frontiers in Marine Science

ORIGINAL RESEARCH
published: 27 October 2020
doi: 10.3389/fmars.2020.578014

Who You Speak to Matters: Information Sharing and the Management of a Small-Scale Fishery

Clara Obregón[1,2], Ryan Admiraal[3], Ingrid van Putten[4,5], Michael Hughes[1,2], James R. Tweedley[1,2] and Neil R. Loneragan[1,2]*

[1] Environmental and Conservation Sciences, College of Science, Health, Engineering and Education, Murdoch University, Murdoch, WA, Australia, [2] Harry Butler Institute, Murdoch University, Murdoch, WA, Australia, [3] School of Mathematics and Statistics, Victoria University of Wellington, Kelburn, New Zealand, [4] CSIRO Oceans and Atmosphere, Hobart, TAS, Australia, [5] Centre for Marine Socioecology, University of Tasmania, Hobart, TAS, Australia

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 operators 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 awareness and tourism groups, 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 state 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 organization (i.e., strong online presence, social media, and phone/email); (v) issues of inclusiveness and representativeness were highlighted for some of the groups and organizations. This is the first study looking at information-sharing patterns through an Australian fishery network. Through this research we have identified logistical and institutional challenges to communicating information regarding the science, management and environmental issues related to a small-scale crab fishery and made suggestions to enhance information flow in the network.

Keywords: Australia, crab, commercial fishing, human dimensions, recreational fishing, social network

OPEN ACCESS

Edited by:
Marta Coll, Institute of Marine Sciences (CSIC), Spain

Reviewed by:
Andrés M. Cisneros-Montemayor, University of British Columbia, Canada
Marta Albo-Puigserver, Institute of Marine Sciences (CSIC), Spain

****Correspondence:***
Clara Obregón
clara.obregon@murdoch.edu.au

Specialty section:
This article was submitted to Marine Fisheries, Aquaculture and Living Resources, a section of the journal Frontiers in Marine Science

Received: *30 June 2020*
Accepted: *21 August 2020*
Published: *27 October 2020*

Citation:
Obregón C, Admiraal R, van Putten I, Hughes M, Tweedley JR and Loneragan NR (2020) Who You Speak to Matters: Information Sharing and the Management of a Small-Scale Fishery. Front. Mar. Sci. 7:578014. doi: 10.3389/fmars.2020.578014

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 et al., 2000). Effective management of SES ideally requires the inclusion of human dimensions such as stakeholder perceptions and knowledge (Bodin and Crona, 2009). Hence, calls for a transition from traditional fisheries management to a transdisciplinary and inclusive approach (i.e., incorporating human dimensions) are gaining support. In the last two decades, the concept of ecosystem-based fisheries management (EBFM) has been increasingly used globally and appears to be the main stated approach to guiding regulation and exploitation of natural aquatic resources in developed countries (Pitcher et al., 2009), although implementation remains limited (Link and Marshak, 2019).

The challenge of EBFM is deepened further by the existing pressures resulting from climate change. Predictions for temperate, south-western Australia suggest that this region will have reduced winter rainfall (25–72% reduction according to different global climate models), and that sea level will increase by 20 to 84 cm above its current level 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 acknowledgment that a transition toward 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 behavioral patterns, amongst individuals, groups, or organizations (Rogers, 1995). This method is increasingly recognized as an interdisciplinary tool with potential to clarify the implications of network properties for natural resource management (Turner et al., 2014). In social networks, interactions between actors can affect individuals' views, decisions, and behaviors. The structure of the social network of fishers and managers, such as the engagement or disengagement of local users and all stakeholders in the design and implementation of management regulations, can influence the effectiveness and efficiency of both adaptive management and EBFM (Bodin and Norberg, 2005). Understanding these networks and the connections within them provides a key to understanding the reasons behind the success of management and governance of a fishery (Cárcamo et al., 2014).

Social networks can influence the resilience of local communities as well as their capacity to adapt to ecosystem change. Indeed, previous research has demonstrated that social network structure greatly influences the potential for collective action (Bodin and Norberg, 2005). It has also shown the importance of collaboration and information sharing (Cohen et al., 2012), as well as the significance of particular organizations, partnerships (Berdej and 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, however, no studies have investigated the patterns of information-sharing through an Australian fishery network.

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., 2015). 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 analyzed fishers' perceptions on current management approaches, revealed that fishers were concerned about the fishery's status and management (Obregón et al., 2020). Consequently, this study used social network analysis to empirically investigate information-sharing patterns among actors in the SES of the PHBSC fishery. We explored three 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 (Ernoul and Wardell-Johnson, 2013).

MATERIALS AND METHODS

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 (∼27%) 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 estuaries and coastal embayments. Events organized to celebrate the catch of crabs in WA, such as the annual "Crabfest" celebration 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 (Department of Primary Industries and Regional Development, 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., a maximum of 10 crabs per person when fishing from the shore, or a maximum of 20 per boat provided that there are at least two people in the boat, 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. In 2019, new management measures were introduced for both fishing sectors in south-western Australia. These include a seasonal closure for all waters from Perth (WA capital city) 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 (Department of Primary Industries and Regional Development, 2018).

Located about 80 km south of Perth, the Peel-Harvey Estuary is the largest estuary in south-western Australia (area ∼130 km^2, **Figure 1**) it is also one of the most popular locations for BSC fishing, and is 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 (Peel Development Commision [PDC], 2019). The estuary's importance as a major natural asset and the population growth in the region create challenges for managing the natural resources depending on this environment.

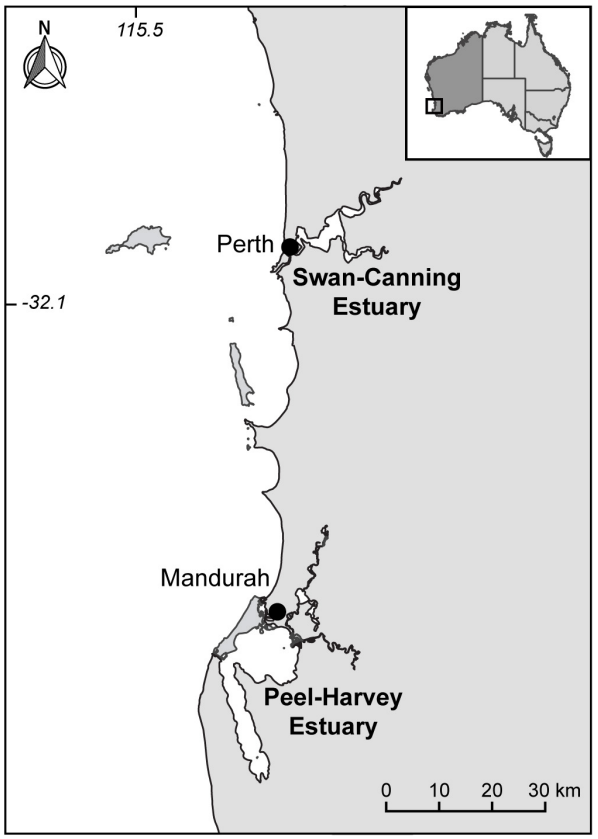

FIGURE 1 | Map of Western Australia (Australia), showing the location of the Peel-Harvey Estuary and the cities of Mandurah and Perth.

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 (Marine Stewardship Council, 2019). Consequently, as part of the certification process much information was shared between individuals and organizations participating in the PHBSC fishery network. Both fishery sectors were required to engage in providing pre-certification information and contribute to annual audits. The information shared among the network of stakeholders was a key element in this process.

Data Collection

The target population for the social network analysis was the PHBSC fishery network, which includes a diverse range of stakeholders, such as non-governmental organization

(NGO) representatives, government bodies, academics, and fishing sectors representatives (**Table 1**). 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

TABLE 1 | Organisations forming the PHBSC fishery network and acronyms used for each organisation, groups they are affiliated with, description of each organisation and total individuals mentioned (*N* = 112) and individuals interviewed (*n* = 35) for each organisation.

Group	Organization	Acronym	*N*	*n*	Description of each organization
Commercial fishing sector	Commercial fishers	MLFA	10	2	Commercial fishers representing 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 Regulations	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 organization for the management of natural resources in the Peel-Harvey Estuary Catchment
	Scientific Certification Systems	SCS	1	1	Third-party organization providing independent assessment of sustainability
Public awareness, Tourism	Dolphin Watch	–	1	0	Partnership between 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 doing river and coastal cruises, based in Mandurah
	Mandurah Times	–	1	0	Local newspaper, based in Mandurah
	Peel Bright Minds	–	1	0	Community-based organization promoting events and regional activities in the Peel region
	Western Angler Magazine	WAM	1	0	WA recreational fishing magazine

the survey). Despite some recreational fishers being mentioned during these interviews (**Table 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.

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, during daylight hours to collect network data, respondents' attitudes and perceptions toward information sharing efficiency, and individuals' demographics. Note that more 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 at 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, and 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, and 3 = high). Data from each respondent/node were also recorded, including the name, affiliation, age and level of seniority (as represented by role) in the organization. To preserve respondent privacy, names of respondents were replaced with a unique identifier code, and organization names were categorized into six broad groups [i.e., commercial sector, recreational sector (formed by organizations representing and managing the recreational fishing sector only), government body, academics, NGOs and conservation groups, public awareness and tourism] according to the general purpose of each organization (**Table 1**). 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.

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 previously described closed population (hereafter "closed population network") and all information sharing relations among respondents who were part of this closed population. We also considered a network of organizations and relations among these organizations corresponding to this closed population.
(3) A bipartite network of surveyed recreational fishers and the organizations with which they shared or received information (hereafter "bipartite network of recreational fishers and organizations").

These networks are described in more detail below.

The statistical analysis of these networks was carried out in R using the 'sna' (Butts, 2019), 'network' (Butts et al., 2019), 'statnet' (Handcock et al., 2019), and 'igraph' (Csardi, 2019) packages. This included calculating descriptive statistics, such as various measures of centrality [relating to out-ties or sharing of information, see **Table 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 these 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)].

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

TABLE 2 | Individual and organisational level network metrics of centrality, definitions, and descriptions.

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

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 analyzed 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).

Closed Population Network

The closed population network included only individuals who had been interviewed by the researchers and their information sharing relations between each other (i.e., it excluded relations with people outside of this closed network). We examined this network at two levels: (i) an actor-level scale where individuals and their relations were considered, and (ii) an organization-level scale where organizations and interactions between organizations were considered. For confidentiality reasons, in the actor-level network we report organizations according to the previously described groups relating to the purpose of the organization (**Table 1**). In the organization-level, on the other hand, we present results according to the individual organizations.

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.

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).

RESULTS

We describe the structure of the closed population network where we focus on the individual and organization level. First, 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. Then 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.

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 section "Materials and 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.

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 on 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.

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.

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 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) (**Table 3**). 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 important. The top five ranked individuals included more representatives of primary users (i.e., recreational and commercial fishing sectors) than government body representatives (**Table 3**).

TABLE 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.

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

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

TABLE 4 | Exponential random graph model (ERGM) results for attribute-based mixing for individual stakeholders (n = 35) forming the egocentric PHBSC fishery network.

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

*See **Supplementary Tables S1–S5** for more details. The symbol '*' denotes the presence of significant differences ($p < 0.001$).*

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 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, and 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; **Supplementary Tables S1, S2**).

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 would be expected if there was no preference for relations based on age (p = 0.0001; **Supplementary Table S3**). 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 S3**), 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 S3**), evidence of heterophily.

Closed Population Network

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

Actor-Based Network

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

The two individuals with highest degree centrality and degree prestige when considering the egocentric network (IDs 33 and 6) also had the highest degree centrality and degree prestige when considering the closed population network (**Table 5** and **Figure 2**). Here, however, their relative rankings were swapped (**Tables 3**, **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 the 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. 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

TABLE 5 | Results showing individuals with highest degree centrality and prestige metrics forming the closed population network and the organizations 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

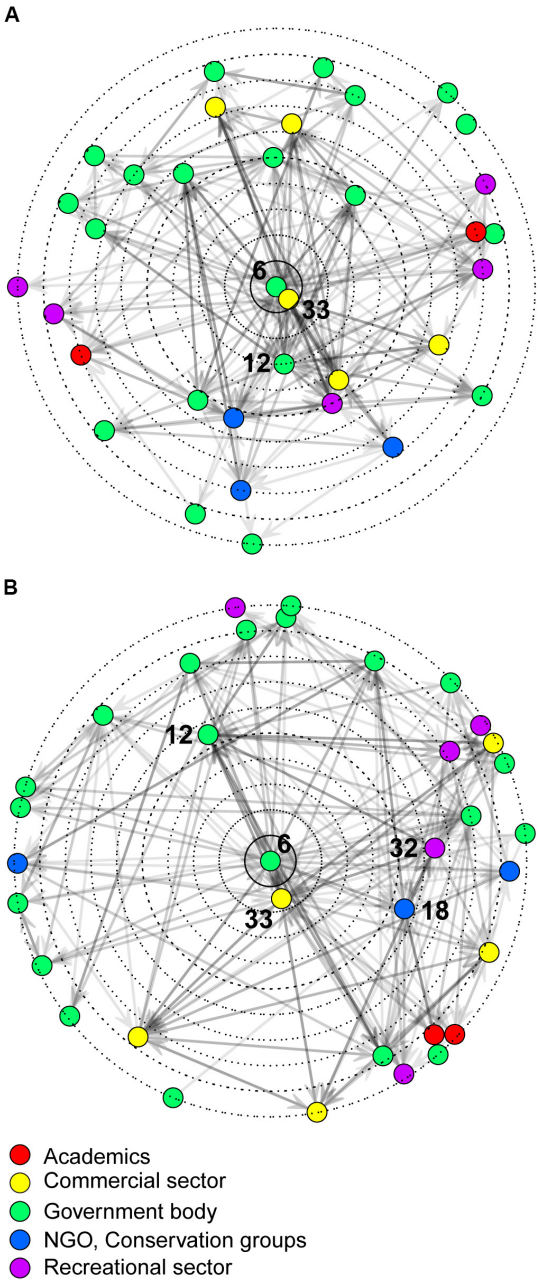

FIGURE 2 | Target plot of degree centrality **(A)** and betweenness centrality **(B)** for individuals forming the closed population network. Numbers indicate individuals with higher centrality and betweenness, These appear near the center of the plot.

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.

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 3**, **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 numbers) in our study having a number of key information-sharing relations outside the key stakeholder groups and potentially being important for the transmission of information to the recreational sector, 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 5**). Both commercial fishers maintained (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.

Organization-Based Network

The 35 individuals comprising the closed population network represented 10 organizations. We considered the 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 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 3A**) and betweenness centrality for organizations (**Figure 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

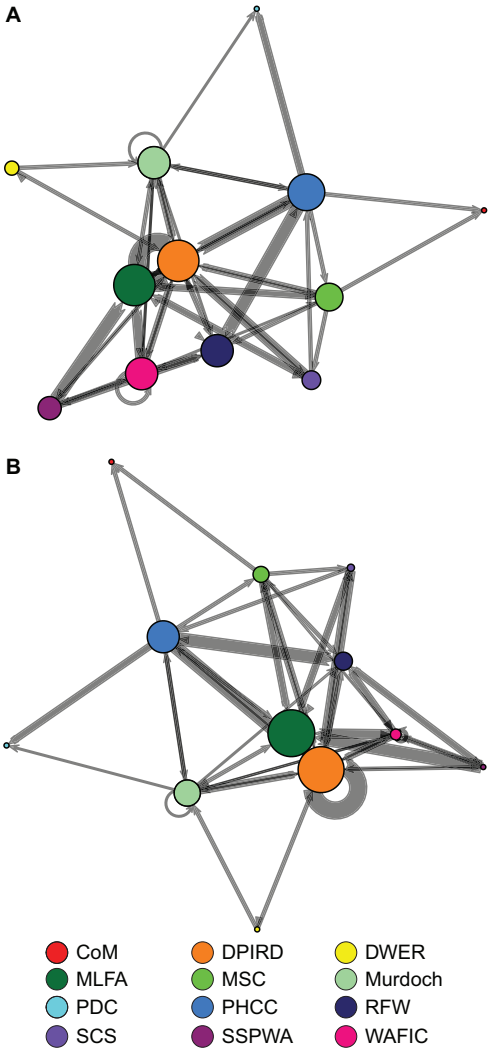

FIGURE 3 | Plots of the network of organizations represented in the closed population network with edge widths representing the frequency of relations between organizations and node sizes representing weighted degree centrality **(A)** and betweenness centrality **(B)** for organizations.

fishing sectors and the environment of the estuary. For example, the topic of discussions started by PHCC focused mainly on environmental and management topics (45% for both) and less so on the fishery science (10%), whereas DPIRD and MLFA talked mainly about management (47.1 and 69.2%, respectively) as well as the fishery (47.1 and 23.1%), with little information exchange focusing on the environment of the estuary (5.78 and 7.7%, respectively).

When considering degree prestige, the analysis of the closed population network based on organizations presented again DPIRD and MLFA as the organizations receiving most information (degree prestige = 0.818 and 0.727, respectively). Recfishwest (RFW) appeared as the third organization in the ranking (degree prestige = 0.636). These are the organizations receiving most often information from others in the network. This is not surprising as these organizations represent the main

TABLE 6 | Results showing centrality and prestige measures for organizations represented in the closed population network, (n = 35).

Organization	Degree centrality	Degree prestige	Betweenness centrality
Department of Primary Industries and Regional Development	0.727	0.818	0.135
Mandurah licensed Fishermen Association	0.727	0.727	0.138
Peel-Harvey Catchment Council	0.636	0.364	0.089
Recfishwest	0.545	0.636	0.043
Murdoch	0.545	0.455	0.071
WA Fishing Industry Council	0.545	0.455	0.019
Marine Stewardship Council	0.455	0.364	0.036
Southern Seafood Producers of WA	0.364	0.364	0
Scientific Certification Systems	0.273	0.364	0.007
Department of Water and Environmental Regulation	0.182	0.091	0

managing bodies and the primary users of the fishery, which are expected to receive and share information with each other.

Finally, when looking at the bridging capacity (i.e., betweenness centrality) of these organizations, DPIRD, MLFA, and PHCC had betweenness centrality scores considerably higher than the rest (betweenness centrality = 0.135, 0.138, 0.089, respectively; **Table 6** and **Figure 3**). These organizations belonged to three different groups (government body, commercial fishing sector and NGOs and 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 was the fourth ranked organization when looking at its bridging capacity (betweenness = 0.067). This is interesting as no individuals from the group of academics, to which this organization is affiliated to, had appeared in previous analyses (**Tables 3**, **5** and **Figures 2**, **3**), suggesting that despite the individuals having low connectivity, the organization 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.

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 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 4**, and further analysis below).

The perceived quality of information received by recreational fishers differed significantly among organizations (from low = 1,

TABLE 7 | Results showing the organisations mentioned by recreational fishers and their degree metrics.

Organization	Degree centrality
Recreational fishers	0.402
Mandurah licensed Fishermen Association	0.196
Department of Primary Industries and Regional Development	0.188
Recfishwest	0.161
Journalist	0.018
Western Angler Magazine	0.018
Local Fishing Club	0.018
Peel-Harvey Catchment Council	0.009

*Organisations are ranked according to their degree centrality. Refer to **Table 1** for information on which acronym corresponds to each organisation, (n = 50).*

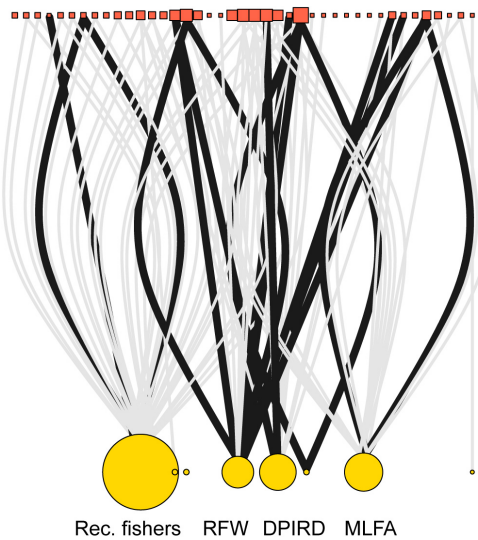

FIGURE 4 | Bipartite network of recreational fishers network and the organizations (i.e., nodes) with which they exchange information. Recreational fishers are denoted by red squares, while organizations are represented by yellow circles. Organizations with degree centralities exceeding 0.1 are labeled, 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 1** for information on which acronym corresponds to each organisation.

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.

There was also considerable variation in terms of the mode of communication used in information exchange between recreational fishers and different organizations (**Figure 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 (**Figure 5**). 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, although a small number of 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 from 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).

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 organized for the peak bodies representing the fishery stakeholders (AMMS, 34.8%); events organized 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 that they were not useful.

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 that they were unaware of events providing information on the management and science of the PHBSC fishery. When asked if they would consider informative events to be beneficial in the future, 70% were supportive of this, whereas 26.7% were not. The fact that a quarter of the interviewees perceived public events as not beneficial could be due to a lack of interest in the information itself or that the information was not presented in a useful manner.

DISCUSSION

Our study demonstrated 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 organization-based analysis); and (iii) a bipartite network of recreational fishers and

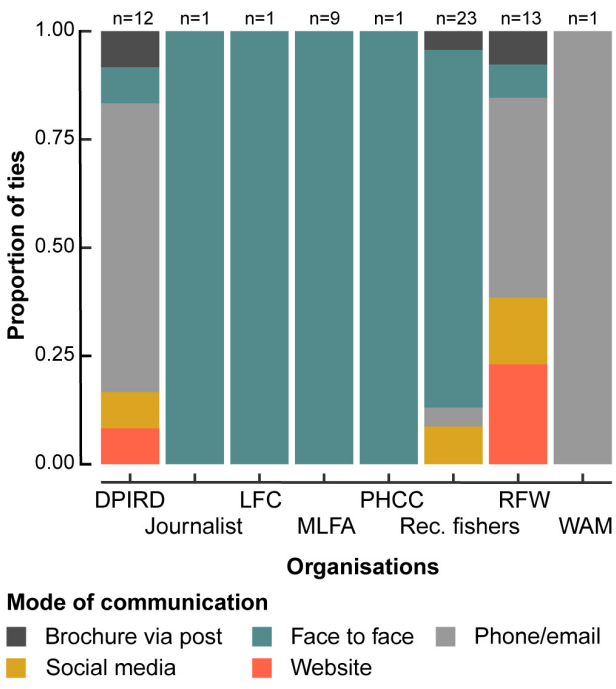

FIGURE 5 | The proportion of information exchanges between recreational fishers and organizations involving various modes of communication, as reported by recreational fishers. Sample sizes (n) on which these proportions are estimated are also presented. Refer to **Table 1** for information on which acronym corresponds to each organisation.

organizations. To our knowledge, this is the first study looking at information sharing in an Australian fishery social network and one of the few network studies looking at information sharing between small-scale fishery stakeholders globally (Bodin and Norberg, 2005; Leonard et al., 2011; Turner et al., 2014).

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's management, instead of being involved in these discussions only through the organization representing the commercial fishing sector in WA (i.e., WAFIC). This is consistent with previous studies showing how the inclusion of fisher-knowledge in management discussions can benefit adaptive management decision making, as fishers adapt their methods and their learning with environmental changes and uncertainty (Grant and Berkes, 2007). Stakeholders from both the commercial and recreational fishing sector figured prominently in the network in terms of measures of centrality and prestige. Increases in degree prestige and decreases in degree centrality for commercial and recreational fishers, relative to other stakeholders for the closed population network, is consistent with commercial and recreational PHBSC fishing representatives largely receiving information from key government bodies, community-based organizations, NGOs, etc., but then disseminating that information outside of those groups, 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 share 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 and Crona, 2009). Overall, homophily has the potential to reduce the efficiency of resource management and therefore reduce the capacity to adapt management if change occurs (Bodin and 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 people across all the groups tended to exchange information with older and more experienced stakeholders 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 and Handock, 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 topic's definition (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 organizations most highly connected, after DPIRD and MLFA. RFW, was one of the most connected organizations in the network. Unlike commercial fishers, it is common for recreational fishers to be represented by a broad recreational fishing organization, as they are often not affiliated to one group or association (Kearney, 2002). The high degree prestige of this organization suggests that most information received is sourced from government bodies and other groups responsible for the management of the fishery. Though a decrease in the degree centrality, combined with a relatively low betweenness centrality suggests that this organization is sharing information with other stakeholders outside these groups, and not so much within it. The PHCC is the only organization that is not directly involved in the fishery, 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.

The above 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.

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 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.

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 et al., 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 and Rowley, 2017). Restricting knowledge exchange within an organization or group impedes the diffusion of information outside the entity and can create clusters or silos of high-quality information that is not shared across the network. As an organization, Murdoch's bridging capacity was among the five highest of all organizations, and mainly shared information with DPIRD and RFW, and less so with groups such as the 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.

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, mainly on fishing spots, catches, bait used and shared opinions on the catches during the season. This is probably a result of sharing the same fishing locations and launching their boats from the same boat ramps. Though these discussions are very informal, they are relevant for the social acceptability (or social license to operate) of the commercial sector in the region. In fact, social license to operate is an increasingly important issue for commercial fishers throughout Australia, as the recreational sector grows, and the commercial sector is pushed out of some fisheries (Cullen-Knox et al., 2017). Conflict between recreational and commercial fishers over a resource has often been reported worldwide (Voyer et al., 2017). Previous studies have demonstrated the importance of communication between stakeholders for achieving understanding between groups, reaching consensus and gaining a social license to operate for commercial resource users (Voyer et al., 2015). Commercial fishers in WA have previously reported that gaining an enhanced social license to operate was a key reason for initiating the certification process of the PHBSC fishery with the Marine Stewardship Council (van Putten et al., 2020).

It has been reported previously that bridging organizations face difficulties in fully representing the views of large numbers of constituents (Berdej and Armitage, 2016). Recreational fishers' perceptions of the quality of information provided by various organizations showed a contrast between how they viewed information related to the 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.

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 to recreational fishers 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 (12%) 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.

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 sharing 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 a small-scale crab fishery. 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 fundamental to sustainable fisheries management, as information might be incorrectly interpreted or even overlooked. This could potentially affect the fishery's social license to operate, reducing acceptance within the local community. Reduced community acceptance could even lead to conflict and failure of effective 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.

DATA AVAILABILITY STATEMENT

The datasets generated in this article are not readily available because of the significantly increased risk that individuals may be more easily identifiable and therefore breach confidentially of the data required by the Human Research Ethics approval conditions. Requests to access the datasets should be directed to clara.obregon@murdoch.edu.au.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Murdoch University Human Research Ethics Committee. All work was conducted in accordance with Murdoch University Human Ethics Permit 2017/129.

The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

CO, MH, NL, and JT conceived and devised the presented idea. CO, IP, and MH designed the surveys. CO and IP classified the data collected and determined planned potential outlines that could be obtained from the results. CO and RA performed the network analysis and structured the manuscript. RA aided in interpreting the results. All authors contributed to writing and reviewing of the manuscript.

FUNDING

This study was supported by funding from the FRDC (FRDC 2016/034) on behalf of the Australian Government, the Recreational Fishing Initiatives Fund and Murdoch University.

ACKNOWLEDGMENTS

Stakeholders from the Peel-Harvey blue swimmer crab fishery, in particular, the commercial and recreational fishers, are thanked for their time and participation in the surveys. Dr. Emily Ogier from the Human Dimension Research subprogram of the Fisheries Research and Development Corporation of Australia (FRDC) and DPIRD staff are thanked for their useful input. The writing of this paper was helped by a research visit to CSIRO in Hobart, and the support of this institution is greatly acknowledged. We also thank the two reviewers, as well as the editor, whose input and feedback greatly improved the clarity and overall quality of the manuscript.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2020.578014/full#supplementary-material

REFERENCES

Admiraal, R., and Handock, M. S. (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. doi: 10.1111/rssa.12067

Ajzen, I. (1991). The theory of planned behavior. *Organ. Behav. Hum. Decis. Process.* 50, 179–211. doi: 10.1016/0749-5978(91)90020-T

Alexander, S. M., Armitage, D., and Charles, A. (2015). Social networks and transitions to co-management in jamaican marine reserves and small-scale fisheries. *Glob. Environ. Change* 35, 213–225. doi: 10.1016/j.gloenvcha.2015.09.001

Barclay, K. (2012). The social in assessing for sustainability. Fisheries in Australia. *Cosmopol. Civil Soc. Interdiscip. J.* 4, 38–53. doi: 10.5130/ccs.v4i3.2655

Barnes-Mauthe, M., Allen Gray, S., Arita, S., Lynham, J., and Leung, P. (2015). What determines social capital in a socialecological system? Insights from a network perspective. *Environ. Manag.* 55, 392–410. doi: 10.1007/s00267-014-0395-7

Berdej, S. M., and Armitage, D. R. (2016). Bridging organizations drive effective governance outcomes for conservation of Indonesia's marine systems. *PLoS One* 11:e0147142. doi: 10.1371/journal.pone.0147142

Berkes, F., Folke, C., and Colding, J. (2000). *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience*. Cambridge, MA: Cambridge University Press.

Bodin, O., and Crona, B. I. (2009). The role of social networks in natural resource governance: what relational patterns make a difference? *Glob. Environ. Change* 19, 366–374. doi: 10.1016/j.gloenvcha.2009.05.002

Bodin, O., and Norberg, J. (2005). Information network topologies for enhanced local adaptive management. *Environ. Manag.* 35, 175–193. doi: 10.1007/s00267-004-0036-7

Butts, C. T. (2019). *Sna. R package version 4.0.2*. Available online at: https://cran.r-project.org/web/packages/sna/index.html

Butts, C. T., Hunter, D. R., Handcock, M. S., Bender-deMoll, S., Homer, J., and Wang, L. (2019). *"Package 'Network"'. R package version 4.0.2*. Available online at: https://cran.r-project.org/web/packages/network/index.html

Caputi, N., Jackson, G., and Pearce, A. (2014). *The Marine Heat Wave Off Western Australia During the Summer of 2010/11: 2 Years on*. Fisheries Research Report No 250. Western Australia: Department of Fisheries.

Cárcamo, P. F., Garay-Flühmann, R., and Gaymer, C. F. (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. doi: 10.1016/j.ocecoaman.2014.01.007

Chizinski, C. J., Martin, D. R., Shizuka, D., and Pope, K. L. (2018). Bipartite networks improve understanding of effects of waterbody size and angling method on anglerfish interactions. *Can. J. Fish. Aquat. Sci.* 75, 72–81. doi: 10.1139/cjfas-2016-0176

Cohen, P. J., Evans, L. S., and Mills, M. (2012). Social networks supporting governance of coastal ecosystems in solomon islands: social networks for ecosystem governance. *Conserv. Lett.* 5, 376–386. doi: 10.1111/j.1755-263X.2012.00255.x

Correa, T., Hinsley, A. W., and Gil de Zúñiga, H. (2010). Who interacts on the web?: the intersection of users' personality and social media use. *Comput. Hum. Behav.* 26, 247–253. doi: 10.1016/j.chb.2009.09.003

Csardi, G. (2019). *Igraph. R package version 4.0.2.* Available online at: https://cran.r-project.org/web/packages/igraph/index.html

Cullen-Knox, C., Haward, M., Jabour, J., Ogier, E., and Tracey, S. R. (2017). The social licence to operate and its role in marine governance: insights from Australia. *Mar. Policy* 79, 70–77. doi: 10.1016/j.marpol.2017.02.013

Cvitanovic, C., van Putten, E. I., Hobday, A. J., Mackay, M., Kelly, R., McDonald, J., et al. (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. doi: 10.1016/j.marpol.2018.04.010

Department of Primary Industries, and Regional Development [DPIRD] (2018). *Protecting Breeding Stock Levels of the Blue Swimmer Crab Resource in the South West*. Fisheries Management Paper No. 288. Western Australia: Department of Primary Industries and Regional Development.

Ernoul, L., and Wardell-Johnson, A. (2013). Governance in integrated coastal zone management: a social networks analysis of cross-scale collaboration. *Environ. Conserv.* 40, 231–240. doi: 10.1017/S0376892913000106

Fletcher, W. J., Mumme, M. D., and Webster, F. J. (2017). *Status Reports of the Fisheries and Aquatic Resources of Western Australia 2015/2016: The State of the Fisheries*. Western Australia: Department of Fisheries.

Fullwood, R., and Rowley, J. (2017). An investigation of factors affecting knowledge sharing amongst UK academics. *J. Knowl. Manag.* 21:38. doi: 10.1108/JKM-07-2016-0274

Grant, S., and Berkes, F. (2007). Fisher knowledge as expert system: a case from the longline fishery of Grenada, the Eastern Caribbean. *Fish. Res.* 84, 162–170. doi: 10.1016/j.fishres.2006.10.012

Gutiérrez, N. L., Hilborn, R., and Defeo, O. (2011). Leadership, social capital and incentives promote successful fisheries. *Nature* 470, 386–389. doi: 10.1038/nature09689

Hallett, C. S., Hobday, A. L., Tweedley, J. R., Thompson, P. A., McMahon, K., and Valesini, F. J. (2018). Observed and predicted impacts of climate change on the estuaries of South-Western Australia, a mediterranean climate region. *Region. Environ. Change* 18, 1357–1373. doi: 10.1007/s10113-017-1264-8

Handcock, M. S., Hunter, D. R., Butts, C. T., Goodreau, S. T., Krivitsky, P. N., Bender-deMoll, S., et al. (2019). *Statnet. R package version 4.0.2*. Available online at: https://cran.r-project.org/web/packages/statnet/index.html

Hardin, G. (1968). The tragedy of the commons. *Science* 162, 1243–1248. doi: 10.1126/science.162.3859.1243

Kearney, R. E. (2002). Co-management: the resolution of conflict between commercial and recreational fishers in victoria, Australia. *Ocean Coast. Manag.* 45, 201–214. doi: 10.1016/S0964-5691(02)00055-8

Leonard, N. J., Taylor, W. W., Goddard, C. I., Frank, K. A., Krause, A. E., and Schechter, M. S. (2011). Information flow within the social network structure of a joint strategic plan for management of great lakes fisheries. *N. Am. J. Fish. Manag.* 31, 629–655. doi: 10.1080/02755947.2011.603651

Link, J. S., and Marshak, A. R. (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. doi: 10.1007/s11160-018-9544-z

Maiolo, J. R., Johnson, J., and Griffith, D. (1992). Applications of social science theory to fisheries management: three examples. *Soc. Nat. Resourc.* 5, 391–407. doi: 10.1080/08941929209380801

Marine Stewardship Council [MSC] (2019). *Get Certified. Your Guide to the MSC Fishery Assessment Process*. London: Marine Stewardship Council.

McPherson, M., Smith-Lovin, L., and Cook, J. M. (2001). Birds of a feather: homophily in social networks. *Annu. Rev. Sociol.* 27, 415–444. doi: 10.1146/annurev.soc.27.1.415

Morison, A., Daume, S., Gardner, C., and Lack, M. (2015). *Western Australia Peel-Harvey Estuarine Fishery MSC Full Assessment Final Report*. Victoria: SCS Global Services Report.

Mueller, K. B., Taylor, W. W., Frank, K. A., Robertson, J. M., and Grinold, D. L. (2008). Social networks and fisheries: the relationship between a charter fishing network, social capital, and catch dynamics. *N. Am. J. Fish. Manag.* 28, 447–462. doi: 10.1577/M07-016.1

Obregón, C., Tweedley, J. R., Loneragan, N. R., and Hughes, M. (2020). Different but not opposed: perceptions between fishing sectors on the status and management of a crab fishery. *ICES J. Mar. Sci.* 2019:fsz225. doi: 10.1093/icesjms/fsz225

Peel Development Commision [PDC] (2019). *Our Region - Fastest Growing Region in Western Australia*. Mandurah: Peel Development Commision.

Pitcher, T. J., Kalikoski, D., Short, K., Varkey, D., and Pramod, G. (2009). An evaluation of progress in implementing ecosystem-based management of fisheries in 33 countries. *Mar. Policy* 33, 223–232. doi: 10.1016/j.marpol.2008.06.002

Potter, I. C., Chrystal, P. J., and Loneragan, N. R. (1983). The biology of the blue manna crab *Portunus pelagicus* in an Australian Estuary. *Mar. Biol.* 78, 75–85. doi: 10.1007/BF00392974

Rogers, E. M. (1995). *Diffusion of Innovations*, 5th Edn. New York, NY: Free Press.

Ryan, K. L., Hall, N. G., Lai, E. K., Smallwood, C. B., Tate, A., Taylor, S. M., et al. (2019). *Statewide Survey of Boat-Based Recreational Fishing in Western Australia 2017/18*. Fisheries Research Report No. 297. Western Australia: Department of Primary Industries and Regional Development.

Stern, P. C., Dietz, T., Abel, T., Guagnano, G. A., and Kalof, L. (1999). A value-belief-norm theory of support for social movements: the case of environmentalism. *Hum. Ecol. Rev.* 6, 81–97.

Taylor, S. M., Blight, S. J., Desfosses, C. J., Steffe, A. S., Ryan, K. L., Denham, A. M., et al. (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. doi: 10.1093/icesjms/fsy066

Turner, R. A., Polunin, N. V. C., and Stead, S. M. (2014). Social networks and fishers' behavior: exploring the links between information flow and fishing success in the northumberland lobster fishery. *Ecol. Soc.* 19:38. doi: 10.5751/ES-06456-190238

Valesini, F. J., Hallett, C. S., Hipsey, M. R., Kilminster, K. L., Huang, P., and Hennig, K. (2019). "Peel-harvey estuary, Western Australia," in *Coasts and Estuaries*, eds E. Wolanski, J. W. Day, M. Elliott and R. Ramesh (Amsterdam: Elsevier), 103–120. doi: 10.1016/b978-0-12-814003-1.00007-1

van Putten, I., Longo, C., Arton, A., Watson, M., Anderson, C. M., Himes-Cornell, A., et al. (2020). Shifting focus: the impacts of sustainable seafood certification. *PLoS One* 15:e0233237. doi: 10.1371/journal.pone.0233237

von Heland, F., Crona, B., and Fidelman, P. (2014). Mediating science and action across multiple boundaries in the coral triangle. *Glob. Environ. Change* 29, 53–64. doi: 10.1016/j.gloenvcha.2014.08.003

Voyer, M., Gladstone, W., and Goodall, H. (2015). Obtaining a social licence for MPAs influences on social acceptability. *Mar. Policy* 51, 260–266. doi: 10.1016/j.marpol.2014.09.004

WAFIC (2020). *Who We Are – Our members*. Fremantle: Western Australian Fishing Industry Council Inc.

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.