a need to look beyond the traditional borders of scientific research and management and consider humans as an integral part of fishery systems, rather than an external disturbance to it (Schoon & Van Der Leeuw 2015).

A major challenge in analysing fisheries as SESs is developing frameworks and approaches to obtain information on the different dimensions of these systems. One of the barriers to achieve this is the current lack of basic understanding of these dynamics (Bailey et al., 2016; Carpenter et al., 2009; Kittinger et al., 2013; Vugteveen et al., 2015), particularly regarding the human dimensions (Brooks et al. 2015, Stojanovic et al. 2016). Traditional fisheries management plans and policies rarely address human interactions within fishery SES, hindering the adaptive capacity of fishers (Aguilera et al. 2015). Problems in fisheries therefore arise when elements such as environmental fluctuations or human system dynamics occur (Aguilera et al. 2015). It is therefore no longer acceptable to disregard the influence of human actions in most fields of environmental scientific research, and particularly fishery systems. In fact, failure to recognize the importance of specific human elements that can impact and influence the adaptive capacity of fishers and fishing communities has previously increased the vulnerability of many fisheries, and particularly SSF, to external drivers (Kittinger et al. 2012, 2017, Aguilera et al. 2015, FAO 2018b).

Global fisheries are currently facing increasing political pressure internationally to demonstrate sustainability and meet global demands for seafood (UN 2015). International accords overseeing the sustainability of natural resources promote the adoption of ecosystem-based management (EBM) or, in the fisheries field, ecosystem-based fisheries management (EBFM). Nowadays, there are different ways of demonstrating sustainability, for example by obtaining a third party certification of sustainability (van Putten et al. 2020), or increasing the social license to operate (Cullen-Unsworth et al. 2014). Currently, four major components are considered essential for effective research and management in fisheries SES: ecological, economic, institutional (*i.e.,* governance) and human.

1.4. The need for interdisciplinarity in fisheries science

One of the current weaknesses of fisheries research and management is that it has mostly remained fragmented within its own discipline and has lacked the creativity to solve challenges, for example by not including wider sources of information and expertise, such as local fisher knowledge (LFK) or understanding fisher behaviour (Johannes et al. 2000, Phillipson & Symes 2013, Alós et al. 2019). As the importance of the various elements forming fisheries are increasingly recognised, new approaches to study and manage fisheries are sought (Barclay et al. 2017, Stephenson et al. 2018). The use of interdisciplinarity for managing natural resources is not a new phenomenon (Klein 1990). Notably, since the landmark study by Costanza et al. (1997), who used different approaches to demonstrate the value of ecosystem services (Máñez et al. 2014). Such valuations, however, typically originate from a biological and economic point of view and fail to include the human dimension.

The integration of different research methods and types of knowledge to solve challenges affecting global fisheries through interdisciplinary solutions should incorporate the natural, economic and social sciences along with the expertise of other stakeholders, including the fishers and fishing communities (Phillipson & Symes 2013). It should also recognise that traditional fisheries management alone does not provide an adequate basis for management of such complex problems affecting dynamic SES as fisheries (Haapasaari et al. 2012). As a result, interdisciplinary studies are becoming increasingly utilised in SES (Morillo et al. 2003, Haapasaari et al. 2012, Schoon & Van Der Leeuw 2015).

An example of a successful transition from traditional fisheries management to adopting an interdisciplinary approach is presented in fisheries management in Canada. This stemmed from the recognition that the national Department of Fisheries and Oceans in Canada needed to take a collaborative approach and include harvesters, academics and government researchers to manage its fisheries, which resulted in the creation of the "Canadian Fisheries Research Network" (CFRN) project. The CFRN helped develop much stronger trust and collaborative relationships among fishery stakeholders, and created new international partnerships, supporting research that guided management, and complemented research programs and initiatives in fisheries science (Thompson et al. 2019, Foley et al. 2020).

An example of the value of rigorous interdisciplinary research comes from the Baltic Sea salmon fishery, where Bayesian belief networks were used to predict fishers' commitments to management plans. This focus on fishers behaviour helped managers identify some of the consequences of applying different management strategies, before establishing them (Levontin et al., 2011). Another illustration of the potential value of interdisciplinarity is the impact caused by the non-inclusion of Solomon Island fishers into decision making. This approach not only missed the opportunity to incorporate community-based management strategies but also partly caused the decline in abundances of parrotfish and humphead wrasse in the local reefs of the Solomons (Hamilton et al. 2019).

Scientists and other stakeholders have had structural and conceptual challenges as they investigate ways of crossing-over between research fields. Structural barriers comprise geographical separation, between universities and other organisations, or the lack of funding sources promoting projects that aim to bridge various disciplines (Stojanovic et al. 2016). This is a key issues as the research funders are usually split by discipline, so most inter- or transdisciplinary research does not fit within a single funders scope. Conceptual challenges include different perspectives and languages used by natural and social scientists on what key objectives are, the methods to be used, differing terminologies used by academics and other stakeholders, and until recently, the lack of a framework integrating different types of data and defining the links between natural and human dimensions of a SES (Sievanen et al. 2012, Stojanovic et al. 2016).

Since the late 1990s, a significant effort has been put into reducing, or even removing, the communication, collaboration and research barriers to conduct effective interdisciplinary research. For example, Ostrom's theoretical framework, in which she suggested an approach to integrate different types of data (Ostrom 2009). Other examples include the "toolbox for philosophical dialogue" developed by Eigenbrode et al., (2007); and new hybrid models, integrating quantitative and qualitative sub-models, developed to understand complex system dynamics (Lade & Niiranen, 2017; Martin & Schlüter, 2015). Despite the increasing effort in developing and applying these new models in research (Hertz & Schlüter 2015, Schoon & Van Der Leeuw 2015, Bergseth et al. 2017, Stephenson et al. 2018), the integration of human dimensions along with ecological dynamics is inherently complicated due to the various amounts of available data, as well as the different theories supporting each discipline. To deal with such level of complexity, the resulting modeling approaches often have simplified the studies systems and have mainly been used for investigating local case studies, and have not yet been integrated as part of national fisheries research and management (Lade & Niiranen 2017).

1.5. Small-scale and data-poor fisheries

1.5.1. Small-scale fisheries

The exact definition of SSF varies between regions, depending on the livelihoods and conditions of the fishers working in the industry, the dependency on the fishery as a way of living and the general regional importance (*e.g.*, main source of protein and income for the local population or not; Hauck, 2008). However, there is general agreement that small-scale fishers tend to use less capital-intensive gear and their catch per unit of effort is much smaller than those in the large-scale fisheries. This sector usually operates from shore or from small fishing vessels (*i.e.,* under 10 m and with three crew members or less) and work only within EEZ waters (Halim et al. 2019, Smith & Basurto 2019). They are characterized by low economical investment, short fishing trips (<1 day) with limited capacity and autonomy, and thus they yield small landings compared to industrial fleets. The term small-scale fishery encompasses commercial, subsistence and indigenous fishing in all aquatic environments (*i.e.,* marine, estuarine and inland waters). For the purpose of this thesis, SSFs are defined as family-led traditional fisheries, using vessels <10 m in length, low-tech gear, operating in local coastal or estuarine waters, undertaking daily trips, often being multi-species fisheries and adapting to changing conditions and seasons. In general, SSF are thought to be adaptable, strongly linked to the local culture and often reflect the community's values and traditions, supporting social cohesion (FAO, 2018b). Recreational fisheries are generally separated from SSF, as recreational fishing does not represent a commercial activity (FAO 2012). However, these often also share many characteristics with SSF, such as the size, gear used and catch.

SSF employ over 90% of people directly dependent on capture fisheries (FAO 2018b), from harvesters to retailers. This sector contributes to two thirds of global catches for human consumption and about half of total global catches. SSF are strongly rooted in local communities

(FAO 2018b) as, for centuries, they have continuously provided local jobs and locally caught wild fish (*i.e.,* referring to fish as both finfish and invertebrates) in developing and developed countries (Cohen et al. 2019, Leitao et al. 2020). Despite their significant contribution to global catches and their importance for maintaining the well-being of millions of people and supporting their livelihoods, SSF have been largely overlooked in the development of fisheries science (Hordyk 2014) and have been marginalized from the international dialogue between environmental and economic factors that determine future strategies to manage aquatic resources worldwide (FAO 2018b, Cohen et al. 2019).

The development of other fishery sectors over the past decades and the resulting over-exploitation of fishery resources has been particularly damaging for SSF (Pauly 2006, Bundy et al. 2008, Pauly & Zeller 2016a, FAO 2018b). The rapid progress of technology has added pressure to local stocks. As a result, historical practices of resource allocation, seasonality of fishing and traditional methods have often been lost with the introduction of industrial fisheries and non-participatory, centralized management systems (FAO 2018b). Meanwhile, small-scale fisheries vulnerability is intensified due to the consequences of long-term effects of climate change, such as catastrophic natural hazards like the hurricane Maria affecting the Commonwealth of Dominica in September 2017 (Pinnegar et al. 2019). Such environmental shifts caused by climate change can also be devastating for fisheries in closed systems, such as some estuaries in Western Australia, where species are spatially restricted and adapting to new conditions is greatly limited, even sometimes impossible (CSIRO 2020, Smith & Lenanton 2021).

Because SSF are adaptable and dynamic, they have been able to persist in many locations, despite increasing pressures. These fisheries will need to continue adapting as climate changes to meet the increasing seafood demand to sustain economic, social and ecological objectives. In regions where other sectors are expanding (*e.g.*, tourism, recreational fishing, conservation), SSF will need to coexist and potentially compete with such sectors (Kittinger et al. 2017, Cohen et al. 2019). The importance of SSF globally and the challenges that this sector faces nowadays are now thoroughly reported (Aguilera et al. 2015, Chuenpagdee & Jentoft 2019, Cohen et al. 2019, Said & Chuenpagdee 2019), and there is a growing realisation that SSF should become a primary focus for fisheries research and management (Hordyk 2014, Chuenpagdee & Jentoft 2019). Organisations such as Too Big To Ignore (TBTI) have been created to address the concerns and issues affaecting the viability and sustainability of SSF globally (see TBTI webpage for more information on the scope of their work). As complex and adaptive SES, with such strong foundation in local culture and tradition, SSF management requires the integration of data representing the social-ecological dimensions forming these systems (Ostrom 2009).

1.5.2. Data-poor fisheries

1.5.2.1. Catch data availability

Accurate, consistent data collected over time is one of the keys to correctly assess past and current fisheries exploitation at local and global scales, and the application of management approaches that will prevent future stock overexploitation. Inaccurate data or the lack of data for various fisheries, and particularly for SSF, is concerning (Pauly & Zeller 2016a, FAO 2017). The FAO therefore is responsible for reporting the official catch data (Zeller et al. 2006, Jacquet et al. 2010, Moutopoulos et al. 2013), and summarises global catches every two years (*e.g.*, FAO 2020). Data are collected by most countries worldwide, and the results are translated into annual fisheries assessments used for management purposes (Zeller & Pauly, 2018) and submitted to the Food and Agriculture Organization (FAO) annually. With this information, the FAO reports on global fisheries catch statistics, providing a global view of capture fisheries and aquaculture (FAO 2020).

Pauly and Zeller (2016) reconstructed global catches from 1950 to 2010 to take into account illegal, unreported and unregulated catches and found that these catches were 50% higher than those reported by FAO (Pauly & Zeller 2016a, Cashion et al. 2018). The size of under-reporting is likely to be greater still for SSF (The & Pauly, 2018). In fact, we now know that unreported recreational catches could be particularly significant for some species and in some developed countries, as sometimes these are estimated to be greater than the commercial landings (Granek et al. 2008, Hyder et al. 2018, Radford et al. 2018). The lack of catch data and estimated under reporting of catch for many SSF globally is an indicator on how this sector has been overlooked and marginalised worldwide (Teh & Pauly 2018, Halim et al. 2020).

1.5.2.2. Data on the human dimensions

Along with traditional catch data, and the difficulties involved in its collection, SSF are also affected by the lack of information regarding the incorporation of elements other than biological factors constituting SES (Pikitch et al. 2004, Scandol et al. 2005, Pitcher et al. 2009, Pita et al. 2019). Most developed countries and associated fisheries management agencies have now recognised that to implement EBFM, we need clear and simple EBFM indicators of biological, ecological and human dimensions, agreed to by the international community, though these are not always available (Pitcher et al. 2009, Triantafillos et al. 2014, Hobday et al. 2016). Management agencies in some regions have already transitioned to using such approaches, such as in Australia, with the implementation of EBFM and the triple-bottom line (TBL), an approach aiming to assist the progress towards a sustainable management of natural aquatic resources by complementing the environmental, economic and social objectives of fisheries (Triantafillos et al. 2014, Brooks et al. 2015, Asche et al. 2018) and the creation of the CFRN in Canada (Marshall et al. 2018, Thompson et al. 2019). Despite these advances, the transition to full SES for fisheries is mainly theoretical, with few studies or projects incorporating these emerging methods or the new knowledge on human dimensions in global small-scale fisheries assessments (Barclay 2012, Barclay et al. 2017).

1.6. Australian fisheries and management

Australia has over 24,000 km of coastline, which provides various habitats for numerous and diverse marine resources such as molluscs, crustaceans and finfish (Galloway & Bahr 1979, Kailola et al. 1993). Despite this richness in biodiversity, most fishing activities in Australia did not become economically significant until the 1940s, when the exploitation of fisheries such as crabs, lobsters and prawns started. Demand for seafood paralleled this effort, transforming these into high-value products (Tull 1993).

1.6.1. Australian commercial fisheries

Despite having the third largest EEZ in the world (8.94 million km^2), Australian commercial fisheries are mostly small-scale, generally represented by small, family businesses. For example, in 1993, 50% of Australian fishing vessels were less than 6 m long (Tull 1993, McPhee et al. 2002), unlike other commercial fisheries worldwide, which are often represented by large trawlers or purse seiners (Thurstan et al. 2010, FAO 2020). Nowadays, Australia is a small producer of typically high-value seafood compared to other nations, in terms of volume and fishing effort (Department of Agriculture 2015). As a result, the value of Australian seafood exports and imports represents about 1% of the global trade value (ABARES 2018).

There are several reasons that delayed the development of the Australian fishing industry to develop and the significance of small-scale fishing. Firstly, the Australian coast is generally low in nutrients all year round, and thus not very productive (Ward 2011). Secondly, the price of seafood products and resulting profit margins were generally low. Furthermore, product delivery entailed covering large distances from the harvest to the market. Finally, the community generally prioritised consumption of red meat over seafood, thus few people were interested in joining the fishing industry (Tull 1993). Gradually, however, the industry became more capital intensive. In WA, for example, the number of rock lobster vessels increased from 103 in 1948 to 695 in 1962 (Tull 1993) and reached over 800 in the early 2000s (Fletcher & Santoro 2008). Currently, in WA, 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 & Santoro 2020; WAFIC, 2020).

1.6.2. Australian recreational fisheries

Recreational fishing is a very popular activity among the Australian community. The national and indigenous fishing survey recorded that 19.5 % of Australians participated in recreational fishing. Of these, about 35% occurred in estuarine waters, whereas 41% was in coastal waters (Henry & Lyle 2003). Particularly in WA, the participation rate was over 28% in 2000 (*i.e.,* ~300,000 people from age 5 or older) (Henry & Lyle 2003). This number increased in the following two decades, and in 2017/2018 it was estimated that over 700,000 people fished recreationally in WA (Ryan et al. 2019). Currently, the participation rate in recreational fishing activities of Western Australians (28.7%, Ryan et al. 2019) is above the national level (19.5%, Henry & Lyle 2003) and well above the 10.5% average across the industrialized world (Arlinghaus et al. 2015). Along with the high participation numbers, the recreational catches are also significant, and in some regions are estimated to exceed those of the commercial industry (Gaughan & Santoro 2020). For example, in Shark Bay (WA), recreational fishing for pink snapper (*Chrysophrys auratus*) was recognised as the main reason for the drastic decline of this species to less than 10% of its pre-exploitation levels (McPhee et al. 2002).

Despite the size of the recreational sector and the potential magnitude of their catches, information on recreational catches is sporadic for most Australian fisheries, or even absent (*e.g.*, some estimates are available only for boat-based fishers; Gaughan & Santoro, 2020). The single Australia-wide study that assessed recreational fishers' catches estimated that ~136 million aquatic animals were harvested between May 2000 and April 2001 (Henry & Lyle 2003). The significance of recreational fishing for the local community becomes apparent when considering the number of people participating in recreational fishing, and the harvest related to this activity. With the growth of the WA population, and the increase in the number of recreational fishers, fishing pressure is rising, and so are other anthropogenic pressures on coastal, estuarine and river systems (Smith & Lenanton, 2021).

1.6.3. Australian fisheries management

Fisheries managers in Australia have been applying an EBFM approach since the 1990s (Scandol et al. 2005), reflecting the same transition as seen in other fisheries globally. Parallel to this transition towards EBFM, government agencies in Australia introduced and promoted the TBL as the most adequate method to assess fisheries (Paterson et al. 2010, Grafton & Kompas 2014, Triantafillos et al. 2014). Although various indicators have been described for human dimensions of Australian fisheries, including fishers' quality of life and various aspects of fishers' social profile, among other characteristics, these have rarely been applied (Barclay 2012, Schirmer et al. 2013). Indeed, a study which reviewed the management of over 102 Australian fisheries, found that only

22 had management objectives with a social focus, and 25 had associated indicators of social performance (Hobday et al. 2016). None of the 41 fisheries examined in WA had a social objective, nor an associated social indicator. In contrast, almost all the fisheries assessed had objectives and indicators to monitor the biological aspect of fisheries, the bycatch involved and the impact of fishing methods on the broader ecosystem where they operated, and more than half of the studied fisheries had indicators to assess their economic performance (Hobday et al. 2016). Several social indicators were used in some Australian states. For example, 11 fisheries in SA have indicators to monitor social sustainability within the fishing community (*i.e.*, via monitoring "fisher satisfaction"), and five fisheries in the Northern Territory have indicators to monitor social sustainability within the wider community (via monitoring "other human uses").

Management agencies and scholars acknowledge that social targets and indicators of fishery performance are necessary elements to enable adequate policy decision making, and consequently enhance sustainable development of fisheries (Barclay 2012, Pascoe et al. 2014, Fletcher & Santoro 2015). To improve the current situation, benchmarks studies need to be developed to integrated information already available into management, new information needs be collected on the human dimensions of fisheries, such as fishers perceptions on management approaches, fisher values and concerns on the state of the stocks, and information on LFK is needed (Barclay 2012, Brooks et al. 2015, Voyer et al. 2017a, Botto-Barrios & Saavedra-Díaz 2020).

1.7. Blue swimmer crab fishery in Western Australia

The *Portunus* spp. complex consists of four species of swimming crabs (*P. armatus, P. pelagicus, P. reticulatus* and *P. segnis)* which are widely distributed throughout the Indo-Pacific region (Kailola et al. 1993). These four species support important commercial fisheries, particularly in south-east Asia, where most of the catch is exported as crab meat to the USA (Prince et al. 2020). This complex of species also supports small-scale commercial and recreational fisheries throughout Australia. In particular, *Portunus armatus* is a very lucrative fishery in Australia, valued at ~ AUD $8 million in SA (Noell et al. 2020), and ~$4 million in Queensland (BDO-Econsearch 2020) and WA (Gaughan & Santoro 2020).

The blue swimmer crab (*P. armatus*) was known until 2011 as *P. pelagicus* (Lai et al. 2010). In Australia, *P. armatus* inhabits coastal and estuarine waters in WA, New South Wales, and the warmer regions of South Australian gulfs (Gaughan & Santoro 2020). In WA, populations of *P. armatus* are limited mainly to the west coast, and are relatively uncommon on the south coast, due to the lower water temperatures in this region. As a result, *P. armatus* is mainly targeted in the coastal waters and estuaries located on the west coast of WA, including i) Shark Bay, ii) the Swan-Canning Estuary; iii) Cockburn Sound; iv) Peel-Harvey Estuary and v) Leschenault Estuary, Figure 1.1; Johnston et al. 2011). The closely spaced estuaries and bays in this region, combined with the effects of the Leeuwin current flowing north to south of the WA coast, increase the mixing capacity of the crab larval stages. The *P. armatus* populations are genetically diverse across this coast and their successful recruitment depends on particular weather and temperature conditions (Johnston et al. 2015).

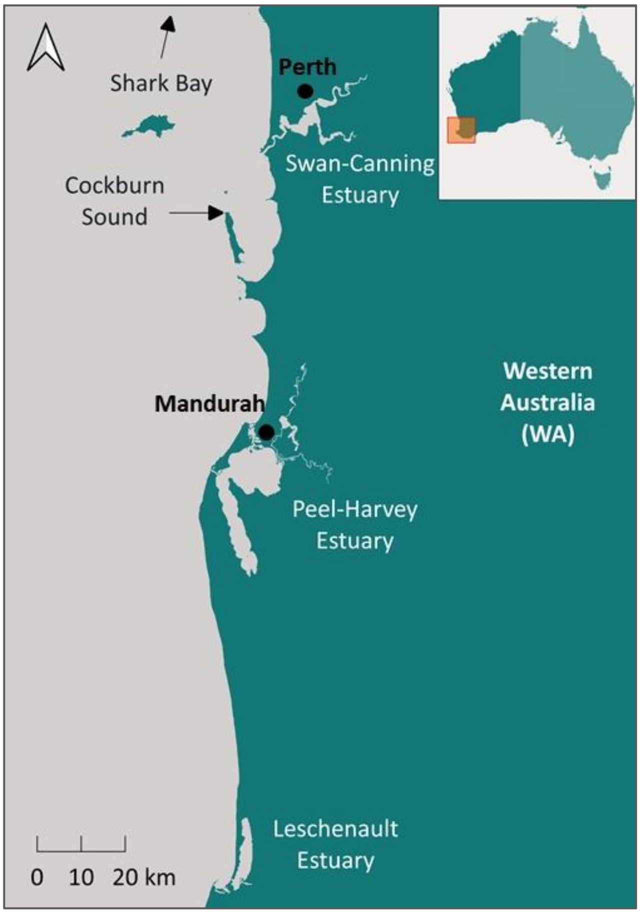


Figure 1.1. Maps showing the region of south-western Australia and the location of the main estuaries studied in this thesis, particularly the Swan-Canning Estuary and the Peel-Harvey Estuary.

1.7.1. Management of blue swimmer crab fishery in WA

The commercial sector is regulated by the Department of Primary Industries and Regional Development (DPIRD) through limiting the numbers of traps and active vessels, and by applying restrictions to the crab's size (Gaughan & Santoro, 2020; see Chapters 2, 4 and 6 for more details). In contrast, the recreational sector for *P. armatus* has many more participants (*i.e.*, 100,000s fishers). *P. armatus* is one of the most popular recreational fisheries in WA, and is mainly targeted recreationally in south-western Australia, with over 670,000 crabs caught recreationally while fishing with traps from a boat during the 2017/18 season (Ryan et al. 2019). The recreational sector is mainly regulated by limiting the catch (bag limits vary depending on the fishing method - *i.e.*, boat-based or shore-based) and limiting the size (same minimum size limit [MSL] as the commercial sector). Recreational fishers crabbing from a boat require a crabbing licence, however, fishers from the shore do not. This fishery is also important culturally for the local community. Events such as "Crab Fest", an annual celebration of crabs and crab fishing in the Peel-Harvey Estuary, by the city of Mandurah, show the importance of the *P. armatus* and the ecosystem supporting it for the community in this region.

In south-western Australia, the most important *P. armatus* fishery in terms of volume caught, and people involved, both for the recreational and commercial sectors, is in the Peel-Harvey Estuary. Since 2016, both, the commercial and recreational sectors of the Peel-Harvey Estuary blue swimmer crab fishery obtained the Marine Stewardship Council (MSC) certification for sustainability (Johnston et al. 2015, Fletcher et al. 2017). Despite the certification of sustainability received by the fishery in the Peel-Harvey Estuary, it is important to note that not all *P. armatus* stocks in the region are classified as sustainable. For example, the fishery in nearby Cockburn Sound has been closed intermittently since 2006 and fully closed since 2 014 (Johnston et al. 2020).

The severe decline of the crab population in this area has been related to a combination of anthropogenic and environmental pressures and a lower level of primary production in the Sound now, than 20-30 years ago (Marks et al. 2020). Predictions for changes in climate conditions by 2030 in this region indicate that the average temperatures will rise continuously in all seasons, the mean sea level will also rise (~ 0.12 m), and the significance of extreme sea-level occurrences and intensity of extreme rainfall events will increase (West & Gordon 1994) (Webb & Hennessy 2015, CSIRO 2020). This could negatively affect the survival of *P. armatus* populations in these regions, as an increase in temperature can impede successful recruitment if water temperatures reach the thermal maxima of juvenile *P. armatus* (Chandrapavan et al., 2019).

Although Australian fisheries management and research is considered world leading (Pitcher et al. 2009, Costello et al. 2012), and despite the early adoption of EBFM (Scandol et al. 2005), fishery resources in Australia are suffering from various anthropogenic and environmental pressures. For the application of an EBFM approach to manage this fishery, managers should consider not only catch-based data for stock assessment and management predictions, but also include the influence of economic, institutional and human interactions on the fishery. Despite the efforts to collect such information, there is little data available on the human dimensions of any fisheries in WA (Hobday et al. 2016), and an approach to collect, analyse and incorporate such data in management has not yet been developed.

1.8. Research and structure of the thesis

1.8.1. Research aims and objectives

This study aimed to provide new knowledge on some of the human dimensions of the blue swimmer crab (*P. armatus*) fishery in south-western Australia and contribute to understanding the human dimensions of fisheries in Australia and other developed countries. To do this, an interdisciplinary approach, combining social science qualitative methods such as open-ended surveys, and quantitative methods with a social focus, such as social network analysis and a biological focus, such as investigating historical catch data through newspaper records. In this thesis, I consider "qualitative analysis" as the analysis of qualitative data (*i.e.*, descriptive interview responses having a categorical structure). I use "quantitative analysis" to refer to the analysis of quantitative data or qualitative data that has been transformed into a numeric value.

During my research, I collected data from three of the four most important estuaries for blue swimmer crab fishing in south-western Australia, with different geographic, biological and social characteristics, including: i) the Swan-Canning Estuary; ii) the Peel-Harvey Estuary and iii) the Leschenault Estuary (Table 1.1). These estuaries were selected according to their importance for *P. armatus* fishing activities as well as their proximity to urbanised areas. Note that the fourth key site for *P. armatus* fishing described above (*i.e.*, Cockburn Sound, an embayment, which extends from the south of the mouth of the Swan-Canning Estuary to Point Peron, near Rockingham; Figure 1.1) was not included in this thesis as the commercial crab fishery and the southern extent of the recreational crab fishery has been closed since 2006 (Johnston et al. 2020).

Table 1.1. Summary of the estuaries included as field sites in this study and description of the social and ecological characteristics of each estuary. (n) indicates number of current, active commercial licenses; * commercial fishery closed in 2000.

Characteristics	Swan-Canning	Peel-Harvey	Leschenault
Tributary rivers	Swan; Canning	Serpentine, Murray, Harvey	Brunswick; Ferguson, Preston, Wellesley
Urban population	~ 2,040,000	~ 80,800	~ 32,240
Fishing sector(s)	Commercial (1) and Recreational	Commercial (6) and Recreational	Recreational only *
Existing ecological data	Yes	Yes	No

With this study, I investigate the human dimensions of the blue swimmer crab fishery while describing some of the barriers to communication and effective research and management that fishers, managers and other fishery stakeholders are facing. I provide a rich description of fishing values, concerns and other human dimensions that were highlighted as important by the fishers. I also investigate how some types of human interactions (particularly, information sharing) might influence communication efficiency between stakeholders, highlighting some of the communications barriers, negatively affecting collaboration and ultimately the management of *P. armatus*. Finally, drawing from research on local ecological knowledge (LEK) of natural resources, I assert the relevance of fisher perceptions as a type of LFK, and suggest how this non-traditional data could be used to monitor fisheries status, particularly when other types of data are missing. Overall, this study contributes to the wider understanding of small-scale fisheries as social-ecological systems, and their management in Australia and globally. Given the scarcity of information on the human dimensions of Australian fisheries, specifically in WA, the overall aim of this study was to empirically study the dynamics between the social and ecological elements of this small-scale fishery.

This is the first study on the human dimensions of blue swimmer crab fisheries in Australia, and on a *Portunus* spp. fishery worldwide. It is also one of the few baseline studies on the human dimensions of crab fishery globally. The approach used in this thesis is transferable to recreational SSFs in other regions of Australia and elsewhere. Finally, the key results can be used as a baseline when little or no information on the human dimensions is available.

The main objectives of this research were to:

i) Describe the structure of the blue swimmer crab fishery social network (*i.e.*, both commercial and recreational fishing sectors) and understand the information-sharing patterns between the different stakeholders;

ii) Use local fisher knowledge (*i.e.*, recreational sector) and other sources of data to understand trends in *P. armatus* catches (*i.e.*, size and abundance) and effort from the 1900s to 2000;

iii) Understand and describe fisher perceptions on the *P. armatus* fishery, fishers' concerns and views on management (*i.e.*, both sectors);

iv) Investigate some of the social justice issues faced by commercial *P. armatus* fishers, particularly the marginalisation of commercial *P. armatus* fishers by an expanding recreational sector;

v) Elicit and measure recreational fishers' beliefs towards restocking of *P. armatus* as a management approach using a two-stage survey method.

Each of the data chapters in this thesis addresses one of the objectives described above. The structure of the thesis is graphically represented and summarised in Figure 1.2. The research on describing the fishery network (Aim 1, Chapter 2) and social justice (Aim 4, Chapter 5) focusses on crabs in the Peel-Harvey Estuary, while all other research considers crab fishing in the three west coast estuaries, particularly the Swan-Canning and Peel-Harvey estuaries (Figure 1.2).

1.8.2. Thesis structure

This thesis consists of seven chapters, five of which are data chapters (Figure 1.2). I also describe the thesis overarching aim, objectives and structured followed. Chapter 1 introduces the topic of fisheries as SES and outlines the difficulties of integrating fisheries' human dimensions, either due to a lack of such data, or due to various barriers to use the data already available. The data chapters (Chapters 2 to 6) were written as a series of stand-alone papers to facilitate publication. Therefore, each paper contains some repetition of key information in the introduction section, and in some of the methods. The final chapter (7) presents the general conclusions and recommendations emerging from my research.

In Chapter 2, I used social network analysis (SNA) to describe the information flow among recreational and commercial fishers and other stakeholders forming the Peel-Harvey fishery network. In this Chapter, I used SNA to describe the network structure of the blue swimmer crab fishery in the Peel-Harvey Estuary, which involved the description of information exchange between individual stakeholders and organisations involved with the fishery, as well as their importance (*i.e.*, position) in the network. Here I highlight some of the communication barriers encountered by stakeholders involved in the management of this fishery.

In Chapter 3, I tackled part of the issue on data availability for the blue swimmer crab fishery in south-western Australia, particularly for the recreational sector. I looked at fisher perceptions of change in the abundance and size of the *P. armatus* caught over time, as well as any environmental changes observed, and compared these perceptions with historical records sourced from Trove (*i.e.*, digitised Australian library including newspaper collections among other historical records). To do so, I collected over 400 historical records sourced from newspapers in WA, since the 1908 to 2000, and combined them with an online survey and a face-to-face interview conducted with recreational fishers in various estuaries.

Chapter 4 provides a baseline on the human dimensions of the blue swimmer crab fishery. Particularly, I collected and analysed the perceptions of commercial and recreational fishers towards management their concerns towards the fishery and the status of stocks and the supported approaches by each sector.

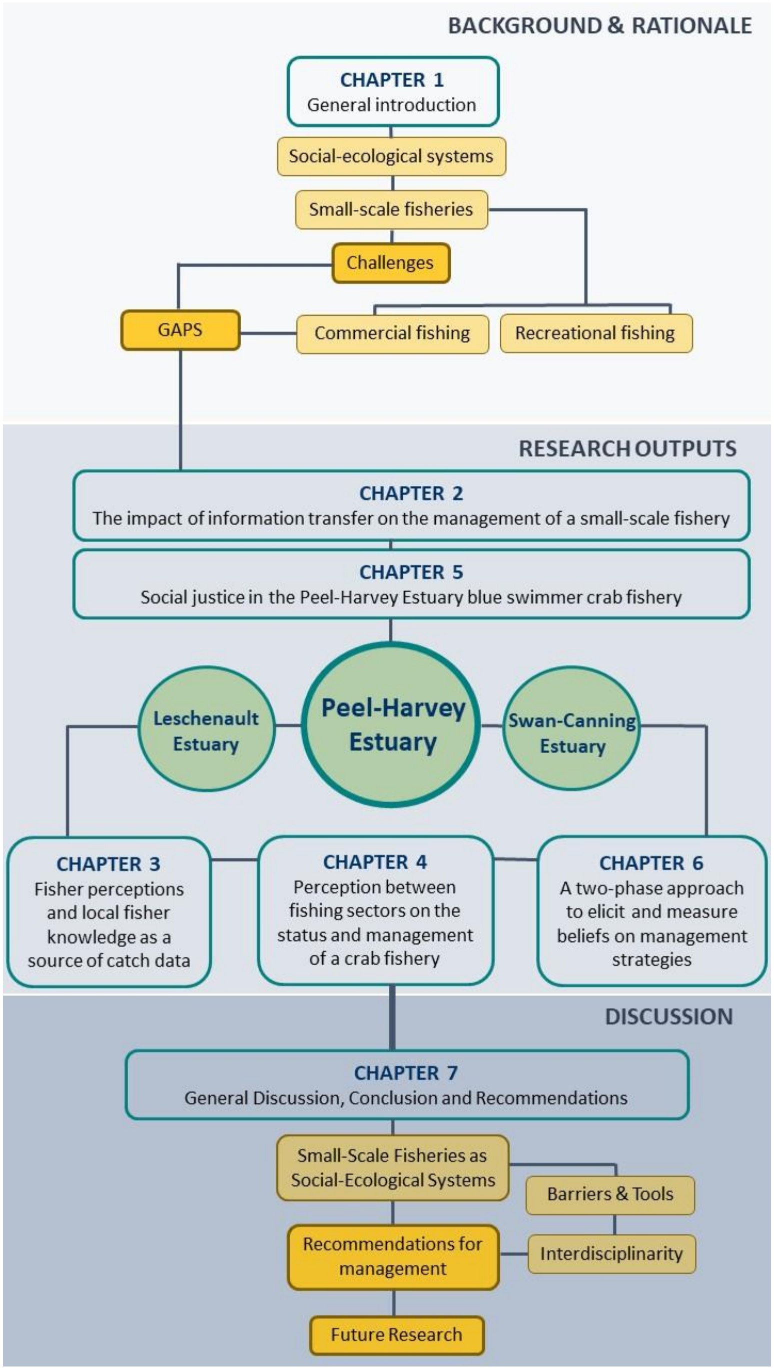


Figure 1.2. Schematic diagram of thesis structure, showing the focus of each major data Chapter and the estuaries studied for each Chapter. Key elements of the General Introduction, General Discussion, Conclusions and Recommendations are also shown.

In Chapter 5, I looked at social justice issues affecting the blue swimmer crab fishery in south-western Australia. Chapter 6 explores this power imbalance between the commercial and recreational fishing sector as a short commentary and puts the small-scale blue swimmer crab fishery of WA in the context global issues on fisheries social justice.

Chapter 6 describes a two-phase method I developed to understand the human dimensions of the blue swimmer crab recreational fishery, particularly focusing on the perceptions of recreational fishers towards restocking as a management approach for the fishery.

Finally, Chapter 7 discusses the conclusions from previous chapters, as well as its inclusion in the management of the *P. armatus* fishery in south-western Australia. Drawing on the key findings from Chapters 2 to 6, I have summarised the overarching themes that emerge from this multidisciplinary thesis, highlighting the theoretical and practical contributions of this study. Finally, I have developed a discussion on the elements described above, as well as recommendations for future research with regards to the human dimensions of small-scale fisheries, and the use of interdisciplinary methods to research this topic.

Chapter 2

Who you speak to matters: Information sharing and the management of a small-scale fishery[1]

Recreational fishing boat, or "Dinghy" moored in the entrance of the Blackwood Estuary, Augusta.

[1] This chapter is published as a co-authored manuscript:

Obregón C., van Putten I., Admiraal R., Hughes M., Tweedley J. R., Loneragan N. R. (2020). "Who you speak to matters: the impact of information transfer on the management of a small-scale fishery". *Frontiers in Marine Science*. 7:578014. Doi: 10.3389/fmars.2020.578014.

Chapter 2

Who you speak to matters: Information sharing and the management of a small-scale fishery

2.1. Abstract

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. This study employed social network analysis 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 *P. armatus* 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. This study has identified logistical and institutional challenges to communicating information regarding the

science, management and environmental issues related to a small-scale crab fishery and makes suggestions to enhance information flow in the network.

2.2. 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 2000). Effective management of SES ideally requires the inclusion of human dimensions such as stakeholder perceptions and knowledge (Bodin & 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 & 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). 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 et al. 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

(BSC, *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 2003). This method is increasingly recognized as an interdisciplinary tool with potential to clarify the implications of network properties for natural resource management (Turner et al. 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 & 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 et al. 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 & Norberg 2005). It has also shown the importance of collaboration and information sharing (Cohen et al. 2012), as well as the significance of particular organizations, partnerships (Berdej & Armitage 2016) and individuals (Gutiérrez et al. 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, there are no peer-review publication analyzing the patterns of information-sharing through an Australian fishery network. We found however one study conducted for Fisheries Queensland which looked at the historical elements which led to the current relationship patters between the regional fisheries department and the professional fishers and other stakeholders. This study also included a social network analysis on communication patterns between stakeholders and Fisheries Queensland (McClean et al. 2019).

The BSC 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 BSC 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. 2020a). Consequently, this study 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.

2.3. Methods

2.3.1. 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 BSC 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 (Gaughan & Santoro 2018). The commercial catch in WA was 518.2 t in 2017 (Fletcher et al. 2017).

Commercial fishing for BSC in WA is managed mainly by restrictions on fishing vessels, fishing traps and enforcing a minimum size limit (MSL) of 127 mm carapace width. Daily time limits and a closed fishing season also apply (Fletcher et al. 2017). Recreational catches are mainly regulated through bag limits and size restrictions (*i.e.*, 10 or 20 crabs per person when fishing from the shore or from a boat, respectively, and MSL of 127 mm carapace width). A fishing license is also needed for recreational fishers using a boat. Shore-based recreational fishers are exempt from this license. Since 2019, new management measures have been introduced for both fishing sectors in south-western Australia. These include a seasonal closure for all waters from Perth (WA capital city; Figure 2.1) to Manjimup Beach (200 km south of Perth) from September to November, a reduction of bag limits for regional systems, and a buy-out of commercial fishing licenses in the Peel-Harvey Estuary (DPIRD 2018).

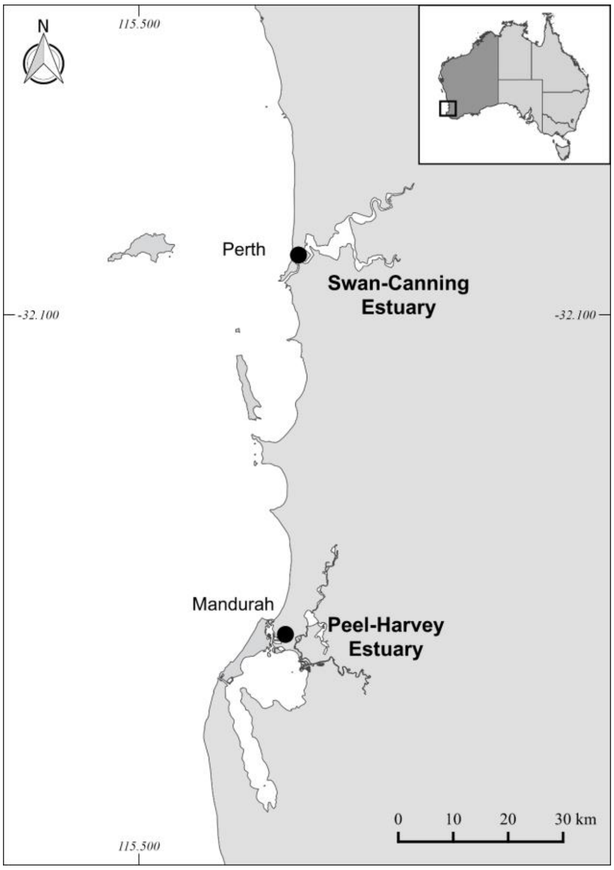


Figure 2.1. Map of Western Australia (Australia), showing the location of the Peel-Harvey Estuary and the cities of Mandurah and Perth.

Located about 80 km south of Perth, the Peel-Harvey Estuary is the largest estuary in south-western Australia (area ~130 km^2, Figure 2.1) and it is also one of the most popular locations for BSC 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 2021). 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 2009). 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.

2.3.2. 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 2.1). 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 (secondary participants; Maiolo et al. 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 2.1), no individuals were mentioned by two or more participants, and therefore recreational fishers were not invited to participate in the survey. Recreational fishers were therefore interviewed separately.

Table 2.1. Organisations forming the PHBSC fishery network and acronyms used for each organisation, groups they are affiliated with, description of each organization 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 BSC research
	University of Western Australia researchers	-	1	0	Established academics involved in BSC 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 BSC 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 (see supplementary material 2.1). 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 BSC 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 2.1). Individual recreational fishers were not included in the recreational fishing sector group as these responded to a different survey and therefore were analyzed 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 BSC fishery was shared.

2.3.3. Network and data analyses

Social network analysis was used to describe, analyze, 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 closed population including only individuals who had been interviewed by the researchers and their information sharing relations between each other (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 2.2 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 they 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)).

2.3.3.1. 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 et al. 2018).

Table 2.2. Individual and organisational level network metrics of centrality, definitions, and descriptions.

Centrality measure	Definition	Description
Degree centrality (i.e., out-degree)	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 (i.e., in-degree)	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.

2.3.3.2. 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 2.1). In the organization-level, on the other hand, we present results according to the individual organizations.

2.3.3.3. 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 BSC 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.

2.3.3.4. 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).

2.4. 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.

2.4.1. 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.

2.4.2. 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 BSC 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.

2.4.3. 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 BSC populations, and 63 related to the environment of the Peel-Harvey Estuary. Note that some of the relations related to more than one topic.

2.4.3.1. 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 2.3). 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.

Table 2.3. 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. Individuals are ranked according to their degree centrality (i.e., out-degree) and degree prestige (i.e., in-degree).

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

2.4.3.2. 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 2.4). 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 Supplementary table S2.1 and S2.2).

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 Supplementary table S2.3). 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 Supplementary table S2.3), 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 Supplementary table S2.3), evidence of heterophily.

2.4.4. 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.

2.4.4.1. 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 closed population network (Table 2.5, Figure 2.2). Here, however, their relative rankings were swapped (Tables 2.3 and 2.5). 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.

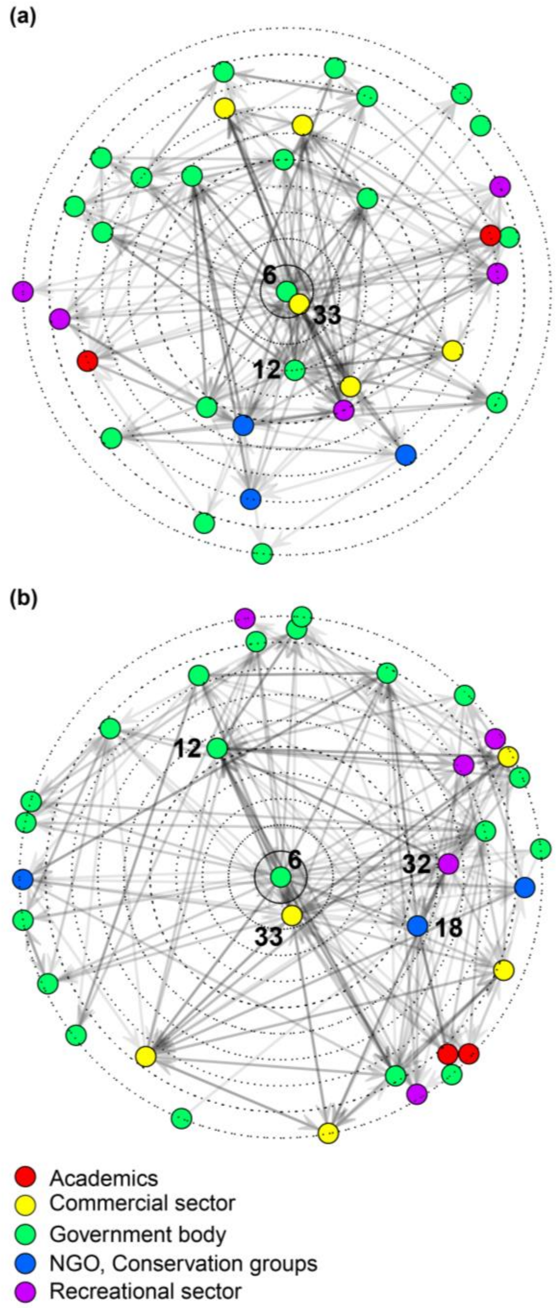


Figure 2.2. Target plot of degree centrality (*top*) and betweenness centrality (*bottom*) for individuals forming the closed population network. Individuals with higher centrality appear near the centre of the plot.

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 2.3 and 2.5). 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 our study 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 2.5). 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 BSC fishery bodies are ensuring that the commercial sector is well-informed.

2.4.4.2. Organization-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 2.3 shows the structure of this network with edge widths reflecting the frequency of directed relations between organizations and node sizes reflecting degree centrality (Figure 2.3a) and betweenness centrality for organizations (Figure 2.3b). 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.

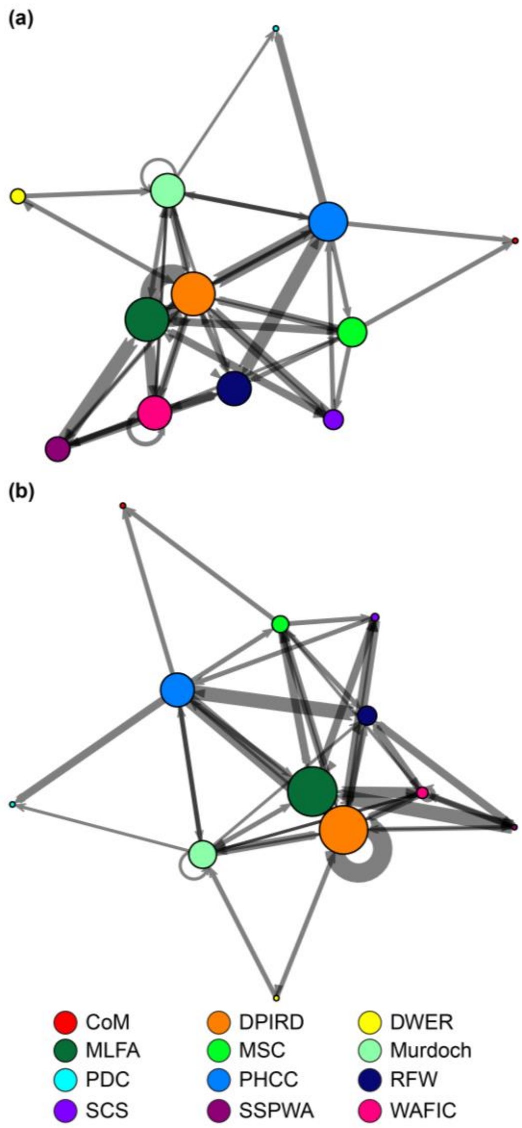


Figure 2.3. Plots of the network of organisations represented in the closed population network with edge widths representing the frequency of relations between organisations and node sizes representing weighted degree centrality (*top*) and betweenness centrality (*bottom*) for organizations.

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.

Table 2.4 Exponential random graph model (ERGM) results for attribute-based mixing for individual stakeholders forming the egocentric PHBSC fishery network. See supplement tables (table S1 to table S5) for more details. The symbol '*' denotes the presence of significant differences ($p<0.001$).

Attribute	***p*-value**
Gender	0.134
Seniority	<0.001*
Age	<0.001*
Organisation	<0.001*
Group	0.1366

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 2.6 and Figure 2.3). 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 (Table 2.3 and Table 2.5, Figure 2.2 and Figure 2.3), 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.

Table 2.5. 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

2.4.5. 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 BSC fishery, but rather aim to share general information on local recreational fisheries with the general public. For this component of the study "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 2.7). 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 2.4, and further analysis below).

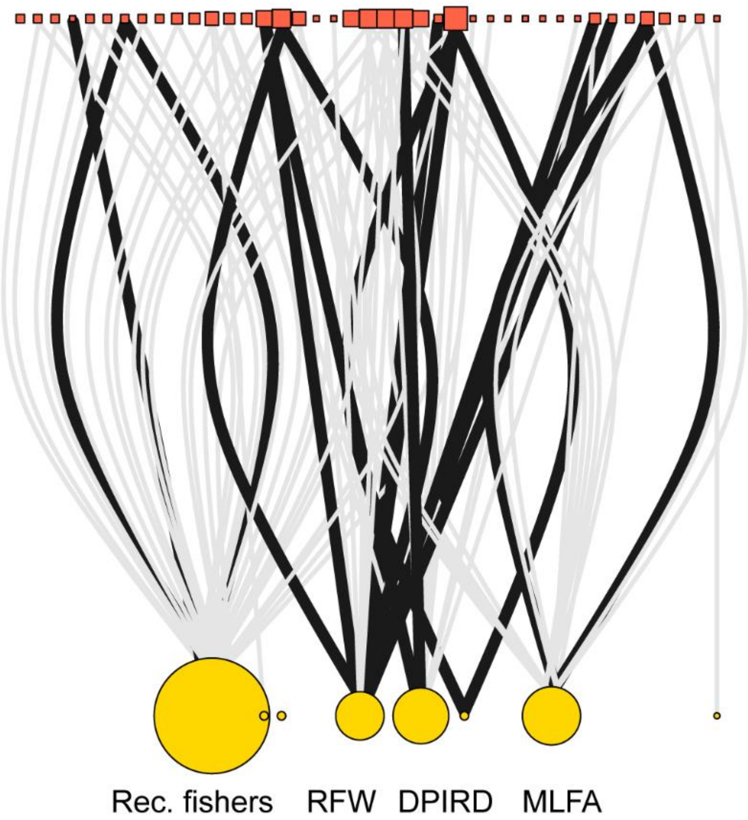


Figure 2.4. Bipartite network of recreational fishers' network and the organizations with which they exchange information. Recreational fishers are denoted by red squares, while organizations are represented by yellow circles. Organizations with degree centralities exceeding 0.1 are labelled, and node 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. Refer to Table 2.1 for information on which acronym corresponds to each organization.

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.

Table 2.6. Results showing centrality and prestige measures for organizations represented in the closed population network. Refer to Table 2.1 for information on which acronym corresponds to each organization.

Organization	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

There was also considerable variation in terms of the mode of communication used in information exchange between recreational fishers and different organizations (Figure 2.5). 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.

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).

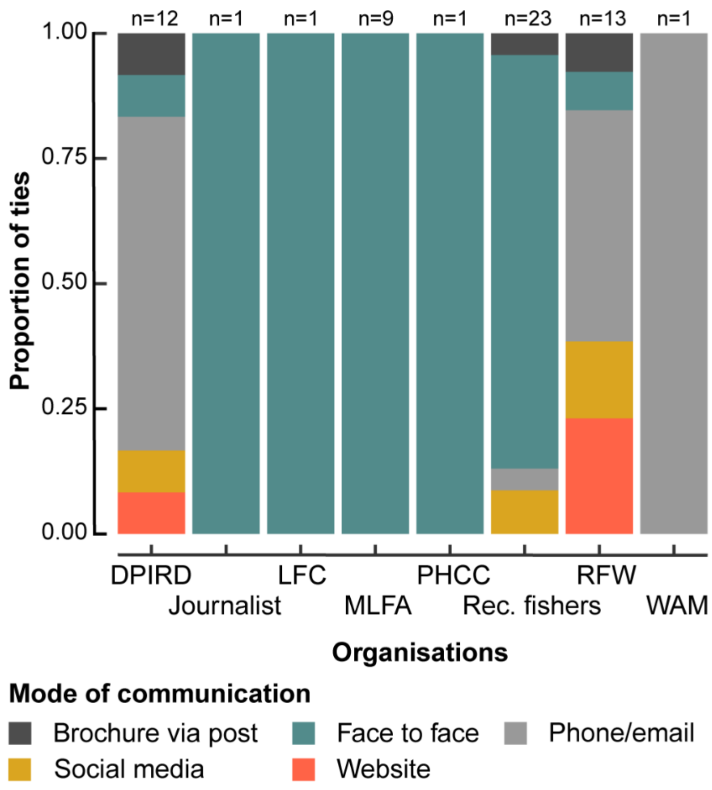


Figure 2.5. The proportion of information exchanges between recreational fishers and organizations involving various modes of communication, as reported by recreational fishers. Sample sizes (n) on which these proportions are estimated are also presented. Refer to Table 2.1 for information on which acronym corresponds to each organisation.

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 boatshow (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.

Table 2.7. Results showing the organisations mentioned by recreational fishers and their degree metrics. Organisations are ranked according to their degree centrality. Refer to Table 2.1 for information on which acronym corresponds to each organisation.

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

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 boatshow 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 remaining 3.3% did not express a preference. 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.

2.5. Discussion

Our study 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 one of the first studies (along with the report from McClean et al. 2019) looking at information sharing in an Australian fishery social network and one of the few network studies looking at information sharing between fishery stakeholders globally (Bodin & Norberg 2005, Leonard et al. 2011, Turner et al. 2014).

2.5.1. 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 & 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 BSC 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 organization. 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 et al. 2001, Bodin & 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 & Norberg 2005, Turner et al. 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 et al. 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 & Handcock 2015). Although, the relatively low level of agreement between actors found in our study 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. 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, unlike commercial fishers which often work together towards form commercial fishing associations and be self-represented (Kearney 2002). Government bodies have a role to share information on the fishery and also have one of the highest degree centrality. Considering this and taking into account the high degree prestige of this organization combined with a lower degree centrality and betweenness centrality it can be hypothesized 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 groups, and not so much within it. The PHCC is the only organization that is not directly involved in the fishery, the research on BSC 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 & 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 BSC 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 et al. 2014, Berdej & 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.

Our study found that 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, Chrystal, and Loneragan 1983). 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 & 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.

2.5.2. 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. 2017a). 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 et al. 2014). 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 BSC 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 study, 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 BSC 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.

2.5.3. 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 et al. 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.

Our study found a mismatch between the public events available with a focus on the fishery and their potential to share information among resource users. 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 study 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.

2.6. 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 et al. 2015). Social network analysis can disentangle some of these questions using an interdisciplinary approach with an emphasis on the human dimensions of fisheries. Our study 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 *P. armatus* 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 study 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 study also illustrate the value of empirical research in understanding stakeholder connections and information flow processes for informing the management of fisheries.

Chapter 3

Local fisher knowledge reveals changes in size of blue swimmer crabs in small-scale fisheries.

"Old town jetty" – One of the main recreational jetties at the Blackwood Estuary in Augusta, south-western Australia.

Chapter 3

Local fisher knowledge reveals changes in size of blue swimmer crabs in small-scale fisheries

3.1. 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, time consuming, and can be limited in temporal and geographic scales. Alternative methods include the use of local fisher knowledge (LFK) to explain observed changes in the 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 the long-term sustainability of this fishery, due to a perceived increase in fishing pressure through time. To understand if fishers' perceptions of change provide useful information on actual changes in the fisheries and/or the underlying stock, a triangulation approach was used to assess changes in the size and abundance of blue swimmer crab in two estuaries (the Peel-Harvey and Swan-Canning) with three types of data: i) fisher recollections over time collected through face-to-face interviews and online surveys; ii) historical records from newspaper articles from 1900 to 2000; and iii) biological data from fishery independent surveys between 2006 and 2019. Four key results were identified: i) Crab size differed between the two estuaries; ii) Crab size decreased in the Peel-Harvey estuary between decades but not in the Swan-Canning Estuary; iii) inter-generational differences in recreational fishers' perceptions regarding changes in size over time; and iv) or historical evidence of crab fishers' observations of changes in the fishery and wider estuarine environment. These findings are evidence of a likely decline in the average size of blue swimmer crabs in south-western Australia, particularly in the Peel-Harvey Estuary. Our comparison of data from different sources demonstrated that LFK may be a valuable source of information when other data sources are lacking.

3.2. Introduction

Globally, anthropogenic pressures on coastal environments are increasing, resulting in the degradation of complex and dynamic systems including the social-ecological systems associated with fisheries (Johnston et al. 2011a, Thurstan et al. 2016b). Fisheries are complex and dynamic SES and are highly impacted by anthropogenic pressures (Edgar et al., 2018; Jackson et al., 2001; Jackson & Jacquet, 2012). Generally, the methods used for measuring change in fisheries focus on quantitative estimates based on biological information and data collected from the fishery or their underlying fish populations (stocks). These methods are often expensive, time consuming, and are limited in temporal and geographic scale (Paterson 2010), but recently developed data-limited methods are rectifying many of these limitations (Froese et al. 2017). The engagement of local communities in resource management and particularly the inclusion of natural resource user observations (i.e., local fisher knowledge – LFK, also called Ecological Fisher Knowledge) has been a useful method of monitoring systems at different temporal and geographical scales (*e.g.,* Johannes et al., 2000).

Fishers have often reported declines in catches before a change is recognised by fishery managers and scientists (Milich 1999). Although LFK has been used to provide comprehensive information on historical changes in local fisheries catches where biological data were incomplete (Johannes et al. 2000, Lozano-Montes et al. 2008), fishers' perceptions are often seen as cautionary tales, rather than reliable information (Papworth et al. 2009). Despite increasing research interest in using LFK for monitoring coastal fisheries, its application to enhance management has been limited, and has mainly focused on recommendations for conservation planning (Drew 2005, Golden et al. 2014, Cisneros-Montemayor et al. 2020).

Fishers' perceptions and recollections can be acquired through personal logbooks, digitised library newspaper collections and government archives, as well as by interviewing the fishers themselves. Information gained from interviews with fishers may have certain biases such as memory illusion. This occurs when fishers recall an extreme event - e.g., a pronounced decline in catches in a specific year can exaggerate memories of change across time as a representation of the past, rather than reflecting actual change (Papworth et al. 2009).

Despite the occurrence of biases, the collection of LFK can help to identify the occurrence of shifting baseline syndrome (SBS), which refers to individuals' change in perception of a SES due to a failure in memory of how the system used to be in the past (Pauly 1995, Sáenz-Arroyo et al. 2005, Papworth et al. 2009). Papworth et al (2009) have identified two main forms of change in perception: i) personal amnesia - where individuals update the recollections of the past based on recent experiences rather than previous ones, forgetting how it used to be; and ii) generational amnesia - when new generations accept their perceptions of a resource status as a baseline and use this to evaluate future changes of the resource (Pauly 1995). To identify the occurrence of SBS, LFK of change needs to be accompanied with the identification of a biological change based on quantitative data. Without other sources of data to confirm the perceptions, it is difficult to integrate LFK in fisheries assessments and management decisions. Other fisher perceptions are not validated with quantitative data showing such change, and this, combined with the difficulties of integrating qualitative data into fisheries assessment and management decisions (Klein & Thurstan 2016), makes the identification of system change through SBS difficult (Papworth et al. 2009, O'Donnell et al. 2010).

Australian fisheries management applies ecosystem-based fisheries management (EBFM) to regulate its fisheries. However, as with fisheries worldwide, data on the impact of recreational fishing on fishery resources have been largely lacking in Australia (McPhee et al. 2002, Arlinghaus et al. 2019). In fact, until recently, recreational catches in Australia and elsewhere have not been accounted for (Freire et al. 2020) when assessing the state of fisheries, and continue to be unaccounted for in Australia's international reporting on catches (FAO 2020). In the last few decades, this has been recognised as a major issue for sustainable fisheries and various studies have shown that, in some fisheries targeted by recreational and commercial fishers, recreational catches can potentially outweigh commercial catches (Christensen & Jackson 2014, Smith & Zeller 2015, Radford et al. 2018, Arlinghaus et al. 2019, Gaughan & Santoro 2020).

While the monitoring of recreational fish catches has been scarce, it is important to note that recreational fishing is an integral part of Australian culture. Recent estimates have shown that in Western Australia (WA), the number of recreational fishers (~700,000) greatly exceeds those in the commercial sector (~9,000; Ryan et al., 2019). Few studies on recreational fishing activities have been undertaken state-wide (Craik 1989, West & Gordon 1994, Malseed & Sumner 2001b, Sumner & Malseed 2004, Webley et al. 2015) and nationally in Australia (Henry & Lyle 2003). However, these broad-scale geographic surveys are very costly, time consuming and in WA, do not account for the shore-based recreational fishers. Only recently pilot studies have tried to estimate shore-based fishing effort in WA (Taylor et al. 2018).

The blue swimmer crab is one of the most popular target species for recreational fishing in WA. It is estimated that over 100,000 fishers target this species (MSC 2016). Despite the importance of this sector, no comprehensive catch and effort time series are available for recreational fisheries in WA. The latest estimates show that boat-based recreational fishing (mainly with traps) in WA is landing as much as ~36 to 50 tonnes of blue swimmer crab per year, which is about half of the 2018/19 annual commercial catches (~70 tonnes) for the state (Gaughan & Santoro 2020). It is likely that shore-based recreational fishing, with scoop nets or traps, also take substantial catches of crabs, particularly from shallow-estuaries, such as the Peel-Harvey and Leschenault, where crabs are readily available to fishers walking through the shallows.

This study aimed to i) empirically identify inter-generational differences in fishers' perceptions of change in size and abundance of crabs; ii) assess if these perceptions align with documented historical changes in newspaper catalogues and published data from fishery independent surveys; and iii) provide a historical background of development and changes in the *P. armatus* estuarine fishery in south-western Australia. Four data sources were used to triangulate understandings of change in the Peel-Harvey and Swan-Canning estuaries following Patton 1999 and Fogliarini et al. 2021. These included:

i) An online survey of recreational blue swimmer crab fishers' perceptions of changes in size, catches and views on management.

ii) Face-to-face interviews with recreational blue swimmer crab fishers' about perceptions of changes in fishing activities, stocks and its environment.

iii) An investigation of historical records sourced primarily from the National Library of Australia digitised collections (*i.e.,* Trove) on the size and abundance of blue swimmer crabs since the beginning of the 20th century. Information on the history of the fishery was also sourced from other historical records, to provide a background on the importance of the fishery to the community in south-western Australia.

iv) Published data on mean size of blue swimmer crabs in various estuaries.

Finally, the study aimed to assess if the trends apparent in each data source aligned and lead to similar conclusions on changes in the crabs' size and abundance of crabs. Note that no records specific to indigenous exploitation of *P. armatus* were found, therefore Aboriginal fisheries were not included in this study.

3.2. Materials and methods

3.2.1. Study area

Two estuaries in south-western Australia, located adjacent to major urban centres, were selected for this study, *i.e.,* the Swan-Canning and Peel-Harvey (Figure 1). These estuaries are both hotspot for recreational blue swimmer crab fishing. However, they have quite large differences in characteristics between each SES and the fishery they support (*i.e.,* scale of commercial and recreational sectors). The Swan-Canning Estuary is located within WA's capital city, Perth (population ~2,039,200). It supports commercial and recreational fishing for blue swimmer crab, though since 2008, only one active commercial fisher has been operating in this estuary (Johnston et al. 2020). The Peel-Harvey Estuary, located ~80 km south of the City of Perth, is adjacent to the City of Mandurah (population ~80,800). As Mandurah developed rapidly in the second half of the 20th century, the Peel-Harvey Estuary emerged as the most popular estuary for crab fishing in south-western Australia (Johnston et al. 2020). It also supports the largest commercial blue swimmer crab fishery in the region. All commercial fishers operating in this fishery (11 prior to

2020, and six active commercial licences since 2020) are members of the Mandurah Licenced Fishermen Association (MLFA).

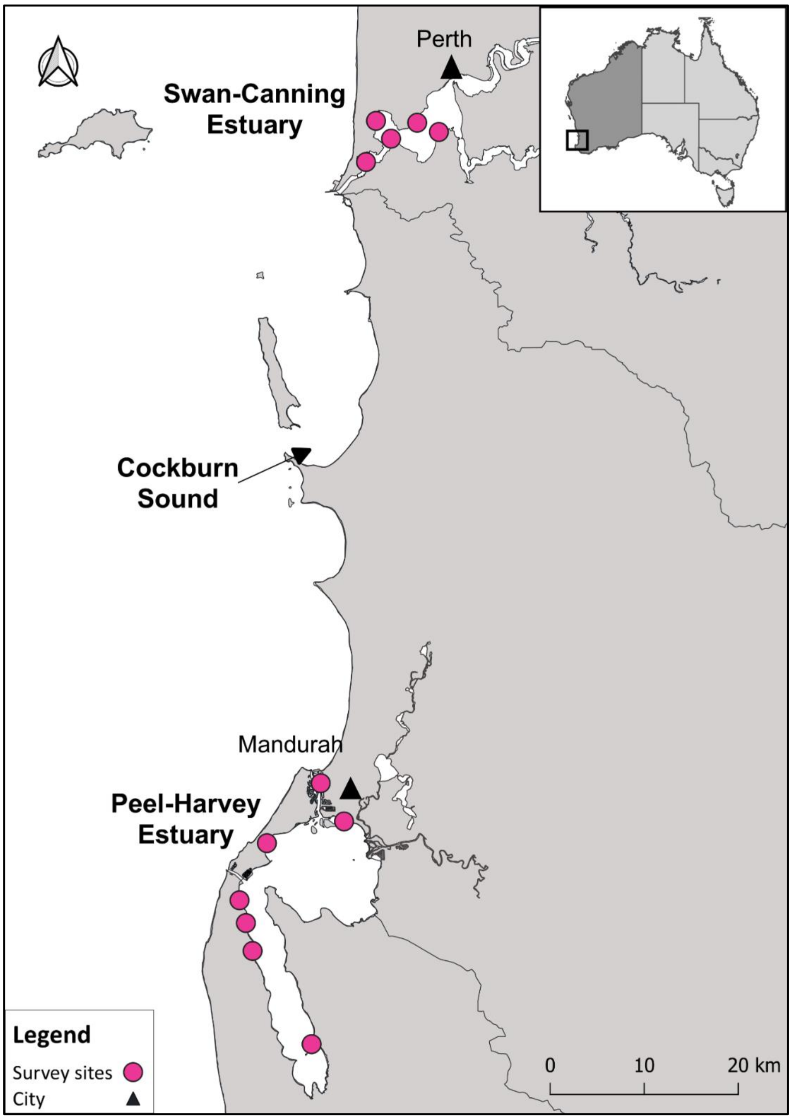


Figure 3.1. Map of Western Australia (Australia), showing the location of the Peel-Harvey Estuary and the cities of Mandurah and Perth.

3.2.2. Data collection

3.2.2.1. Online survey

Eight questions from a comprehensive 46-question online survey (see Materials & Methods in Chapter 4 and Chapter 6, and Obregón et al. 2020b) were included for the current study (for full details of the survey and its administration see Materials & Methods sections in Chapter 4 and Chapter 6, and Obregón et al. 2020a). These questions covered the topics of views on management; concerns on the fishery status; fishery values, general demographics, distance travelled, and time spent to reach each fishing spot (Supplementary material 3.1). The questionnaire was distributed via Surveygizmo, an online survey tool (Widgix 2005). Survey participation was promoted via newspapers, social media and flyers posted at popular fishing sites. The online survey was accessible from December 2017 to July 2018.

3.2.2.2. Face-to-face interviews

Recreational blue swimmer crab fishers were interviewed on-site at popular crab fishing spots, including jetties, boat ramps and other shore locations with easy access to the water. All selected sites (n = 5 in the Swan-Canning, and n = 7 in the Peel-Harvey estuary, Figure 1) were visited once, on each survey day and all fishers present at each site were invited to participate. The interviews were conducted during daylight hours in the Austral summer between November 2018 and February 2019, which is the peak season for crab fishing in WA. Interviews included 29 closed-ended questions (Supplementary material 3.1) and lasted on average 10-15 minutes. Interviews were conducted under Human Ethics Permit 2017/228.

During the face-to-face interviews, respondents were asked to indicate their perceptions of any potential changes affecting the abundance and size of crabs since the year when they started fishing by selecting one of four options: “not changed”, “seasonal”, “decreased” or “increased”. If a change was reported, recreational fishers were asked to indicate the extent of this change. For changes in size, they were asked to recall the average carapace width (CW) of crabs (in mm) in the year when they first started fishing and the current average size (i.e. when the interview was conducted in 2018/19). Reported sizes were grouped into four categories, using fisher terms of “undersized” for <127 mm CW; “sized” for 127-129 mm CW; “big” for 130-200 mm CW and “monster” for >200 mm CW. Note that the maximum size reported for blue swimmer crabs in south-western Australia is ~220 mm CW (Johnston & Yeoh 2020). If a decrease in crab abundance was reported, recreational fishers were asked to estimate the magnitude of the decrease, by choosing from a five-category scale ranging from a <10% to >70% decrease.

In addition to demographic information on the fishers, information on their fishing experience, size and abundance of the crabs, their perceptions of changes in the distance they needed to travel to catch crabs within the estuary, and the time spent travelling to a good fishing spot, were also elicited. No personal identification data were requested or collected.

3.2.2.3. Historical records

Historical records of crab size and abundance in the Swan-Canning and the Peel-Harvey estuaries were sourced from newspaper articles available in Trove, a comprehensive online search tool that accesses digitised content held in the collections of Australian libraries, museums, archives, galleries, universities and research organisations (Trove 2020). Newspapers were targeted as they provided readily available information (*i.e.,* qualitative descriptions on size and abundance of crabs). Other information sources such as images, were considered but excluded because of inherent limitations, for example the difficulty of estimating the real size of a crab from a newspaper image (Shortis et al. 2013). Newspaper articles digitally available on Trove included information on crab size, abundance and generally the blue swimmer crab fishery in the Peel-Harvey Estuary and the Swan-Canning Estuary from the early 1900's to the year 2000. A few newspapers, including "The West Australian" (founded in 1833) and the "Sunday Times" (founded in 1897), stopped being digitised after 1954 due to copyright restrictions (Trove Reference Librarian, pers. comm. 2020; TROVE 2021). To bypass this, we used the data extracted from the scanned articles from the Sunday Times fishing column scanned from the original microfilm at the state library since its commencement in January 1957 until December 2000.

To enhance access to potentially relevant records, two researchers identified a range of keywords used to describe blue swimmer crab fishing by the general public as well as by management authorities (*i.e.*, "crabbing"; "blue manna"; "blue swimmer crab" and "fishing"; and "crabs"). Qualitative data on the historical background of the fishery, and its importance to the Western Australian community (*e.g.,* environmental concerns, seasonality of the fishery and perceptions of management), and quantitative information regarding the catches, sizes and other elements associated with recreational fishing activities were also extracted from the newspaper articles.

Additional information on environmental and social values related to the fishery was also recorded from the documents to identify the longstanding cultural significance of the fishery. Historical records were compiled and separated according to the type of data they provided (quantitative versus qualitative).

Semi-quantitative data obtained from Trove newspaper records included: i) abundance of crabs; and ii) size of the crabs caught. Information on abundance was classified into four different categories: "excellent" (*i.e.*, very abundant), "good", "fair" and "poor", according to the descriptions extracted from newspapers. To facilitate comparison, the size of the crabs was classified using the same four-level scale as for the face-to-face interviews (i.e. "small" to "monster").

3.2.2.4. Published biological data

Quantitative data on the average size of crabs (i.e., carapace width CW in mm) in the Swan-Canning and Peel-Harvey estuaries were sourced from the resource assessment report by the DPIRD (Johnston et al., 2020), which covered the years between 2006 and 2019. These data were collected by government researchers during fishery independent surveys in each estuary (Johnston et al., 2020).

3.2.3. Data analyses

Changes in size and abundance of crabs were assessed for each of the four data sources (Patton 1999, Carter et al. 2014) using the built-in statistical tests in R (R, version 4.0.2). Trends in the size and abundance of crabs were outlined through collation of data sets.

3.2.3.1. Online survey

Chi-square tests were used to analyse if recreational fishers' perceptions, collected through the online survey, on size and abundance changes, distance travelled by fishers to a fishing spot and time spent travelling to a good fishing spot, differed significantly ($P < 0.05$) between demographic groups of fishers (age and level of education) and between estuaries.

3.2.3.2. Face-to-face interviews

Face-to-face interview data on fishers' perceptions of change in average crab size (*i.e.,* decrease, increase, not changed, seasonal); perceived size of catch (in mm) and abundance (*i.e.,* decrease, increase, not changed, seasonal) were formatted as three different contingency tables to compare the perceptions between estuaries (one table) and within each estuary (one table per estuary). Chi-square tests were used to test the association between the different variables in each contingency table, including the estuary, fishing experience (*i.e.,* how many years or decades they had been fishing, originally recorded in decades from the 1940s to 2010s) and age. Due to low numbers of respondents in some of the age categories, these were merged from six age groups into three: "young" (18-35 years old), "middle aged" (35-64) and "older" (65+). For the same reason, fishing experience was reclassified into three categories; "very experienced" (people with >30 years crab fishing), "moderately experienced" (10–30 years experience) and "less experienced" (<10 years experience).

3.2.3.3. Historical records

A contingency table was used to compare the historical data extracted from Trove newspapers on size and abundance of crabs recorded between estuaries and through time *i.e.,* between decades from 1908 to 2000. Publication dates were grouped by decadal period so that each period would have ≥5 records, except for the years 1908-1919, which were grouped into a single "<1920" period (Table 1). Kruskal-Wallis tests were used to determine whether crab size and abundance differed significantly between estuaries or among decades. Qualitative data, such as those on perceived environmental conditions, or management approaches, were used to identify perceptions of the fishery, including concerns and the significance of these, by recreational fishers and other members of the community.

Table 3.1. Summary of the number of newspaper articles extracted from Trove, per estuary and decade. "N total" indicates the total number of articles included in the study; "n size" indicates the number of articles included in this study which provided information on the size of the crabs and "n abun." indicates the number of articles included in this study which provided information on the abundance of the crabs.

	Peel-Harvey			Swan-Canning		
Decade	*N total*	*n size*	*n abun.*	*N total*	*n size*	*n abun.*
<1920	1	-	-	19	1	7
1920-1929	1	-	1	17	-	12
1930-1939	-	-	-	63	2	39
1940-1949	1	-	1	51	14	37
1950-1959	8	3	7	28	11	16
1960-1969	1	-	1	1	1	1
1970-1979	11	5	6	5	2	2
1980-1989	30	16	26	12	7	9
1990-2000	25	15	19	21	11	15
Total**	**78**	**39**	**61**	**217**	**49**	**138**

3.2.3.4. Published biological data

Annual data on the mean carapace widths of blue swimmer crabs for the Peel-Harvey and Swan-Canning estuaries were obtained from a 2020 assessment report for blue swimmer crabs in south-western Australia (Johnston et al., 2020). A Kruskal-Wallis test was used to determine whether there were significant differences between the average carapace width from 2006 to 2019.

3.3. Results

The online survey was completed by 572 recreational fishers, while 90 recreational fishers participated in the face-to-face interviews. A total of 62.1% of the online survey participants responded to all questions, while 73.3% of fishers responded to all questions in the face-to-face interview. Most online respondents (55.5%) went crabbing most of the time in the Peel-Harvey Estuary, and 37.2% of all respondents went mostly to the Swan-Canning Estuary. The rest fished in other estuaries and therefore were not included in this study.

3.3.1. Respondent demographics

Respondents to the online survey were mainly men (87%) and ranged from 18 to over 65 years old, with most (27%) belonging in the 35-44 years old category. Over one third of the respondents (36%) had completed tertiary education. Face-to-face interviewees were also mostly men (91%), with most being between 45-54 years old (3%). About 30% of fishers had been crab fishing since the 1980s, and around 15% for less than 10 years. Most respondents (49%) had completed tertiary studies.

3.3.2. Online survey

Generally, most respondents to the online survey (*i.e.*, 54% in the Swan-Canning Estuary and 56% in the Peel-Harvey Estuary) reported a decrease in crab size in both estuaries since the year they started crab fishing. Furthermore, over 70% of respondents in each estuary reported a perceived decrease in abundance of size crabs. A majority (~62% of respondents in both estuaries) also reported an increase in the time spent catching crabs to reach their bag limit. Most fishers travelled as far as previously to reach a good fishing spot (~56% in both estuaries) and some travelled even further (42% of recreational fishers in the Peel-Harvey Estuary and 38% in the Swan-Canning Estuary). The perceptions of change in the size and abundance of crabs did not differ between estuaries (Kruskal-Wallis, $p = 0.35$, $p = 0.98$, respectively), or with fishing frequency or age of the fishers ($p > 0.21$, Supplementary material 3.2).

3.3.3. Face-to-face interview

3.3.3.1. Size

Fishers in both estuaries reported a perceived decrease in the average size of crabs but the proportion reporting a decrease was much greater in the Peel-Harvey (>90%) than in the Swan-Canning (55%), where one third of fishers perceived that size had not changed (Figure 3.2). The perceptions of change did not differ between different age categories or fishing experience through the region (p = 0.49). However, the decrease in crab size was perceived significantly less in the Swan-Canning than in the Peel-Harvey estuaries ($p < 0.01$, Supplementary material 3.2).

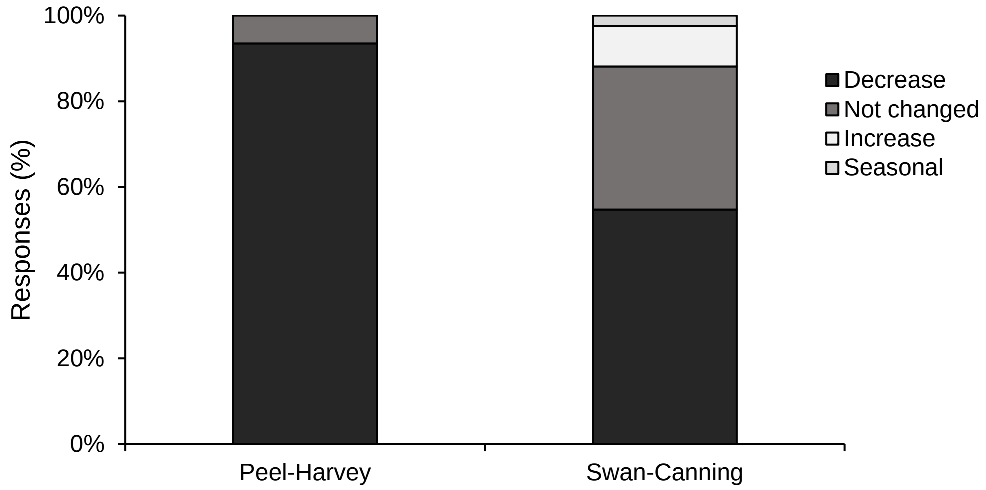


Figure 3.2. Perceived changes of blue swimmer crab size since fishers started fishing to current average sizes in the Peel-Harvey (n = 46) and Swan-Canning estuaries (n = 42) in south-western Australia, provided by recreational fishers through face-to-face interviews, between November 2018 and February 2019. Note that PH stands for Peel-Harvey and SC for Swan-Canning Estuary.

Most recreational fishers in the Peel-Harvey Estuary (60%) recalled catching big crabs in the year they first started fishing, with 26% recalling catching "sized" crabs and 13% "monster" crabs. No "undersized" crabs were recalled when describing past catches in this estuary. This contrasts with their descriptions of the current size categories of crabs, where most caught "sized" crabs (56%) and a large proportion caught "undersized" (40%) crabs. Less than 5% of interviewees reported "big" crabs, and none reported "monster" sized crabs (Figure 3.3).

Similarly, in the Swan-Canning Estuary, the average size of crabs in the past (i.e., when fishers first started fishing) was perceived as "big" (reported by 50% of respondents), while about 31.8% of respondents described crabs as "sized", and 18% as "monster". No undersized crabs were reported when describing the periods when fishers started fishing (Figure 3.3). In contrast to the Peel Harvey Estuary, the current average size most frequently mentioned in the Swan-Canning Estuary was "big" (43% of respondents), followed by "sized" (30%), and lastly "undersized" (26%). Like in the Peel-Harvey Estuary, perceptions of current catches did not include "monster" crabs in the Swan-Canning Estuary (Figure 3.3). The current average size of crabs was perceived as significantly smaller in the Peel-Harvey Estuary ($p < 0.01$, Supplementary material 3.2), than in the Swan-Canning Estuary. Analysis of the recalled current (when the interview was conducted) average carapace width (CW) of crabs (in mm) identified a mean CW of 126.5 mm for Peel-Harvey crabs compared to 131.1 mm for those in the Swan-Canning.

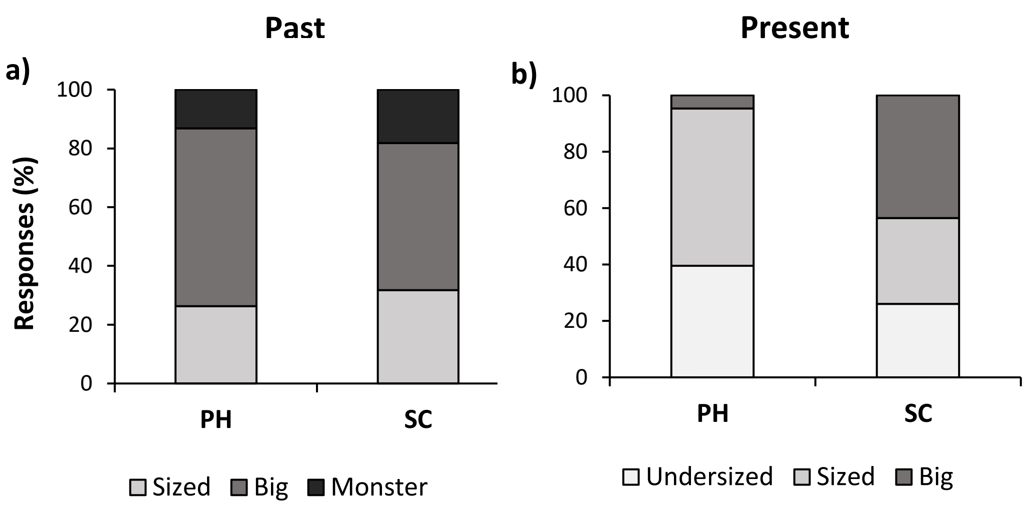


Figure 3.3. Perceived changes in *Portunus armatus* size categories through time from interviews with fishers (**a**) in the past, when fishers started fishing (PH: n = 46; SC: n = 44), and (**b**) currently, when the interviews were conducted (PH: n = 46; SC: n = 44), in the Peel-Harvey and Swan-Canning estuaries, south-western Australia.

In the Peel-Harvey Estuary, the recollections on the current and past average sizes of crabs differed between fishing experience categories ($p = 0.02$ and $p = 0.04$, respectively; Supplementary material 3.2, Figure 3.4a & b). Fishers with over 30 years of recreational fishing experience were the only ones who recalled seeing "monster" crabs in the estuary when they first started fishing (26%). Moderately experienced fishers (10-30 years of experience) mainly caught "big" crabs in the past (92%), whereas less experienced fishers (<10 years of experience) recalled catching "big" and "sized" crabs when they started fishing (50% each; Figure 4a). On the other hand, less experienced fishers mainly reported "undersized" crabs as part of their current catch (75%), whereas moderately and very experienced fishers mainly caught "sized" crabs (61.5% and 59.1%, respectively). A minority of moderately experienced fishers (15%) reported currently catching "big" crabs. When this study was conducted, very experienced fishers did not recall catching big crabs anymore (Figure 3.4b). The larger variance in the data for past sizes is possibly a result of recall bias affecting the recall of such memories (Thurstan et al. 2016a).

Perceptions in the Swan-Canning Estuary regarding the past and current size of crabs did not differ between fishing experience categories (Figure 3.4 c & d). However, the perceptions on past sizes significantly differed between age groups. Young individuals reported seeing mostly undersized crabs the year they first started fishing, whereas middle-aged individuals reported seeing mainly big crabs ($p = 0.03$; Supplementary material 3.2).

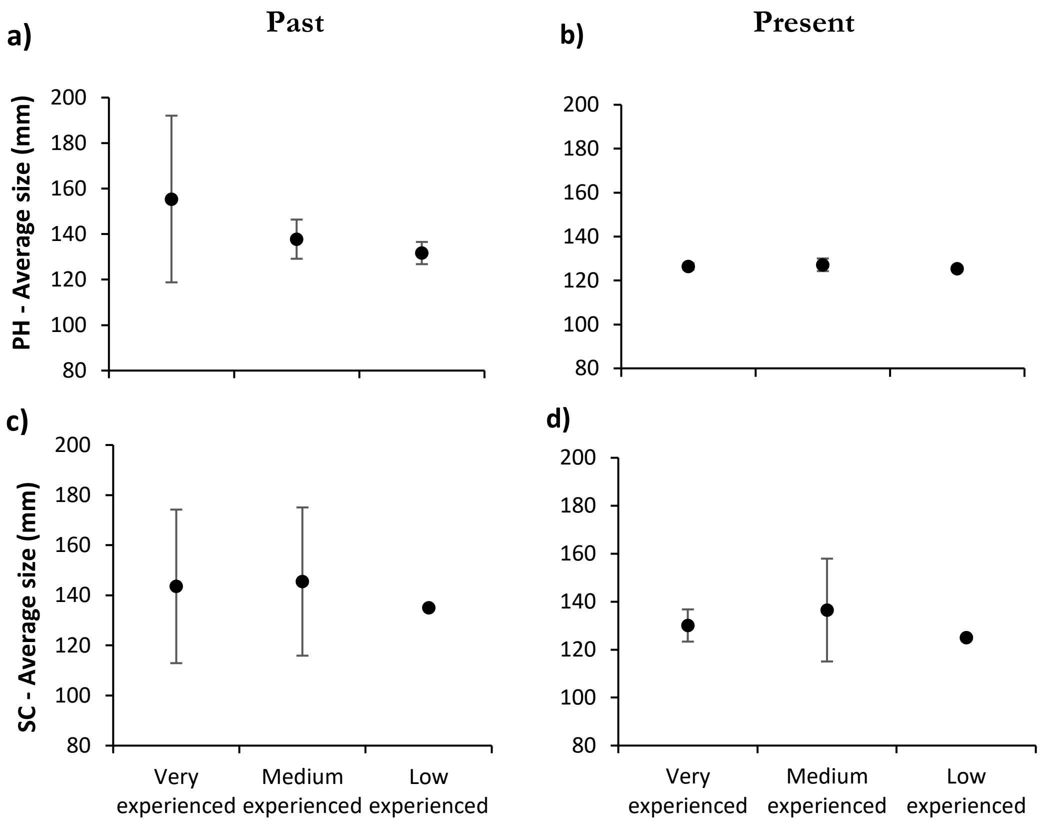


Figure 3.4. Perceived changes in *Portunus armatus* average size. **(a)** shows the perceived sizes in the past (*i.e.,* when they started fishing) and **(b)** shows the current size categories according to different fishing experience (i.e., number of years since they first started fishing) in the Peel-Harvey Estuary; **(c)** shows the perceived sizes in the past (i.e., when they started fishing) and **(d)** shows the current size categories according to different fishing experience in the Swan-Canning Estuary, in south-western Australia. This data was provided by recreational fishers through a face-to-face survey, between November 2018 and February 2019.

3.3.3.2. Abundance

Most fishers in the Peel-Harvey Estuary (67.2%) reported a perceived decrease in the number of blue swimmer crab caught over time (*i.e.,* abundance; Figure 4). Of the fishers reporting a perceived decrease in abundance, 36.9% said that abundance had declined by ≥50% compared to when they first started crabbing, whereas 15.2% reported a decline of 30-50% in abundance, and 6.5% a decline in abundance of less than 30%. Similarly, 52.2% of fishers in the Swan-Canning Estuary perceived a decrease in crab abundance (Figure 4). Of these, 22.7% of respondents suggested that abundance had decreased by 30% or less, similar to the 27.2% reporting a decrease of ≥50%. Chi-square tests between estuaries, age or fishing experience showed no significant differences in perceived changes in abundance (Supplementary material 3.2).

3.3.4. Historical records

Approximately 35,000 newspaper records were obtained from Trove in the initial search. From these, 405 newspaper articles (which combine articles freely available on the Trove digital library as well as the digitised Sunday Times fishing columns) published between 1908 and 2000 were found for south-western Australia that included information on the fishery or description of the size and/or abundance of the crabs caught. Note that the information available for the period between 1954 to 2000 was mainly sourced from The Sunday Times, along with two other local newspapers (i.e., The Beverley Times, founded in 1905 and the Hamersley News, founded in 1969).

3.3.4.1. Size

The first newspaper records on the size and abundance of blue swimmer crabs in the Peel-Harvey Estuary were from the 1950s (Supplementary Table S3) and generally described the crabs caught as "big". However, from the 1980s onwards, newspaper records described crabs as "sized", or even "undersized", with a minority being classified as "big" and the proportion of articles describing crabs as "big" declined from 60% in 1970-79 to 6% in 2000-10 (Figure 5). Newspaper records on crab sizes and abundance in the Swan-Canning Estuary go back to 1908 and most articles focusing on crabs during this period classified crabs as "big" (57.1%). Crabs described as "sized" and "undersized" were not mentioned for this estuary until the 1940s and were mentioned more often in the following decades (Figure 6). Articles reporting "monster" crabs did not appear after the 1960s. Although the proportion of articles describing crabs as "big" in the Swan-Canning also declined between 1970-79 and 2000-10, 55% of articles in the latter decade (n=11) still described crabs as big.

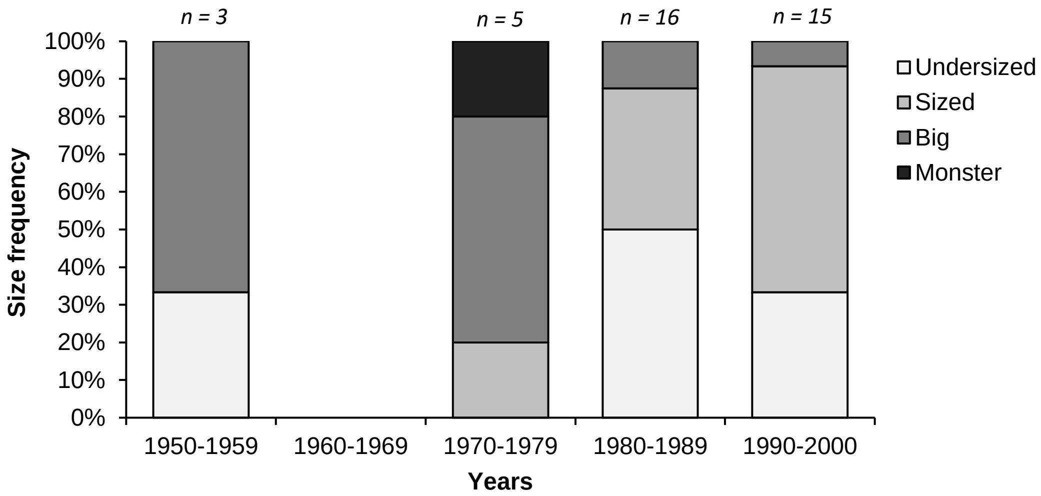


Figure 3.5. Perceived changes in blue swimmer crab size in the Peel-Harvey Estuary, in south-western Australia between 1950 and 2000 reported from newspaper records sourced from Trove.

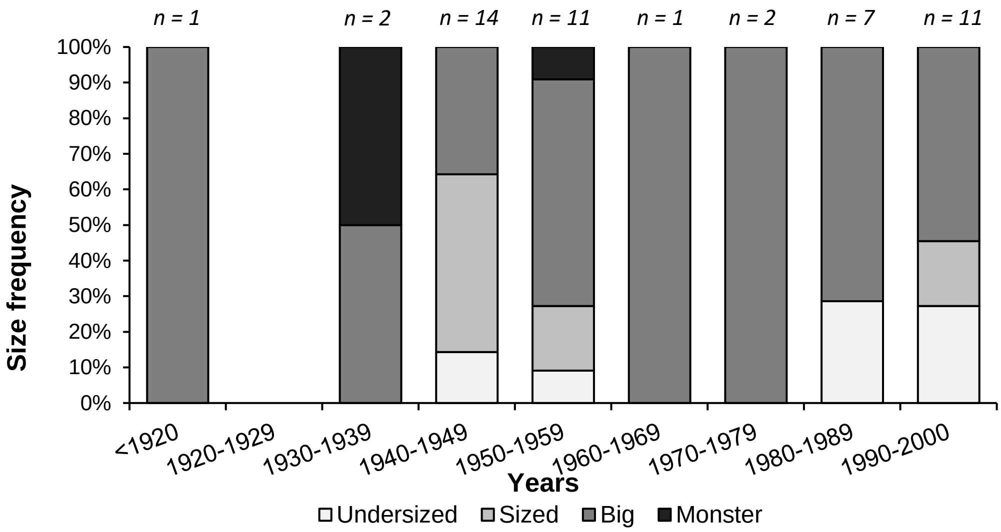


Figure 3.6. Perceived changes in *Portunus armatus'* size in the Swan-Canning Estuary, in south-western Australia between 1910 and 2000, from newspaper articles sourced from Trove historical records.

Overall, crabs from the Peel-Harvey Estuary were significantly smaller on average than in the Swan-Canning Estuary ($p < 0.01$, Supplementary material 3.3). In the Peel-Harvey, the decline in size was more apparent over time ($p = 0.02$, Supplementary material 3.3), suggesting that the average size of crabs has declined since the 1950s. No significant differences were in the size of crabs among decades for the Swan-Canning Estuary.

3.3.4.2. Abundance

Trove records on crab abundance differed significantly between the two estuaries, with a greater proportion of fishing seasons qualified as fair or poor in abundance in the Swan-Canning Estuary, compared to the Peel-Harvey Estuary (Kruskal-Wallis $p = 0.04$, Supplementary material 3.3). Records from the early 1900s identified several fishing seasons of "excellent" abundance in the Swan-Canning Estuary. However, the frequency of good fishing seasons decreased with time, the last one being between 1940 and 1950 (Figure 3.7). Even though articles reported a few good seasons since the 1970s, none of these were described as "excellent". In the 1980s and 1990s, abundance in the Swan-Canning was described mostly as "good", though "poor" and "fair" seasons occurred too (Figure 3.7). Crab abundance from Trove records did not vary significantly through time in the Swan-Canning Estuary (Supplementary material 3.3).

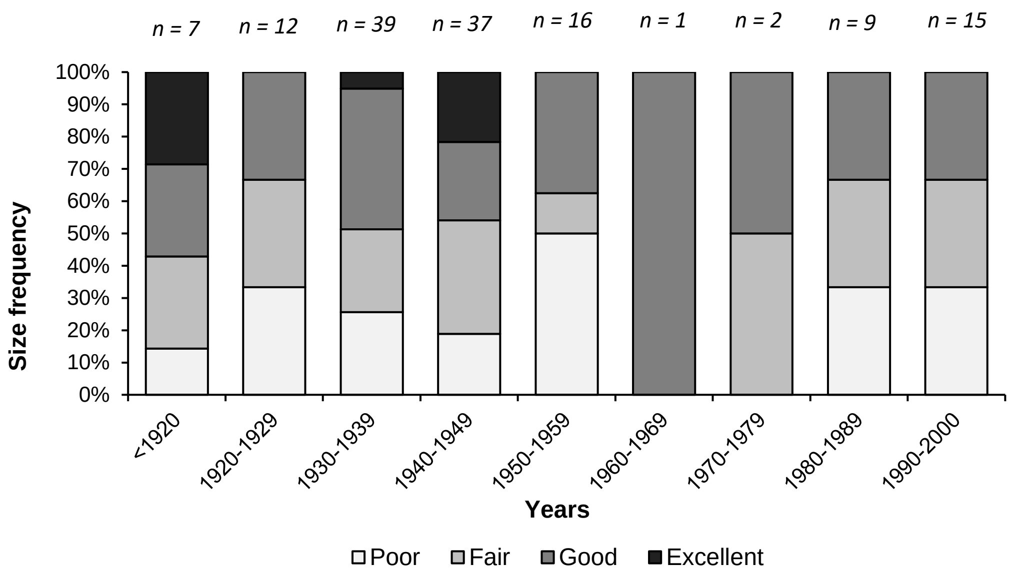


Figure 3.7. Perceived changes in *Portunus armatus* abundance in the Swan-Canning Estuary, in south-western Australia between 1910 and 2000, sourced from Trove historical records.

3.3.4.3. Biological data

Data from Johnston et al. (2020) show that the mean CW of crabs in the Swan-Canning Estuary ranged from 144 mm (smallest) to 161 mm (biggest) between 2007 and 2019 (*i.e.*, "big" size category), with an overall mean of 153.1 mm CW (Figure 8). The mean sizes in the Swan-Canning were significantly greater than those in the Peel-Harvey by ~15 to 30 mm, depending on year: mean CW in the Peel-Harvey ranged from 130 mm to 136 mm (*i.e.*, "sized" to "big" size categories), with an overall mean of 132.7 mm CW, 20 mm smaller than that of the Swan-Canning (Figure 8). These results parallel the trends from fisher perceptions recollected during face-to-face interviews and in historical newspaper records, reflecting that blue swimmer crab in the Peel-Harvey Estuary are generally smaller than the crabs in the Swan-Canning Estuary (Figure 8). Though there was a significant difference in crabs CW between estuaries, no significant differences were found through time for either of the estuaries studied.

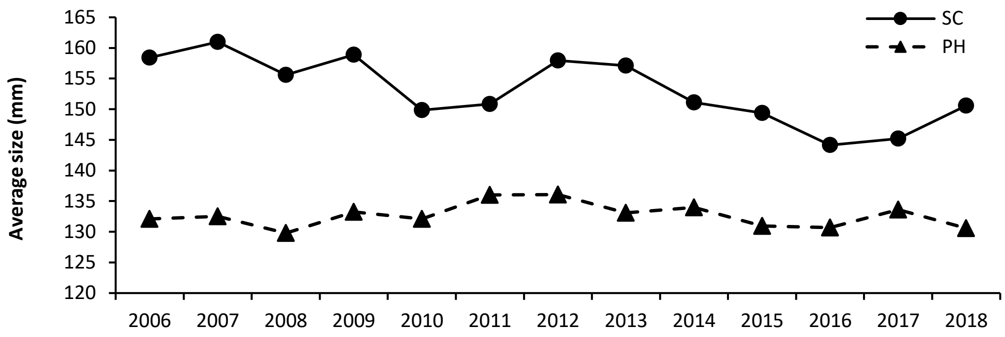


Figure 3.8. Changes on the mean carapace widths of blue swimmer crabs for the Peel-Harvey **(a)** and Swan-Canning **(b)** estuaries (n = 13, per estuary), in south-western Australia. These data were obtained from the last resource assessment report in the region for this fishery resource (Johnston et al., 2020), which covered between 2006 and 2019.

3.3.4.4. Insights on the fishery's history

Qualitative data from Trove newspaper records showed that recreational blue swimmer crab fishing in the Swan-Canning started shortly after European settlement in 1829 (Smith, 2006). Since the beginning of the 20th century, Western Australians organised crabbing parties during summer in the Swan-Canning and other locations, where they fished crabs and cooked them by the estuary (Sunday Times, 1939, p. 84; South Western times, 1949, p.16; Sunday Times, 1976, p. 105).

Therefore, fishing for blue swimmer crabs became a relatively easy and cheap way of "getting a meal" for Western Australians, as well as a social activity.

The perceived fishing effects and associated changes in sizes and abundances of blue swimmer crabs have been a concern for the recreational fishing community since as early as the 1940s. At the time, recreational fishers reported in local newspapers that small crabs (*i.e.,* described as reaching ~70-110 mm CW) caught in the Swan-Canning Estuary were being sold. These letters generally included a call for the introduction of regulations to manage blue swimmer crab fishing activities, such as minimum size limits (Daily News, 1944, p. 3). Initially, the then Department of Fisheries considered such concerns unjustified. In 1944, Mr. Brownfield, the Chief Inspector of Fisheries, said that *"… to suggest that the taking of crabs would lead to the depletion of those available in the future was nonsense*". Once regulations on minimum size limits for crabs were introduced in the late 1940s, illegal fishing of undersized crabs became a cause of concern for the local community. In 1949, a commercial fisher from the Swan-Canning Estuary reported *"thousands of crabs are being eaten (…) often with the help of a magnifying glass"* (West Australian, 1949, p. 2). Similar concerns over illegal fishing of undersized crabs were still being raised more than 70 years later by the recreational fishing community (see Results Section in Chapter 4).

Finally, concerns over the environmental condition of these two estuaries were also documented in the newspapers. As early as 1934 anglers voiced concerns over the impacts of pollution on crabs and the increasing growth of algae in the Swan-Canning (The Daily News, 1934, p. 4). In 1952, a recreational fisher wrote *"…40 years ago the [Swan-Canning] River was a paradise for prawn and crab netting but now is covered with a prolific growth of algae and other marine weed. This weed (…), was almost unknown at the close of the last century*" (West Australian, 1952, p. 3). In the Peel-Harvey, these concerns became more and more common from the 1980s onwards (e.g., Potter et al. 1991). In 1994, the Dawesville Channel (commonly called "The Cut"), a second, artificial entrance channel into the Peel-Harvey estuary, was constructed in an attempt to solve the negative effects of the increasingly occurring algal blooms (Valesini et al. 2019). Despite the support of the angling community for this project "*Come on the Dawesville cut!' Scream the locals, because the estuary is in poor nick."* (Sunday Times, 1991, p. 89), there were still concerns regarding the resulting environmental changes in the estuary. "*Anglers and crustacean collectors at Mandurah are asking themselves (…) what will happen when the $64 million Dawesville Channel goes through?*" (Sunday Times, 1994, p. 84).

3.4. Discussion

Overall, through the collation of findings from four different data sources (online survey, face-to-face interviews with recreational fishers, historical records from newspapers, and biological data) four key results were identified: i) Crab size differed between the two estuaries; ii) Crab size decreased in the Peel-Harvey estuary between decades and currently but not in the Swan-Canning Estuary; iii) inter-generational differences in recreational fishers' perceptions (depending on their age and length of time they had spent fishing) regarding changes in size over time; and iv) or historical evidence of crab fishers' observations of changes in the fishery and wider estuarine environment. Firstly, the face-to-face interviews, historical newspaper records and biological data, all indicated that crabs in the Peel-Harvey Estuary are significantly smaller than crabs in the Swan-Canning Estuary (Supplementary material 3.2). Secondly, results from the face-to-face interviews and newspaper records (1900s to 2000) indicated a consistent strong perception by the recreational fishing community of a decrease in the average size of crabs in the Peel-Harvey over time, whereas perceptions for the Swan-Canning showed a decrease in "big" crabs, though results were not significant and the fishery independent data from 2006 to 2018. Additionally, the qualitative data from newspaper records provided an understanding of the importance of the fishery for the local community since the early 20th century. Finally, historical data also demonstrated fishers' awareness of environmental issues affecting the stocks and their interest in the management approaches available that would enhance the conservation of the fishery and the estuary supporting it.

3.4.1. Size changes

All sources of data analysed suggested that blue swimmer crabs in the Peel-Harvey are smaller than those from the Swan-Canning. Furthermore, the responses from face-to-face interviews showcased inter-generational differences in perceptions between the most experienced and least experienced fishers – the most experienced fishers perceived a greater decline in size than those with the least experience. This suggests that generational amnesia, a type of shifting baseline syndrome, *i.e.,* individuals' change in perception of a SES due to memory loss on how the system used to be in the past (Pauly 1995, Papworth et al. 2009), may be occurring. This correlates with the trends identified through historical records.

Two conditions are required to identify SBS i) a biological change in the SES, ii) a parallel between the perceptions of change and age or experience-related differences (Papworth et al. 2009). Our study demonstrated that fishers perceived a decrease in the average size of blue swimmer crabs through time. In particular, the results showed inter-generational differences in the perceived average size of crabs, mostly according to fishing experience, and sometimes age. These perceived changes are consistent with the records obtained from newspaper articles and with those from other studies that have identified a shifting baseline among resource users. For example, a study on environmental changes in Baja California found that older fishers recalled catching up to 25 times more Gulf grouper (*Mycteroperca jordani*) than did younger, less experienced fishers (Sáenz-Arroyo et al. 2005). Similarly, a study of commercial fishers in Queensland, Australia, found that fishers recalled past species caught and catch rates accurately and that perceived catch rates had dramatically decreased in 50 years (Thurstan et al. 2016a). Even though previous studies of blue swimmer crabs have shown that growth can be quite variable and influenced by levels of chlorophyll *a* and density of juvenile crabs (Marks et al. 2020), our study suggests that the size of crabs in the Peel-Harvey estuary are now on average smaller than 70 years ago (based on fisher perceptions and newspaper records). This study therefore provides empirical evidence to support that, for these fisheries, local fisher knowledge (LFK) can identify biological changes in the blue swimmer crab populations and suggests that shifting baseline syndrome (SBS) might be occurring.

3.4.2. Insights on the fishery's history

The qualitative data sourced from Trove and the State Library of WA showcased the popularity of the fishery in the region since the early 1900s, as well as the concerns expressed by fishers on the management and overall status of crab stocks. These results align with the findings from a study on the human dimensions of blue swimmer crab fisheries in south-western Australia, which found that recreational fishers were concerned about overfishing, fishing pressure, and compliance with regulations in the estuaries (see Results section in Chapter 4). Notably, historical newspaper articles indicate that the blue swimmer crabs have been a target for fishing in south-western Australia since at least the early 1900s. Commercial fishing for blue swimmer crabs started in the 1830s, shortly after European settlement in south-western Australia (Johnston et al., 2020). Not only has this fishery been targeted by commercial fishers in the region, but since at least 1910, it has also provided food and a recreational activity for the local settler population of Perth and surrounding areas (Johnston et al., 2020). Overall, the socio-cultural importance of the crab fishery to the local community is clearly supported by the consistent and frequent reporting of blue swimmer crab catches, crab fishing parties organized by local groups, and recreational fishing community concerns about the status of crab stocks over the years. This is partly an outcome of accessibility, as crabs are found in relatively shallow waters and are easily fished from shore or in small boats and crabbing is one of the cheapest and easiest forms of recreational fishing to engage in.

Concerns about the unregulated catch of blue swimmer crabs emerged during the 1940s, when regulations on netting as well as size limits were established by the Department of Fisheries. From then on, concerns seemed to focus on compliance with these regulations, rather than overfishing. The delay between fishers voicing their concerns in the early 1940s and the establishment of these regulations at the end of this decade seems understandable when put into historical context. Australian fisheries management was almost non-existent until the early 1900s (Tull 1993, Christensen 2009). Later on, and in parallel with other nations worldwide (NOAA 2019), management prioritised production of seafood rather than its conservation. Through the two world wars and after World War II, efforts were made to increase the production of seafood for high value exports and local food production (Harrison 1991). It is important to note that newspaper articles are likely to be biased by the political, social and economic situation in the period of study, and therefore the news published, and the number of articles available for a specific year are influenced accordingly. This can be observed in our study where some years are represented by very few articles (small sample size) and is a limitation in our study. This could be compensated in the future by combining newspaper articles with another source of data, independent from historical events, such as market prices of fish, if available (Fortibuoni et al. 2017). Nevertheless, the concerns identified in the news articles (*e.g.,* overfishing, minimum size limits and lack of compliance with size limits), concur with current concerns of blue swimmer crab fishers in the region (Obregón et al. 2020a). Thus, independently on the historical background, the articles do highlight the importance of the fishery for the local community, the understanding of environmental issues by resource users affecting the fishery, as well as their concerns on the fishery and its management.

In our study we used the terms "undersized", "sized", "big" and "monster" to describe the average size of crabs, as well as "poor", "fair", "good" and "excellent" to describe the abundance. These terms were adequate for the classification, analysis and interpretation of the data as they were the terms used by resource users and appeared in the newspaper articles selected for this study. Yet, they are also intrinsically subjective. This subjectivity, combined with recall bias may have contributed to the lack of differences in perceptions related to age or fishing experience in some components of this study, such as the online survey. Other studies have previously described a progressive decrease in the average size of species that have been exploited by fishing activities through time in Australia. For example, a study on snapper fishing on the east coast of Australia (Thurstan et al. 2016b). Another consideration is that fishers might modify their responses to match those that they think will be socially desirable answers about their past catches, leading to a social-desirability response bias (Paulhus 1991, Andrews et al. 2018). This could be a result of respondents being concerned about how others view their answers, how the data will be used, and what message will be extracted from it (Paulhus 1991). We attempted to reduce these biases by explaining the objectives of the study to the respondents before starting the survey and emphasising that all respondents would remain anonymous. From the authors perspective, the perception of responses did not seem to be an issue during the interviews, as most fishers were keen to voice their thoughts and point out details in the changes in sizes and abundances, as well as other characteristics of the fishery.

3.4.3. Abundance changes

Finally, fisher recollections and historical newspapers showed no consistent trend in changes of crab abundance through time. In fact, a previous study on the blue swimmer crab fishery in WA showed that some commercials fishers reported such changes to be seasonal (Obregón et al. 2020c). Given the alignment between LFK, literature data and newspaper records on the decline of crab sizes in the Peel-Harvey Estuary, and due to the less detailed information on abundance in the literature, we suggest that perceived trends in abundance of blue swimmer crabs identified by recreational fishers' could be viewed as reliable. Thus, more generally when quantitative data are lacking, Local Fisher Knowledge (LFK) could be viewed as more reliable than it often is, as evidenced by other studies, such as those on several small-scale fisheries in the upper Gulf of Mexico (Lozano-Montes et al. 2008) and the snapper fishery (*Pagrus auratus*) in Queensland, Australia (Thurstan et al. 2016a).

3.5. Conclusion

The status of a fishery is generally assessed from on a time series of catch and effort data sourced from independent surveys and the fishery. In most regions, quantitative fisheries data, and therefore the scientifically standardized formal data on the status of the underlying stocks, are often available only for a few decades of commercial fisheries, and rarely are they available for recreational fisheries (Freire et al. 2020), despite many resources having been exploited for centuries or longer (Roberts 2008). Even though long-term data are also necessary to tease apart the impact of fisheries and climate, as climate change happens over long periods of time, without comprehensive, quantitative data on the magnitude of stock exploitation, any estimate of current stock sizes and changes over time may be misleading or at least somewhat uncertain. This This study provides evidence that fishers' perception, combined with historical records and data from research surveys reflect a significant difference in the average size of blue swimmer crabs in the Peel-Harvey compared to the Swan-Caning Estuary. Particularly, fishers' perception, combined with historical records highlight a decline in the average size of blue swimmer crabs through time, in at least one of the examined estuaries, the Peel-Harvey. The comparison of the findings from different data sources (i.e., triangulation) has therefore highlighted some changes that are consistent across all sources, demonstrating that Local Fisher Knowledge (LFK) may be a valuable source of information when other data sources are lacking, and/or a valuable additional source of insight and information accompanying traditional, quantitative data. The spatial and inter-generational differences identified through LFK are evidence of a likely decline in the average size of blue swimmer crabs in south-western Australia, particularly for the Peel-Harvey Estuary. Additionally to biological change, archival records can also be used to complement data on the human dimensions of a fishery (*i.e.,* perceptions and LFK), which is often lacking for fisheries worldwide (Barclay et al. 2017). Moreover, these can provide a more detailed picture on the importance of the fishery for the local community, the understanding of environmental issues by resource users affecting the fishery, as well as their concerns over the fishery and its management.

Chapter 4

Different but not opposed: perceptions between fishing sectors on the status and management of a crab fishery[2]

Views from main boat ramp by the Leschenault Estuary, south-western Australia.

[2] This chapter is published as a co-authored manuscript:

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Chapter 4

Different but not opposed: perceptions between fishing sectors on the status and management of a crab fishery

4.1. Abstract

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 both sectors believed that reducing fishing and increasing compliance would benefit crab stocks, the mechanisms for achieving this differed. Recreational fishers favored increasing the length of the seasonal closure, while commercial fishers favored 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.

4.2. Introduction

Fisheries scientists and managers have traditionally utilised landings or catch data to assess the status of commercially exploited stocks (Pauly 2006). However, managing fisheries successfully also entails managing human behaviour (*e.g.* Hilborn 2007; Gutiérrez et al. 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. 2014). 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 & 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, Gaughan & Santoro 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* (formerly *P. pelagicus*), occurs in estuaries and coastal waters around most of Australia and supports valuable recreational and commercial fisheries (ABARES 2018). In Western Australia, for example, *P. armatus* 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 et al. 1985, Johnston et al. 2011b).

The importance of *P. armatus* 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 *P. armatus* 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 *P. armatus* fishery maintains a 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.

Commercial fishing for *P. armatus* 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 (Fletcher et al. 2017). Recreational catches are mainly regulated through size restrictions (*i.e.,* 127 mm carapace width) and bag limits of 10 or 20 crabs per person when fishing from the shore, or from a boat, respectively. A fishing licence system is also in use but only for the recreational fishers using a boat. Shore-based recreational crab fishers are thus exempt from any licence. In August 2019, a seasonal closure was introduced in south-western Australia, in all waters from Perth to Minnimup Beach (~ 200 km south from Perth, Figure 4.1), from 1st September to 30th November. Prior to this, a seasonal closure applied only in the Peel-Harvey Estuary, from 1st September to 31st October.

Despite the difficulties of managing a multisector fishery and the impact of environmental variation (Johnston et al. 2011b), *P. armatus* 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. 2011b, Gaughan & Santoro 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 *P. armatus* 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. 2011b). This has led to growing concerns about the status of the *P. armatus* stocks in the region. As a result, managers initiated a public consultation process in 2017, and conducted a review on the management of the *P. armatus* 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 makes a decision on those recommendations to be implemented. On this occasion, the Minister asked for an additional submission from the Industry before releasing the new management arrangements for the fishery. 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 few of a number 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 2006). 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 study 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.

4.3. Materials and methods

4.3.1. Sampling regime

Recreational and commercial *P. armatus* 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. The questions 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 *P. armatus* and the management of the fishery; and iii) proposed solutions to their concerns (Table 4.1). The interviews followed belief elicitation procedures applied previously (Hughes et al. 2012, Obregón et al. 2020b). The open-ended question format 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 2014). To ensure that the questions were clear and did not cause confusion, the survey was pre-tested with a small sample of crab fishers (n = 7). These responses are not included in the current study.

Interviews were conducted with recreational *P. armatus* 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 4.1), were chosen because i) they are the hotspots for recreational *P. armatus* 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 et al. 1985, 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 *P. armatus* 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 *P. armatus* is less abundant in waters south of the Leschenault Estuary (Fletcher & Santoro 2008), sampling was not conducted in these systems.

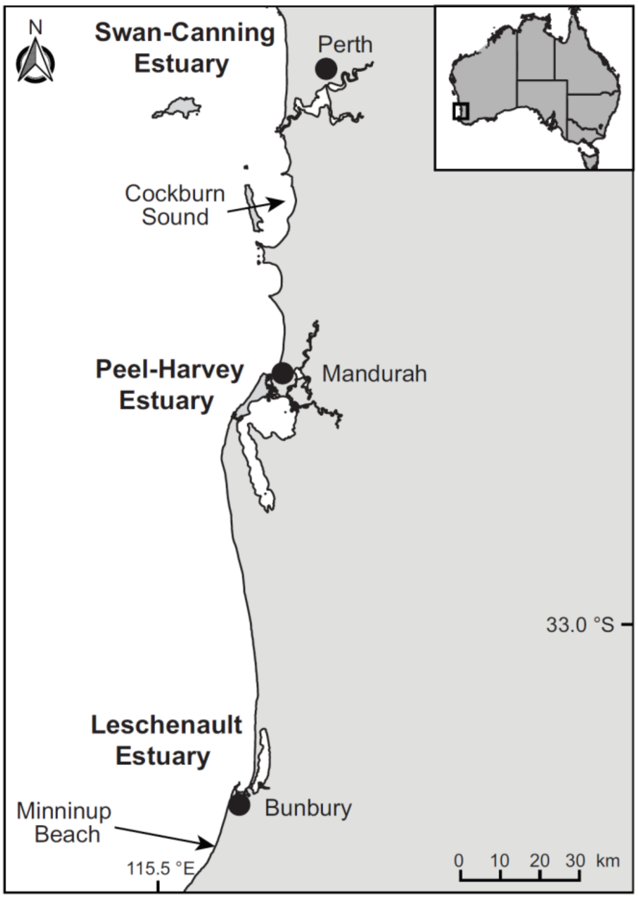


Figure 4.1. Location of the three estuaries in south-western Australia where interviews with recreational fishers were conducted: i) Swan-Canning Estuary (area = 55 km^2) ii) Peel Harvey Estuary (area = 131 km^2); iii) Leschenault estuary (25 km^2). Commercial fisheries present in the Swan-Canning and Peel-Harvey estuaries.

Table 4.1. Categories of questions (bold italics) and the questions asked of *Portunus armatus*.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 for each respondent.

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

Recreational fishers were interviewed at 18 sites (*i.e.*, jetties, boat ramps and shore line areas frequented by crab fishers) across the three systems, providing a cross section of recreational *P. armatus* fishing in south-western Australia (n = 93 interviews; 24 from the Swan-Canning Estuary; 41 from the Peel-Harvey Estuary and 28 from the Leschenault Estuary). Interviews were carried out on weekdays and weekends, during the main fishing times (*i.e.*, from 06:00 to 10:00 and 12:00 to 16:00; Yeoh, D. 2017, *pers. comm.*) and mainly over the austral summer (December to February), which is the peak fishing season in the region (Sumner & Malseed 2004, Ryan et al 2017). At each site on each sampling occasion, all recreational crab fishers present were invited to participate in an interview and responses were recorded on paper using the fishers' words, instead of the researcher paraphrasing the responses, which could potentially result in the interpretation by the researcher of the respondent's perceptions (Obregón et al. 2020b).

To gather responses from commercial fishers, a one-on-one meeting or a phone call was arranged with each fisher operating in the Peel-Harvey (n = 9) and Swan-Canning estuaries (n = 2). While there is only one commercial *P. armatus* fishing licence in the Swan-Canning, the current license holder only started fishing in 2018 (< 1 year in the fishery) and so the previous fisher, who had

12 years of experience, was also interviewed. When analysing commercial fishers' perceptions on historical changes in *P. armatus* catches in the Swan-Canning Estuary, we used only responses from the most experienced fisher (currently not a licence holder) as the fisher currently holding the licence did not have enough knowledge to answer this section of the interview accurately. Responses from fishers representing this sector were recorded following the same method described above for recreational fishers.

4.3.2. 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 et al. 2012). Theoretical saturation was then confirmed by adapting species accumulation techniques (Ugland et al. 2003), to plot response type accumulation curves (Vanwindekens et al. 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, Version 4.0.2), 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). 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).

4.4. 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 4.2). 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.

4.4.1. Fishery characteristics

Respondents from the recreational sector in south-western Australia had been fishing for *P. armatus* 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 respondents resided in Western Australia (98.9%) and were male (86.7%), which parallels the male proportion recorded for recreational fishing statewide (Ryan et al. 2017) . 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%).

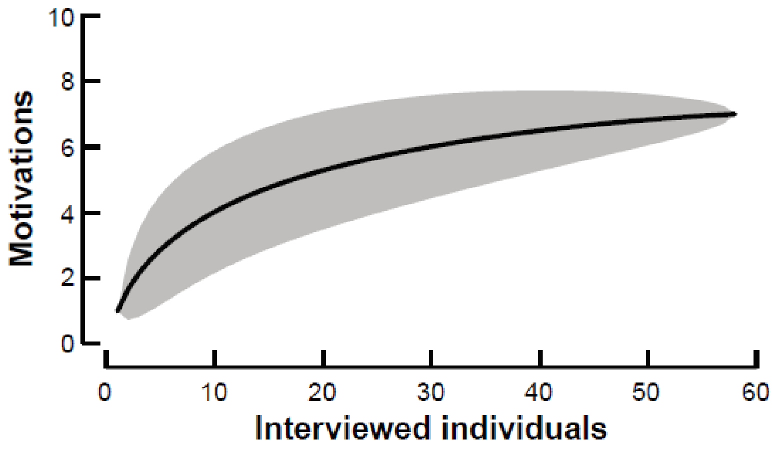


Figure 4.2. Response-accumulation curve showing that data saturation was reached after around 30 interviews with recreational *Portunus armatus* fishers in Peel-Harvey, Swan-Canning, and Leschenault estuaries in south-western Australia. Grey shaded area shows the 95% confidence intervals (modified from (Obregón et al. 2020b).

4.4.2. Perceived changes in crab size and fishing effort

4.4.2.1. Changes in size

Across all estuaries, over half (53.8%) of the recreational fishers reported a decline in the average size of *P. armatus* 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 *P. armatus* had declined

(70.7%), than respondents in the Leschenault (53.6%) and the Swan-Canning Estuary (25.0%, Figure 4.3a). 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 *P. armatus* caught, whereas only one commercial fisher (11.1%) reported a decline (Figure 4.3b). 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.

4.4.2.2. 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 *P. armatus*, *i.e.*, "Crabs are harder to catch". Only 6.5% reported that the effort required to catch *P. armatus* 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 4.3c).

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 *P. armatus,* whereas only 22.2% of commercial fishers held this view (Figure 4.3d). Conversely, two thirds of commercial fishers in the Peel-Harvey (66.7%) said that the fishing effort required to catch *P. armatus* had not changed over time, compared with only 17.1% of recreational fishers.

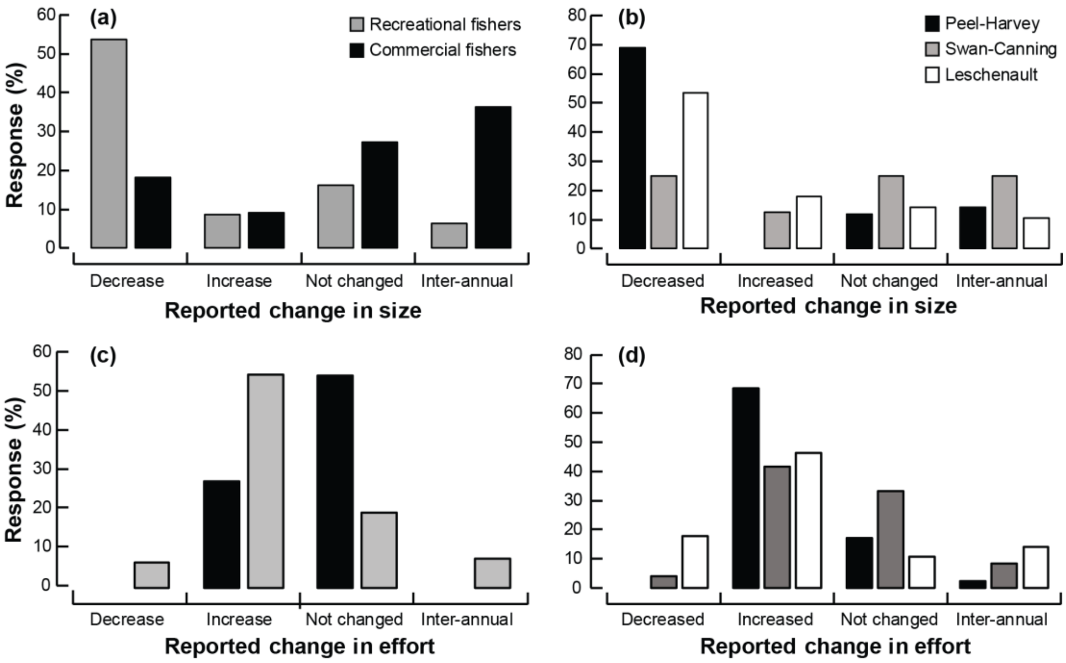


Figure 4.3. Perceived changes in average size (a, b) and fishing effort (c, d) of *Portunus armatus* provided by (**a, c**) recreational (n = 41) and commercial fishers (n = 9) in the Peel-Harvey Estuary and (**b, d**) recreational fishers (n = 93) fishing in the Peel-Harvey, Swan-Canning and Leschenault Estuary.

4.4.3. Concerns on the current *P. armatus* 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 *P. armatus* 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 *P. armatus* 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 *P. armatus* 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 4.2). 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).

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 4.2). Each of these concerns, except for the last, was also mentioned by recreational fishers, albeit less frequently (Table 4.2).

Table 4.2. Percentage number of recreational and commercial fishers who reported various concerns affecting the *Portunus armatus* fisheries in the Peel-Harvey, Swan-Canning and Leschenault estuaries in south-western Australian during face-to-face interviews. The number of fishers surveyed from each sector in each system is given in parentheses.

Concerns reported (*n*)	Recreational fishers				Commercial fishers		
	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
NA	**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	

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 4.4a). 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 4.4a). 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 4.3a). Lack of compliance and overfishing were more prevalent in the Peel-Harvey Estuary, distinguishing this system from the other two.

Table 4.3. 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 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.

(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

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 4.4b). 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 4.3b). 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.

4.4.4. Proposed solutions for the issues impacting the *P. armatus* fishery

Overall, 15 solutions (excluding the "NA", "None" and "Unsure" categories) were proposed to help manage the *P. armatus* fishery in the three estuaries, with four solutions expressed by both sectors (Table 4.4). Across all estuaries, recreational fishers proposed two solutions that were supported by considerably more fishers than any of the other proposed solutions (Table 4.4): 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 4.4). 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.

Table 4.4. Percentage number of recreational and commercial fishers who reported perceived solutions to improve the management of *Portunus armatus* fisheries in the Peel-Harvey, Swan-Canning and Leschenault estuaries in south-western Australian provided by recreational and commercial fishers during face-to-face interviews. The number of fishers surveyed from each sector in each system is given in parentheses.

Solutions reoported (*n*)	**Recreational fishers**				**Commercial fishers**		
	All	Peel	Swan	Lesch.	All	Peel	Swan
	(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	
NA	**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	

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 4.4) 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 4.4). 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%).

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 4.5a). 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 4.5a). 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 4.5a).

Table 4.5. 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. Note that the text in superscript denotes the group of fishers that each distinguishing response was most selected by recreational fishers in the Swan-Canning and Leschenault estuaries

(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

The fisher responses on potential solutions differed significantly between sectors in the Peel-Harvey Estuary (ANOSIM Global R = 0.385; *p* = 0.001; Figure 4.5b). 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 4.5b).

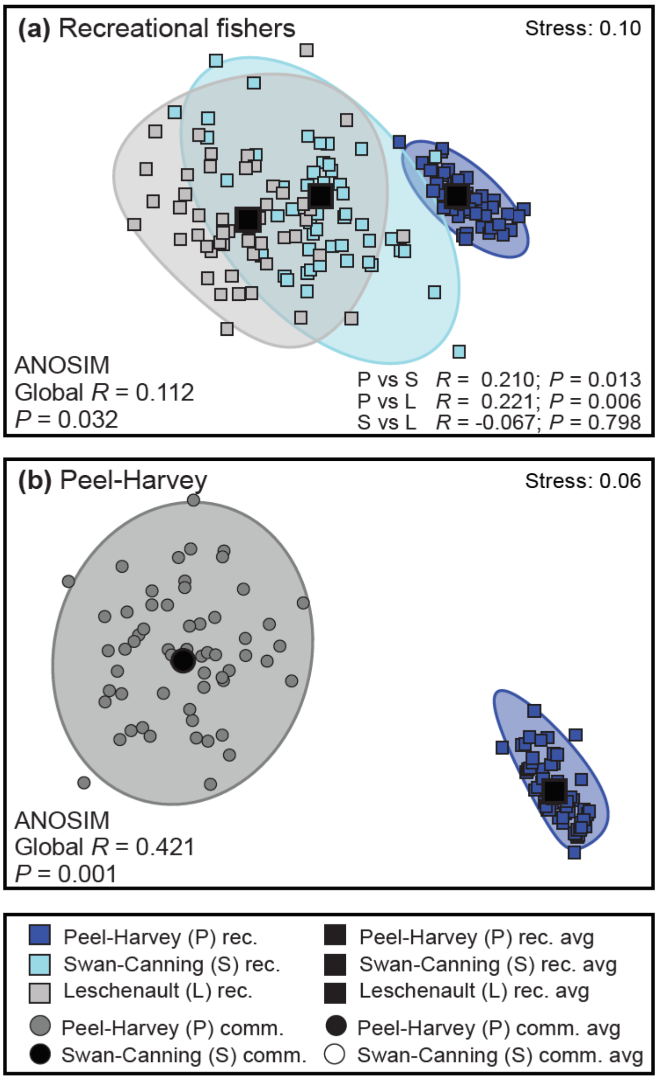


Figure 4.4. Two-dimensional nMDS ordination plots constructed from bootstrap averages of the presence/absence of the perceived concerns reported by (**a**) recreational P. armatus fishers in the Peel-Harvey, Swan-Canning, and Leschenault estuaries and (**b**) commercial and recreational fishers in the Peel-Harvey Estuary. 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.

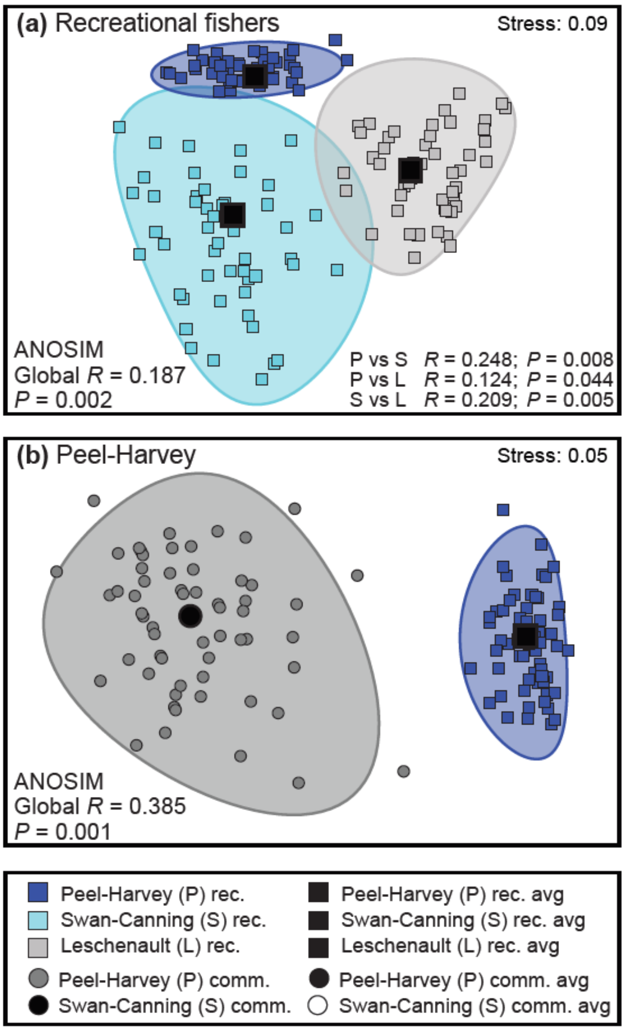


Figure 4.5. Two-dimensional nMDS ordination plots constructed from bootstrap averages of the presence/absence of the perceived solutions reported by (**a**) recreational *P. armatus* fishers in the Peel-Harvey, Swan-Canning, and Leschenault estuaries and (**b**) commercial and recreational fishers in the Peel-Harvey Estuary. 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.

4.5. Discussion

This paper 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 study to investigate the human dimensions of a portunid fishery anywhere in the world. The interview approach used in this study 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.

4.5.1. Reported changes in the size of *P. armatus* and fishing effort

Recreational and commercial fishers in south-western Australia reported perceived changes in the catches of *P. armatus,* 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 benthic macroinvertebrate and fish fauna of the estuary (Potter et al. 2016). Tweedley et al. (2014) 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 *P. armatus*, as well as increased recreational fishing pressure (de Lestang et al. 2003). 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 *P. armatus* 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 *P. armatus* in the northern regions. As a self-recruiting population, with little interaction between *P. armatus* populations in other water bodies, changes in environmental conditions can lead to inter-annual fluctuations in population abundance and crab size (Johnston et al. 2011b).

The analysis of recollections from fishing communities, sometimes referred as local ecological knowledge (LEK), 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 study each sector reported a different perception of the types of changes affecting the *P. armatus* 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 a bag, 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 LEK 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 & 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 *P. armatus* 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.

4.5.2. 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 *P. armatus* 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 *P. armatus* 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 *P. armatus* fishing, with many fishers travelling from areas outside the region to catch crabs in this estuary (Fletcher & Santoro 2012). 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. 2011b). 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 & 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 et al. 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 (DPAW 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 & 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 & 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. 2009).

4.5.3. 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 *P. armatus* 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 *P. armatus* 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 study. 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 (Gaughan & Santoro 2018). A universal recreational fishing licence has also been advocated as a management approach by fisheries managers and scientists globally (Arlinghaus & 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 & Cooke 2005, Cooke & 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 & 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 & Cooke 2005, Carr & 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 *P. armatus* 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 *P. armatus* 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 the *P. armatus* 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, our study 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 *P. armatus* 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 *P. armatus* 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 *P. armatus* were not fully understood at the time of the management intervention and therefore could not be included in the decision process.

4.5.4. 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 & Heyman 2012). Nowadays, managers are transitioning towards the inclusion of fishers in the management of a fishery. This is usually achieved either by collecting LEK from fishing communities (*i.e.*, information sharing on catches) and including these data in their analyses when assessing fishing stocks (Neis 1992, Ulman & 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 & 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 et al. 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 & Clem 2015). The views of fishers can also provide guidance to managers on approaches that would be supported by the local community (Stankey & 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 et al. 2010, Bender et al. 2014). It is worth noting that most *P. armatus* commercial fishers participating in the current study are part of a fishing association (*i.e.*, the Mandurah Licensed Fisherman's Association) and appear as having "one voice". Yet, as Carr and Heyman reported in their study (2012), and as the current study 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 & Heyman 2012).

4.5.5. Study limitations

The current study provides anecdotal data and describes fishers' perceptions on the status and management of the *P. armatus* 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 study, 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 study represents a census sample of the *P. armatus* commercial 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 study.

The use of open-ended questions in face-to-face interviews provided a voice to recreational and commercial *P. armatus* 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 2014, 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 favorably by others (Duffy et al. 2005). For example, Andrews et al (2018) compared recall error in surveys with the recreational fishers when using one and two-month reference period (*i.e.,* treatment). They found that interviewees reported similar number of fishing trips despite the treatment used (Andrews et al. 2018). Interview questions in this thesis were carefully designed to minimize response bias by, for example, articulating these as accurately as possible and avoiding biased questions. Additionally, 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.

4.6. Conclusion

This study 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 (*P. armatus*). 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 *P. armatus* 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 the current study 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 study 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 study. 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.

Chapter 5

Feeling the pinch: perceived marginalization of small-scale commercial crab fishers by an expanding recreational sector.

Commercial crab pots in the Peel-Harvey Estuary, south-western Australia. Photo credit of MSC.

Chapter 5

Feeling the pinch: perceived marginalization of small-scale commercial crab fishers by an expanding recreational sector

5.1. Abstract

Human dimensions are increasingly recognized as a key element of fisheries globally. In Australia, information on the human dimensions, particularly in the context of governance and social justice, is often lacking. Social justice includes the principles of fairness and equal opportunity and is a central concern for the governance of natural resources, such as fisheries. Currently, no information on social justice has been collected for any Australian fishery. The blue swimmer crab (*Portunus armatus*) fishery is multisector and iconic, particularly in south-western Australia, where an estimated 100,000 recreational fishers target this species, but has only seven active small-scale commercial operators. This study draws on separate face-to-face and online surveys, with commercial and recreational blue swimmer crab fishers and identifies the main concerns reported by the commercial sector. We explore the concerns through the lens of the three orders of social justice. Results indicated that commercial fishers' main concerns regarding social justice at the first order were a lack of local community support for commercial fisheries and marginalization by the numerically dominant recreational sector. Additionally, this study highlighted a contrast between the prioritization of purchasing local seafood and the lack of support for the local commercial fishing sector. This suggests recreational fishers miss the link between values and norms associated with purchasing local seafood products and support for the local fishing industry extracting them. Finally, commercial fishers reported concerns related to the inequity of fishery management regulations processes that influenced fishery management (second order social justice) which were seen as promoting recreational over commercial fishing. Small-scale commercial fishers are concerned about the future of their industry as they feel pressured from

the larger recreational sector and feel that the value of their fishery is not supported by the broader community.

5.2. Introduction

Social justice is a central element to fisheries governance that is often overlooked. In its broad sense, social justice relates to the equitable distribution of costs and benefits between stakeholders, in this case, small-scale fishers (Miller 1999). Small-scale fisheries (SSF) encompass the largest group of marine resource users and are also prone to be more exposed to injustice and marginalisation than large-scale fisheries globally (Cohen et al. 2019). To date, most issues flagged by research on social justice in SSF relate to the marginalisation of fishers in developing countries by industrial fishing fleets, conservation agendas to close areas to fishing, or large-scale aquaculture taking over traditional fishing grounds (Cohen et al. 2019). While some of the challenges faced by small-scale fishers in developed countries will be similar to those in developing countries, there is also a different range of environmental and social pressures that small-scale commercial fishers face in developed countries. In this vein, previous studies have highlighted a need to further examine social justice challenges associated with small-scale commercial fisheries in developed countries (Salmi & Sipponen 2016, Teh et al. 2020).

The Blue Economy is a relatively new concept in marine governance, which encourages the use of oceans for economic growth, as well as improved jobs and ecosystem health (The World Bank 2012). In Australia, the Blue Economy concept has been developed and integrated to a lesser extent than in other regions, such as the European Union (Voyer et al. 2017b, 2018). Along with the benefits of further developing the use of oceanic resources sustainably, the trend towards ocean-based economic development raises questions regarding the importance of social equity and blue justice objectives, and highlights the risk of sidelining the human dimensions through prioritising ocean development (Bennett 2018).

In Australia, the importance of considering human dimensions in the governance and management of fisheries has been recognised for some time (Triantafillos et al. 2014). Despite this, a 2016 study of 120 Australian fisheries found that only 28 (23.3%) had performance measures relating to human dimensions, with no fisheries in Western Australia (WA) having such measures (Hobday et al. 2016). Furthermore, we are not aware of any studies on social justice and orders of governance in Australian fisheries to date, and know of only a few studies that have looked at fishers' well-being (*e.g.*, King et al. 2019). This lack of information in social justice fisheries research worldwide, with only limited studies in certain regions, for example, the impact of re-introduced species on customary fisheries in Canada, the impact of bigeye tuna longline commercial fishery on traditional Hawaiian fishers in Hawai'i, USA (Loring 2017, Ayers et al. 2018a) and several reviews discussing equity and power dynamics in fisheries management (Bundy et al. 2008, Cohen et al. 2019, Song & Soliman 2019). Given the marginalisation of SSF globally, it is imperative that fisheries governance takes into account the human dimensions of SSF (Ayers et al. 2018b, Cohen et al. 2019).

The blue swimmer crab (*Portunus armatus*) is an iconic SSF fishery in south-western Australia. The Peel-Harvey Estuary (Figure 5.1), an estuary adjacent to the city of Mandurah (~80, 000 people), is the main location for blue swimmer crab fishing in this region. Mandurah, the fastest growing city in the state of WA, is located about 100 km south of the Swan-Canning Estuary, which flows through the city of Perth (the state's capital, population ~2,000,000). In 2016, the commercial and recreational fisheries for blue swimmer crab in the Peel-Harvey Estuary became the first to be jointly certified as sustainable by the Marine Stewardship Council (MSC) and is currently undergoing reassessment. However, increasing population growth in the Perth and Peel region has resulted in larger numbers of recreational fishers targeting blue swimmer crabs and other species, as well as increasing urbanization around the Peel-Harvey and Swan-Canning estuaries. This increasing growth in population and urbanization is progressively adding pressure to the blue swimmer crab populations, as well as on other natural resources of estuaries in south-western Australia (Johnston et al. 2011b).

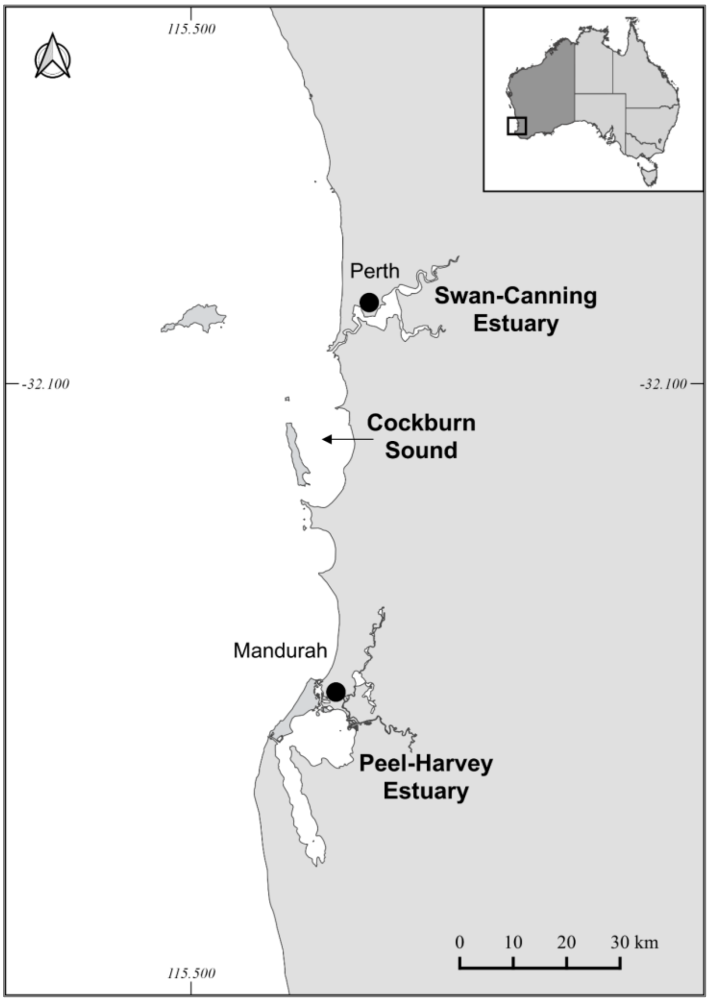


Figure 5.1. Map showing the location of the two estuaries that support commercial blue swimmer crabs fishing in south-western Australia and the two major urban centres adjacent to the estuaries. Box inset shows the location of the region in south-western Australia.

The importance of crab fishing for the local community in south-western Australia, and particularly in the Peel-Harvey Estuary, is highlighted by the number of people (mainly recreational fishers) targeting this species, and the magnitude of catches from the recreational and commercial sector (Ryan et al. 2019, Gaughan & Santoro 2020). The cultural value of the fishery to the local community is also shown through the promotion of blue swimmer crabs and crab fishing at regional events, such as the annual festival "Crab Fest", or annual "fishing clinics" organized by the local recreational fishing club, and supported by Recfishwest, the peak recreational fishing organization recognized by the WA government (Obregón et al. 2020c).

Fishing in WA is managed by the Department of Primary Industries and Regional Development (DPIRD). Commercial and recreational catches are managed mainly by regulating the number of fishing licenses and traps, minimum size and bag limits for retention, a fishing season and daily time (Gaughan & Santoro 2020, Obregón et al. 2020b). A recreational license to fish is required when fishing from a boat, but shore-based recreational crab fishers do not need a license. In 2019, new regulations for managing blue swimmer crab fishing in south-western Australia were introduced with the aim of protecting further female crab breeding stock. These included bag limits for recreational fishers, an extension of the seasonal closure to crab fishing and a buyout of licenses for commercial fishers in the Peel-Harvey Estuary. These new regulations restrict access to the fishery for both sectors, though in different ways. Buying out commercial fishing licenses directly reduces the number of commercial fishers operating in the fishery and therefore limits their accessibility to the resource. On the other hand, while recreational fishing bag limits were reduced and seasonal closures extended, no measures were put in place to control the actual number of recreational fishers targeting blue swimmer crabs in the region. Additionally, individuals fishing from the shore (shore-based fishers) do not require a fishing license in south-western Australia. These differences in the regulation of the commercial and recreational sector create potential for perceived injustices based on issues of inequitable regulation of access to the resource and marginalization of the commercial fishing sector.

This study focusses on perceived social justice issues affecting commercial blue swimmer crab fishers. Four different data sources were used to explore and triangulate the primary concerns reported by the commercial sector in the context of recent changes to the fishery's management through the lens of blue justice. The social justice issues were framed according to two of the three governance orders described by Berkes (2017) and drawing from Kooiman's "interactive governance" framework (Kooiman 2008). The first order of governance includes individual interactions *(e.g.,* among stakeholders). The second order of governance focuses on institutions and related arrangements. The third order (meta-order) discusses the principles of governance, and societal values (Kooiman 2008). We argue that "blue justice" should be explored at all three orders of governance: meta-(third), second, and first order (Kooiman 2003). When applied to the blue swimmer crab fishery, these include: i) interactions among stakeholders (first order of governance), ii) norms and values of the recreational fishing community (first order of governance), and iii) institutional setting and subsequent processes influencing the management regulations put in place (second order of governance). These issues affecting the blue swimmer crab fishing industry in south-western Australia are placed in the Australian context and data gaps on blue justice research on Australian fisheries are identified.

5.3. Materials and methods

The exploration of justice issues related to the blue swimmer crab fishery involved the analysis of four different elements forming the fishery, including recreational and commercial fishers' viewpoints, based on different data sources, as follows:

I. A review of various government reports about the trends in fisher-participation, catches and management approaches for each sector;
II. Face-to-face interviews with the commercial and recreational fishers regarding their concerns about management and its influence in the accessibility to the fishery (Obregón et al. 2020a);
III. A national scale video project which collected the perceptions of several Australian small-scale commercial fishers on their own well-being, as well as the well-being of the fishing industry in general by King (2018) and a follow-up study by King et al. (2019);
IV. An online survey of recreational fishers regarding the overall acceptability of blue swimmer crab commercial fishing industry in south-western Australia (Obregón et al. 2020b).

These four different data sources are described in more detail below.

I. Government reports on trends in participation, catches and management

Information on the trends in fisher-participation, as well as the catches for each sector of the blue swimmer crab fishery were extracted from various reports published by DPIRD on the state of the fishery (Fletcher & Santoro 2008, 2012, Gaughan & Santoro 2020), as well as the latest resource assessment report for the blue swimmer crab fishery in south-western Australia (Johnston & Yeoh 2020).

II. Interviews about commercial and recreational fishers' concerns and fishery accessibility

The face-to-face survey aimed to identify commonalities and differences in the concerns and supported solutions for fishery management by the recreational and commercial sector. Interviews were conducted between 2017 and 2018 (Obregón et al. 2020a). In the current study, the concerns and proposed solutions reported by both sectors in that survey were compared with the management approaches introduced following a review of fishery management (DPIRD 2019).

III. National project on well-being and social justice regarding commercial fishers

The perceptions of social justice were put into context at a national scale, by examining well-being issues of commercial fishers throughout Australia collected through a video project (King 2018) and a follow-up study by King et al. (2019). The video project compiled stories of commercial fishers all over Australia, including one commercial fisher operating in the Peel-Harvey Estuary. Though the subsequent study (King et al. 2019) was not specifically focused on social justice, some of the issues reported paralleled the experience described by blue swimmer crab commercial fishers and can be related to justice.

IV. Online recreational fisher survey on acceptability of crab fishing industry in south-western Australia

Finally, an online survey was conducted exclusively with recreational crab fishers in 2017/18. While some of the results have been published by Obregón et al. (2020b), those that focused on recreational fishers' seafood preferences and perceptions of recreational fishers on the local fishing industry have not been presented previously. In this study, the proportion of respondents prioritizing local seafood was compared to the proportion of respondents supporting the local fishing industry.

5.4. Results

5.4.1. Government reports on trends in participation, catches and management

In WA, the number of commercial blue swimmer crab fishers has decreased over time. For example, in 2007-2008, 33 people were employed as skippers and crew on fishing vessels across the whole of the state (Fletcher & Santoro 2008), but this declined to 28 in 2010-2011 (Fletcher & Santoro 2011). By 2018, 20 fishers were employed directly in the crab fishery state-wide, of which 11 operated in two estuaries in south-western Australia – 10 in the Peel-Harvey Estuary and one in the Swan-Canning Estuary (Fletcher & Santoro 2012). In a 2018 management review, the number of commercial crab fishers has been reduced to seven – six in the Peel-Harvey Estuary and one in the Swan-Canning Estuary (DPIRD 2018). Commercial crab fisheries in south-western Australia work from small vessels (< 8 m long) either alone or with one crew, using small light-weight traps (Figure 5.2). Management changes towards the end of 2019 further reduced the number of commercial fishing licenses to seven across these two estuaries: six in the Peel-Harvey and one in the Swan-Canning. The total commercial catch of blue swimmer crabs in the region has also decreased over time, from ~160 t in 2011-2012 , to ~75 t in 2017-2018 (Gaughan & Santoro 2020). The annual catch for the blue swimmer crab commercial fishery in 2019 was 70.1 t, and the average catch over the previous five years (2013-18, ± 1 SE) was 83.3 ± 22.9 t (Johnston & Yeoh 2020).

Generations of commercial fishers have fished the Peel-Harvey Estuary (Figure 5.2), catching blue swimmer crabs and finfish since the beginning of the 20th century (Johnston & Yeoh 2020). Most fishers formed family businesses and have been transferring their licenses down through successive generations. This partly explains why "family tradition" and "love for fishing" appeared as the main motivations for commercial fishers fishing in south-western Australia (Obregón et al. 2020a). All active commercial fishers in the Peel-Harvey Estuary are members of the Mandurah Licensed Fishermen's Association (MLFA).

Figure 5.2. Commercial fisher in the Peel-Harvey Estuary, preparing the drop net before starting crabbing (source: © MSC 2016)

On the other hand, the estimated total number of recreational fishers doubled in 30 years from ~300,000 (McLeod & Lindner 2018) to ~700,000 (DPIRD 2019). The overall participation rate in recreational fishing activities of Western Australians (28.7%,Ryan et al. 2019) is above the national level (19.5%), and well above the average of 10.5% across the industrialized world (Arlinghaus et al. 2015). The blue swimmer crab is one of the most popular recreational fisheries in WA (Ryan et al., 2019). Crabbing is very accessible to recreational fishers due to the simple and inexpensive gear (*i.e.,* traps or scoop nets that cost between AU$10 - 15). Moreover, crabs can be scooped by wading from shore in the shallows (Figure 5.3), by dropping pots/traps from public jetties or from a boat in a similar manner to the commercial fishers (Figure 5.2). It is estimated that ~100,000 recreational fishers go crabbing in WA each year (MSC 2016).

Estimates of boat-based catches of blue swimmer crabs in south-western Australia vary among years. In 2014/2015 catches were estimated to reach between 50-66 t (Fletcher & Santoro 2012), and the most recent estimates in 2018/19 suggest that recreational catches reached ~ 61 t. Note that these data do not include catches from shore-based fishers (Ryan et al. 2019), who were estimated to represented ~27% of all fishers recorded crabbing during a creel survey conducted in 2001 in the Peel-Harvey Estuary (Malseed & Sumner 2001b). If catch rates from shore-based recreational fishers represent at least one third of those in boats (~20 t), it is likely that the current total recreational crab catch is similar, or even greater in magnitude to that of the commercial sector (Malseed & Sumner 2001b).

Figure 5.3. Recreational fishers crabbing from shore using scoop nets in the Peel-Harvey Estuary (source: © DPIRD, 2018)

5.4.2. Commercial Interviews about commercial and recreational fishers' concerns and fishery accessibility

The face-to-face survey highlighted some of the perceived concerns and proposed solutions raised by commercial and recreational blue swimmer crab fishers in south-western Australia (Obregón et al. 2020a). For example, commercial fishers supported the introduction of a universal recreational fishing licence (*i.e.*, a license to encompass recreational fishing from both boats and shore for any species) and a greater monitoring and enforcement of recreational fisher compliance. Increased compliance based on enhanced monitoring and enforcement was also supported by recreational fishers (Table 5.1; Obregón et al. 2020a).

Table 5.1. Percentage number of perceived solutions for improving the management of blue swimmer crab (*Portunus armatus*) fisheries for recreational and commercial fishers in south-western Australia derived from face-to-face interviews. The number of fishers surveyed from each sector is shown in parentheses. Modified from (Obregón et al. 2020b). Note that the symbol " - " indicates "not mentioned".

Solutions reported *(n)*	**Recreational fishers (%)** *(93)*	**Commercial fishers (%)** *(11)*
None	30.1	–
Increase compliance	20.4	27.3
Longer closed season	19.4	9.1
Universal recreational licence	3.2	54.5
Reduce bag limits	3.2	–
Ban female catches	2.2	–

The revised management approaches introduced in 2019 for the blue swimmer crab fishery in south-western Australia included an extended regional closed season and various changes on recreational fishing bag limits in specific estuaries (Table 5.2). While the closed season was supported by the recreational sector, none of the other approaches introduced were strongly supported by either the recreational or commercial sector (Table 5.1; Obregón et al. 2020a). In fact, recreational fishers reported that they had already adopted (voluntarily) some of these approaches, such as releasing all female crabs (Obregón et al. 2020a)and not taking the bag limit, before the new regulations were introduced. The rationale behind these voluntary actions was "to allow them to breed", an action taken by both commercial and recreational fishers. Many other fishers reported never catching their quota, as the bag limit of 10 crabs (or total of 20 if two or more people are fishing from a boat) is enough "to get a feed" (Obregón et al. 2020a). There is no information on the proportion of recreational fishers already applying these measures voluntarily. However, it could be argued that for those who do, these new restrictions will have little impact on their recreational fishing activity, as they were already releasing females, or only keeping crabs over the minimum size limit.

Table 5.2. Suggested approaches by commercial and recreational fishers for the future management of the blue swimmer crab fishery and whether they were implemented in the 2019 management regulations.

Suggested approach	**Approaches**	
	Implemented	*Not implemented*
Limit female catches (*site specific*)	✓	–
Reduction in bag limit (*site specific*)	✓	–
Seasonal closure	✓	–
Buy-out of commercial licence(s)	✓	–
Shore-based recreational licence	–	✓
Enhanced compliance	–	✓

5.4.3. National project on well-being and social justice regarding commercial fishers

The face-to-face surveys identified some of the concerns of commercial and recreational fishers on the management of the blue swimmer crab fishery and the status of the stocks (see also Obregón et al. 2020a). Concerns for well-being and social justice were apparent in interviews with commercial fishers (present in 60% of the interviews). These concerns were expressed in terms of perceiving management as being driven by vested interests and politics rather than what was fair and equitable. For example, a commercial fisher said "… what concerns me is the ineffective management. Fisheries management is all about politics, and not the fish". Another commercial fisher responded that the biggest concern was "… the constant recreational pressure on the political sector to remove us". These statements suggest that commercial fishers did not perceive that well-being and social justice were a priority for management bodies, and instead, political factors were considered more important.

Commercial fishers also perceived that they were not supported by the local community. Two leaders of the MLFA, the association which represents the commercial fishing community in the Peel-Harvey Estuary, reported that commercial fishers felt "pushed out" from the fishery by the recreational sector. For example, a commercial fisher said "(…) our industry brings to the Perth consumer fresh, local and sustainable seafood. I am proud to do that and be allowed to do that, and this should be respected, as farmers are, and their industry". They also resented the lack of recognition by the community for some of their voluntary actions for the sustainability of the fishery (*e.g.*, by voluntarily increasing the minimum size limit from 127 to 130 mm carapace width, and by reducing the number of females caught). It is worth noting that one commercial fisher mentioned that during the COVID-19 lockdown in 2020, there was a "…slight resurgence of people wanting local products and a push back against imported products." However, the same fisher mentioned that commercial fishers that had voluntarily sold their licences during the recent buy-out had done so "… knowing the ever-increasing pressure [*to leave the fishery*] was too much for them personally" (Chapter 4, unpublished data).

The sense of powerlessness from the commercial fishing sector aligns with the findings from interviews conducted with commercial fishers around Australia (King 2018), and a wider study on fishers' well-being in a range of Australian fisheries (King et al. 2019). The video study demonstrated that commercial fishers, despite targeting different species in different locations across Australia, are exposed to similar pressures (King 2018) to those identified for the Peel-Harvey blue swimmer crab fishers. Results from the follow-up study by (King et al. 2019) showed that commercial fishers have higher incidences of mental health issues, particularly depression, than the general Australian population. The main factors causing anxiety were identified as: i) changes in government regulations on fishing access (> 50%); and ii) negative media and poor public image (*i.e.,* social licence to operate; > 30%). The high incidence of depression was linked to several factors, including a lack of support from management bodies and the community in general, as well as isolation, insecurity and uncertainty (King et al. 2019).

5.4.4. Online recreational fisher survey on acceptability of crab fishing industry in south-western Australia

The online survey was completed by 575 recreational crab fishers in south-western Australia. The responses to the online survey (Table 5.3) indicated that most recreational crab fishers (64%) prioritized purchasing a local product over a cheaper product or an imported product.

Table 5.3. Questions included in the 2017/18 online survey from interviews in Obregón et al. (2020b), covering the views of the recreational crab fishing community on purchasing seafood, and on the commercial fishing sector.

Selected online survey questions
1. *If you had to buy seafood from the supermarket, what would be your main priority?* ☐ Local product ☐ Better quality product ☐ Cheaper product ☐ I do not buy seafood
2. *Overall, what is your opinion of the blue swimmer crab commercial fishery sector using the estuary you fish most at?* ☐ Completely unacceptable ☐ Unacceptable ☐ Neutral ☐ Acceptable ☐ Completely acceptable

Some recreational fishers (19%) preferred a better-quality product, over its price regardless of where it came from (Figure 5.4a). Despite results indicating most recreational fishers prioritize purchasing local seafood products (Figure 5.4a), only 30% of the respondents thought that the use of the estuary by the commercial blue swimmer crab fishers was acceptable or completely acceptable (Figure 5.4b).

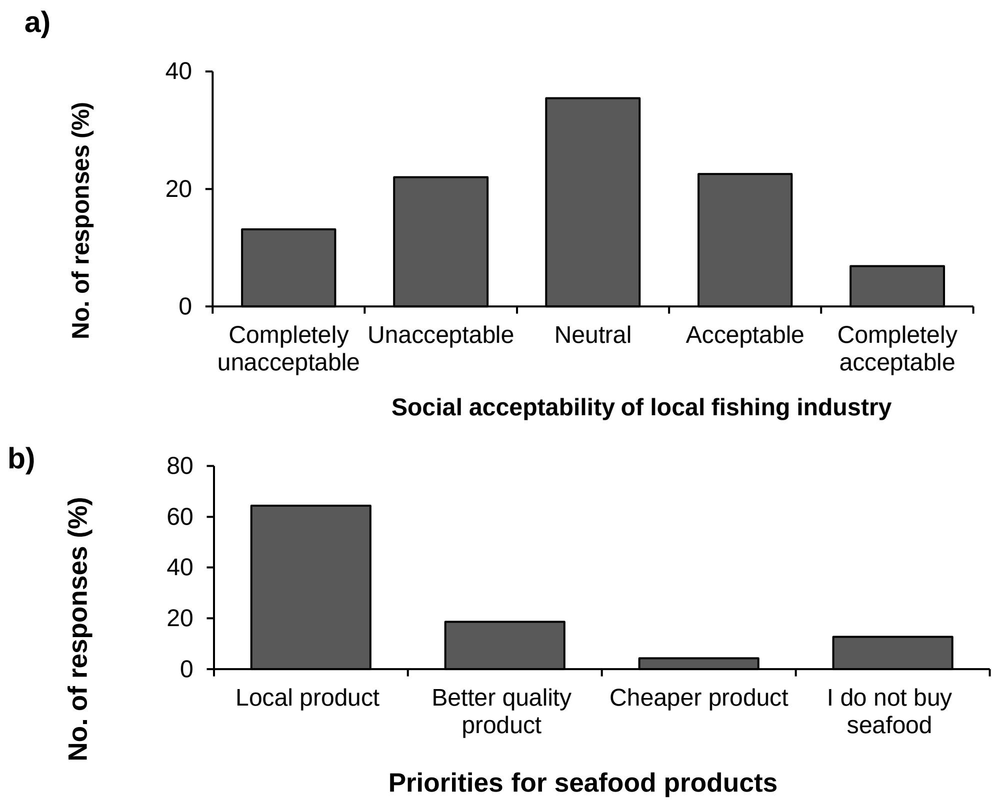


Figure 5.4. Percentage number of responses by recreational fishers in an online survey to the question (**a**) "What is your opinion of the blue swimmer crab commercial fishery sector using the estuary you fish most at?" (n = 350); and (**b**) **"**If you had to buy seafood from the supermarket, what would be your main priority?" (n = 354).

The remaining respondents were split equally between having no opinion (35%) and those indicating that the use of estuaries by the local commercial crab fishing industry was unacceptable or completely unacceptable (35%; Figure 5.4b). This suggests that a significant number of recreational fishers are potentially "missing the link" between the purchase of local seafood products and the commercial fishing industry catching the product in local estuaries and providing seafood to the local community (Table 5.4). Recreational fishers' conceptual disconnect between the seafood product and the means to obtain it devalues the role of commercial fishers in the community, impacting the social license of small-scale commercial fishing.

Table 5.4. Summary of social justice issues affecting the blue swimmer crab fishery in south-western Australia. Issues affecting the commercial and recreational sectors are interpreted and assessed through the three orders of governance described in Berkes (2017).

Order of governance	Fishing sector	Case study interpretation	Fishery description
1st order	Commercial sector	-Interactions among stakeholders; -Conflict over resource use and access.	-Lack of support to the local fishing industry from local community; -Perceived marginalization due to a growing recreational fishing community for blue swimmer crabs; -Contrast between prioritisation of local seafood produce, and the lack of support to the local commercial fishing sector.
2nd order	Commercial sector	Management regulations	-Perceived inequity of fishery management regulations are seen promoting recreational over commercial fishing.

5.5. Discussion

This research focussed on perceptions of social justice in a highly valued small-scale recreational and commercial blue swimmer crab fishery in south-western Australia. Issues of power imbalance and inequity were reported in a previous study by commercial blue swimmer crab fishers operating in the Peel-Harvey Estuary (Obregón et al. 2020a). To further investigate social justice issues, four data sources were analysed to collate information relating to recreational and commercial fisher interactions, fisher perceptions, and fishery regulation. Results reflect perceived injustices experienced by the blue swimmer crab commercial sector across three orders of governance. These are discussed in turn.

5.5.1. Perceived social justice issues of the first order

The reported negative interactions between recreational and commercial fishers over resource use and access are indicative of first order social injustices. Commercial fishers reported personal property damage, as well as physical harm from recreational fishers (WAFIC 2014, Fitzgerald 2015, DPIRD 2016). Furthermore, some recreational fishers support the elimination of the commercial sector in the region, claiming that this industry "wipes out the crabs from the system" (Obregón et al. 2020a). Conflict between resource users over resource allocation is a common issue affecting fisheries globally (Pomeroy et al. 2007, Bower et al. 2014, Boucquey 2017, Voyer et al. 2017a, Bellanger et al. 2020) and has been described in the past between fishery sectors in the Peel-Harvey region (Malseed & Sumner 2001b). The perceived first order injustices are positioned within a broader context of commercial fisher concerns about government regulation of the fishery. This indicates a consistency between perceived social injustice at the first and second orders of governance.

A potential inconsistency within the first order of justice was also identified. A mismatch between recreational fishers' preference for local seafood produce and the lack of support for the local fishing industry suggests a conceptual disconnect between recreational fishers' norms and values. This disconnect between the product (*i.e.,* seafood) and the means to source it (*i.e.,* local commercial fishing) is probably one of the elements behind the lack of support from the recreational sector to the small-scale commercial fishing community (Table 5.4). These elements could potentially impact the social acceptance of commercial fishing in the community. However, more research is needed to relate this disconnect to the issue of injustice in terms of understanding how the community norms and values influence the marginalisation perceived by the commercial sector.

5.5.2. Perceived social justice issues of the second order

Social justice issues influenced by specific characteristics of the governance system (Table 5.4) were also apparent. The current differences in monitoring and licensing requirements between recreational and commercial fishers raised concerns about equitable regulation of access to the fishery resource. Equitable regulation of access to a valued resource is a key aspect of social justice (Miller 1999). The WA government amendments to the blue swimmer crab fishery management plan introduced in 2019 included limiting seasonal access and bag limits (DPIRD 2018, Gaughan & Santoro 2020). At the same time the government promoted an increase in the number of all recreational fishing participation to 30% of the WA population (Recfishwest 2020). When contrasted with the more comprehensive regulation of commercial fishers and actions to reduce commercial fisher numbers, it may be understandable that commercial fishers perceive the regulatory "rules" favour recreational fishers.

The perceptions of second order injustice appear to be exacerbated by the absence of a universal recreational fishing licence as part of the new management measures, despite support from most of the commercial fishers operating in the region. Such a licence would enable a more accurate picture of recreational fishing effort and participation in south-western Australia. It should be acknowledged that collecting recreational crab fishing data and enforcing fishing regulations is inherently difficult in the region due to the large area of the Peel-Harvey Estuary (~133 km^2) and the number of easy access points around the estuary. In addition, a significant portion of recreational fishing occurs at night-time, when monitoring is more difficult (Taylor et al. 2018). The limited data available for participation rates and catches associated with recreational fishing is a common problem for fisheries management globally and is a barrier for estimating recreational fishing catches and effort (Arlinghaus et al. 2015, Pauly & Zeller 2016b, Townhill et al. 2019).

This study showed that some of the regulatory measures implemented in 2019 had a large impact on the commercial sector. For example, the buy-out of commercial licences further marginalises this sector in two ways that reflect social justice issues in the second order of governance. Firstly, reducing the number of commercial licences further reduces the voice of commercial fishers in the region. Secondly, the small and decreasing numbers of commercial fishers is likely to progressively reduce their role in negotiations with the government agencies for research and management, as well as other stakeholders of the blue swimmer crab fishery. That is, the power imbalance between the smaller commercial and much larger recreational sectors will continue to increase. These factors will potentially limit the commercial sector's overall lobbying power, and as a result, could potentially affect their influence on the fishery management process relative to the recreational sector (Table 5.4; Obregón et al. 2020b).

The potential benefits of taking fishers' views and perceptions into consideration as part of regulatory design and implementation is globally recognised (Johannes et al. 2000, Kearney 2002, Barclay et al. 2017), and has recently been highlighted for the blue swimmer crab fishery in south-western Australia (Obregón et al. 2020c). Taking these elements into consideration when managing the fishery, would potentially enhance compliance and increase communication efficiency and overall trust between fishery stakeholders (Kearney 2001, Obregón et al. 2020b). Furthermore, understanding the commonalities and differences in perceptions between fishing sectors could help alleviate conflict between commercial and recreational fishers (Voyer et al. 2017a, Obregón et al. 2020b). That is, adjustment of second order governance approaches could work to address first order injustices.

Overall, analysis through the lens of governance orders and social justice found consistencies within the perceived injustices across the first and second order. Further research could be conducted to determine how the consistencies of injustice at the first and second order align with the third order of governance.

5.6. Conclusion

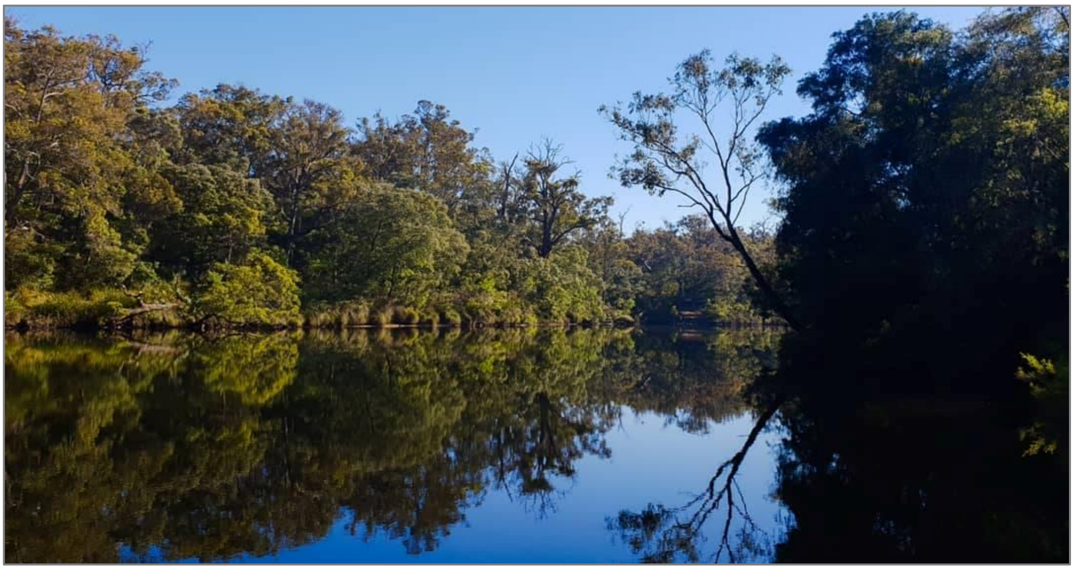
Scholars worldwide are concerned that a focus on the Blue Economy for the development of global oceanic resources will put emphasis on maximizing economic gain at the detriment of natural resources, and in particular, the human dimensions. This is also the case for fisheries. Small-scale fisheries support millions of livelihoods globally, and social justice is imperative for small-scale fishers to allow a fair and equitable access to resources as well as the market. Strong institutions combined with the interaction and integration of fishers and other fishery stakeholders in decision making are central to obtaining justice in SSF. However, in some Australian SSFs, such as the Peel-Harvey blue swimmer crab fishery, it is apparent that with a growing recreational sector, commercial fishers often feel marginalised and 'pushed out' of the fishery and the community.

This study is the only research explicitly examining social justice in a WA fishery, and one of the few detailing the human dimensions of fisheries in Australia. We identified a discrepancy within the first order of governance and consistency between the first and second order of governance. We have demonstrated that commercial crab fishers felt unsupported by the local community and increasingly marginalised. Meanwhile, the perceived lack of community support was reinforced by regulations and policies limiting commercial fishers' role in governance and access to the fishery. These elements of social injustice across two orders governance will negatively influence on the ability of small-scale commercial fishers to continue operating in the region. We believe identifying these injustices between governance orders is the first step towards finding practical solutions to address them. A pathway towards advancing social justice issues in the first and second order is needed. This pathway could involve strategies to enhance recreational fisher recognition of the commercial sector as a supplier of the preferred locally sourced seafood. Injustice at the second order may prove a greater challenge given the numerical dominance of recreational fishers and their lack of support for further regulatory restrictions on access to the fishery, such as a shore-based fishing license.

Blue swimmer crab commercial fishers feel concerned about the future of this small-scale fishery as they watch the recreational sector grow. Further research on social justice issues affecting small-scale commercial fisheries would be beneficial to increase understanding of the scale and complexities of the problem and identify how to implement strategies to promote equity and enhance the sense of social justice for the commercial sector in small-scale fisheries.

Chapter 6

A two-phase approach to elicit and measure beliefs on management strategies: Fishers supportive and aware of trade-offs associated with stock enhancement[3]



Views from one of the recreational fisher survey sites at the Blackwood Estuary, south-western Australia.

[3]This chapter is published as a co-authored paper:

Obregón, C., Hughes, M., Loneragan, N.R., Poulton, S. and Tweedley, J. R. (2019). A two-phase approach to elicit and measure beliefs on management strategies: Fishers supportive and aware of trade-offs associated with stock enhancement. *AMBIO*. Doi: 10.1007/s13280-019-01212-y.

Chapter 6
A two-phase approach to elicit and measure beliefs on management strategies: Fishers supportive and aware of trade-offs associated with stock enhancement

6.1. Abstract

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 and then measure the strength of common fishers' beliefs and associated attitudes regarding stock enhancement. Specifically, this research focused on recreational fishers of an estuarine crab fishery (*Portunus armatus*) in south-western Australia. 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, though the latter are perceived as less likely to happen. This contrasts with previous research on fisheries stocking and demonstrates the value of using the two-phase approach to clarify fishers' perceptions of particular management approaches. To reduce fisher dissatisfaction with management actions, careful communication on the benefits and costs of stock enhancement is recommended. 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.

6.2. 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 & 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 2006, Cooke & 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, 2019, Hyder et al. 2018). 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 & 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 et al. 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 et al. 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 et al. 2010). Stock enhancement is widely used in freshwater, estuarine and marine environments (Bell et al. 2008, Broadley et al. 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 & Lorenzen 2017). Therefore, its use as a management intervention is projected to grow (Cooke & Cowx 2006, Von Lindern & 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 et al. 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 et al. 2011, Camp et al. 2017) ; iii) increased numbers of smaller individuals and slower growth to maturity, due to density-dependent effects on growth (Satake & Araki 2012, Anderson et al. 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 (van Poorten et al. 2011, Von Lindern & 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 (van Poorten et al. 2011, Garlock & 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 & 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 & Knuth 2002).

In Australia, the portunid crab *Portunus armatus* holds great social and economic importance as a recreational and small scale commercial fishery (*e.g.,* Sumpton et al. 2003, Ryan et al. 2015).

Recreational crab fishers may be boat-based or shore-based (jetties, snorkelling/diving or wading), using a variety of simple, cheap equipment such as drop nets and scoop nets (Johnston et al. 2015). In Western Australia, *P. armatus* is the most popular target species among recreational fishers (Sumner & Williamson 1999, Malseed & Sumner 2001b), with an estimated 900,000 crabs caught by boat-based recreational fishers 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 & Sumner 2001b). The recreational crab fishery is considered a food-motivated fishery, with the main motivation of recreational crab fishers being to "Catch crabs to eat" (Poulton 2018). 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 *P. armatus* stocks in south-western Australian estuaries being subjected to increasing pressures, such as environmental degradation due to urbanisation and increasing fishing pressure (Johnston et al. 2011b, Tweedley et al. 2016).

In light of the pressures on estuarine stocks, (Johnston et al. 2011b) suggested that stock enhancement be considered as a way of increasing the abundance of *P. armatus.* 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. 2017). 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 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 *P. armatus* presented an ideal opportunity for eliciting and measuring the beliefs and attitudes of recreational fishers regarding stock enhancement 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 *P. armatus* fishery in the Swan-Canning, Peel-Harvey and Leschenault estuaries in south-western Australia (Figure 6.1).

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 influential people who may approve or disapprove of a behaviour; and control beliefs about factors that may help or hinder attempts to perform a behavior (Hughes et al. 2012). The aim of the study is to apply a method which first identifies fisher beliefs and attitudes about the likely outcomes of stock enhancement as a management approach then relates these beliefs to the level of support for stock enhancement. This study appears to be the first application of such an approach to a fishery and focusses on the *P. armatus* recreational fishery, in south-western Australia.

Figure 6.1. Location of the three estuaries in south-western Australia where interviews with recreational fishers were conducted. i) Swan-Canning Estuary (area = 55 km^2, maximum depth = 21 m and average depth = <5 m) ii) Peel Harvey Estuary (area = 131 km^2, maximum depth = 2.5 m and average depth = 0.5); iii) Leschenault estuary has an area of 25 km^2, a maximum depth of 2 m, which on average reaches < 1 m. Surveys to elicit and then measure the beliefs and attitudes of recreational fishers towards management of the *Portunus armatus* fishery were conducted during the Austral summer (November 2017 to March 2018).

6.3. 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 et al. 2009, 2012, Brown et al. 2010). The first phase identified recreational fisher beliefs about the likely outcomes of stock enhancement *P. armatus* (Phase 1), with these responses then used to develop the belief measurement survey (Phase 2).

6.3.1. 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 6.1). 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 *P. armatus* 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' words, the beliefs associated with stock enhancement of the *P. armatus* fishery. Belief elicitation questions were paired and focussed on the positive or negative outcomes a fisher might expect from crab stock enhancement, and his or her evaluations of those outcomes, drawing on the behavioural belief component of the TPB procedure (Hughes et al. 2012). Consenting recreational crab fishers were asked a series of open-ended questions (see Table 6.1). 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 fishing for crabs (*i.e.,* during the morning or afternoon) on weekends and weekdays during the peak of the *P. armatus* fishing season (austral summer, *i.e.,* November 2017 to March 2018; Malseed & Sumner 2001). 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' words. A theoretical saturation approach was adopted for belief elicitation. Accordingly, interviews with recreational crab fishers were carried out across the three estuaries until no new response types were recorded 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). Additional interviews were conducted once saturation was achieved to ensure that no salient beliefs were overlooked.

Table 6.1. Questions asked to recreational fishers' about their awareness, beliefs and attitude to restocking in the belief elicitation survey.

Restocking awareness
1. Do you know what restocking is? [explain]
2. Are you aware of any past fishery restocking events?
Restocking beliefs
3. What do you think are the advantages or good things that could occur if restocking 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 restocking is used to manage the crab fishery in this estuary?
Attitude towards restocking
5. Overall, what is your attitude towards restocking?
Demographics
Age, gender, place of residence

Responses were transcribed to a spreadsheet and reviewed to develop categories of response representing salient beliefs. Three researchers independently conducted content analysis independently, to group responses with 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.

6.3.2. Phase 2: belief measurement

The second phase involved an online, fixed-item questionnaire distributed to the Western Australian recreational crab fishing community. The survey included a range of questions about *P. armatus* fishing and management (see Supplementary material 6.1. to review the full questionnaire used). This paper specifically focuses on the stock enhancement belief strength (*i.e.,* likely-unlikely) and evaluation (*i.e.*, good-bad) measurement components of this online survey.

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 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 *P. armatus*, 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 (Widgix, 2005). 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 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 also 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 (Version 4.0.2) 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).

6.4. Results

The respondents of the Phase 1 (face-to-face interviews) 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.

6.4.1. 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 6.2).

Salient beliefs associated with positive outcomes of crab stock enhancement were more frequently stated (91.5% of respondents) than those associated with negative outcomes (39.4%). The two most frequently stated beliefs were that stock enhancement would i) increase the number of crabs in the estuary and ii) result in more crabs to catch, that is, more crabs of minimum legal size in the catch (Table 6.2). Interestingly, while many respondents indicated there were no disadvantages associated with stock enhancement, almost 40% of respondents reported that enhancement of *P. armatus* 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.

Table 6.2. Salient (*i.e.,* positive and negative) beliefs recreational fishers associated with the restocking of *Portunus armatus* in the estuary where they fished, (n=94).

Question and answers	**Frequency (n)**	**Percentage of respondents (%)**
Q. What are the advantages or good things that could occur if restocking 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
Good for environment and other species	8	8.5
Good for tourism/economy	5	5.3
Total respondents	**86**	**91.5**
Q. What are the disadvantages or bad things that could occur if restocking is used to manage the crab fishery in this estuary?		
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
Affect crabs' genetics and produce diseases	2	2.1
Crabs could leave the estuary	2	2.1
Total respondents	**37**	**39.3**

6.4.2. 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 stock enhancement crabs (*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 6.3). 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.,* 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 stock enhancement crab was +1.75 (scale from -3 to +3; n = 308; Figure 6.3) indicating general support for the management practice. This was also reflected in the frequencies of response, where 86.4% of responses were positive (supportive), 4.2% were neutral and 9.4% were negative (not supportive) toward stock enhancement of crab (Figure 6.3).

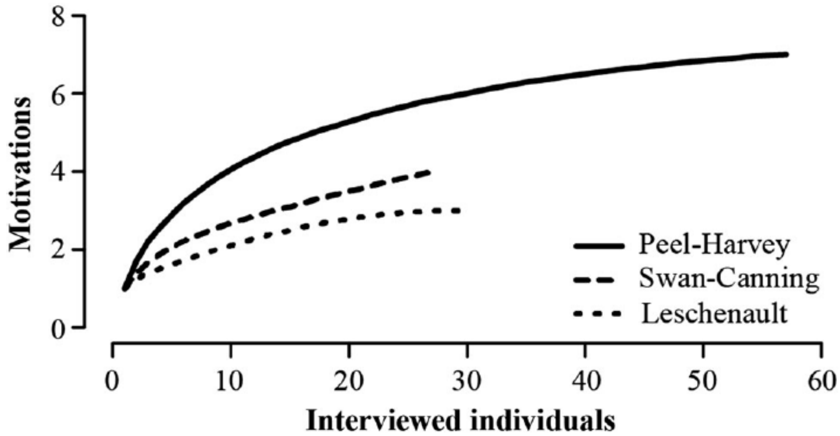


Figure 6.2. Response-accumulation curve showing that data saturation was reached during Phase 1 of the surveys with recreational *Portunus armatus* fishers in three estuaries in south-western Australia. Grey shaded area shows the 95% confidence intervals.

The mean belief strength and evaluation ratings towards crab stock enhancement crab 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 6.4). 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 6.4). In terms of the disadvantages of stock enhancement, all three groups rated these outcomes as equally bad, however, the unsupportive and neutral groups rated them as being significantly more likely than the supportive group. Overall, recreational fishers supporting stock enhancement believe that the disadvantages of enhancing crabs are less likely to occur, while the advantages are more likely and good, compared to the response of fishers who were unsupportive or neutral about this enhancement.

Table 6.3. Summary of mean belief strength; valuation ratings and cross products associated with restocking of *Portunus armatus*.

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	4.8	351	2.1	319	11.5
More crabs to catch	331	4.8	352	2.2	317	11.5
Increase the fishing pressure on crabs	283	3.1	318	-1.5	265	-4.1
Impact on the environment and other species	284	2.9	278	-1.3	237	-2.5

6.5. Discussion

By implementing an open-ended interview (Phase 1) followed by an online survey (Phase 2), this paper provided added insights into 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 et al. 2013). Understanding fisher perceptions can provide insights into how to build support and mitigate conflict associated with fisheries management (Mikalsen & Jentoft 2001, Fulton et al. 2011).

In this regard, Ham et al. (2008) and Hughes et al. (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 (*e.g.,* Anderson et al. 2007, van Poorten et al. 2011, Garlock & Lorenzen 2017). The findings indicate that fishers' support for crab stock enhancement of 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 *P. armatus* (Johnston et al. 2011b). As a result of this interest in enhancement, a pilot release of 3,700 juvenile crabs was made in the Peel-Harvey Estuary to explore the feasibility and logistics of enhancement (Jenkins et al. 2017).

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 *P. armatus* 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. These findings on a short-lived invertebrate parallel with those for longer-lived fin-fish (red drum, *Sciaenops ocellatus*) by Garlock and Lorenzen (2017), and generic modelled results for fish by van Poorten et al. (2011), who both found 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 lead to greater catches of crabs (*i.e.,* more crabs of at least minimum legal size), may be an unrealistic belief.

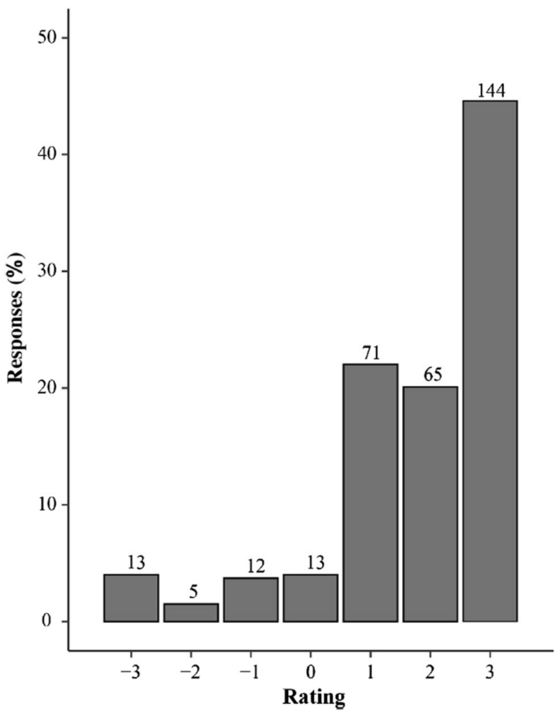


Figure 6.3. Responses to question "Overall, I think using restocking as a management option for blue swimmer crabs in the estuary where I fish most is:" indicating the overall attitude of fishers towards restocking as a management approach for the *Portunus armatus* fishery. The number of respondents who chose each rating is provided above each bar; n = 323.

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 of *P. armatus* is not guaranteed to increase the number of crabs caught because many will be below the minimum legal-size limit. The catch-related beliefs aligns with findings from previous studies on various fish species in the northern hemisphere (*e.g.,* Anderson et al. 2007, Garlock & Lorenzen 2017), which noted that consumptive oriented fishers tend to support stock enhancement as it is perceived to help them achieve their aims of catching many and large fish. It was also noted that these expectations might be unrealistic, requiring managers to carefully communicate the benefits and costs of stock enhancement to reduce fisher dissatisfaction (Garlock & 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 et al. 2012), predation and competition between stocked and wild fish, and reducing the abundance of wild fish populations (Bell et al. 2008, Ingram et al. 2011, Taylor et al. 2017). 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 simply being unaware of the negative outcomes resulting from stock enhancement.

Perhaps it is not so much a general lack of awareness, but more an 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.

Table 6.4. Mean values from the online survey responses regarding the mean belief strength, evaluation ratings and cross products associated with restocking *Portunus armatus*, for the three fishing groups studied: Supportive (S); Neutral (N) and Unsupportive (US) to restocking. Population size is specified for each belief in the "n" column.

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*

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 2006), we demonstrate here that some fishers are also aware of the potential for negative outcomes from stock enhancement. Our findings, based on the two-phase approach, provide additional insight to the notion of incomplete understanding by fishers regarding the advantages and disadvantages of stock enhancement identified in previous studies (Hunt et al. 2013). This two-phase method could be applied to other fishery sectors (including commercial, artisanal and subsistence fisheries) to further improve understanding of fisher beliefs and attitudes toward management. Better understanding of fishers views on fisheries and their management can contribute to greater acceptance and compliance with management actions (McPhee et al. 2002, Sténs et al. 2016).

6.6. 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 fisheries. As with past studies of recreational finfish fisheries, crab fishers appeared to generally support stock enhancement as a tool to manage this fishery. Our elicitation method indicated that recreational crab fishers were aware of positive outcomes of stock enhancement, and in contrast to other studies, demonstrated that near 40% were also aware of potential negative outcomes. We found that a primary difference between fishers who strongly support stock enhancement and those who do not is the perceived likelihood of negative and positive outcomes. Thus, in managing fisher expectations on the outcomes of stock enhancement, while recreational fishers may be aware of positive and negative outcomes, communicating the relative likelihood of positive and negative outcomes may be warranted.

The use of a two-phase approach firstly allowed fishers to describe their beliefs, without experts (*i.e.,* resource managers and scientists) imposing their assumptions to which fishers must respond. The belief elicitation approach afforded a reliable sample of the range of beliefs within the target fisher population. Secondly, measuring the strength and evaluation of elicited beliefs based on a wider sample of the fisher population provided more nuanced data in relation to fisher attitudes toward stock enhancement as a management approach. This two-phase method is a reliable means for identifying the complexities of fisher perceptions while minimising influence of manager or researcher assumptions on what fishers think. While the focus of this study is on a recreational crab fishery, this method could be applied to different fisheries (*i.e.,* different target species) as well as different fishery sectors, such as commercial or subsistence fisheries. Our findings and those from previous studies emphasise the importance of communication and engagement in fisheries management based on a firm understanding of the social dimensions of fishers (Mikalsen & Jentoft 2001, McPhee et al. 2002, Fulton et al. 2011, Sténs et al. 2016, Garlock & Lorenzen 2017). Adopting the two-phase method could help inform management more accurately of to whether fisher beliefs are aligned with those of fishery managers and the available scientific knowledge. This more nuanced information could contribute to more targeted communication and engagement, and thus avoid conflict and loss of support for management, and foster greater compliance with the regulations.

Chapter 7
General Discussion & Conclusions

Views at sunset from the main boat ramp at Nornalup Inlet in Walpole, south-western Australia.

Chapter 7

General Discussion and Conclusions

The aim of this thesis was to contribute to the understanding of the human dimensions (*e.g.,* fishers' perceptions on management approaches, fisher values and concerns on the state of the stocks, and local fisher knowledge) of small-scale fisheries (SSF). The blue swimmer crab fishery is one of the most popular recreational fisheries in the state of Western Australia and is also a very lucrative commercial SSF in Australia and in most regions of south-east Asia. This study was the first to explore the human dimensions of SSF in Western Australia and one of only a few studies on this topic in Australia and globally. To do so, this thesis describes the blue swimmer crab (*Portunus armatus*) fishery in south-western Australia and provides new insights into the values of recreational and commercial crab fishing, and identifies some of the challenges and potential opportunities for future sustainable management. Using an interdisciplinary approach, I analysed the following aspects of the blue swimmer crab fishery:

- Patterns of communication among stakeholders through a social network analysis (Chapter 2);
- The reliability and value of recreational fisher recollections to identify ecosystems change, as demonstrated in the biological changes influencing catches (Chapter 3);
- The concerns and management approaches supported by commercial and recreational fishers (Chapter 4);
- The perceived marginalisation of the small-scale commercial crab fishers by an expanding recreational sector (Chapter 5);
- Recreational fishers' beliefs and attitudes towards stock enhancement as a management approach (Chapter 6).

Detailed discussions of the specific research findings have been provided in the relevant data chapters, however, some major themes emerged from my research: i) Identification of historical change in the crab fishery through fisher perceptions and local fisher knowledge; ii) Views on stock enhancement as a management approach; and iii) Value of different communication modes for fishery management. After discussing these themes, I evaluate new directions for research on the human dimensions of the blue swimmer crab fishery and recreational fisheries more generally, and identify the implications of the findings for SSF, particularly those in Australia.

7.1. Fisher perceptions and local fisher knowledge

The collection of fisher perceptions on the blue swimmer crab fishery and its management (Chapter 4) provided a baseline for the human dimensions of this fishery in south-western Australia. In particular, the differences and similarities of recreational and commercial fishers brought important insights into the concerns and management approaches supported by each sector in several estuaries. Although their main concerns differed, *e.g.,* recreational fishers generally focused on overfishing, while commercial fishers called for a recreational fishing licence for recreational crab fishers whether fishing from shore or a boat (*i.e.,* hereafter called a recreational crab fishing licence), both sectors were worried about fishing pressure on stocks, and supported strategies to enhance compliance.

The support from fishers in both sectors for enhanced compliance was very strong in the Peel-Harvey Estuary, as illegal fishing is a significant threat to the sustainability of the blue swimmer crab fishery here. This is not surprising as this fishery has the highest levels of non-compliance recorded for any fishery in WA. Enforcing fishery regulations is challenging in this estuary due to its size, and the number of people fishing recreationally during the day and night. While some technologies are being trialed, such as the use of thermal cameras for night-time monitoring (Taylor et al. 2018), new approaches need to be developed to enhance our understanding of recreational fishing impact on fishery resources.

The lack of a times series data on recreational catch and effort for the blue swimmer crab fishery in the Peel-Harvey is consistent with recreational fisheries globally (Young et al. 2014). Most recreational fishing worldwide are unaccounted for, and very few data are available on the impact of recreational fishing activities on global stocks (Chapter 3). Though boat-based catches are monitored yearly in Western Australia (Malseed & Sumner 2001a, Ryan et al. 2017, 2019), the lack of data on shore-based landings masks the total number of recreational fishers, making it even harder to estimate recreational catches.

Another difficulty for the management of the recreational sector is information-sharing with resource users. The social network study (Chapter 2) suggested that findings from research were not shared as effectively as they might be across resource users and the broader community, because of differences in the way the information is communicated from key informants. For example, the Department of Primary Industries and Regional Development (DPIRD) communicated mainly via email or through published reports, and used social media infrequently, whereas recreational fishers preferred to receive information through face-to-face meetings and social media. This probably hinders the access to reliable information, as well as the communication between resource users and researchers and managers (Chapter 2). As in other data-limited fisheries, these challenges render the sustainable management of stocks challenging.

Globally, recreational fisheries are typically data-limited (Young et al. 2014, Hyder et al. 2018, Townhill et al. 2019), making it difficult to complete stock assessments and set harvest strategies and catch quotas for different sectors of a fishery. However, previous research has demonstrated that local fisher knowledge (LFK) might provide a good understanding of the past and current status of stocks (Johannes et al. 2000, Berkes 2003, Lozano-Montes et al. 2008, Frezza & Clem 2015). The lack of historical information has been identified as another challenge faced by most SSF globally, particularly in relation to recreational fisheries (Zeller et al. 2006) . Likewise, due to the lack of historical data, the status of the blue swimmer crab stocks prior to the start of intensive fishing, around the 1960s (Tull 1993), is unknown. The research in this thesis shows that recreational blue swimmer crab fishers perceived a decrease in the average size of crabs in south-western Australia over the last 40 years, particularly in the Peel-Harvey Estuary. This perceived change is consistent with quantitative biological data on size, published by the DPIRD for the period from 2006-2019, providing empirical evidence that the average size of blue swimmer crabs in the Peel-Harvey Estuary had declined since the beginning of the 20th century (Johnston et al. 2020). This supports the idea that recreational fishers' perceptions on change can be a reliable source of information for the blue swimmer crab fishery and potentially for other fisheries in Australia and elsewhere. The value of collecting local fisher knowledge is particularly important in data-poor scenarios (Thurstan et al. 2016a) and to pursue perceptions of change reported by resource users (Neis 1992, Johannes et al. 2000) . The results from my thesis also emphasized the importance of understanding information-sharing patterns between resource users and other stakeholders, and *vice versa*, to identify if current communication between network stakeholders allows for the collection of fisher perceptions as data (Chapter 2).

The evaluation of newspaper reports dating back to 1910 in Trove (*i.e.,* digitalised collection of the National Library of Australia) revealed that blue swimmer crabs have supported a significant fishery and that the fishery has had a remarkable cultural value to the community for many years. The historical documents in Trove are also consistent with the findings on major concerns on the fishery identified in Chapters 4 and 6, which have not changed greatly over the last 70 years (*e.g.,* concerns over compliance, overfishing and pollution of the estuaries). It also provides evidence that recreational fishers were, and are still interested, in being involved with the fishery and understanding the regulations in place to manage fishing activities. For this thesis, the use of LFK, along with other data sources, largely focused on the identification of biological change (*i.e.,* biological dimensions of blue swimmer crabs). However, LFK methods could be used to refine our understanding of fisheries' human dimensions (e.g., social and cultural values of a fishery, fisher perceptions) and gather data on perceptions of management and fishery values. This method could be applied to other recreational fisheries in WA, such as shore fishing for whiting (*Sillago* spp.) and Australian herring (*Arripes georgianus*), and other data-limited fishery sectors elsewhere.

7.2. Views on stock enhancement as a management option

Generally, recreational fishers tend to support fisheries stock enhancement as a management tool, though often they are not aware of the potential economic costs and biological trade-offs of this approach to the stocks and the ecosystem they depend on (Camp et al. 2014). Similarly, recreational crab fishers in south-western Australia supported stock enhancement (Chapter 6). However, unlike other studies, the two-phase approach applied in this thesis found that recreational fishers understood the benefits and drawbacks of such a strategy, though they believed that the drawbacks were less likely to occur than the benefits. This is possibly due to a lack of deeper understanding of stock enhancement as a management strategy and the potential for density-dependent effects to lead to a slower growth and an increase in the catches of under-sized crabs. As highlighted in the description of the fishery network (Chapter 2), better communication on the rationale for different management strategies might enhance fishers understanding of the regulations that are currently in place or those that are being considered for future implementation. If fishers understand the reasoning behind managers' choice of one policy over another, they may have a greater chance to actively participate as part of the fishery network and will likely better acknowledge and follow management regulations, resulting in a reduction in compliance issues. Greater fisher understanding of management regulations and the adoption of co-management as a strategy to manage fisheries would enhance fishers' trust in the management system. By increasing trust among resource users and managers, social capital is enhanced, facilitating collaboration and the sustainable management of such fishery (Grafton 2005, Armitage et al. 2009, Anbleyth-Evans & Lacy 2019).

Effective communication on management regulations is a common challenge in fisheries management, particularly for the recreational sector. Recreational fishers are generally not part of a wider, formal organisation, but rather, tend to be individuals or small, discrete social groups who mostly do not interact with each other (Cumming et al. 2006). Sharing information efficiently is therefore more difficult with this sector, than with the commercial sector, which are often part of the same formal organisation, like the Mandurah Licensed Fishermen Association (MLFA) in the Peel-Harvey Estuary and the Western Australian Fisheries Industry Council (WAFIC). Annual meetings are also a venue to share information among fishery stakeholders. Though annual audits for all stakeholders have been organised as part of the MSC certification, commercial fishers also have an annual meeting with fisheries managers and researchers, providing an additional platform for this sector to communicate and engage with management (Chapter 2).

Finally, this study highlighted a parallelism between fishers' concerns on the stocks (Chapter 4), and the evidence showing a decrease in the average size of crabs over time (Chapter 3). The application of stock enhancement as a management approach is highly complex and depends on many factors. The average size of crabs in the Peel-Harvey Estuary has decreased through time, though abundance has not changed significantly. This has resulted in great numbers of small crabs, an issue that has already been reported by crab fishers (Poulton 2018). Using stock enhancement would add a significant number of undersized crabs to the system, thus exacerbating this issue. This may not be sustainable as ecologically it could limit resources for the crabs population, it could be quite costly, and finally, resource users could be disappointed.

7.3. Value of communication for management

Decision making in fisheries management is influenced by communication and collaboration between fishery stakeholders (Sueur et al. 2012). The analysis of communication patterns (*i.e.,* information sharing and receiving information) in the Peel-Harvey blue swimmer crab fishery showed that the DPIRD and the only commercial fishing association (MLFA) were key for information sharing, shaping the centralised structure of the fishery network (Chapter 2). Though communication paths existed between all groups, some of these interactions were not very important for sharing or receiving information. The various organisations forming the network had different ways of communicating. Research and management groups shared information mostly via email and through reports, whereas resource users and the general community preferred to communicate via face-to-face meetings, phone or social media. These different modes of communication used by all groups are consistent with the general pattern described for different social groups (Correa et al. 2010). Likewise, different types of information might be efficiently shared in different ways. Thus, depending on the type of information, and the social group receiving it, there are many approaches to communicate efficiently. Based on these insights, fishery stakeholders should target the mode of communication according to the target group (and the preferred mode of communication of such group) and the type of information being communicated. For example, more planning from researchers and managers to have a profile at planned events is needed, such as Crab Fest, as well as greater promotion of such events through targeted social media. This would amplify the potential of such events for raising awareness among recreational fishers on the science and management on the fishery Additionally, better promotion of information events, different mechanisms for advertising them and a greater inclusion of bridging organisations (*i.e.,* those organisations with the greatest capacity to connect different groups that would otherwise not be connected, like the Peel-Harvey Catchment Council) would potentially improve resource users' awareness on the sustainability and fisheries science that has been used to decide on the management approaches in place.

Through this thesis, I highlighted where the means of communication were likely to have effected information-sharing among fishery stakeholders, for example to publicise events, or raise awareness on the fishery research among the recreational sector. Local NGOs, such as the Peel-Harvey Catchment Council (PHCC) were flagged as having a high bridging potential*, i.e.,* the ability to link groups that otherwise would not be connected. This suggests that such organisations could potentially have a larger role in sharing information on the fishery and its management to fishers and the local community. In the Swan and Leschenault regions, other organisations, such as natural resource management groups may have similar bridging capacity in their fishery networks to that of the PHCC in the Peel region. If so, consideration could be given to integrating these in the local fisheries networks, particularly by including such organisations in the communication pathways for the local fisheries.

Interviews with the commercial blue swimmer crab fishers identified that this sector felt marginalised by a continuously growing recreational sector, and by some of the recently implemented management approaches in place (Chapter 5). As in other regions of Australia (King 2018), recreational fishing in WA is one of the most popular recreational activities. In fact, Western Australians participate in recreational fishing activities to a greater extent than Australians in any other state (Ryan et al. 2019) and much more than most developed countries (10.5%; Arlinghaus et al., 2015). When recreational and commercial fishing activities occur in the same area, it is not uncommon for conflicts to arise between sectors (West & Gordon 1994, Kearney 2002, Bower et al. 2014, Boucquey 2017, King et al. 2019). Commercial fishers identified that a shore-based recreational fishing licence would be a valuable addition to ensuring the sustainability of the stocks and petitioned the WA government on this proposal. The absence of such a license from the recent management package for crabs in south-western Australia (DPIRD 2018), combined with a new buyout of commercial licences in the Peel-Harvey Estuary, accentuated the existing tensions between the commercial and recreational sector and increased the feeling of marginalisation in the commercial sector (Chapter 5).

Interviews with the recreational sector highlighted a disconnect between the value placed on local fish product by most recreational fishers when consuming seafood and the commercial industry operating in the region (Chapter 5). Indeed, recreational fishers seemed to be missing the link between their values supporting local produce, and the means to achieve it. Better communication on the management of the fishery, the sustainability assessments that it undergoes, and the meaning and significance of the third party Marine Stewardship Certification (MSC) for sustainability (van Putten et al., 2020), might reduce such disconnects and enhance the social acceptability of the commercial SSF among the recreational fishing community and local seafood consumers (see also Chapter 2).

In theory, communications to the recreational sector should be led by DPIRD and Recfishwest, the two organisations managing and representing recreational fishers in WA (respectively). However, the network analysis demonstrated that the communication role of Recfishwest with recreational fishers was not always efficient. Other existing groups, such as the PHCC might be able to contribute to the communication with the recreational sector based in the Peel region and to raising awareness of the science supporting the fishery and its sustainability among the local community. Additionally, other initiatives, such as citizen science projects on the fishery might also be a good way for sharing information among the recreational fishing sector and the local community. Currently, the "True Blue Swimmer Supporter" project is the only initiative that resembles a citizen science project. This program collects information through voluntary log books recording fishers catches (Harris et al. 2017) and covers the Swan-Canning, and Leschenault estuaries, and the Bunbury region, but not the Peel-Harvey Estuary.

7.4. Further research and recommendations

While new, promising technologies to monitor recreational activities are being developed, such as video monitoring of boat ramps and night video stations (Taylor et al. 2018, Desfosses et al. 2019), I have identified various key elements, as well as challenges and opportunities to sustainably manage the blue swimmer crab fishery in south-western Australia (Figure 7.1). Based on these findings, I make the following recommendations:

1. **Introduction of a crab recreational fishing licence**.

   A crab recreational fishing licence covering shore-based and boat-based crab fishers would enable managers and scientists to collect fishers' contact details, thus facilitating the organisation and delivery of future surveys, research findings and overall enhancing information-sharing from managing bodies to the recreational sector (*i.e.*, top-down communication). It would also provide a comprehensive list of people to canvas for volunteers to complete logbooks providing data on their catches, fishing effort and size of crabs caught, which would enhance the monitoring of the state of the fishery periodically.

2. **A citizen science project to enhance the monitoring capacity of fisheries officers.**

   In addition to further researching the human dimensions of non-compliance among recreational fishers (Thomas et al. 2016, Boonstra et al. 2017), a citizen science project to monitor illegal activities, and collect social-ecological data would enhance the monitoring of recreational fishing activities. Despite the challenges inherent in the development and delivery of citizen science projects (Conrad & Hilchey 2011), these are recognized as effective tools for involving fishing communities in science (Conrad & Hilchey 2011, Fulton et al. 2019). In fact, this type of initiative has been previously applied in WA through the Volunteer Fisheries Liaisons Officer (VFLO) program, which started in 1995 and ran for over 10 years. This initiative engaged more than 600 volunteers throughout the state until its termination in 2007 and collected information on the catches, sizes and fishing location of 226 species caught by recreational fishers. It was considered vital for monitoring local fisheries and raising awareness of local recreational fishing rules and fisheries sustainability among the local community (Rogers 2003, Green 2009).

The quality and reliability of the data collected by volunteers through this initiative had to be corrected by researchers for its use, which is a common drawback of citizen science projects (Conrad & Hilchey 2011). After 12 years, the program was terminated because of a lack of resources to maintain the collection and verification of these data. In the future, an efficient training program with a thorough methodology for data collection, its processing and delivery of feedback to volunteers should be developed prior to implementing the project. Indeed, if the data collection methodology and resulting dataset is enhanced, it is likely that the quality and overall reliability of such dataset will be greatly enhanced (Smallwood et al. 2010). A citizen science program, such as the VFLO, could potentially be a good initiative aiming to increase compliance, while efficiently raising awareness on regulations and sustainability of fisheries by bridging information between scientists, managers and the fishers (see also Chapter 2). Such program could focus on blue swimmer crab catches in the Peel-Harvey Estuary or could include other species and cover a greater area in WA.

3. **Stock enhancement is not the most socially sustainable, or economically viable option in the long term**.

The issue of using stock enhancement as a management tool to increase yields for fishers is complex and ecological outcomes might differ between systems, due to density dependence effects. Previous research on blue swimmer crabs has advocated for the enhancement of stocks to replenish and maintain crab populations, particularly in Cockburn Sound where crab stocks have been severely depleted and the commercial fishery has been closed since 2014 (Johnston et al. 2020). Trials on aquaculture-based enhancement with portunids have been conducted elsewhere. For example, in Chesapeake Bay in the USA, trials with small-scale releases demonstrated that in certain habitats and seasons, stock enhancement had the potential to be successful (Tweedley et al. 2017). However, these trials faced various challenges, which are inherent to the aquaculture of portunids. For example, studies in Malaysia and in WA, have previously reported the cost of aquaculture and crab cannibalism as significant barriers to enhancing portunid stocks (Azra & Ikhwanuddin 2015, Jenkins et al. 2018). Despite the high value of blue swimmer crabs throughout south-east Asia and Australia, and the need to recover some overfished or collapsed populations (Johnston et al. 2011b, Kunsook et al. 2014, Seafood Watch Consulting Researcher 2018, Prince et al. 2020), no commercial-scale restocking program has been initiated in Australia (Jenkins et al. 2018). Additionally, this thesis identified that fishers' support for stock enhancement was based on an incomplete understanding of the potential costs and benefits of stocking.

4. Use of recreational and commercial local fisher knowledge (LFK) as a means of monitoring of the human dimensions of fisheries.

Most studies on LFK have used commercial fishers' recollections to estimate a change in the fishery or the environment where the fishery operates (Papworth et al. 2009, Zukowski et al. 2011, Ulman & Pauly 2016, Anbleyth-Evans & Lacy 2019, Berkström et al. 2019, Colloca et al. 2020). These studies have mainly focussed on commercial LFK, rather than on recreational LFK (Thurstan et al. 2017, Pita et al. 2020). This thesis is one of the few studies where LFK from recreational fishers has been matched with historical records and independent quantitative data on sizes to investigate the reliability of recreational fishers' knowledge. Results showed that recreational fishers' perceptions of reduced crab size in the Peel-Harvey were consistent with the other data sources. I suggest that LFK methods could be used to refine our understanding of fisheries' human dimensions (e.g., social and cultural values of a fishery, fisher perceptions) and gather data on perceptions of change, management and fishery values. This method could be applied to other recreational fisheries in WA, such as shore fishing for whiting (*Sillago* spp.) and Australian herring (*Arripes georgianus*), and other data-limited fishery sectors elsewhere.

5. **Developing a structured process for the collection, classification and analysis of information on the human dimensions.**

   To ensure that the collection of information on fisheries' human dimensions from fisheries is effective, such as fishers' perceptions data, a framework for the collection, verification and analysis of bottom-up information (*i.e.*, from fishers to managers and scientists) is needed. The development of such a structured process to enable resource users to share information to researchers and managers is crucial for understanding the fishers and fishery social-ecological dynamics (Putnam 2000, Grafton 2005). These data are essential for enhancing the information available on the fishery stocks and its environment, as well as the coordination and collaboration between fishers and other stakeholders (Putnam 2000). Developing the understanding of bottom-up information sharing, in the same way as top-down communication in the fishery could also reduce potential conflicts between fishery sectors (see Chapter 2 and Chapter 5) and overall facilitate the use of a co-management approach, where resource users are included as part of decision making (Pomeroy 1995, Grafton 2005).

6. **Improvement of the viability and public engagement of the commercial fishing sector, in the Peel-Harvey region**.

   A comparative analysis between the structure of the Peel-Harvey commercial crab fishery and other SSFs in Australia or elsewhere could also benefit the future management of the fishery and its sustainability. For example, the blue crab (*Callinectes sapidus*) fishery in Chesapeake Bay or the blue swimmer crab (*Portunus pelagicus*) in south-east Asia, take place in very different social-ecological settings and as a consequence face different challenges and use different tools to overcome these (Prince et al. 2020). Understanding these similarities and differences could help Peel-Harvey commercial fishers find alternative, new ways to approach issues affecting their fishery. In fact, Chapter 2 showed that most stakeholders of the blue swimmer crab fishery are based in the Peel or Perth regions in WA. This limits the acquisition of new knowledge and new ideas in the fishery network. Particularly for the small-scale commercial fishers, the creation of a communication platform with commercial fishers operating in other fisheries in Australia and elsewhere might enable individual fishers and fishing communities to find new ways of getting involved in the fishery network and management.

One potential pathway could be the introduction of a Community Supported Fisheries (CSFs) initiative in Australia. Interest in this initiative is growing, notably in South Australia (SA), where various small-scale commercial fisheries targeting Australian herring (*A. georgianus*) and snook (*Sphyraena novaehollandie*), among other species. These commercial fishers in SA were facing similar challenges to commercial SSF in North Carolina (USA), including resource-sharing conflict with the recreational sector, low support from the community, and ageing boats and gear (McPhail, 2020). After several meetings between SA commercial small-scale fishers with fisher representatives from the USA. and visits to the CSFs based in North Carolina, some SSFs in SA embraced the CSF concept and created FairFish (see link), an alternative business model for SSF to sell their fish as a CSF. This new approach promotes local fisheries while reducing the carbon footprint associated with fisheries and marketing new species as seafood that otherwise would be discarded, thus enhancing the sustainability of SSFs in SA (Campbell et al. 2014, McClenachan et al. 2014).

7. **Raising awareness among the recreational sector on sustainability and local commercial fisheries**.

The marginalisation of small-scale fisheries is a global challenge in fisheries management, though it is most often reported in developing countries and has been frequently described for small- and large-scale fishing sectors, with the large-scale, industrial fisheries taking over the artisanal traditions (Pauly 2006, Sowman 2006, FAO 2018b). More communication with the recreational sector through, for example, raising awareness on the management and sustainability of the commercial fishery will enhance the understanding on the sustainability of the fishery, the science supporting the current management and general fishing rules (see Chapter 2 and Chapter 4). This strategy might improve recreational fishers understanding of their impact on the stocks and generally the pressures affecting the fishery. This will also potentially reduce fishers disconnect between the local seafood product they support, and the commercial fishers catching it. Overall, this would enhance the social licence to operate for commercial fishers, and as a result reduce the feeling of marginalisation expressed by the commercial sector (Chapter 5).

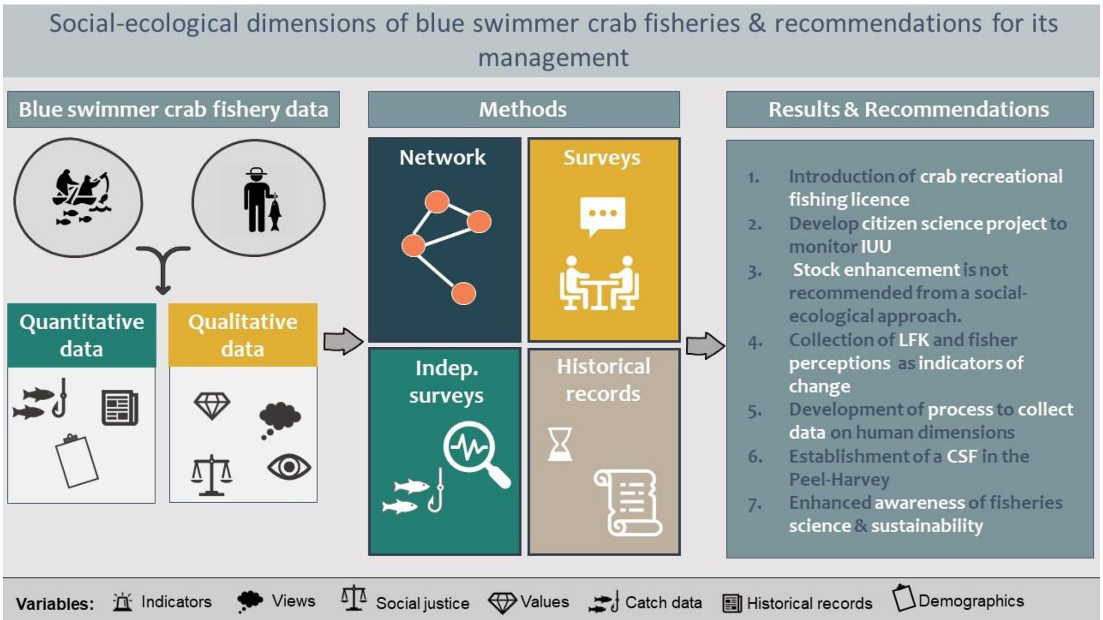


Figure 7.1. Infographic summarising the different types of data collected through this research and subsequent recommendations for the future research and management of the blue swimmer crab fishery in south-western Australia.

7.5. Conclusion

The overall aim of this thesis was to contribute to the understanding of the human dimensions of SSF (Figure 7.1). The study of blue swimmer crab (*Portunus armatus*) fisheries in south-western Australia is the first baseline study of a selection of human dimensions of a WA fishery, and provides an important contribution to understanding fisheries' human dimensions. The research in this thesis has identified fishers views on the management and the status of the fishery, and some of their local fisher knowledge (Figure 7.1). The interdisciplinary method applied could undoubtedly be refined and expanded, depending on the fishery and aims of the research. Even so, the findings described in this thesis have the potential to provide direction for future research and management of blue swimmer crab fisheries in this region, and other data-limited and small-scale fisheries elsewhere. The knowledge gained from this thesis identifies the importance of fishers' role in fisheries networks and management, and provides a significant contribution to addressing the issues relating to the human dimensions of small-scale sustainable fisheries. This research recognises and supports the need for enabling fishers to have a greater contribution to the stewardship of small-scale fisheries.

References

ABARES (2018) Australia's trade in fisheries and aquaculture products 2018. https://www.agriculture.gov.au/abares/research-topics/fisheries/fisheries-and-aquaculture-statistics/trade-2018 (accessed 24 February 2021)

ABS (2017) 2016 Census quickstats from the Australian Bureau of Statistics. http://www.censusdata.abs.gov.au/census_services/getproduct/census/2011/quickstat/306 (accessed 12 October 2021)

Admiraal R, Handcock MS (2015) A log-linear modelling approach to assessing the consistency of ego reports of dyadic outcomes with applications to fertility and sexual partnerships. J R Stat Soc Ser A Stat Soc 178:363–382.

Aguilera SE, Cole J, Finkbeiner EM, Le Cornu E, Ban NC, Carr MH, Cinner JE, Crowder LB, Gelcich S, Hicks CC, Kittinger JN, Martone R, Malone D, Pomeroy C, Starr RM, Seram S, Zuercher R, Broad K (2015) Managing small-scale commercial fisheries for adaptive capacity: Insights from dynamic social-ecological drivers of change in monterey bay. PLoS One 10:1–22.

Ajzen I (1991) The theory of planned behavior. Orgnizational Behav Hum Decis Process 50:179–211.

Alexander KA, Hobday AJ, Cvitanovic C, Ogier E, Nash KL, Cottrell RS, Fleming A, Fudge M, Fulton EA, Frusher S, Kelly R, Macleod CK, Pecl GT, Van Putten I, Vince J, Watson RA (2019) Progress in integrating natural and social science in marine ecosystem-based management research. Mar Freshw Res 70:71–83.

Alexander SM, Armitage D, Charles A (2015) Social networks and transitions to co-management in Jamaican marine reserves and small-scale fisheries. Glob Environ Chang 35:213–225.

Alós J, Campos-Candela A, Arlinghaus R (2019) A modelling approach to evaluate the impact of fish spatial behavioural types on fisheries stock assessment. ICES J Mar Sci 76:489–500.

Anbleyth-Evans J, Lacy SN (2019) Feedback between fisher local ecological knowledge and scientific epistemologies in England: building bridges for biodiversity conservation. Marit Stud 18:189–203.

Anderson DK, Ditton RB, Hunt KM (2007) Measuring angler attitudes toward catch-related aspects of fishing. Hum Dimens Wildl 12:181–191.

Anderson JL, Anderson CM, Chu J, Meredith J, Asche F, Sylvia G, Smith MD, Anggraeni D, Arthur R, Guttormsen A, McCluney JK, Ward T, Akpalu W, Eggert H, Flores J, Freeman MA, Holland DS, Knapp G, Kobayashi M, Larkin S, MacLauchlin K, Schnier K, Soboil M, Tveteras S, Uchida H, Valderrama D (2015) The fishery performance indicators: A management tool for triple bottom line outcomes. PLoS One 10:1–20.

Andrews WR, Papacostas KJ, Foster J (2018) A comparison of recall error in recreational fisheries surveys with one- and two-month reference periods. North Am J Fish Manag 38:1284–1298.

Anseel F, Lievens F, Schollaert E, Choragwicka B (2010) Response rates in organizational science, 1995-2008: A meta-analytic review and guidelines for survey researchers. J Bus Psychol 25:335–349.

Arlinghaus R (2006) Overcoming human obstacles to conservation of recreational fishery resources, with emphasis on central Europe. Environ Conserv 33:46–59.

Arlinghaus R, Abbott JK, Fenichel EP, Carpenter SR, Hunt LM, Alós J, Klefoth T, Cooke SJ, Hilborn R, Jensen OP, Wilberg MJ, Post JR, Manfredo MJ (2019) Governing the recreational dimension of global fisheries. Proc Natl Acad Sci U S A 116:5209–5213.

Arlinghaus R, Cooke SJ (2005) Global impact of recreational fisheries. Science 307:1561–1562.

Arlinghaus R, Cooke SJ, Sutton SG, Danylchuk AJ, Potts W, de Freire KMF, Alós J, da Silva ET, Cowx IG, van Anrooy R (2016) Recommendations for the future of recreational fisheries to prepare the social-ecological system to cope with change. Fish Manag Ecol 23:177–186.

Arlinghaus R, Tillner R, Bork M (2015) Explaining participation rates in recreational fishing across industrialised countries. Fish Manag Ecol 22:45–55.

Armitage DR, Plummer R, Berkes F, Arthur RI, Charles AT, Davidson-Hunt IJ, Diduck AP, Doubleday NC, Johnson DS, Marschke M, McConney P, Pinkerton EW, Wollenberg EK (2009) Adaptive co-management for social-ecological complexity. Front Ecol Environ 7:95–102.

Asche F, Garlock TM, Anderson JL, Bush SR, Smith MD, Anderson CM, Chu J, Garrett KA, Lem A, Lorenzen K, Oglend A, Tveteras S, Vannuccini S (2018) Three pillars of sustainability in fisheries. Proc Natl Acad Sci U S A 115:11221–11225.

Ayers AL, Hospital J, Boggs C (2018a) Bigeye tuna catch limits lead to differential impacts for Hawai'i longliners. Mar Policy 94:93–105.

Ayers AL, Kittinger JN, Vaughan MB (2018b) Whose right to manage? Distribution of property rights affects equity and power dynamics in comanagement. Ecol Soc 23:37.

Azra MN, Ikhwanuddin M (2015) Larval culture and rearing techniques of commercially important crab, Portunus pelagicus (Linnaeus, 1758): Present status and future prospects. Songklanakarin J Sci Technol 37:135–145.

Bailey JL, Liu Y, Davidsen JG (2016) Bridging the gap between fisheries science and society: exploring fisheries science as a social activity. ICES J Mar Sci J du Cons 74:fsw203.

Barclay K (2012) The social in assessing for sustainability. Fisheries in Australia. Cosmop Civ Soc An Interdiscip J 4:38–53.

Barclay K, Voyer M, Mazur N, Payne AM, Mauli S, Kinch J, Fabinyi M, Smith G (2017) The importance of qualitative social research for effective fisheries management. Fish Res 186:426–438.

Barnes-Mauthe M, Gray SA, Arita S, Lynham J, Leung PS (2015) What determines social capital in a social–ecological system? Insights from a network perspective. Environ Manage 55:392–410.

BDO-Econsearch (2020) Economic and social indicators for the Queensland blue swimmer crab fishery, 2017/18 and 2018/19. A report to fisheries Queensland. Adelaide.

Bell JD, Leber KM, Blankenship HL, Loneragan NR, Masuda R (2008) A new era for restocking, stock enhancement and sea ranching of coastal fisheries resources. Rev Fish Sci 16:1–9.

Bellanger M, Speir C, Blanchard F, Brooks K, Butler JRA, Crosson S, Fonner R, Gourguet S, Holland DS, Kuikka S, Le Gallic B, Lent R, Libecap GD, Lipton DW, Nayak PK, Reid D, Scemama P, Stephenson R, Thébaud O, Young JC (2020) Addressing marine and coastal governance conflicts at the interface of multiple sectors and jurisdictions. Front Mar Sci 7:1–21.

Bender MG, Machado GR, De Azevedo Silva PJ, Floeter SR, Monteiro-Netto C, Luiz OJ, Ferreira CEL (2014) Local ecological knowledge and scientific data reveal overexploitation by multigear artisanal fisheries in the Southwestern Atlantic. PLoS One 9:9.

Bennett NJ (2018) Navigating a just and inclusive path towards sustainable oceans. Mar Policy 97:139–146.

Berdej SM, Armitage DR (2016) Bridging organizations drive effective governance outcomes for conservation of Indonesia's marine systems. PLoS One 11:1–25.

Bergseth BJ, Williamson DH, Russ GR, Sutton SG, Cinner JE (2017) A social–ecological approach to assessing and managing poaching by recreational fishers. Front Ecol Environ 15:67–73.

Berkes F (2003) Alternatives to conventional management: Lessons from small-scale fisheries. Environments 31:5–20.

Berkes F (2017) Environmental governance for the anthropocene? Social-ecological systems, resilience, and collaborative learning. Sustain 9:12.

Berkes F, Folke C (2000) Linking social and ecological systems management practices and social. Berkes F, Folke C (eds) Cambridge University Press.

Berkström C, Papadopoulos M, Jiddawi NS, Nordlund LM (2019) Fishers' local ecological knowledge (LEK) on connectivity and seascape management. Front Mar Sci 6:1–10.

Bodin Ö, Crona BI (2009) The role of social networks in natural resource governance: What relational patterns make a difference? Glob Environ Chang 19:366–374.

Bodin Ö, Norberg J (2005) Information network topologies for enhanced local adaptive management. Environ Manage 35:175–193.

Bodin Ö, Tengö M (2012) Disentangling intangible social-ecological systems. Glob Environ Chang 22:430–439.

Boonstra WJ, Birnbaum S, Björkvik E (2017) The quality of compliance: investigating fishers' responses towards regulation and authorities. Fish Fish 18:682–697.

Botto-Barrios D, Saavedra-Díaz LM (2020) Assessment of Ostrom's social-ecological system framework for the comanagement of small-scale marine fisheries in Colombia: From local fishers' perspectives. Ecol Soc 25.

Boucquey N (2017) 'That's my livelihood, it's your fun': The conflicting moral economies of commercial and recreational fishing. J Rural Stud 54:138–150.

Bower SD, Nguyen VM, Danylchuk AJ, Jr. TDB, Cooke SJ (2014) Inter-sectoral conflict and recreational fisheries of the developing world: Opportunities and challenges for co-operation. In: *Enhancing Stewardship in Small-Scale Fisheries: Practices and Perspectives*. McConney P, Medeiros R, Pena M (eds) Too Big To Ignore, p 88–97

Broadley AD, Tweedley JR, Loneragan NR (2017) Estimating biological parameters for penaeid restocking in an Australian temperate estuary. Fish Res 186:488–501.

Brooks K, Schirmer J, Pascoe S, Triantafillos L, Jebreen E, Cannard T, Dichmont CM (2015) Selecting and assessing social objectives for Australian fisheries management. Mar Policy 53:111–122.

Brown TJ, Ham SH, Hughes M (2010) Picking up litter: An application of theory-based communication to influence tourist behaviour in protected areas. J Sustain Tour 18:879–900.

Brummett RE, Beveridge MCM, Cowx IG (2013) Functional aquatic ecosystems, inland fisheries and the Millennium Development Goals. Fish Fish 14:312–324.

Bundy A, Chuenpagdee R, Jentoft S, Mahon R (2008) If science is not the answer, what is? An alternative governance model for the world's fisheries. Front Ecol Environ 6:152–155.

Butts CA (2019) Package 'sna'. https://cran.rproject.org/web/packages/sna/index.html

Butts CA, Hunter D, Handcock M, Bender-deMoll S, Horner J, Wang L, Butts MCT (2019) Package 'network'. https://cran.r-project.org/web/packages/network/index.html

Camp E V., Larkin SL, Ahrens RNM, Lorenzen K (2017) Trade-offs between socioeconomic and conservation management objectives in stock enhancement of marine recreational fisheries. Fish Res 186:446–459.

Camp E V., Lorenzen K, Ahrens RNM, Allen MS (2014) Stock enhancement to address multiple recreational fisheries objectives: An integrated model applied to red drum Sciaenops ocellatus in Florida. J Fish Biol 85:1868–1889.

Campbell LM, Boucquey N, Stoll J, Coppola H, Smith MD (2014) From Vegetable Box to Seafood Cooler: Applying the Community-Supported Agriculture Model to Fisheries. Soc Nat Resour 27:88–106.

Caputi N, G J, Peace A (2014) The marine heat wave off Western Australia during the summer of 2010/11 – 2 years on.

Cárcamo PF, Garay-Flühmann R, Gaymer CF (2014) Collaboration and knowledge networks in coastal resources management: How critical stakeholders interact for multiple-use marine protected area implementation. Ocean Coast Manag 91:5–16.

Carpenter SR, Mooney HA, Agard J, Capistrano D, DeFries RS, Diaz S, Dietz T, Duraiappah AK, Oteng-Yeboah A, Pereira HM, Perrings C, Reid W V., Sarukhan J, Scholes RJ, Whyte A (2009) Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. Proc Natl Acad Sci 106:1305–1312.

Carr LM, Heyman WD (2012) 'It's about seeing what's actually out there': Quantifying fishers' ecological knowledge and biases in a small-scale commercial fishery as a path toward co-management. Ocean Coast Manag 69:118–132.

Carter N, Bryant-Lukosius D, Dicenso A, Blythe J, Neville AJ (2014) The use of triangulation in qualitative research. Oncol Nurs Forum 41:545–547.

Cashion T, Al-Abdulrazzak D, Belhabib D, Derrick B, Divovich E, Moutopoulos DK, Noël SL, Palomares MLD, Teh LCL, Zeller D, Pauly D (2018) Reconstructing global marine fishing gear use: Catches and landed values by gear type and sector. Fish Res 206:57–64.

Chizinski CJ, Martin DR, Shizuka D, Pope KL (2018) Bipartite networks improve understanding of effects of waterbody size and angling method on angler-fish interactions. Can J Fish Aquat Sci 75:72–81.

Christensen J (2016) Perspectives on oceans past: A handbook of marine environmental history. Perspect Ocean Past:1–211.

Christensen J (2009) Recreational Fishing and Fisheries Management: a HMAP Asia Project Paper.

Christensen J, Jackson G (2014) Shark Bay Snapper: Science, Policy, and the Decline and Recovery of a Marine Recreational Fishery. In: *Historical Perspectives of Fisheries Exploitation in the Indo-Pacific*. Christensen J, Tull M (eds) MARE Publication Series, p 251–268

Chuenpagdee R, Jentoft S (2019) Small-scale fisheries: Too important to fail. In: *The future of Ocean governance and capacity development,*. Brill Nijhoff, p 349–353

Cisneros-Montemayor AM, Zetina-Rejón MJ, Espinosa-Romero MJ, Cisneros-Mata MA, Singh GG, Fernández-Rivera Melo FJ (2020) Evaluating ecosystem impacts of data-limited artisanal fisheries through ecosystem modelling and traditional fisher knowledge. Ocean Coast Manag 195.

Clarke KR, Gorley R, Sommerfield PJ, Warwick RM (2014) Change in marine communities - statistical analysis.

Cohen PJ, Allison EH, Andrew NL, Cinner J, Evans LS, Fabinyi M, Garces LR, Hall SJ, Hicks CC, Hughes TP, Jentoft S, Mills DJ, Masu R, Mbaru EK, Ratner BD (2019) Securing a just space for small-scale fisheries in the blue economy. Front Mar Sci 6:1–8.

Cohen PJ, Evans LS, Mills M (2012) Social networks supporting governance of coastal ecosystems in Solomon Islands. Conserv Lett 5:376–386.

Colloca F, Carrozzi V, Simonetti A, Di Lorenzo M (2020) Using Local Ecological Knowledge of Fishers to Reconstruct Abundance Trends of Elasmobranch Populations in the Strait of Sicily. Front Mar Sci 7:1–8.

Connelly NA, Knuth BA (2002) Using the coorientation model to compare community leaders ' and local residents ' views About Hudson River ecosystem restoration. Environ Manage 15:933–948.

Conrad CC, Hilchey KG (2011) A review of citizen science and community-based environmental monitoring: Issues and opportunities. Environ Monit Assess 176:273–291.

Cooke SJ, Cowx IG (2006) Contrasting recreational and commercial fishing: Searching for common issues to promote unified conservation of fisheries resources and aquatic environments. Biol Conserv 128:93–108.

Cooke SJ, Lennox RJ, Bower SD, Horodysky AZ, Treml MK, Stoddard E, Donaldson LA, Danylchuk AJ (2017) Fishing in the dark: The science and management of recreational fsheries at night. Bull Mar Sci 93:519–538.

Copsey J, Rajaonarison L, Randriamihamina R, Rakotoniaina L (2009) Voices from the marsh: Livelihood concerns of fishers and rice cultivators in the Alaotra wetland. Madagascar Conserv Dev 4:25–30.

Correa T, Hinsley AW, de Zúñiga HG (2010) Who interacts on the Web?: The intersection of users' personality and social media use. Comput Human Behav 26:247–253.

Costanza R, D'Arge R, de Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill R V., Paruelo J, Raskin RG, Sutton P, van den Belt M (1997) The value of the world's ecosystem services and natural capital. Nature 387:253–260.

Costello C, Ovando D, Hilborn R, Gaines SD, Deschenes O, Lester SE (2012) Status and solutions for the world's unassessed fisheries. Science 338:517–520.

Craik W (1989) Management of Recreational Fishing in the Great Barrier Reef Marine Park. GBR Mar Park Auth - Tech Memo No 23:1–5.

CSIRO (2020) Climate Change in Australia. https://www.climatechangeinaustralia.gov.au/en/ (accessed 12 October 2020)

Cullen-Knox C, Haward M, Jabour J, Ogier E, Tracey SR (2017) The social licence to operate and its role in marine governance: Insights from Australia. Mar Policy 79:70–77.

Cullen-Unsworth LC, Nordlund LM, Paddock J, Baker S, McKenzie LJ, Unsworth RKF (2014) Seagrass meadows globally as a coupled social-ecological system: Implications for human wellbeing. Mar Pollut Bull 83:387–397.

Cumming GS, Cumming DHM, Redman CL (2006) Scale mismatches in social-ecological systems: Causes, consequences, and solutions. Ecol Soc 11.

Cvitanovic C, van Putten EI, Hobday AJ, Mackay M, Kelly R, McDonald J, Waples K, Barnes P (2018)

Building trust among marine protected area managers and community members through scientific research: Insights from the Ningaloo Marine Park, Australia. Mar Policy 93:195–206.

Department of Agriculture (2015) Australia's seafood trade. Canberra.

Desfosses CJ, Adams P, Blight SJ, Smallwood CB, Taylor SM (2019) The feasibility of using remotely piloted aircraft systems (RPAS) for recreational fishing surveys in Western Australia. Fisheries Occasional Publication No. 137, Department of Primary Industries and Regional Development, Western Australia. Perth.

Dickey A, Grenié M, Thompson R, Selzer L, Strbenac D (2019) Package 'igraph'. https://cran.r-project.org/web/packages/igraph/index.html

DPAW (2000) 'Summer surprise'. The Swan River blue-green algal bloom.

DPIRD (2019) Department of Primary Industries and Regional Development annual report 2019. Perth.

DPIRD (2016) Interfering with commercial crab fishing gear is costly. http://www.fish.wa.gov.au/Pages/news_archive/Interfering-with-commercial-crab-fishing-gear-is-costly.aspx (accessed 5 October 2020)

DPIRD (2018) Protecting breeding stock levels of the blue swimmer crab resource in the south west. Perth.

Drew JA (2005) Use of traditional ecological knowledge in marine conservation. Conserv Biol 19:1286–1293.

Duffy B, Smith K, Terhanian G, Bremer J (2005) Comparing data from online and face-to-face surveys. Int J Mark Res 47:615–630.

Edgar GJ, Ward TJ, Stuart-Smith RD (2018) Rapid declines across Australian fishery stocks indicate global sustainability targets will not be achieved without an expanded network of 'no-fishing' reserves. Aquat Conserv Mar Freshw Ecosyst 28:1337–1350.

Eigenbrode SD, O'Rourke M, Wulfhorst JD, Althoff DM, Goldberg CS, Merrill K, Morse W, Nielsen-Pincus M, Stephens J, Winowiecki L, Bosque-Pérez NA (2007) Employing philosophical dialogue in collaborative science. Bioscience 57:55–64.

FAO (2012) FAO Technical guidelines for responsible fisheries.

FAO (2017) Improving our knowledge on small-scale fisheries: data needs and methodologies. Food and Agriculture Organization of the United Nations, Rome.

FAO (2018a) The state of the world fisheries and aquaculture - Meeting the sustainable development goals. Rome.

FAO (2020) The state of world fisheries and aquaculture 2020. Sustainability in action. Rome.

FAO (2018b) Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries, Second edi. San Salvador.

Fitzgerald B (2015) Professional West Australian crab fishers say recreational fishers are stealing product and damaging fishing gear. https://www.abc.net.au/news/rural/2015-11-10/thieves-steal-from-commercial-crab-fishers/6926716 (accessed 5 October 2020)

Fletcher WJ, Santoro K (2011) State of the fisheries and aquatic resources report 2010/11. Perth.

Fletcher WJ, Santoro K (2008) State of the fisheries report 2007/08. Perth.

Fletcher WR, Santoro K (2015) Review and refinement of an existing qualitative risk assessment method for application within an ecosystem-based management framework. ICES J Mar Sci 72:1043–1056.

Fletcher WR, Santoro K (2012) Status reports of the fisheries and aquatic resources of Western Australia 2011/12. Perth.

Fletcher WRJ, Mumme MD, Webster FJ (2017) Status reports of the fisheries and aquatic resources of Western Australia 2014/15. Perth.

Fogliarini CO, Ferreira CEL, Bornholdt J, Barbosa MC, Giglio VJ, Bender MG (2021) Telling the same story: Fishers and landing data reveal changes in fisheries on the Southeastern Brazilian Coast. PLoS One 16:e0252391.

Foley P, Pinkerton E, Wiber MG, Stephenson RL (2020) Full-spectrum sustainability: An alternative to fisheries management panaceas. Ecol Soc 25:1–9.

Fortibuoni T, Libralato S, Arneri E, Giovanardi O, Solidoro C, Raicevich S (2017) Fish and fishery historical data since the 19th century in the Adriatic Sea, Mediterranean. Sci data 4:170104.

Freire KMF, Belhabib D, Espedido JC, Hood L, Kleisner KM, Lam VWL, Machado ML, Mendonça JT, Meeuwig JJ, Moro PS, Motta FS, Palomares MLD, Smith N, Teh L, Zeller D, Zylich K, Pauly D (2020) Estimating Global Catches of Marine Recreational Fisheries. Front Mar Sci 7:1–18.

Frezza PE, Clem SE (2015) Using local fishers' knowledge to characterize historical trends in the Florida Bay bonefish population and fishery. Environ Biol Fishes 98:2187–2202.

Froese R, Demirel N, Coro G, Kleisner KM, Winker H (2017) Estimating fisheries reference points from catch and resilience. Fish Fish 18:506–526.

Fullwood R, Rowley J (2017) An investigation of factors affecting knowledge sharing amongst UK academics. J Knowl Manag 21:1254–1271.

Fulton EA, Smith ADM, Smith DC, van Putten IE (2011) Human behaviour: The key source of uncertainty in fisheries management. Fish Fish 12:2–17.

Fulton S, López-Sagástegui C, Weaver AH, Fitzmaurice-Cahluni F, Galindo C, Melo FFR, Yee S, Ojeda-Villegas MB, Fuentes DA, Torres-Bahena E (2019) Untapped potential of citizen science in Mexican small-scale fisheries. Front Mar Sci 6:30.

Gallagher AJ, Hammerschlag N, Danylchuk AJ, Cooke SJ (2017) Shark recreational fisheries: Status, challenges, and research needs. Ambio 46:385–398.

Galloway RW, Bahr ME (1979) What is the length of the Australian coast? Aust Geogr 14:244–247.

Garlock TM, Lorenzen K (2017) Marine angler characteristics and attitudes toward stock enhancement in Florida. Fish Res 186:439–445.

Gaughan DJ, Santoro K (2018) Status reports of the fisheries and aquatic resources of Western Australia 2016/17. Perth.

Gaughan DJ, Santoro K (2020) Status reports of the fisheries and aquatic resources of Western Australia 2018/19. Perth.

Gelcich S, Buckley P, Pinnegar JK, Chilvers J, Lorenzoni I, Terry G, Guerrero M, Castilla JC, Valdebenito A, Duarte CM (2014) Public awareness, concerns, and priorities about anthropogenic impacts on marine environments. Proc Natl Acad Sci U S A 111:15042–15047.

Gillanders BM, Elsdon TS, Halliday IA, Jenkins GP, Robins JB, Valesini FJ (2011) Potential effects of climate change on Australian estuaries and fish utilising estuaries: A review. Mar Freshw Res 62:1115–1131.

Gilmour PW, Dwyer PD, Day RW (2013) Enhancing the agency of fishers: A conceptual model of self-management in Australian abalone fisheries. Mar Policy 37:165–175.

Golden AS, Naisilsisili W, Ligairi I, Drew JA (2014) Erratum: Combining natural history collections with fisher knowledge for community-based conservation in Fiji. PLoS One 9:101407.

Grafton RQ (2005) Social capital and fisheries governance. Ocean Coast Manag 48:753–766.

Grafton RQ, Kompas T (2014) Three pillars of fisheries policy. Asia Pacific Policy Stud 1:609–614.

Granek EF, Madin EMP, Brown MA, Figueira W, Cameron DS, Hogan Z, Kristianson G, De Villiers P, Williams JE, Post J, Zahn S, Arlinghaus R (2008) Engaging recreational fishers in management and conservation: Global case studies. Conserv Biol 22:1125–1134.

Grant S, Berkes F (2007) Fisher knowledge as expert system: A case from the longline fishery of Grenada, the Eastern Caribbean. Fish Res 84:162–170.

Green TJ (2009) Compliance program evaluation and optimisation in commercial and recreational Western Australian fisheries. Perth.

Guillory V, Perry H, Steele P, Wagner T, Hammerschmidt P, Heath S, Moss C (1998) The Gulf of Mexico blue crab fishery: Historical trends, status, management, and recommendations. J Shellfish Res 17:395–403.

Gutiérrez NL, Hilborn R, Defeo O (2011) Leadership, social capital and incentives promote successful fisheries. Nature 470:386–389.

Haapasaari P, Kulmala S, Kuikka S (2012) Growing into interdisciplinarity: How to converge biology, economics, and social science in fisheries research? Ecol Soc 17.

Halim A, Loneragan NR, Wiryawan B, Fujita R, Adhuri DS, Hordyk AR, Sondita MFA (2020) Transforming traditional management into contemporary territorial-based fisheries management rights for small-scale fisheries in Indonesia. Mar Policy 116:103923.

Halim A, Wiryawan B, Loneragan NR, Hordyk A, Sondita MFA, White AT, Koeshendrajana S, Ruchimat T, Pomeroy RS, Yuni C (2019) Developing a functional definition of small-scale fisheries in support of marine capture fisheries management in Indonesia. Mar Policy 100:238–248.

Hallett CS, Hobday AJ, Tweedley JR, Thompson PA, McMahon K, Valesini FJ (2018) Observed and predicted impacts of climate change on the estuaries of south-western Australia, a Mediterranean climate region. Reg Environ Chang 18:1357–1373.

Ham S, Weiler B, Hughes M, Brown T, Curtis J, Poll M (2008) Asking visitors to help : Research to guide strategic communication for protected area management. Perth.

Ham SH, Brown TJ, Curtis J, Weiler B, Hughes M, Poll M (2009) Promoting persuasion in protected areas - A guide for managers who want to use strategic communication to influence visitor behaviour. Perth.

Hamilton RJ, Hughes A, Brown CJ, Leve T, Kama W (2019) Community-based management fails to halt declines of bumphead parrotfish and humphead wrasse in Roviana Lagoon, Solomon Islands. Coral Reefs 38:455–465.

Handcock AMS, Hunter DR, Butts CT, Goodreau SM, Krivitsky PN, Bender-demoll S, Morris M, Morris

MM, Date RC (2019) Package 'statnet". https://cran.r-project.org/web/packages/statnet/index.html

Hardin G (1968) The tragedy of the commons. Science 162:1243–1248.

Harris D, Johnston D, Baker J, Foster M (2017) Adopting a Citizen Science approach to develop cost-effective methods that will deliver annual information for managing small-scale recreational fisheries: The Southwest Recreational Crabbing Project. Perth.

Harrison T (1991) The Development of Australian Fisheries Management.

Hauck M (2008) Rethinking small-scale fisheries compliance. Mar Policy 32:635–642.

von Heland F, Crona B, Fidelman P (2014) Mediating science and action across multiple boundaries in the Coral Triangle. Glob Environ Chang 29:53–64.

Henry GW, Lyle JM (2003) The national recreational and indigenous fishing survey. Canberra.

Hertz T, Schlüter M (2015) The SES-Framework as boundary object to address theory orientation in social-ecological system research: The SES-TheOr approach. Ecol Econ 116:12–24.

Hilborn R (2007) Defining success in fisheries and conflicts in objectives. Mar Policy 31:153–158.

Hilborn R (1998) The economic performance of marine stock enhancement projects. Bull Mar Sci 62:661–674.

Hobday AJ, Ogier EM, Fleming A, Hartog JR, Thomas L, Stobutzki I, Finn M (2016) Fishery status reports : healthcheck for Australian fisheries. CSIRO, Oceans and Atmosphere, Hobart.

Hordyk AR (2014) The development and application of a length-based method to estimate the spawning potential ratio in data-poor fish stocks. Murdoch University

Hughes M, Ham SH, Brown T (2009) Influencing park visitor behavior : A belief-based approach. J Park Recreat Admi 27:38–53.

Hughes M, Weiler B, Curtis J (2012) What's the problem? River management, education, and public beliefs. Ambio 41:709–719.

Hunt LM, Sutton SG, Arlinghaus R (2013) Illustrating the critical role of human dimensions research for understanding and managing recreational fisheries within a social-ecological system framework. Fish Manag Ecol 20:111–124.

Hyder K, Weltersbach MS, Armstrong M, Ferter K, Townhill B, Ahvonen A, Arlinghaus R, Baikov A, Bellanger M, Birzaks J, Borch T, Cambie G, de Graaf M, Diogo HMC, Dziemian Ł, Gordoa A, Grzebielec R, Hartill B, Kagervall A, Kapiris K, Karlsson M, Kleiven AR, Lejk AM, Levrel H, Lovell S, Lyle J, Moilanen P, Monkman G, Morales-Nin B, Mugerza E, Martinez R, O'Reilly P, Olesen HJ, Papadopoulos A, Pita P, Radford Z, Radtke K, Roche W, Rocklin D, Ruiz J, Scougal C, Silvestri R, Skov C, Steinback S, Sundelöf A, Svagzdys A, Turnbull D, van der Hammen T, van Voorhees D, van Winsen F, Verleye T, Veiga P, Vølstad JH, Zarauz L, Zolubas T, Strehlow H V. (2018) Recreational sea fishing in Europe in a global context—Participation rates, fishing effort, expenditure, and implications for monitoring and assessment. Fish Fish 19:225–243.

Ingram BA, Hayes B, Rourke ML (2011) Impacts of stock enhancement strategies on the effective population size of Murray cod, Maccullochella peelii, a threatened Australian fish. Fish Manag Ecol 18:467–481.

Jackson G, Moran M (2012) Recovery of inner Shark Bay snapper (Pagrus auratus) stocks: Relevant research and adaptive recreational fisheries management in a World Heritage Property. Mar Freshw Res 63:1180–1190.

Jackson J, Jacquet J (2012) The shifting baselines syndrome: perception, deception, and the future of our oceans. Ecosyst Approaches to Fish:128–142.

Jackson JBC, Kirby MX, Berger WH, Bjorndal KA, Botsford LW, Bourque BJ, Bradbury RH, Cooke R, Erlandson J, Estes JA, Hughes TP, Kidwell S, Lange CB, Lenihan HS, Pandolfi JM, Peterson CH, Steneck RS, Tegner MJ, Warner RR (2001) Historical overfishing and the recent collapse of coastal ecosystems. Science 293:629–637.

Jacquet J, Fox H, Motta H, Ngusaru A, Zeller D (2010) Few data but many fish: Marine small-scale fisheries catches for Mozambique and Tanzania. African J Mar Sci 32:197–206.

Jenkins G, Michael R, Tweedley J (2017) Identifying future restocking options for Blue Swimmer Crabs (Portunus armatus). 1–30.

Jenkins GI, Michael R, Tweedley JR, Oberstein D, Loneragan NR, Johnston DJ (2018) Blue Swimmer Crab (Portunus armatus) stocking trial : reducing costs and increasing survival. Perth.

Jennings S, Stentiford GD, Leocadio AM, Jeffery KR, Metcalfe JD, Katsiadaki I, Auchterlonie NA, Mangi SC, Pinnegar JK, Ellis T, Peeler EJ, Luisetti T, Baker-Austin C, Brown M, Catchpole TL, Clyne FJ, Dye SR, Edmonds NJ, Hyder K, Lee J, Lees DN, Morgan OC, O'Brien CM, Oidtmann B, Posen PE, Santos AR, Taylor NGH, Turner AD, Townhill BL, Verner-Jeffreys DW (2016) Aquatic food security: insights into challenges and solutions from an analysis of interactions between fisheries, aquaculture, food safety, human health, fish and human welfare, economy and environment. Fish Fish 17:893–938.

Johannes RE (1998) The case for data-less marine resource management: Examples from tropical nearshore finfisheries. Trends Ecol Evol 13:243–246.

Johannes RE, Freeman MMR, Hamilton RJ (2000) Ignore fishers' knowledge and miss the boat. Fish Fish 1:257–271.

Johnston D, Harris D, Caputi N, de Lestang S, Thomson A (2011a) Status of the Cockburn Sound Crab Fishery.

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

Johnston D, Smith K, Brown J, Travaille K, Crowe F, Oliver R, Fisher E (2015) West coast estuarine managed fishery (Area 2: Peel-Harvey Estuary) and Peel-Harvey Estuary Blue Swimmer Crab recreational fishery. Perth.

Johnston D, Yeoh D, Harris D, Denham A, Fisher E (2020) Blue swimmer crab (Portunus armatus) resource in the west coast bioregion, Western Australia. Part 1: Peel-Harvey Estuary, Cockburn Sound and Swan-Canning Estuary. Perth.

Johnston DJ, Yeoh DE (2020) Carapace width-weight relationships of blue swimmer crab Portunus armatus (A. Milne-Edwards, 1861) (Crustacea: Brachyura: Portunidae) in southwestern Australia: Influences of sex, decadal change, environment, and season. J Crustac Biol 40:526–533.

Kailola PJ, Williams MJ, Stewart PC, Reichelt RE, Mcnee A, Grieve C (1993) Australian fisheries resources. Department of Primary Industries and Energy and the Fisheries Research and Development Corporation, Canberra.

Kearney RE (2002) Co-management: The resolution of conflict between commercial and recreational fishers in Victoria, Australia. Ocean Coast Manag 45:201–214.

Kearney RE (2001) Fisheries property rights and recreational/commercial conflict: Implications of policy developments in Australia and New Zealand. Mar Policy 25:49–59.

King T (2018) Project Regard. https://www.youtube.com/watch?v=e-QQqx3qGck&ab_channel=TanyaKing

King TJ, Abernethy K, Brumby S, Hatherell T, Kilpatrick S, Munksgaard K, Turner R (2019) Sustainable fishing families: Developing industry human capital through health, wellbeing, safety and resilience. FRDC Proj No 2016/400:172.

Kittinger JN, Finkbeiner EM, Ban NC, Broad K, Carr MH, Cinner JE, Gelcich S, Cornwell ML, Koehn JZ, Basurto X, Fujita R, Caldwell MR, Crowder LB (2013) Emerging frontiers in social-ecological systems research for sustainability of small-scale fisheries. Curr Opin Environ Sustain 5:352–357.

Kittinger JN, Finkbeiner EM, Glazier EW, Crowder LB (2012) Human dimensions of coral reef social-ecological systems. Ecol Soc 17.

Kittinger JN, Teh LCL, Allison EH, Bennett NJ, Crowder LB, Finkbeiner EM, Hicks C, Scarton CG, Nakamura K, Ota Y, Young J, Alifano A, Apel A, Arbib A, Bishop L, Boyle M, Cisneros-Montemayor AM, Hunter P, Le Cornu E, Levine M, Jones RS, Koehn JZ, Marschke M, Mason JG, Micheli F, McClenachan L, Opal C, Peacey J, Peckham SH, Schemmel E, Solis-Rivera V, Swartz W, Wilhelm TA (2017) Committing to socially responsible seafood: Ocean science must evolve to meet social challenges in the seafood sector. Science 356:912–913.

Klein ES, Thurstan RH (2016) Acknowledging long-term ecological change: the problem of shifting baselines. In: *Perspectives on Oceans Past.* p 1–19

Klein JT (1990) Interdisciplinarity. History, theory, and practice. Wayne State University Press, Detroit,USA.

Kloser RJ, Sutton C, Krusic-Golub K, Ryan TE (2015) Indicators of recovery for orange roughy (Hoplostethus atlanticus) in eastern Australian waters fished from 1987. Fish Res 167:225–235.

Kollmuss A, Agyeman J (2002) Mind the Gap: Why do people act environmentally and what are the barriers to pro-environmental behavior? Environ Educ Res 8:239–260.

Kooiman J (2008) Interactive governance and governability. Crit Reflections Interact Gov Self-organization Particip Public Gov:29–50.

Kunsook C, Gajaseni N, Paphavasit N (2014) A stock assessment of the Blue Swimming crab Portunus Pelagicus (Linnaeus, 1758) for sustainable management in Kung Krabaen Bay, gulf of Thailand. Trop Life Sci Res 25:41–59.

Lade SJ, Niiranen S (2017) Generalized modeling of empirical social-ecological systems. Nat Resour Model 30:1–25.

Lai JCY, Ng PKL, Davie PJF (2010) A revision of the Portunus pelagicus (Linnaeus, 1758) species complex (Crustacea: Brachyura: Portunidae), with the recognition of four species. Raffles Bull Zool 58:199–237.

Leitao P, Henriques S, Pérez-Ibarra I, Trujillo M, García-Charton JA, Vasconcelos RP (2020) Shifting baselines in a Mediterranean small-scale fishery. Ocean Coast Manag 183.

Lek E, Fairclough D V., Platell ME, Clarke KR, Tweedley JR, Potter IC (2011) To what extent are the dietary compositions of three abundant, co-occurring labrid species different and related to latitude, habitat, body size and season? J Fish Biol 78:1913–1943.

Lenanton RCJ, Loneragan NR, Potter IC (1985) Blue-green algal blooms and the commercial fishery of a large Australian estuary. Mar Pollut Bull 16:477–482.

Leonard NJ, Taylor WW, Goddard CI, Frank KA, Krause AE, Schechter MG (2011) Information flow within the social network structure of a joint strategic plan for management of great lakes fisheries. North Am J Fish Manag 31:629–655.

de Lestang S, Hall NG, Potter IC (2003) Reproductive biology of the blue swimmer crab (Portunus pelagicus, Decapoda: Portunidae) in five bodies of water on the west coast of Australia. Fish Bull 101:745–757.

Levontin P, Kulmala S, Haapasaari P, Kuikka S (2011) Integration of biological, economic, and sociological knowledge by Bayesian belief networks: The interdisciplinary evaluation of potential management plans for Baltic salmon. ICES J Mar Sci 68:632–638.

Von Lindern E, Mosler HJ (2014) Insights into fisheries management practices: Using the theory of planned behavior to explain fish stocking among a sample of Swiss anglers. PLoS One 9:1–20.

Link JS, Marshak AR (2019) Characterizing and comparing marine fisheries ecosystems in the United States: determinants of success in moving toward ecosystem-based fisheries management. Rev Fish Biol Fish 29:23–70.

Lorenzen K (2008) Understanding and managing enhancement fisheries systems. Rev Fish Sci 16:10–23.

Lorenzen K (2014) Understanding and managing enhancements: Why fisheries scientists should care. J Fish Biol 85:1807–1829.

Lorenzen K, Beveridge MCM, Mangel M (2012) Cultured fish: Integrative biology and management of domestication and interactions with wild fish. Biol Rev 87:639–660.

Loring PA (2017) The political ecology of gear bans in two fisheries: Florida's net ban and Alaska's Salmon wars. Fish Fish 18:94–104.

Lowry M, Murphy J (2003) Monitoring the recreational gamefish fishery off south-eastern Australia. Mar Freshw Res 54:425–434.

Lozano-Montes HM, Pitcher TJ, Haggan N (2008) Shifting environmental and cognitive baselines in the upper Gulf of California. Front Ecol Environ 6:75–80.

Maiolo JR, Johnson J, Griffith D (1992) Insights and applications: Applications of social science theory to fisheries management: Three examples. Soc Nat Resour 5:391–407.

Malseed BE, Sumner NR (2001a) A 12-month survey of recreational fishing in the Peel-Harvey Estuary of Western Australia during 1998-99. Fish Res Rep No 127:52.

Malseed BE, Sumner NR (2001b) A 12-month survey of recreational fishing in the Swan- Canning Estuary Basin of Western Australia during 1998-99. Fish Res Rep No 126:44.

Máñez KS, Holm P, Blight L, Coll M, MacDiarmid A, Ojaveer H, Poulsen B, Tull M (2014) The future of the oceans past: Towards a global marine historical research initiative. PLoS One 9.

Marks R, Alex Hesp S, Johnston D, Denham A, Loneragan N (2020) Temporal changes in the growth of a crustacean species, Portunus armatus, in a temperate marine embayment: Evidence of density dependence. ICES J Mar Sci 77:773–790.

Marshall KN, Levin PS, Essington TE, Koehn LE, Anderson LG, Bundy A, Carothers C, Coleman F, Gerber LR, Grabowski JH, Houde E, Jensen OP, Möllmann C, Rose K, Sanchirico JN, Smith ADM (2018) Ecosystem-Based Fisheries Management for Social–Ecological Systems: Renewing the Focus in the United States with Next Generation Fishery Ecosystem Plans. Conserv Lett 11:1–7.

Marshall S, Warburton K, Paterson B, Mann D (2005) Cannibalism in juvenile blue-swimmer crabs Portunus pelagicus (Linnaeus, 1766): Effects of body size, moult stage and refuge availability. Appl Anim Behav Sci 90:65–82.

Martin R, Schlüter M (2015) Combining system dynamics and agent-based modeling to analyze social-ecological interactions-an example from modeling restoration of a shallow lake. Front Environ Sci 3:1–15.

Mascia MB, Claus CA, Naidoo R (2010) Impacts of marine protected areas on fishing communities. Conserv Biol 24:1424–1429.

McClean N, Voyer M, Davila F, Barclay K, Cunningham R, Schnierer S (2019) Milestone 3: Analytical report on historical factors and barriers, thematic analysis, typology of stakeholders and social network analysis. Sydney.

McClenachan L, Neal BP, Al-Abdulrazzak D, Witkin T, Fisher K, Kittinger JN (2014) Do community supported fisheries (CSFs) improve sustainability? Fish Res 157:62–69.

McLeod P, Lindner R (2018) Economic dimension of recreational fishing in Western Australia. Perth.

Mcphail J (2020) Identifying opportunities for developing community supported fisheries in South Australia's small scale , multi - species , multi-gear community based fisheries.

McPhee DP, Leadbitter D, Skilleter GA (2002) Swallowing the bait: Is recreational fishing in Australia ecologically sustainable? Pacific Conserv Biol 8:40–51.

Mcpherson M, Smith-lovin L, Cook JM (2001) Birds of a feather: Homophily in social networks. Annu Rev Sociol 27:415–44.

Mikalsen KH, Jentoft S (2001) From user-groups to stakeholders? The public interest in fisheries management. Mar Policy 25:281–292.

Milich L (1999) Resource mismanagement versus sustainable livelihoods: The collapse of the newfoundland cod fishery. Soc Nat Resour 12:625–642.

Miller D (1999) Principles of social justice. Harvard University Press.

Morillo F, Bordons M, Gómez I (2003) Interdisciplinary in science: A tentative typology of disciplines and research areas. J Am Soc Inf Sci Technol 54:1237–1249.

Morison A, Daume S, Gardner C, Lack M (2016) Western Australia Peel-Harvey estuarine fishery MSC full report - Assessment public certification report Mandurah Licensed Fishermen's Association and Recfishwest. Perth.

Moutopoulos DK, Katselis G, Kios K, Tsotskou A, Tsikliras AC, Stergiou KI (2013) Estimation and reconstruction of shore-based recreational angling fisheries catches in the Greek Seas (1950-2010). J Biol Res 20:376–381.

MSC (2009) Get certified-Your guide to the MSC fishery assessment process.

MSC (2016) Looking after 'Bluey'. The Australian crab that became an icon. Perth.

Mueller KB, Taylor WW, Frank KA, Robertson JM, Grinold DL (2008) Social networks and fisheries: The relationship between a charter fishing network, social capital, and catch dynamics. North Am J Fish Manag 28:447–462.

Neis B (1992) Fishers' ecological knowledge and stock assessment in Newfoundland. Newfoundl Labrador Stud 8:0823–1737.

Neuman WL (2014) Social research methods: Qualitative and quantitative approaches, 7th ed. Pearson, Essex.

NOAA (2019) The Historical Development of Fisheries Science and Management. http://www.nefsc.noaa.gov/history/stories/fsh_sci_history2.htm%5Cnhttp://www.nefsc.noaa.gov/history/stories/fsh_sci_history1.html

Noell CJ, Beckmann CL, Hooper GE (2020) Blue Crab (Portunus armatus) Fishery 2018/19. fishery assessment report to PIRSA Fisheries and Aquaculture.

O'Donnell KP, Pajaro MG, Vincent ACJ (2010) How does the accuracy of fisher knowledge affect seahorse conservation status? Anim Conserv 13:526–533.

Obregón C, Admiraal R, van Putten I, Hughes M, Tweedley JR, Loneragan NR (2020a) Who you speak to matters: Information sharing and the management of a small-scale fishery. Front Mar Sci 7.

Obregón C, Hughes M, Loneragan NR, Poulton SJ, Tweedley JR (2020b) A two-phase approach to elicit and measure beliefs on management strategies: Fishers supportive and aware of trade-offs associated with stock enhancement. Ambio 49:640–649.

Obregón C, Tweedley JR, Loneragan NR, Hughes M (2020c) Different but not opposed: perceptions between fishing sectors on the status and management of a crab fishery. ICES J Mar Sci 77:2354–2368.

Ostrom E (2007) A diagnostic approach for going beyond panaceas. Proc Natl Acad Sci U S A 104:15181–15187.

Ostrom E (2009) A general framework for analyzing sustainability of Socio-Ecological Systems. Science 325:419–422.

Palmer CT (1991) Kin-selection, reciprocal altruism, and information sharing among Maine lobstermen. Ethol Sociobiol 12:221–235.

Papworth SK, Rist J, Coad L, Milner-Gulland EJ (2009) Evidence for shifting baseline syndrome in conservation. Conserv Lett:93–100.

Pascoe S, Brooks K, Cannard T, Dichmont CM, Jebreen E, Schirmer J, Triantafillos L (2014) Social objectives of fisheries management: What are managers' priorities? Ocean Coast Manag 98:1–10.

Paterson B (2010) Integrating fisher knowledge and scientific assessments. Anim Conserv 13:536–537.

Paterson B, Isaacs M, Hara M, Jarre A, Moloney CL (2010) Transdisciplinary co-operation for an ecosystem approach to fisheries: A case study from the South African sardine fishery. Mar Policy 34:782–794.

Paterson B, Mann D, Kelly B, Barchiesi M (2007) Limb-loss in pond-reared blue swimmer crabs Portunus pelagicus (L.): Effect on growth in an indoor shedding system. Aquac Res 38:1569–1579.

Patton MQ (1999) Enhancing the quality and credibility of qualitative analysis. Health Serv Res 34:1189–208.

Paulhus DL (1991) Measurement and control of response bias, Third Revi. Academic Press, Inc.

Pauly D (1995) Anecdotes and the shifting baseline syndrome of fisheries. Trends Ecol Evol 10:430.

Pauly D (2006) Major trends in small-scale marine fisheries, with emphasis on developing countries, and some implication from social sciences. Marit Stud 4:7–22.

Pauly D, Zeller D (2016a) Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. Nat Commun 7:1–9.

Pauly D, Zeller D (2016b) Global atlas of marine fisheries: A critical appraisal of catches and ecosystem impacts. Island Press.

PDC (2021) Welcome to the Peel Development Commission. https://www.peel.wa.gov.au/ (accessed 19 March 2021)

Peel L, Delvenne JC, Lambiotte R (2018) Multiscale mixing patterns in networks. Proc Natl Acad Sci U S A 115:4057–4062.

Phillipson J, Symes D (2013) Science for sustainable fisheries management: An interdisciplinary approach. Fish Res 139:61–64.

Pikitch EK, Santora C, Babcock EA, Bakun A, Bonfil R, Conover DO, Dayton P, Doukakis P, Fluharty D, Heneman B, Houde ED, Link J (2004) Ecosystem-based fishery management. Science 305:346–348.

Pinnegar JK, Engelhard GH, Norris NJ, Theophille D, Sebastien RD, Hidalgo M (2019) Assessing vulnerability and adaptive capacity of the fisheries sector in Dominica: Long-term climate change and catastrophic hurricanes. ICES J Mar Sci 76:1353–1367.

Pita C, Pierce GJ, Theodossiou I (2010) Stakeholders' participation in the fisheries management decision-making process: Fishers' perceptions of participation. Mar Policy 34:1093–1102.

Pita C, Villasante S, Pascual-Fernández JJ (2019) Managing small-scale fisheries under data poor scenarios: lessons from around the world. Mar Policy 101:154–157.

Pita P, Antelo M, Hyder K, Vingada J, Villasante S (2020) The use of recreational fishers' ecological knowledge to assess the conservation status of marine ecosystems. Front Mar Sci 7:1–14.

Pitcher TJ, Kalikoski D, Short K, Varkey D, Pramod G (2009) An evaluation of progress in implementing ecosystem-based management of fisheries in 33 countries. Mar Policy 33:223–232.

Pomeroy R, Parks J, Pollnac R, Campson T, Genio E, Marlessy C, Holle E, Pido M, Nissapa A, Boromthanarat S, Thu Hue N (2007) Fish wars: Conflict and collaboration in fisheries management in Southeast Asia. Mar Policy 31:645–656.

Pomeroy RS (1995) Community-based and co-management institutions for sustainable coastal fisheries management in Southeast Asia. Ocean Coast Manag 27:143–162.

van Poorten BT, Arlinghaus R, Daedlow K, Haertel-Borer SS (2011) Social-ecological interactions, management panaceas, and the future of wild fish populations. Proc Natl Acad Sci U S A 108:12554–12559.

Potter IC, Chrystal PJ, Loneragan NR (1983) The biology of the blue manna crab Portunus pelagicus in an Australian estuary. Mar Biol 78:75–85.

Potter IC, Manning RJG, Loneragan NR (1991) Size, movements, distribution and gonadal stage of the western king prawn (Penaeus latisulcatus) in a temperate estuary and local marine waters. J Zool

223:419–445.

Potter IC, Veale L, Tweedley JR, Clarke KR (2016) Decadal changes in the ichthyofauna of a eutrophic estuary following a remedial engineering modification and subsequent environmental shifts. Estuar Coast Shelf Sci 181:345–363.

Poulton SJ (2018) Beyond biology : social dimensions of Blue Swimmer Crab fishing , restocking and other management options. Murdoch University

Prince J, Creech S, Madduppa H, Hordyk A (2020) Length based assessment of spawning potential ratio in data-poor fisheries for blue swimming crab (Portunus spp.) in Sri Lanka and Indonesia: Implications for sustainable management. Reg Stud Mar Sci 36:101309.

Prior SP, Beckley LE (2007) Characteristics of recreational anglers in the Blackwood Estuary, a popular tourist destination in south western Australia. Tour Mar Environ 4:15–28.

Putnam RD (2000) Bowling alone: the collapse and revival of american community. Simon and Schuster Paperbacks, New York.

van Putten I, Longo C, Arton A, Watson M, Anderson CM, Himes-Cornell A, Obregón C, Robinson L, Van Steveninck T (2020) Shifting focus: The impacts of sustainable seafood certification. PLoS One 15:1–24.

Radford Z, Hyder K, Zarauz L, Mugerza E, Ferter K, Prellezo R, Strehlow HV, Townhill B, Lewin WC, Weltersbach MS (2018) The impact of marine recreational fishing on key fish stocks in European waters. PLoS One 13:1–16.

Recfishwest (2020) Cockburn Sound ' s pink snapper stocks on the line after State Government accepts taskforce's flawed report. https://recfishwest.org.au/news/cockburn-sounds-pink-snapper-stocks-on-the-line-after-state-government-accepts-taskforces-flawed-report/ (accessed 24 September 2020)

Ritchie H, Roser M (2020) Seafood production: What share of the stocks are overexploited? 1–11.

Roberts CM (2008) The unnatural history of the sea. Washington.

Rogers P (2003) Fish for the future - Annual report to Parliament. Perth.

Ryan KL, Hall NG, Lai EK, Smallwood CB, Taylor SM, Wise BS (2017) Statewide survey of boat-based recreational fishing in Western Australia 2015/16. Perth.

Ryan KL, Hall NG, Lai EKM, Smallwood CB, Tate A, Taylor SM, Wise BS (2019) State-wide survey of boat-based recreational fishing in Western Australia 2017/18. Perth.

Ryan KL, Hall NG, Lai EKM, Smallwood CB, Taylor SM, Wise BS (2015) State-wide survey of boat-based recreational fishing in Western Australia 2015/16. Perth.

Sáenz-Arroyo A, Roberts CM, Torre J, Cariño-Olvera M, Enríquez-Andrade RR (2005) Rapidly shifting environmental baselines among fishers of the Gulf of California. Proc R Soc B Biol Sci 272:1957–1962.

Said A, Chuenpagdee R (2019) Aligning the sustainable development goals to the small-scale fisheries guidelines: A case for EU fisheries governance. Mar Policy 107:103599.

Salmi P, Sipponen M (2016) Cultural strengths and governance challenges of a northern inland fishery. TBTI Publication Series, St. Johns, Canada.

Satake A, Araki H (2012) Stocking of captive-bred fish can cause long-term population decline and gene pool replacement: Predictions from a population dynamics model incorporating density-dependent mortality. Theor Ecol 5:283–296.

Scandol JP, Holloway MG, Gibbs PJ, Astles KL (2005) Ecosystem-based fisheries management: An Australian perspective. Aquat Living Resour 18:261–273.

Schirmer J, Binks B, Kancans R, Stenekes N (2013) Social indicators for Australia's forest and wood products industries Discussion paper.

Schoon M, Van Der Leeuw S (2015) The shift toward social-ecological systems perspectives: Insights into the human-nature relationship. Natures Sci Soc 23:166–174.

Seafood Watch Consulting Researcher (2018) Blue swimming crab.

Shepperson J, Murray LG, Cook S, Whiteley H, Kaiser MJ (2014) Methodological considerations when using local knowledge to infer spatial patterns of resource exploitation in an Irish Sea fishery. Biol Conserv 180:214–223.

Shortis MR, Ravanbakskh M, Shaifat F, Harvey ES, Mian A, Seager JW, Culverhouse PF, Cline DE, Edgington DR (2013) A review of techniques for the identification and measurement of fish in underwater stereo-video image sequences. Videometrics, Range Imaging, Appl XII; Autom Vis Insp 8791:87910G.

Sievanen L, Campbell LM, Leslie HM (2012) Challenges to Interdisciplinary Research in Ecosystem-Based Management. Conserv Biol 26:315–323.

Silva P, Cabral H, Rangel M, Pereira J, Pita C (2019) Ready for co-management? Portuguese artisanal octopus fishers' preferences for management and knowledge about the resource. Mar Policy 101:268–275.

Smallwood CB, Thomson A, Harris D, Johnston D (2010) The Volunteer Fisheries Liason Officer (VFLO) program: an analysis of recreational fishing data from 1995-2007. Fiisheries Research Report No. 203. Perth.

Smith ADM, Brown CJ, Bulman CM, Fulton EA, Johnson P, Kaplan IC, Lozano-Montes H, Mackinson S, Marzloff M, Shannon LJ, Shin YJ, Tam J (2011) Impacts of fishing low-trophic level species on marine ecosystems. Science 333:1147–1150.

Smith H, Basurto X (2019) Defining small-scale fisheries and examining the role of science in shaping perceptions of who and what counts: A systematic review. Front Mar Sci 6:19pp.

Smith KA, Lenanton RCJ (2021) Almost forgotten: Historical abundance of eel-tail catfish populations in south-western Australian estuaries and their decline due to habitat loss and historical overfishing. Reg Stud Mar Sci 41:101605.

Smith NS, Zeller D (2015) Unreported catch and tourist demand on local fisheries of small island states: The case of the Bahamas, 1950-2010. Fish Bull 114:117–131.

Smith RL, Huyer A, Godfrey JS, Church JA (1991) The Leeuwing Current off Western Australia, 1986-1987. Am Meteorol Soc 21:323–345.

Song AM, Soliman A (2019) Situating human rights in the context of fishing rights – Contributions and contradictions. Mar Policy 103:19–26.

Sowman M (2006) Subsistence and small-scale fisheries in South Africa: A ten-year review. Mar Policy 30:60–73.

Stankey GH, Shindler B (2006) Formation of social acceptability judgments and their implications for management of rare and little-known species. Conserv Biol 20:28–37.

Sténs A, Bjärstig T, Nordström EM, Sandström C, Fries C, Johansson J (2016) In the eye of the stakeholder: The challenges of governing social forest values. Ambio 45:87–99.

Stephenson RL, Paul S, Wiber M, Angel E, Benson AJ, Charles A, Chouinard O, Clemens M, Edwards D, Foley P, Jennings L, Jones O, Lane D, McIsaac J, Mussells C, Neis B, Nordstrom B, Parlee C, Pinkerton E, Saunders M, Squires K, Sumaila UR (2018) Evaluating and implementing social–ecological systems: A comprehensive approach to sustainable fisheries. Fish Fish 19:853–873.

Stern PC, Dietz T, Abel T, Guagnano GA, Kalof L (1999) A value-belief-norm theory of support for social movements: The case of environmentalism. Hum Ecol Rev 6:81–97.

Stojanovic T, McNae HM, Tett P, Potts TW, Reis J, Smith HD, Dillingham I (2016) The "social" aspect of social-ecological systems: A critique of analytical frameworks and findings from a multisite study of coastal sustainability. Ecol Soc 21.

Strieder Philippsen J, Minte-Vera CV, Okada EK, Carvalho AR, Angelini R (2017) Fishers' and scientific histories: An example of consensus from an inland fishery. Mar Freshw Res 68:980–992.

Sueur C, Deneubourg JL, Petit O (2012) From social network (centralized vs. decentralized) to collective decision-making (unshared vs. shared consensus). PLoS One 7.

Sumner NR, Malseed BE (2004) Quantification of changes in recreational catch and effort on blue swimmer crabs in Cockburn Sound and Geographe Bay. Fish Res Rep No 147, Dep Fish West Aust 147:48.

Sumner NR, Williamson PC (1999) Fisheries Research Report No. 117, 1999. Perth.

Sumpton W, Gaddes S, McLennan M, Campbell M, Tonks M, Good N, Hagedoorn W, Skilleter G (2003) Fisheries biology and assessment of the blue swimmer crab (Portunus pelagicus) in Queensland. Rep to Fish Res Dev Corp Proj 98:17.

Suwannarat S, Sangthong D, Samipak S, Sangthong P (2017) A multiplex PCR assay for the identification of five commercially important Portunid crabs: Portunus pelagicus, P. gladiator, P. sanguinolentus, Charybdis natator, and C. feriatus. Food Biotechnol 31:177–192.

Taylor MD, Chick RC, Lorenzen K, Agnalt AL, Leber KM, Blankenship HL, Haegen G Vander, Loneragan NR (2017) Fisheries enhancement and restoration in a changing world. Fish Res 186:407–412.

Taylor SM, Blight SJ, Desfosses CJ, Steffe AS, Ryan KL, Denham AM, Wise BS, Thurstan R (2018) Thermographic cameras reveal high levels of crepuscular and nocturnal shore-based recreational fishing effort in an Australian estuary. ICES J Mar Sci 75:2107–2116.

Teh LCL, Pauly D (2018) Who brings in the fish? The relative contribution of small-scale and industrial fisheries to food security in Southeast Asia. Front Mar Sci 4:1–9.

Teh LCL, Teh LSL, Abe K, Ishimura G, Roman R (2020) Small-scale fisheries in developed countries: Looking beyond developing country narratives through Japan's perspective. Mar Policy 122:5.

The World Bank (2012) Hidden harvest : The global contribution of capture fisheries. Washington DC.

Thomas AS, Milfont TL, Gavin MC (2016) New approach to identifying the drivers of regulation compliance using multivariate behavioural models. PLoS One 11:1–12.

Thompson SA, Stephenson RL, Rose GA, Paul SD (2019) Collaborative fisheries research: The Canadian fisheries research network experience. Can J Fish Aquat Sci 76:671–681.

Thurstan RH, Brockington S, Roberts CM (2010) The effects of 118 years of industrial fishing on UK bottom trawl fisheries. Nat Commun 1:1–6.

Thurstan RH, Buckley SM, Ortiz JC, Pandolfi JM (2016a) Setting the record straight: assessing the reliability of retrospective accounts of change. Conserv Lett 9:98–105.

Thurstan RH, Campbell AB, Pandolfi JM (2016b) Nineteenth century narratives reveal historic catch rates for Australian Snapper (Pagrus auratus). Fish Fish 17:210–225.

Thurstan RH, Game E, Pandolfi JM (2017) Popular media records reveal multi-decadal trends in recreational fishing catch rates. PLoS One 12:1–13.

Townhill BL, Radford Z, Pecl G, van Putten I, Pinnegar JK, Hyder K (2019) Marine recreational fishing and the implications of climate change. Fish Fish 20:977–992.

Triantafillos L, Brooks K, Schirmer J, Pascoe S, Cannard T, Dichmont C, Thebaud O, Jebreen E (2014) Developing and testing social objectives for fisheries management. Adelaide.

Trove (2020) What's inside the treasure Trove? Join the voluntroves brought to you by Trove partners. 2–3.

TROVE (2021) Newspapers and Gazettes category. https://trove.nla.gov.au/help/categories/newspapers-and-gazettes-category

Tull M (1993) The development of the Australian fishing industry: A preliminary survey. Int J Marit Hist 5:95–126.

Turner RA, Polunin NVC, Stead SM (2014) Social networks and fishers' behavior: Exploring the links between information flow and fishing success in the Northumberland lobster fishery. Ecol Soc 19.

Tweedley J, Campbell T, Loneragan N, Johnston D (2017) Aspects of the biology and husbandry of portunid crabs relevant to aquaculture-based enhancement and fisheries management. Perth.

Tweedley J, Warwick R, Potter I (2016) The contrasting ecology of temperate macrotidal and microtidal estuaries. In: *Hughes, R.N., Hughes, D.J., Smith, I.P. and Dale, A.C., (eds.) Oceanography and Marine Biology: An Annual Review. CRC*, CRC Press. Hughes, R.N., Hughes, D.J., Smith, I.P. and Dale AC (ed) p 73–172

Tweedley JR, Warwick RM, Clarke KR, Potter IC (2014) Family-level AMBI is valid for use in the north-eastern Atlantic but not for assessing the health of microtidal Australian estuaries. Estuar Coast Shelf Sci 141:85–96.

Ugland KI, Gray JS, Ellingsen KE (2003) The species-accumulation curve and estimation of species richness. J Anim Ecol 72:888–897.

Ulman A, Pauly D (2016) Making history count: The shifting baselines of Turkish fisheries. Fish Res 183:74–79.

UN (1987) Report of the World Commission on environment and development. Our common future.

UN (2015) Transforming our world: The 2030 Agenda for sustainable development.

Valesini FJ, HAllet CS, Hipsey MR, Kilminster KL, Huang P, Hennig K (2019) Peel-Harvey Estuary , Western Australia. In: *Coasts and Estuaries*. p 103–120

Vanwindekens FM, Stilmant D, Baret P V. (2013) Development of a broadened cognitive mapping approach for analysing systems of practices in social-ecological systems. Ecol Modell 250:352–362.

Voyer M, Barclay K, McIlgorm A, Mazur N (2017a) Connections or conflict? A social and economic analysis of the interconnections between the professional fishing industry, recreational fishing and marine tourism in coastal communities in NSW, Australia. Mar Policy 76:114–121.

Voyer M, Barclay K, McIlgorm A, Mazur N (2017b) Using a well-being approach to develop a framework for an integrated socio-economic evaluation of professional fishing. Fish Fish 18:1134–1149.

Voyer M, Gladstone W, Goodall H (2014) Obtaining a social licence for MPAs - influences on social acceptability. Mar Policy 51:260–266.

Voyer M, Quirk G, McIlgorm A, Azmi K (2018) Shades of blue: what do competing interpretations of the Blue Economy mean for oceans governance? J Environ Policy Plan 20:595–616.

Vugteveen P, Rouwette E, Stouten H, van Katwijk MM, Hanssen L (2015) Developing social-ecological system indicators using group model building. Ocean Coast Manag 109:29–39.

WAFIC (2014) Media statement: Interference with commercial fishing gear. 1.

WAFIC (2020) Our industry. https://www.wafic.org.au/our-industry/ (accessed 12 October 2020)

Walters C, Maguire JJ (1996) Lessons for stock assessment from the northern cod collapse. Rev Fish Biol Fish 6:125–137.

Ward TJ (2011) Australia state of the environment report biodiversity and productivity.

Webb LB, Hennessy K (2015) Climate Change in Australia. Projections for selected Australian cities. Australia.

Webley J, McInnes K, Teixeira D, Lawson A, Quinn R (2015) Statewide recreational fishing survey 2013–14.

West RJ, Gordon GNG (1994) Commercial and recreational harvest of fish from two australian coastal rivers. Mar Freshw Res 45:1259–1279.

Worm B, Barbier EB, Beaumont N, Duffy JE, Folke C, Halpern BS, Jackson JBC, Lotze HK, Micheli F, Palumbi SR, Sala E, Selkoe KA, Stachowicz JJ, Watson R (2006) Impacts of biodiversity loss on ocean ecosystem services. Science 314:787–790.

Yates KL (2014) View from the wheelhouse: Perceptions on marine management from the fishing community and suggestions for improvement. Mar Policy 48:39–50.

Young MAL, Foale S, Bellwood DR (2014) Impacts of recreational fishing in Australia: Historical declines, self-regulation and evidence of an early warning system. Environ Conserv 41:350–356.

Young OR (2002) The institutional dimensions of environmental change. Choucri N (ed) MIT Press.

Zeller D, Booth S, Craig P, Pauly D (2006) Reconstruction of coral reef fisheries catches in American Samoa, 1950-2002. Coral Reefs 25:144–152.

Zukowski S, Curtis A, Watts RJ (2011) Using fisher local ecological knowledge to improve management: The Murray crayfish in Australia. Fish Res 110:120–127.

Appendices

Chapter 2: Supplementary data tables

Supplementary material 2.1. Social network of the blue swimmer crab fishery in the Peel-Harvey Estuary

Interview plan

Throughout the interview, I will be asking you questions on :

- Details on your current role, in relation to the blue swimmer crab fishery (BSC);
- To name the 10 people you interact the most with, in regard to the blue swimmer crab fishery;
- Who do you exchange information with (among those 10 people you named before) related to the blue swimmer crab;
- Who do you collaborate with, on anything related with the blue swimmer crab fishery (again, among the 10 people cited at first);
- Follow up questions to better understand the significance of the interactions with the 10 people you cited at first.

The whole interview lasts generally around 30 – 40 minutes. However, this might take longer, depending on the amount of details given, and also the discussion resulting from these questions.

The survey is completely confidential and voluntary, and you are free to stop at any time. You can also choose not to answer particular questions during the interview without any need to explain why.

Please know that there are no right or wrong answers, nor are some responses better or worse than others. We simply want to understand better the flow of information within the blue swimmer crab fishery network.

If you would prefer this interview not to be recorded, please do let me know.

Name:	**Job position:**
Age:	**Address (region) & time living there:**
Gender:	**Level of education:**

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1. Background of stakeholder interviewed

- **How** many years have you been working in this organisation?

- **How many years have you been involved** in the management or anything related to the BSC fishery in the Peel-Harvey estuary?

- Before working here, **were you previously involved** with anything related to the BSC fishery?

2. Communication & Information flow

We are interested in general information on **who** you contact to share information about BSC, **how often** and **how useful** the information was.

1. Can you name the 10 people you interact with most, how and how often you contact them and whether the information was useful?
2. Can you indicate, from the list of people you have cited, who is the most important person, regarding information sharing?

Individual (Please name up to 10 individuals you interact with most outside of your team)	**Group, Organisation**	What **type of information exchange** do you usually have with this person (i.e.: receive information, give information, both)	**Type of contact** *(i.e.: phone; email; face to face)*	**What topic links you to this person in terms of information sharing and collaboration** (i.e.: governance, biology & ecology, social information, …)	**Frequency of contact** *(i.e.: daily, weekly, monthly, few times a year, …)*	**Relation length** (i.e.: How long have you worked with this person for?)	**Quality of information** (1 to 5) *[from useless to very useful]*

- **Who** do you formally report to regarding topics related to the BSC fishery?

3. Changes in communication

- Do you talk about the blue swimmer crab fishery differently (i.e.: more or less often) depending on the **season**?
- The following table aims to record **what happens when someone reports a specific change** in the **environment, fishers catches or fishers' behaviour** that could potentially impact (i.e.: positive; negative; both) the blue swimmer crab fishery.

	Change in catches	**Change in the estuary**	**Illegal fishing**
Who might report the information ?			
How do they generally report the information (*i.e.: means of contact)*			
Who do they generally contact?			

- Could you describe **up to three important environmental events** that affected the fishery in the last decade or since you started working in this position?
  1.
  2.
  3.

- Could you describe **any change in the communication or collaboration** with other stakeholders, after those events?

	Communication	**Collaboration**
Frequency		
Quality		
Means used		

- Have you **noticed a change in communication** between yourself and the other stakeholders you communicate with, **before the fishery was MSC certified and after** the certification of the fishery?

4. About collaboration

This section is about collaboration. We are interested in general information on **who you work with to achieve shared objectives**, **how often** and **how useful** this collaboration is.

- **Who** do you formally collaborate (or work with) **within your organisation** regarding topics related to the BSC fishery, its management and its environment?
  1.
  2.
  3.

- Do you work with anyone **outside of your organisation** on anything related to the BSC fishery, its management and its environment?
  1.
  2.
  3.
- Do you work with anyone **outside of WA** on anything related with the fishery, its management and its environment?
  1.
  2.
  3.
- How **useful are these collaborations for the work you do** (i.e.: have these collaborations been instrumental in reaching the outputs you were aiming for)? *[Use the scale from 1 to 5, 1 being not very useful, and 5 being very high useful]*.
- Overall, **how satisfied are you with your ability to communicate the information related to blue swimmer crab,** within this organisation and to other organisations/stakeholders? *[Use the scale from 1 to 5, 1 being very low, and 5 being very high]*.

5. Information on fishers

- Do you think blue swimmer crab fishers are satisfied with the **management of the BSC fishery?** *[Use the scale from 1 to 5, 1 being very low satisfaction, and 5 being very high satisfaction]*.

- Are you aware of **any concern(s)** that **blue swimmer crab fishers** might have regarding the factors that could negatively impact the blue swimmer crab fishery? *[List these in order of importance]*
  1.
  2.
  3.

- **Where do you think blue swimmer crab fishers get information** related to the fishery management and regulations? *[List these in order of importance]*

- Are you aware of any **organised event which helps inform fishers** about the status of the blue swimmer crab fishery and its management?

- IF yes, do you think these organised events are **useful** to the **fishing community for communicating management related issues**?

- Do you think these events **spark an increase in communication** between the fishery stakeholders?

Close up & Thanks to the participant

If you are **interested** in **hearing about the results of this study**, please do let me know and I'll include you in **our mailing list.**

If later on you decide you do not want to receive more updates on the project, contact me and I will delete your details from the list.

Chapter 2: Supplementary data tables

Supplementary table S2.1: Exponential random graph model results for attribute-based mixing for the attribute 'Seniority' of individual stakeholders forming the extended PHBSC fishery network

Attribute	***P* value**
mix.seniority.1.1	0.5442
mix.seniority.2.1	0.4922
mix.seniority.3.1	0.9434
mix.seniority.1.2	0.5345
mix.seniority.2.2	0.9032
mix.seniority.3.2	0.6873
mix.seniority.1.3	0.9144
mix.seniority.2.3	0.3669
mix.seniority.3.3	0.0415 *
mix.seniority.NA.3	0.3364

Supplementary table S2.2: Exponential random graph model results for attribute-based mixing for the attribute 'Organisation' of individual stakeholders forming the extended PHBSC fishery network.

Attribute	***P* value**
mix.organisation.DPIRD.Birdlife Australia	0.027938 *
mix.organisation.City of Mandurah.City of Mandurah	0.507585
mix.organisation.DBCA.City of Mandurah	0.511813
mix.organisation.DPIRD.City of Mandurah	0.000457 ***
mix.organisation.MSC.City of Mandurah	0.941173
mix.organisation.PHCC.City of Mandurah	0.079310 .
mix.organisation.City of Mandurah.DBCA	0.511813
mix.organisation.DPIRD.DBCA	0.004293 **
mix.organisation.DPIRD.Dolphin Watch	0.027938 *
mix.organisation.Birdlife Australia.DPIRD	0.027938 *
mix.organisation.DPIRD.DPIRD	0.003940 **
mix.organisation.DWER.DPIRD	0.000206 ***
mix.organisation.General public.DPIRD	0.004293 **
mix.organisation.MLFA.DPIRD	0.002231 **
mix.organisation.MSC.DPIRD	0.087013 .
mix.organisation.Murdoch.DPIRD	<1e-04 ***
mix.organisation.PDC.DPIRD	0.004293 **
mix.organisation.PHCC.DPIRD	<1e-04 ***
mix.organisation.Rec. fishers.DPIRD	0.000104 ***
mix.organisation.RFW.DPIRD	0.000337 ***
mix.organisation.SCS.DPIRD	0.044152 *
mix.organisation.SSPWA.DPIRD	0.027938 *
mix.organisation.WAFIC.DPIRD	<1e-04 ***
mix.organisation.DPIRD.DWER	0.000206 ***
mix.organisation.MLFA.DWER	0.013898 *
mix.organisation.Murdoch.DWER	0.016655 *
mix.organisation.PHCC.DWER	0.048730 *
mix.organisation.Murdoch.FRDC	0.284999
mix.organisation.City of Mandurah.General public	0.511813
mix.organisation.DPIRD.General public	0.004293 **
mix.organisation.MLFA.Mandurah cruises	0.376357
mix.organisation.RFW.Mandurah times	0.869625
mix.organisation.DPIRD.MLFA	0.000358 ***
mix.organisation.MLFA.MLFA	0.001895 **
mix.organisation.MSC.MLFA	0.376357
mix.organisation.Murdoch.MLFA	0.000531 ***
mix.organisation.PHCC.MLFA	0.009425 **
mix.organisation.RFW.MLFA	0.033696 *
mix.organisation.SCS.MLFA	0.827128
mix.organisation.SSPWA.MLFA	0.039969 *
mix.organisation.WAFIC.MLFA	0.031496 *
mix.organisation.RFW.MOFSC	0.869625
mix.organisation.DPIRD.MSC	0.087013
mix.organisation.MLFA.MSC	0.827128
mix.organisation.PHCC.MSC	0.721402
mix.organisation.Rec. fishers.MSC	0.721402
mix.organisation.WAFIC.MSC	0.721402
mix.organisation.DPIRD.Murdoch	<1e-04 ***
mix.organisation.DWER.Murdoch	0.009425 **
mix.organisation.MLFA.Murdoch	0.000531 ***
mix.organisation.Murdoch.Murdoch	0.003554 **

mix.organisation.PDC.Murdoch	0.07931
mix.organisation.PHCC.Murdoch	0.004708 **
mix.organisation.WAFIC.Murdoch	0.005034 **
mix.organisation.DPIRD.PDC	0.006114 **
mix.organisation.DWER.PDC	0.312605
mix.organisation.Murdoch.PDC	0.157806
mix.organisation.PHCC.PDC	0.240903
mix.organisation.RFW.PDC	0.827128
mix.organisation.DPIRD.Peel Bright Minds	0.027938 *
mix.organisation.DPIRD.PHCC	0.000157 ***
mix.organisation.DWER.PHCC	0.048730 *
mix.organisation.MLFA.PHCC	0.008470 **
mix.organisation.Murdoch.PHCC	0.004708 **
mix.organisation.RFW.PHCC	0.176857
mix.organisation.SCS.PHCC	0.721402
mix.organisation.MLFA.Politician	0.242055
mix.organisation.RFW.Rec. fishers	0.75419
mix.organisation.SCS.Rec. fishers	0.721402
mix.organisation.DPIRD.RFW	0.067397
mix.organisation.MLFA.RFW	0.033696 *
mix.organisation.MOFSC.RFW	0.869625
mix.organisation.MSC.RFW	0.869625
mix.organisation.Murdoch.RFW	0.008470 **
mix.organisation.PDC.RFW	0.376357
mix.organisation.PHCC.RFW	0.176857
mix.organisation.Rec. fishers.RFW	0.75419
mix.organisation.RFW.RFW	0.599309
mix.organisation.SSPWA.RFW	0.869625
mix.organisation.WAFIC.RFW	0.322136
mix.organisation.DPIRD.SCS	0.087013
mix.organisation.MLFA.SCS	0.376357
mix.organisation.MSC.SCS	0.966213
mix.organisation.RFW.SCS	0.869625
mix.organisation.WAFIC.SCS	0.721402
mix.organisation.MLFA.Seafood producer	0.242055
mix.organisation.DPIRD.SSPWA	0.027938 *
mix.organisation.MLFA.SSPWA	0.674105
mix.organisation.RFW.SSPWA	0.869625
mix.organisation.WAFIC.SSPWA	0.197742
mix.organisation.Murdoch.UWA	0.284999
mix.organisation.DPIRD.WAFIC	0.000157 ***
mix.organisation.MLFA.WAFIC	0.031496 *
mix.organisation.MSC.WAFIC	0.721402
mix.organisation.Murdoch.WAFIC	0.005034 **
mix.organisation.PHCC.WAFIC	0.031845 *
mix.organisation.RFW.WAFIC	0.322136
mix.organisation.SCS.WAFIC	0.721402
mix.organisation.SSPWA.WAFIC	0.607926

Supplementary table S2.3: Exponential random graph model results for attribute-based mixing for the attribute 'Age' of individual stakeholders forming the extended PHBSC fishery network.

Attribute	*P* value
mix.age.25-34.25-34	0.22583
mix.age.35-44.25-34	0.43251
mix.age.45-54.25-34	0.00116 **
mix.age.55-64.25-34	0.13232
mix.age.NA.25-34	0.03122 *
mix.age.25-34.35-44	0.22647
mix.age.35-44.35-44	0.03728 *
mix.age.45-54.35-44	0.01076 *
mix.age.55-64.35-44	0.19174
mix.age.NA.35-44	0.25101
mix.age.25-34.45-54	0.01048 *
mix.age.35-44.45-54	0.03917 *
mix.age.45-54.45-54	< 1e-04 ***
mix.age.55-64.45-54	0.04091 *
mix.age.NA.45-54	0.04045 *
mix.age.25-34.55-64	0.13232
mix.age.35-44.55-64	0.07094 .
mix.age.45-54.55-64	0.00544 **
mix.age.55-64.55-64	0.98693
mix.age.65+.55-64	0.38007
mix.age.NA.55-64	0.01187 *
mix.age.NA.65+	0.26155
mix.age.25-34.NA	0.03122 *
mix.age.35-44.NA	0.19714
mix.age.45-54.NA	0.04990 *
mix.age.55-64.NA	0.08021

Supplementary table S2.4: Exponential random graph model results for attribute-based mixing for the attribute 'Group of individual stakeholders forming the extended PHBSC fishery network.

Attribute	*P* value
mix.group.Academics.Academics	0.003858 **
mix.group.Commercial sector.Academics	< 1e-04 ***
mix.group.Government body.Academics	< 1e-04 ***
mix.group.NGO, Conservation groups.Academics	0.001415 **
mix.group.Academics.Commercial sector	< 1e-04 ***
mix.group.Commercial sector.Commercial sector	0.190926
mix.group.Government body.Commercial sector	< 1e-04 ***
mix.group.NGO, Conservation groups.Commercial sector	0.004476 **
mix.group.Recreational sector.Commercial sector	0.000879 ***
mix.group.Academics.Government body	< 1e-04 ***
mix.group.Commercial sector.Government body	< 1e-04 ***
mix.group.Government body.Government body	< 1e-04 ***
mix.group.NGO, Conservation groups.Government body	< 1e-04 ***
mix.group.Public awareness & Tourism.Government body	< 1e-04 ***
mix.group.Recreational sector.Government body	< 1e-04 ***
mix.group.Academics.NGO, Conservation groups	0.001415 **
mix.group.Commercial sector.NGO, Conservation groups	0.001375 **
mix.group.Government body.NGO, Conservation groups	< 1e-04 ***
mix.group.NGO, Conservation groups.NGO, Conservation groups	0.019445 *
mix.group.Recreational sector.NGO, Conservation groups	0.013346 *
mix.group.Commercial sector.Public awareness & Tourism	0.000347 ***
mix.group.Government body.Public awareness & Tourism	< 1e-04 ***
mix.group.Recreational sector.Public awareness & Tourism	0.003047 **
mix.group.Academics.Recreational sector	0.001334 **
mix.group.Commercial sector.Recreational sector	0.000879 ***
mix.group.Government body.Recreational sector	< 1e-04 ***
mix.group.NGO, Conservation groups.Recreational sector	0.013346 *
mix.group.Public awareness & Tourism.Recreational sector	0.004420 **

Supplementary table S2.5: Exponential random graph model results for attribute-based mixing for the attribute 'Organisation' of individual stakeholders forming the extended PHBSC fishery network.

Attribute	*P* value
mix.gender.Female.Female	0.0402 *
mix.gender.Male.Female	0.1044
mix.gender.Female.Male	0.1252
mix.gender.Male.Male	NA

Chapter 3: Survey questions

Supplementary material 3.1

1) *Face-to-face interviews on fisher perceptions of the blue swimmer crab recreational fishery*

A. Crabbing experience

- What year did you first go crabbing in xxx [*name of the survey location*]?
- How often do you go crabbing in xxx [*name of the survey location*]?
- Who taught you how to fish for crabs?
- If you don't go crabbing in xxx [*name of the survey location*] anymore, what year did you stop?
- Do you fish for crabs in places other than xxx [*name of the survey location*]?

B. Perceptions of changes in catch over time

B.1. Abundance (numbers of crabs)

- From the time you first started crabbing in xxx [*name of the survey location*] until the present day or until the time you stopped crabbing, would you say that the abundance of crabs xxx [*name of the survey location*] has:
  - ☐ Increased
  - ☐ Decreased
  - ☐ Not changed

- If you reported any change in the abundance of blue swimmer crabs in xxx [*name of the survey location*] since when did you notice this change (in years)?

- If you noticed a decline in the abundance of blue swimmer crab fishing from the time you first started crabbing in xxx [*name of the survey location*] until the present day or until the time you stopped crabbing, would you say there has been a…:
  - ☐ >90% decline in the number of crabs
  - ☐ 70-90% decline in the number of crabs
  - ☐ 50-70% decline in the number of crabs
  - ☐ 30-50% decline in the number of crabs
  - ☐ 10-20% decline in the number of crabs
  - ☐ <10% decline in the number of crabs

- With the two following questions, and considering your previous answers regarding crab catches, we would be interested in knowing how you would rate the state of the fishery in xxx [*name of the survey location]:*

When you started crabbing:

- ☐ Excellent
- ☐ Very good
- ☐ Good
- ☐ Fair
- ☐ Poor
- ☐ Very poor
- ☐ Terrible

At the moment:

- ☐ Excellent
- ☐ Very good
- ☐ Good
- ☐ Fair
- ☐ Poor
- ☐ Very poor
- ☐ Terrible

- Over what consecutive 5-year period did you see the greatest number of crabs per crabbing trip in xxx [*name of the survey location*]?

- Over what consecutive 5-year period did you see the lowest number of crabs per crabbing trip in xxx [*name of the survey location*]?

B.2. Size (i.e.: Carapace width - cm)

- From the time you first started crabbing in xxx [*name of the survey location*] until the present day or until the time you stopped crabbing, would you say that the size of crabs has:
  ☐ Increased
  ☐ Decreased
  ☐ Not changed

- If you reported a change in the size of blue swimmer crabs in xxx [*name of the survey location*] since when did you notice this change?

- What crab size (on average) did you expect to catch when you first started crabbing?

- What crab size (on average) do you expect to catch now/when you stopped crabbing in xxx [*name of the survey location*]?

B.3. Other species

- Do you know of any species in xxx [*name of the survey location*] that have disappeared during the time you have been fishing?

- Do you know of any species in the area that have increased in numbers during the time you've been fishing xxx [*name of the survey location*]?

C. Perceptions on changes in the environment

- Since you started crabbing in xxx [*name of the survey location*] have you noticed a change on the season/time of year when you find sized crabs in xxx [*name of the survey location*]? EXPLAIN

- How many other recreational crab fishers did you see <u>in the past</u>, when you first started crabbing in xxx [*name of the survey location*]?

- How many other recreational crab fishers do you see <u>now</u>/when you stopped catching crabs in xxx [*name of the survey location*]?

- Have you observed any other trends or changes in the environment where you fish for blue swimmer crab since you started?

- Is there anything else you would like to tell us about the blue swimmer crab fishery?

D. Demographics and close up

- Age: 18-24 25-34 35-44 45-54 55-64 65+

- Gender: Male Female Other

- Where do you live most of the time?
  - ☐ Mandurah region
  - ☐ Other Perth Metro region
  - ☐ Other (specify)

- How long have you lived here for?

- Highest level of education:

- Do you fish from:
  - ☐ Boat
  - ☐ Land
  - ☐ Both but mostly boat
  - ☐ Both but mostly shore
  - ☐ Both equally

2) Online survey on fisher perceptions of the blue swimmer crab recreational fishery

We are interested in your opinion about current state of the blue swimmer crab fishery compared to when you first started fishing. The following list includes different aspects of the blue swimmer crab fishery. Using the options provided, please indicate your opinion about the current state of the fishery.

1. **Crab size has:**
   a. Decreased
   b. The same
   c. Increased

2. **Crab amount has:**
   a. Decreased
   b. The same
   c. Increased

3. **The number of people fishing has:**
   a. Decreased
   b. The same
   c. Increased

4. **The abundance of other species has:**
   a. Decreased
   b. The same
   c. Increased

5. **The number of sites where you fish regularly has:**
   a. Decreased
   b. The same
   c. Increased

6. The amount of time spent at one site to catch the same amount of crabs has:

a. Decreased
b. The same
c. Increased

7. The distance travelled to get to a good fishing location has:

a. Decreased
b. The same
c. Increased

Supplementary material 3.2. Summary of the Chi-square test conducted in this study and results obtained for the face-to-face interviews. Note that * denotes statistical significance.

Method	Statistical analysis results				
	Dependent variable	*Independent variable*	*chi-sq*	*Degrees of freedom*	*p-value*
Face-to-face interviews All estuaries	size change	estuary	18.03	1	<0.01*
	size change	education	3.70	16	1.00
	size change	fishing experience	1.39	6	0.97
	size change	age class	5.43	6	0.49
	size start	estuary	0.66	1	0.72
	size start	education	18.69	14	0.18
	size start	fishing experience	4.08	4	0.40
	size start	age class	7.69	4	0.10
	size end	estuary	15.26	1	<0.01*
	size end	education	13.39	14	0.50
	size end	fishing experience	9.18	4	0.06
	size end	age class	4.11	4	0.39
	abundance change	estuary	4.36	1	0.23
	abundance change	education	15.55	24	0.90
	abundance change	fishing experience	4.51	10	0.92
	abundance change	age class	6.15	10	0.80
Face-to-face interviews Peel-Harvey Estuary	size change	education	3.62	7	0.82
	size change	fishing experience	1.47	2	0.48
	size change	age class	0.84	2	0.66
	size start	education	22.73	14	0.06
	size start	fishing experience	11.68	4	0.02*
	size start	age class	7.11	4	0.13
	size end	education	24.25	14	0.04*
	size end	fishing experience	9.79	4	0.04*
	size end	age class	2.63	4	0.62
	abundance change	education	12.02	21	0.94
	abundance change	fishing experience	7.27	8	0.51
	abundance change	age class	5.68	8	0.68
Face-to-face interviews Swan-Canning Estuary	size change	education	2.86	6	0.83
	size change	fishing experience	2.01	6	0.92
	size change	age class	6.58	6	0.36
	size start	education	4.20	4	0.38
	size start	fishing experience	5.02	4	0.29
	size start	age class	10.50	4	0.03*
	size end	education	3.62	4	0.46
	size end	fishing experience	2.96	4	0.56
	size end	age class	3.44	6	0.49
	abundance change	education	5.81	9	0.76
	abundance change	fishing experience	6.33	8	0.61
	abundance change	age class	4.47	8	0.81

Supplementary material 3.3. Summary of Kruskal-Wallis test conducted in this study and results obtained for the data sourced from Trove. Note that * denotes statistical significance.

Method	Statistical analysis results				
	Dependent variable	*Independent variable*	*chi-sq*	*Degrees of freedom*	*p-value*
Trove All estuaries	abundance	location	4.27	1	0.04*
	abundance	article date	187.96	179	0.31
	abundance	date bracket	11.11	8	0.20
	size	location	10.98	1	<0.01*
	size	date bracket	20.64	7	<0.01*
Trove Peel-Harvey Estuary	abundance	article date	60.00	59	0.44
	abundance	date bracket	10.12	6	0.12
	size	date bracket	10.31	3	0.02*
Trove Swan-Canning Estuary	abundance	article date	136.34	132	0.38
	abundance	date bracket	8.49	8	0.39
	size	date bracket	8.92	7	0.26

Chapter 6: Supplementary material

Supplementary material 6.1.

Social Values Survey – Blue Swimmer Crab fisheries

1) Initial Open Question Survey for Recreational Fishers

Importance of the fishery in the region

Q1. What is your main motivation to fish for Blue Swimmer Crabs?

Q1.b. How long have you been fishing for crabs?

Q1c. Thinking about when you go fishing for Blue Swimmer Crab, in your opinion, what makes your fishing trip successful?

Q2a. Do you fish for crabs in any places other than the ____ (*change location depending on survey site*), if yes where? Do you fish for any other species? If yes, which one(s)?

Q2b. Do you feel this species is key to your identity, or to your survival?

Q3. If the Blue Swimmer Crab fishery was not available, what activity(s) would you do instead?

Changes in catch over time

Q4. Has the average size of Blue Swimmer Crab you caught increased/decreased over the time you have been fishing?

Q5. Have you changed the method/gear/bait used to catch Blue Swimmer Crab over time?

Q6. Have you always targeted Blue Swimmer Crab or did you use to target other species before?

Q7. In your opinion, 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 i) Increased ii) No change iii) Decreased
b) 10-20 years i) Increased ii) No change iii) Decreased

Q8. In your opinion, has the effort needed to catch a **big Blue Swimmer Crab** per fishing day /trip increased, decreased, or not changed in the last:

a) 5-10 years i) Increased ii) No change iii) Decreased
b) 10-20 years i) Increased ii) No change iii) Decreased

Q9. Have you observed any other trends or changes in the catch of Blue Swimmer Crab or other crab species in that timeframe?

Fish as food

Q10. Do you eat the Blue Swimmer Crab you catch?

Q11. Do you buy seafood/fish in the supermarket besides what you catch?

Q12. (IF THEY BUY) Do you look at where the product comes from in the supermarket?

Q13. Would you prioritise a local product or a cheaper product?

Relation between the recreational and commercial sector

Q14. Are you aware that there is a commercial fishery for Blue Swimmer Crab?

Q15: If yes, do you know anyone working for the commercial Blue Swimmer Crab fishery?

Q16. What do you think of this fishing industry?

Q17. Would you rather buy their product than a product coming from abroad?

Views on fishery management methods

Q18. Were you aware of what fishery restocking is before this interview? (*if they don't know or get it wrong - explain*)

Q19. Are you aware of any past fishery restocking events?

Q20. What do you think are the advantages or positive outputs that could occur if restocking is used to manage the Blue Swimmer Crab fishery in the ______ estuary (*change location depending on survey site*)?

Q21. What do you think are the disadvantages or negative outputs that could occur if restocking is used to manage the Blue Swimmer Crab fishery in the ______ estuary (*change location depending on survey site*)?

Q22. Do you think other management options could be implemented for Blue Swimmer Crabs instead of a restocking program? If so, what?

Perception of issues affecting the fishery

Q23. Do you have any concerns on the status of Blue Swimmer Crab populations the ______ estuary? (*change location depending on survey site*)

Q24. Are there any political, economic or environmental factors that negatively affect your activity as recreational fisher?

Q25. What do you think are the main issues affecting the Blue Swimmer Crab fishery?

Q26. Is there anything else you would like to tell us about the Blue Swimmer Crab fishery?

Demographic Questions

Age: 18-24 25-34 35-44 45-54 55-64 65+

Gender: Male Female Other

Where do you live most of the time:

a) In Australia

b) Outside Australia

[If Live outside Australia:] Please indicate which country you live in:

[If live in Australia] Please indicate which Australian state or territory you live in:

- ☐ ACT
- ☐ NSW
- ☐ NT
- ☐ Qld
- ☐ SA
- ☐ Tas
- ☐ Vic
- ☐ WA
- ☐ Other

[If live in WA:] Please indicate which suburb or town in Western Australia you live in:

b) Type in suburb or town:
c) What is your main occupation:

What is your usual weekly income (or annual income), which includes all types of income that your household usually receives before tax is removed:

- ☐ Negative income (less than $0)
- ☐ no income ($0)
- ☐ $1-$399 ($1-$20,799)
- ☐ $400-$799 ($20,800-$41,599)
- ☐ $800-$1199 ($41,600-$62,399)
- ☐ $1200-1599 ($62,400-$83,199)
- ☐ $1600-$1999 ($84,000-$103,999)
- ☐ $2000-$2749 ($104,000-$142,999
- ☐ $2750-$3499 ($143,000-$181,999
- ☐ $3500-$4499($182,000-$233,999)
- ☐ $4500-$5499 ($234,000-$285,999)
- ☐ $5500-$6499 ($286,000-$337,999)
- ☐ >$6500 ($338,000 - >)

What is your highest level of education:

- ☐ Primary school
- ☐ Secondary school
- ☐ Technical or Further educational institution
- ☐ University or other Tertiary Institution
- ☐ Other
- ☐ Not stated

Do you fish from:

- ☐ Boat
- ☐ Land
- ☐ Both but mostly boat
- ☐ Both but mostly shore
- ☐ Both equally

When you go fishing, do you:

- ☐ Fish less than the allowed limits
- ☐ As much as I can fish legally
- ☐ Sometimes more than the legal limits
- ☐ All the answers (depending on the day)
- ☐ I don’t know