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Information access and knowledge exchange in co-managed coral reef fisheries

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ABSTRACT

Effectively managing ecosystems is an information intensive endeavour. Yet social, cultural, and economic barriers can limit who is able to access information and how knowledge is exchanged. We draw on social network theory to examine whether co-management institutions break down these traditional barriers. We examined the factors that predict information access and knowledge exchange using interview and knowledge sharing network data from 616 Kenyan coral reef fishers operating in four communities with formal co-management institutions. For access to fisheries management information, we found disparities in fisher's age, leadership status, and wealth. Yet once we accounted for formal engagement in the co-management process, only wealth disparities remained significant. In contrast, knowledge exchange was insensitive to whether or not we accounted for engagement in co-management. We found that community leaders and external actors, such as NGO representatives, were primary sources of fisheries-related knowledge. Among fishers, knowledge exchange tended to occur more often between those using the same landing site. Fishers engaged in the co-management process and community leaders were likely to transfer knowledge widely (acting as 'central communicators'), yet only leaders bridged disconnected groups (acting as 'brokers'). Ethnic minorities and those with higher levels of education were more likely to fall on the periphery of the knowledge exchange networks. Taken together, our results suggest that co-management can break down traditional social and cultural – but perhaps not economic – barriers to information access; while social, cultural, and economic factors remain important for structuring knowledge exchange.

1. Introduction

Coral reefs are one of the most productive and biologically diverse ecosystems on the planet, providing millions of people with ecosystem goods and services that play a critical role in shaping livelihoods and supporting human wellbeing. Reefs are critical for supporting biodiversity (Connell, 1978), and global estimates suggest the value of the economic, livelihood, and food security benefits provided by reefs is some US$375 billion (Costanza et al., 1997). Most coral reefs are located across the tropics in developing counties, where reef fisheries play a particularly important role in generating income and supporting food security (Cinner, 2014). Recent estimates suggest that some six million people, overwhelmingly in developing countries, are directly dependent on reef fisheries for their livelihoods (Teh et al., 2013). Moreover, artisanal fisheries (including reef fisheries) make up more than half of the protein and mineral intake for over 400 million people in Africa and south Asia, whereas fish accounts for 50–90% of the protein consumed in some coral dominated Pacific Island communities (Cinner, 2014).

In spite of the importance of reef fisheries for supporting biodiversity (Graham et al., 2015) and their role in national and local economies (Grafeld et al., 2017), reef fisheries have generally suffered from weak governance, inadequate funding to support conservation, and neglect across all levels of government (Purcell and Pomeroy, 2015). Part of the challenge in managing reef fisheries sustainably has been the common-pool nature of the resource, which creates management vulnerabilities due to the difficulty in excluding users and the fact that reef fisheries are rivalrous by nature (i.e., fishing is competitive in the sense that once a fish is caught by one person, it is no longer available for another) (Gardner et al., 1990). Reef fisheries are also

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inherently complex in terms of both the resource base and associated harvesting strategies, i.e., they are often comprised of multiple species being targeted or incidentally caught by multiple individuals using multiple gears (Barnes et al., 2019). As a result, many reefs have effectively operated as open access and have been severely overfished (Pandolfi et al., 2003). In response to ongoing declines in reef health and the perceived failure of centralized, top-down approaches to sustain reef functions and services, governance reforms in recent decades have focused on devolving power, authority, and responsibility for reef conservation and management to local institutions and users (i.e. fishers) through different types of participatory and collaborative governance arrangements, such as co-management (Cinner et al., 2012; Purcell and Pomeroy, 2015). Though co-management arrangements are diverse, they typically involve some form of shared management authority between state-level institutions and resource users at the local level (Ayers and Kittinger, 2014). This move is thus somewhat reflective of the reality that in many locations, day-to-day decisions regarding the conservation and management of reef resources has, in practice, been left in the hands of local users for some time (Alexander et al., 2018).

Despite the specific governance arrangement, effectively managing any resource base to achieve conservation goals and support human well-being is an information intensive endeavour. It requires access to key information that can guide and support adaptive conservation and management decisions, as well as the transfer of knowledge among various, diverse actors involved in managing and/or using the resource (Carlsson and Berkes, 2005; Gezelius, 2007). At the most basic level, setting appropriate conservation and/or management targets requires accurate information on the biological aspects of the resource base, such as the prevalence and location of the resource; while reaching these targets requires knowledge of strategies that can be used to achieve them. In addition, though reaching conservation and/or management targets relies on many factors, such as capacity and enforcement, a critical first step is ensuring that people who depend on or use the resource are well-informed of any devised rules with which they are expected to comply (Keane et al., 2008). Yet ecological resources are known to be affected by a much broader range of biological, environmental, and social factors; thus, conservation and management requires not only basic knowledge of the resource, but also knowledge of the full complexity of the social-ecological system in which the resource base is embedded (Berkes et al., 2003). Such knowledge can include how the resource is affected by (and affects), e.g., (a) environmental and biophysical conditions, such as temperature and habitat (Graham et al., 2007); (b) technological and economic conditions, such as the gear available for resource extraction and market dynamics (Cinner et al., 2018); and (c) social conditions, such as human use and cultural connections to resources (Hicks et al., 2016). Though historically, local knowledge of social-ecological system dynamics guided cultural norms and practices that were highly successful in managing pressures on reef fish in some locations (e.g., the “ahupua'a” system in Hawaii), many of these traditional systems have since broken down (Cudney-Bueno and Basurto, 2009; Cudney-Bueno et al., 2009; Jokiel et al., 2011).

Reef conservation and management now faces considerable challenges. For example, many reefs are located in tropical regions characterized by high levels of dependence on reef resources and high rates of poverty (Cinner, 2014); most reefs are characterized by a socially, culturally, and economically diverse array of actors targeting multiple species using multiple gears (McClanahan and Kosgei, 2018; Barnes et al., 2019); and all reefs now face unprecedented pressures that are escalating in both scope and scale, such as globalization, climate change, and human migration (Cudney-Bueno and Basurto, 2009; Hughes et al., 2017). All of these factors compound the already high information needs of achieving reef conservation and management that supports both biodiversity and the livelihoods of reef-dependent communities.

Information access and knowledge exchange are key components of co-management (Berkes, 2009). By nature, co-management empowers communities with a greater say over the allocation and use of their resources, but it is also argued to empower local communities by enhancing community access to information and providing avenues for participation which can facilitate knowledge exchange and learning (Pomeroy et al., 2001). Many co-management institutions also incorporate components of adaptive management by striving to be reflexive to environmental change and the continuous acquisition of new knowledge, often referred to as ‘adaptive co-management’ (Armitage et al., 2009). Effective communication and information dissemination is thus a key principle of co-management in practice (Gruber, 2010), as informed and adaptive decision-making relies upon the existence of strong communication channels and knowledge exchange among and between resource users and other external actors (Berkes, 2009). Yet in complex social-ecological systems such as coral reefs, there are a number of factors that can influence people's access to information and whether and how knowledge is (or isn't) exchanged (Crona and Bodin, 2006; Fazey et al., 2013), which can severely inhibit decision-making and the learning necessary to sustain reefs into the future. Whether these barriers to information access and knowledge exchange persist despite the collaborative nature and participatory structure of formal co-management institutions remains unknown.

Here, we address the critically important question of whether and how certain social, economic, and cultural factors structure access to, and the exchange of key information and knowledge that can support reef conservation and management, and whether formal co-management institutions help to break down these traditional barriers. We first review the theoretical and empirical evidence regarding factors that may inhibit and/or facilitate information access and knowledge transfer in the coral reef context. We then integrate insights from social network science (e.g., Freeman, 1979; Marsden, 1990; Burt, 1992; Everett and Borgatti, 1999) to empirically examine how these factors relate to information access and knowledge exchange in four reef fishing communities operating over a large spatial scale along the Kenyan coast, and test whether formal engagement in the co-management process breaks down any identified barriers associated with information access and knowledge exchange.

1.1. Barriers to information access and knowledge exchange

There are many definitions of information, knowledge, and knowledge exchange (Fazey et al., 2013). Here, we refer to information as data that provides answers to questions such as “who”, “what”, “where”, and “when”; knowledge as the internalized product of information (answering the “how” question) that allows for it to be applied and conclusions to be drawn (Ackoff, 1989); and knowledge exchange as the process of generating and/or sharing knowledge between two or multiple parties (Fazey et al., 2013; Table 1).

Social, cultural, and economic factors are known to affect who is able to access information and whether and how knowledge is exchanged in social-ecological systems. These factors can range from an actor's personal or socioeconomic characteristics to the structure of their social relationships (Bodin and Crona, 2008), which are often intertwined (Barnes-Mauthe et al., 2015). For example, in reef-dependent communities, socioeconomic characteristics such as education, wealth, and formal leadership status are known to create social hierarchies (Cinner et al., 2009a). These hierarchies can privilege those at the top with greater access to information and more opportunities for shaping knowledge (thereby becoming ‘knowledge producers’) as well as the knowledge exchange process (Mbaru and Barnes, 2017). Moreover, communities with a stake in fishery resources in a particular location are rarely comprised of homogeneous groups; there can be geographical boundaries that distinguish sets of actors from others (Alexander et al., 2018), or actors may form cohesive groups driven by cultural or ethnic differences (Barnes et al., 2016) or certain activities, such as using a particular fishing gear (Crona and Bodin, 2006). These

Table 1
Summary of our empirical strategy.

	Information access	Knowledge exchange
Definitions	Here we refer to information as data that provides answers to questions such as "who", "what", "where", and "when" (Ackoff, 1989).	Here we refer to knowledge as the internalized product of information (answering the "how" question) that allows for it to be applied and for conclusions to be drawn, and knowledge exchange as the process of generating and/or sharing knowledge between two or multiple parties (Ackoff, 1989, Fazey et al., 2013).
Measurement	5-Point Likert scale question that asked fishers how easy or difficult it was for them to access information related to fisheries management, recoded as [−1] difficult to access, [0] neutral (neither difficult nor easy to access), or [1] easy to access (see Fig. S1 for full frequency distributions).	Directed knowledge exchange networks capturing both the outward flow of fisheries-related information and advice (i.e., i → j exists if j stated that i is an important source of information and advice) and reciprocal knowledge exchanges (i.e., i ↔ j exists if j stated that i is an important contact for the reciprocal exchange of information and advice, or i stated that j is an important contact for the reciprocal exchange of information and advice).
Analyses	(A) Ordinal logistic regression predicting information access using age, education, wealth, landing site, gear use, and leadership status as independent variables; (B) Same as above, but including engagement in co-management (i.e., BMU member) as an additional independent variable. See Section 3.3.	Step 1: Qualitative characterization of the knowledge exchange networks including non-respondent leaders to identify key knowledge sources, supplemented by an ANOVA on the mean no. of outgoing ties per node across key stakeholder groups (i.e., fishers, fisher leaders, non-fisher leaders). See Section 3.2. Step 2: Calculation of three key structural network measures for all (respondent) fishers: (1) central communicators (i.e., outdegree centrality), (2) network periphery (i.e., [1] if the fisher falls outside the main network component, [0] if not), (3) network brokers (i.e., [1] if the fisher brokers key subgroups in each community, [0] if not). See Section 3.2. Step 3 (A) Regression models predicting central communicators, network periphery, and brokers using age, education, wealth, landing site, gear use, and leadership status as independent variables; (B) Same as above, but including engagement in co-management (i.e., BMU member) as an additional independent variable. See Section 3.3.

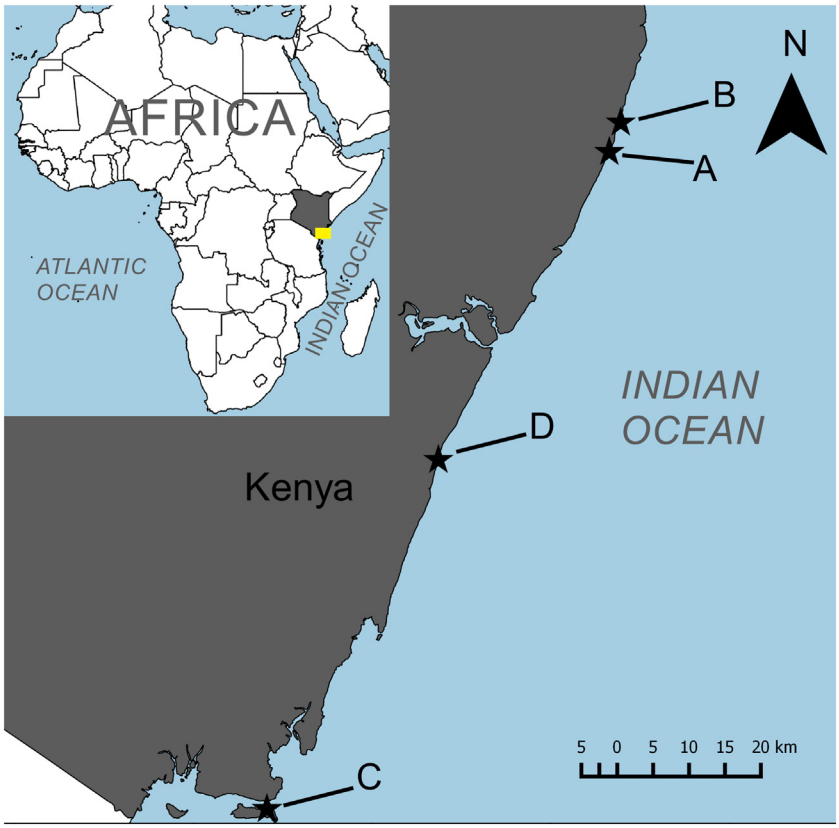

Fig. 1. Map of the Kenyan coastal seascape showing the geographical distribution of the four co-managed coral reef fishing study communities (A–D).

groups can result in strong social identities and fragmented social network structures that inhibit the flow of information and the exchange of knowledge among the wider community of stakeholders (McPherson et al., 2001; Barnes-Mauthe et al., 2013), thereby advantaging dominant groups while disadvantaging others.

Even in the absence of strong sub-group formation, the manner in which individuals are embedded in the structure of social networks can have a significant impact on the way they are able to share or receive information. For example, individuals well-connected or central in a network tend to be better situated to both access and transfer information (Freeman, 1979), whereas those on the periphery with few ties or those that are completely isolated from primary hubs of social

activity can be marginalized from the knowledge exchange process (Everett and Borgatti, 1999). Importantly, these network characteristics have also been shown to be associated with specific social, cultural, and economic factors, such as fishing gear use, ethnic affiliation, and wealth (Crona and Bodin, 2006; Barnes-Mauthe et al., 2015; Mbaru and Barnes, 2017). These barriers to information transmission and exchange created by social network structures and characteristics can have meaningful impacts on ecological and economic sustainability (Crona and Bodin, 2006; Barnes et al., 2016; Barnes et al., 2017). For example, recent evidence suggests that social cleavages preventing information exchange across ethnic groups in a large-scale commercial fishery impeded the diffusion of sustainable fishing practices – practices which could have substantially mitigated shark bycatch (Barnes et al., 2016). Whether bringing potentially divergent stakeholders together in a participatory fashion through formal co-management institutions helps to break down the barriers to information access and knowledge exchange thus remains an important empirical question.

2. Study context

In order to confront declining resource trends, a number of conservation-oriented initiatives that focus on joint collaborative management processes that are reflexive to environmental change and the continuous acquisition of new knowledge have recently been implemented along the Kenyan coast (Cinner and McClanahan, 2015; McClanahan et al., 2016). Arguably the most notable of these initiatives has been the formal establishment of co-managed beach management units (BMUs) (McClanahan et al., 2016; Kawaka et al., 2017). Our inquiry is thus focused on four Kenyan reef fishing communities where BMUs have been established (Fig. 1).

BMUs are decentralized entities legally mandated by the fisheries department in Kenya to co-manage coastal resources at the local level. The primary activity managed by BMUs to date is fishing, and the goals of management are by nature often both ecological (e.g., improve resources, conservation) and social (e.g., improving livelihoods, changing perceptions about the environment). BMUs maintain multi-stakeholder representation in specific geographic locations that typically include one or more fish landing site(s). To be a member of a BMU, a person must register him/herself with that BMU and pay a membership fee. They must also fulfil the stakeholder criteria, i.e., they must be a fisher or associated with fisheries in the location of the BMU (such as boat crew, boat owners, managers, fish processors, fish traders, local gear makers/repairers, or fishing equipment dealers), and be vetted by the fisheries officer a priori. Currently, BMU members comprise not only fishers, but also fish traders, vessel owners, local gear makers, fish processors, and other coastal stakeholders who traditionally depend on marine activities for their livelihoods.

The director of fisheries (a senior level government employee responsible for regulation and management of fisheries) in consultation with members of the BMU are mandated to develop co-management plans that detail the management measures to be undertaken within the co-management area to ensure resource sustainability (Cinner et al., 2009b). However, within their area of jurisdiction, BMUs are required to develop their own bylaws, e.g., they can restrict space, time, gear, species, and life history stages of fish being caught, or establish a complete fishery closure (Cinner et al., 2009b). At the local level, an executive committee of representatives that formally lead the BMU is responsible for organizing and coordinating meetings to facilitate information and knowledge exchange among stakeholders and other learning activities that require, and benefit from, multi-stakeholder engagement. Occasionally, government and local NGOs also engage some fishers in public forums to emphasize the involvement of the larger community in managing natural resources as well as build the capacity of fishing communities in marine resource management. Existing research suggests these forums have resulted in more empowered fishing communities due to the opportunities they create for communities to learn from the successes and shortcomings of each other (Cinner et al., 2012; McClanahan et al., 2016).

Community can be defined in many ways; e.g., they can be spatial, occupational, cultural, or interest-based (Ayers and Kittinger, 2014). Here, our focal communities were geographically defined consisting of common living (i.e., villages) and fishing areas and included both major and minor fish landing sites. These areas coincided with where BMUs had been established (Fig. 1); yet it's important to note that not all fishers in these communities were BMU members. Though there are a variety of different types of stakeholders whose livelihoods depend on coastal resources and whose actions may affect reef management outcomes, to date the primary activity supporting coastal livelihoods in these communities is fishing, and fishing is also the primary activity targeted for conservation and management activities. We therefore focused our analysis on all fishers operating in each community (whether or not they were a BMU member). Fishing is these communities is predominantly small-scale and artisanal focused on mobile, reef-associated species and based on gear such as seine nets, different types of gillnets, spearguns, handlines, and traps.

3. Methods

A summary of our empirical strategy is detailed in Table 1. Fieldwork was carried out between January and April 2016 at all major and minor landing sites in each community. We conducted face-to-face interviews with a total of 616 fishers (hereinafter 'respondents') in four communities with co-management institutions (BMUs), representing 74–88% of the total estimated number of fishers operating in these areas. Interviews focused on information access regarding fisheries management, detailed fisheries-related knowledge exchange networks, and sociodemographic and socioeconomic characteristics. Research protocols were approved by the Institutional Review Board of the Office of Research Compliance Human Studies Program at the University of Hawaii at Manoa and the Human Ethics Research Committee at James Cook University. Informed consent was obtained from all respondents. All interviews were done in Kiswahili.

3.1. Information access

In our interviews, we asked fishers to state how easy or difficult it was for them to access information related to fisheries management on a 5-point Likert scale, where 1 = very difficult and 5 = very easy. In our analysis, we recoded this 5-point Likert scale variable into a categorical variable that captured three possible accessibility scenarios: [−1] difficult to access, [0] neutral (neither difficult nor easy to access), or [1] easy to access (see Fig. S1 for the frequency distribution of responses).

3.2. Knowledge exchange

To understand primary sources of fisheries-related knowledge and how knowledge was exchanged among fishers, we also asked respondents to name up to 10 individuals with whom they exchanged information and advice about fishing. We prompted fishers to consider a range of relevant fisheries-related topics that they may seek or share information about, such as fishing locations, gears/technology, fish prices/buyers, and fishing rules and management.[1] Respondents could

[1] Throughout this paper, we conceptually distinguish 'information' (i.e., basic facts about fisheries management, such as who, what, when and where) from 'knowledge' (i.e., internalized information about various fishing topics that that allows conclusions to be drawn about fishing and fisheries management). In regards to our specific network question, we therefore appreciate the distinction between 'information and advice' and 'knowledge'. However, in practice this distinction is often unclear. In this particular context, we are confident

list their crew members, captains, or any other stakeholder they deemed important for exchanging information or advice about fishing. We used free recall methods (Marsden, 1990), where each respondent reported his/her relations. From the list of persons generated, respondents were asked to briefly describe the relation, the value of the information shared, and the frequency of interaction. We also inquired about the directionality of the advice seeking and accounted for reciprocal knowledge exchange (from the perspective of respondents) by asking if they, or the nominated alter normally provided the advice and information, or if the information and advice sharing was reciprocal in nature.

As our primary focus here was on access to information and knowledge exchange, we focus our analysis on the outward flow of information and advice (i.e., $i \rightarrow j$ exists if j stated that i is an important source of information and advice) and on reciprocal knowledge exchanges (i.e., $i \leftrightarrow j$ exists if j stated that i is an important contact for the reciprocal exchange of information and advice, or i stated that j is an important contact for the reciprocal exchange of information and advice). To capture more complex relational states relevant for our study, we used tie weight (strength). Theoretically, the weight of a tie can be a function of either duration, emotional intensity, intimacy, or exchange of services (Granovetter, 1973). Here, type of relation, frequency of information sharing, and value of the information shared for each tie identified were summed to create one tie weight. Tie weights for these three dimensions, i.e., relation, frequency, and value were derived as follows. For relation, we assigned a weight of [1] for acquaintance, [2] for friend, and [3] for relative. For frequency, we assigned a weight of [1] for information shared a few times a year, [2] for monthly [3] for weekly, and [4] for every day. For value, we assigned a weight of [1] for not very valuable, [2] for somewhat valuable, and [3] for very valuable. The rationale behind considering tie strength in this analysis stems from the fact patterns of relations may differ depending on the type of relations involved and the frequency of interactions (Burt, 1992). Capturing the weight of ties, probative value of information shared, as well as frequency of sharing, can thus help us better understand the complexities of communication networks in these communities. We dropped all ties to non-respondent fishers, but retained all ties to key community leaders and external actors (such as NGO representatives and government officials) whether or not they were respondents because existing research has shown that these actors can be important sources of information and advice for fishers, and can play a prominent role in the structure of fisheries-related knowledge exchange networks (Alexander et al., 2018).

We first qualitatively characterized the knowledge exchange networks to identify key sources of knowledge, or 'knowledge producers' (Weiss et al., 2011). To add value to our qualitative characterization, we ran an ANOVA on the mean number of outgoing ties per node [i.e., the number of outgoing information and advice ties as identified by respondents, measured by out-degree centrality (Freeman, 1979)] across key stakeholder groups (i.e., fishers, fishers who are also leaders, and external actors/leaders who are not involved in fishing) using UCINET (Borgatti et al., 2002). Next, we examined three key aspects of the knowledge exchange networks related to the structural position of individual (respondent) fishers which can substantially affect their ability to both access and share knowledge. We refer to these structural positions as *central communicators*, *peripherals*, and *brokers*; which we describe in turn below.

3.2.1. Central communicators

We define central communicators as fishers (respondents) with the greatest number of outgoing information and advice ties (i.e., outdegree centrality) in the knowledge exchange network. Theoretical and empirical work on social networks has demonstrated that central actors have many options for sharing and receiving information, and can hold power over information transmission (Freeman, 1979; Borgatti et al., 1998; Barnes-Mauthe et al., 2015). Outdegree centrality captures the number of outgoing ties that an actor holds in a given social network (Freeman, 1979). Actors with high outdegree centrality in our case are those that many fishers go to for fisheries-related knowledge, and thus they are likely to be central (key) communicators in the network.

3.2.2. Network periphery

One type of fragmentation in social networks results when a tightly connected group (i.e., where actors are very densely tied to each other) are not engaged with other actors in the periphery (i.e., actors exhibiting few or no links and who are not connected to the main component) (Borgatti and Everett, 2000). In this case, though peripheral fishers may not be active in the knowledge exchange networks, they remain critical in the overall success of reef conservation and management. Indeed, existing research has demonstrated that networks with peripheral actors can have important implications for information diffusion, access to diverse knowledge, and for mobilization of support at critical moments in the resource governance process (Bodin and Crona, 2009). Given the structure of the knowledge exchange networks in our study communities, we defined peripheral actors ('network periphery') as fishers that were not connected to the largest connected component (i.e., the biggest connected cluster) in the knowledge exchange networks including leaders/external actors presented in Fig. 2.

3.2.3. Network brokers

Brokers link disconnected actors and are thus ideally placed to transmit information between disjoint groups (Borgatti et al., 1998; Burt, 2002; Barnes-Mauthe et al., 2015). Indeed, existing empirical research demonstrates that brokers enhance the extent of information transferred to those they are connected to (Fritsch and Kauffeld-Monz, 2008). Numerous methods to identify brokers have emerged in social network science in order to distinguish subsets of individuals based on reachability of non-group members (Freeman, 1979; Borgatti et al., 1998; Burt, 2000). Here, we defined brokers using a two-stage process: (1) we first examined whether the knowledge exchange networks exhibited cohesive subgroups and/or homophily [where a higher proportion of ties would be expected among fishers with similar backgrounds or characteristics, such as ethnic affiliation or gear use (McPherson et al., 2001)]; (2) we then used the results from this analysis to identify brokers between (any) disjointed groups. We tested for subgroups using the Newman-Girvan algorithm (Girvan and Newman, 2002). In fisheries settings, empirical evidence suggests that geographical boundaries, gear specialization, and ethnicity can be important drivers of homophily (Barnes-Mauthe et al., 2013; Alexander et al., 2018). Thus, we tested for homophily in tie formation among these attributes using the density models of variable homophily in the UCINET program (Borgatti et al., 2002). This model tests the likelihood that the density of ties within each group defined by a particular attribute differs from all ties that are not within groups. Because both male and female fishers were present in (only) one of our sites (site C), we also tested for gender homophily in this site following the same procedure. For all density models or variable homophily, we removed all non-respondents (i.e., non-respondent community leaders and external actors) because we had incomplete network data for these actors which could have meaningfully affected the results. Drawing on the results from our analyses of sub-groups and homophily, we determined the primary factors (if any) structuring groups or preferential tie formation among fishers. We then identified brokers as (respondent) fishers whose knowledge exchange ties bridged between these groups using the E-I index method (Krackhardt and Stern, 1988).

(*footnote continued*)
given our experience living and working along the Kenyan coast that the ties identified by respondents are highly unlikely to have differed despite the way the question was phrased.

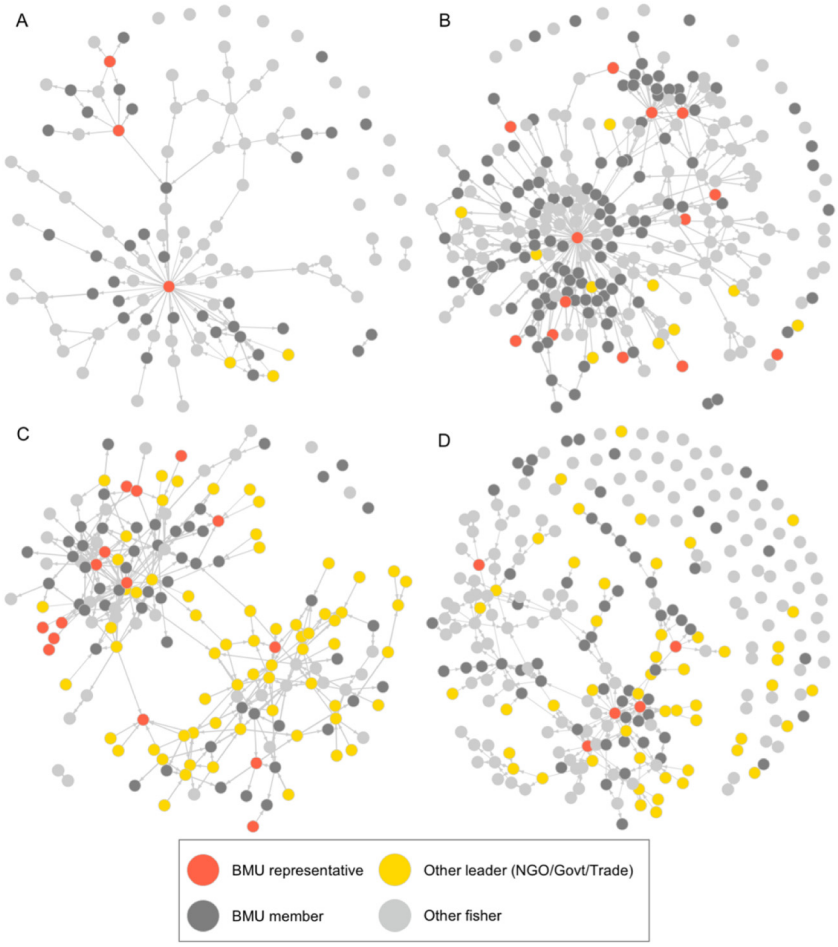

Fig. 2. Knowledge exchange networks in four Kenyan coral reef fishing communities with formal co-management institutions (known as BMUs, or beach management units). Nodes represent (respondent) fishers (some of whom are also leaders, and are thus identified as such via node color), non-respondent fisher leaders, and other non-respondent/non-fisher leaders who were identified as important sources of fisheries-related information and advice. The direction of arcs captures the outward flow of information and advice; arrows therefore point to fishers receiving information from those they are linked to. The thickness of the edges corresponds to the tie weight.

3.3. Modelling procedure

To determine the role of social, cultural, and economic factors on fisher's information access and knowledge exchange and whether any potential barriers associated with these persisted despite formal engagement in co-management, we ran a series of models. Here, a fisher was considered to be formally engaged in co-management if they were an official BMU member, as members are expected to fulfil a range of duties such as approving the co-management plan, budget, work-plan, annual financial reports, and any fees charged by the BMU at the beach. BMU members are also expected to adopt or amend by-laws, abide by these by-laws, and when necessary, remove from office members of the BMU executive committee. As described in Table 1, in our models we predicted information access and fisher's roles in the knowledge exchange network (i.e., whether they were a central communicator, network periphery, or network broker) using key social, cultural, and economic characteristics in a two-stage process: (1) not accounting for engagement in co-management, and (2) accounting for engagement in co-management. Only respondents were included in these models. Predictors (aside from engagement in co-management) included age, education, wealth, ethnicity, landing site, gear use, and leadership status; described in turn.

Age is often highly correlated with experience. As such, in the context of reefs, older fishers are often seen as more knowledgeable due to the fishing experiences they have accumulated over time (McClanahan et al., 2012). Older fishers thus may be sought out more for information and advice, giving them more control over knowledge exchange. Moreover, fishers who are thought to be more experienced tend to be disproportionately selected by external agencies to participate in conservation and management initiatives (Mbaru and Barnes, 2017), which is likely to place them in advantageous positions to access key information. Similarly, wealth and education can be key indicators of social status (Cinner et al., 2009a). Collectively, these factors can create social hierarchies whereby the more privileged can dominate decision making processes (Mbaru and Barnes, 2017) and, potentially at the expense of other groups, improve their access to collective benefits, such as information (Hess and Ostrom, 2003). Here we measured age as the age of fishers. Education was measured as the highest grade completed. We used material style of life (MSL) as a measure of wealth based on household possessions and house structure (see SI).

Ethnicity, landing site, and gear use were used as proxies to capture important cultural, geographical, and social characteristics of fishing communities that may be important for information access and knowledge exchange (Crona and Bodin, 2006; Barnes et al., 2016; Alexander et al., 2018). Ethnic affiliation and dominance is particularly important to consider in the Kenyan context, where the population is highly diverse and ethnic tensions and inequalities have been shown to affect access to knowledge (Schech and Alwy, 2004). In our sample, there was a clear dominant ethnic group that comprised the majority of fishers in each community (Table S1), and in most cases remaining groups were not represented by enough people within each community to be modelled independently. We therefore created a binary variable to represent ethnicity as: [0] for the dominant group in each community (e.g., the dominant ethnic group), and [1] for the minority (i.e., all other minority ethnic groups). Existing research along the Kenyan coast has similarly shown that gear-based dominance (i.e., fishers primarily using the dominant fishing gear in a specific area) can be particularly important for structuring knowledge and the knowledge exchange process (Crona and Bodin, 2006), and recent evidence suggests landing sites may also play an important role (Alexander et al., 2018; Barnes

et al., 2019). We therefore followed the same procedure for our gear and landing site variables, i.e., we created a binary variable where [0] = the dominant gear type and landing site being used in each community, and [1] the minority gears and landing sites being used (Tables 1, S1). We defined leaders as fisher representatives; those who were involved in the trade of fish products; and/or those who were an NGO, community-based organization, county, or national government representative. Leaders can shape and determine the societal view of a given community (Valente, 1996). They are therefore often selected by organizations for engagement in conservation and resource management (Mbaru and Barnes, 2017), providing them with advantageous access to information and knowledge (Alexander et al., 2018). An examination of variance inflation factors indicated there were no signs of multicollinearity among the covariates included in our models.

For information access, we ran an ordinal logistic regression on fisher's stated ability to access fisheries management information, where [−1] = it was either very difficult or difficult to access fisheries management information, [0] = neutral (neither difficult nor easy), or [1] = it was either easy or very easy to access fisheries management information (see Fig. S1). To predict central communicators in the knowledge exchange network, we ran a linear regression on normalized outdegree centrality. We ran binary logistic regression models to determine the factors that predicted whether a fisher was either on the periphery of the network (peripheral), or a network broker (broker) between important subgroups. In all models, site was included as a random factor to account for potential differences across sites. To account for the non-independent nature of the network data in our knowledge exchange models (central communicators, peripheral, broker), we employed a bootstrapping procedure with 1000 random samples using replacement from the full sample to estimate robust standard errors and a 0.95 confidence interval following Barnes et al. (2017).

In our first round of models we did not account for formal engagement in the co-management process. Thus, BMU membership was not considered, and all actors with a leadership position were collectively considered 'leader' (whether they were a BMU representative or other type of community leader). In the second stage of our analysis, we accounted for formal engagement in the co-management process by including BMU membership as a predictor, and by separating BMU representatives from other types of leaders, i.e., those involved in trade, those who held positions of power such as community leaders, NGO/Community-Based Organization (CBO) representatives, or government officials. We used the Akaike information criterion (AIC) to evaluate the fit of our first and second stage models. All models were run in R (version 3.4.5) and model outputs plotted in SigmaPlot (version 11).

4. Results

4.1. Information access

Across our study communities, we found that 18–40% of fishers felt it was either difficult or very difficult to access fisheries management information while 32–61% felt it was either easy or very easy. Between 20 and 26% felt it was neither easy nor difficult (Table 2, Fig. S1). Summary statistics of the social, economic, and cultural factors we focus on across the four study communities are presented in Table 2 and described in further detail in Table S1.

4.2. Factors structuring information access

Results from our initial models suggest that some social, cultural, and economic factors played an important role in determining how easy or difficult it was for fishers to access fisheries management information (Fig. 3). Specifically, we found that older fishers ($\beta = 0.02$, $p < 0.01$), wealthier fishers ($\beta = 0.3$, $p < 0.01$), and fishers with leadership roles ($\beta = 0.79$, $p < 0.05$) had significantly easier access to fisheries management information than others (Fig. 3; Table S5). However, once we accounted for formal engagement in the co-management process by including BMU membership and BMU representative as covariates in the model, we found that age and leadership were no longer significant, yet wealth still played an important role (Fig. 3; Table S6). Aside from wealth ($\beta = 0.28$, $p < 0.01$), the only other factor that significantly predicted access to fisheries management information once engagement in the co-management process was accounted for was BMU membership ($\beta = 1.62$, $p < 0.001$; Fig. 3; Table S6). Evaluations of model AICs suggest the model accounting for engagement in the co-management process is a better fit to the data than the initial model (AIC = 1329.3 vs. 1418.6; Tables S5–S6).

Table 2
Summary statistics across the four study communities (total n = 616). Unless otherwise stated, all statistics correspond to our sample of respondent fishers. See Table S1 for additional detail on ethnicity, landing sites, and gear use.

	Study community			
Description	A	B	C	D
Estimated fisher population	124	316	151	290
n	109[a]	241[a]	123	214
Social, cultural, and economic factors				
Age				
Mean	31.03	34.58	40.48	34.22
SD	11.77	14.15	16.12	12.66
Education				
Mean	7.37	6.06	6.32	7.11
SD	3.05	3.01	3.34	3.11
Wealth (Material Style of Life)				
Mean	-0.25	-0.33	0.01	0.49
SD	0.69	0.66	0.68	1.36
Ethnic minority	39 (36%)	110 (46%)	11 (9%)	3 (1%)
Landing site minority	53 (49%)	159 (66%)	2 (2%)	133 (62%)
Gear minority	63 (58%)	141 (59%)	71 (58%)	137 (63%)
Leaders (other/non-BMU reps)	0	4 (2%)	28 (23%)	53 (21%)
Engagement in co-management				
BMU representatives	1 (1%)	1 (1%)	6 (5%)	5 (2%)
BMU members	35 (32%)	115 (48%)	77 (63%)	74 (30%)
Information access				
Easy	52 (48%)	117 (49%)	75 (61%)	70 (33%)
Neutral	24 (22%)	58 (24%)	25 (20%)	57 (27%)
Difficult	33 (30%)	66 (27%)	23 (19%)	87 (41%)
Knowledge exchange networks				
No. of nodes[b]	114	260	171	250
No. of edges	118	375	343	276
Central communicators[c]				
Mean	0.006	0.004	0.011	0.005
SD	0.01	0.008	0.017	0.011
Network periphery	20 (18%)	28 (12%)	7 (6%)	86 (40%)
Network brokers	22 (20%)	26 (11%)	35 (29%)	45 (21%)

[a] 71 respondents were associated with, and fished in, both communities A and B. These individuals were therefore included in each community's network, and their network metrics were calculated for each community independently.

[b] This includes fishers who participated in this research, as well as non-respondent fisher leaders (e.g., BMU representatives) and non-respondent/non-fisher leaders who fell outside of our target population but were identified as important sources of fisheries-related information and advice (such as NGO actors, government representatives, etc.).

[c] Central communicators were identified using normalized outdegree centrality, where a higher score represents a higher propensity for having been identified by multiple actors as an important contact for knowledge exchange regarding fishing and fisheries management.

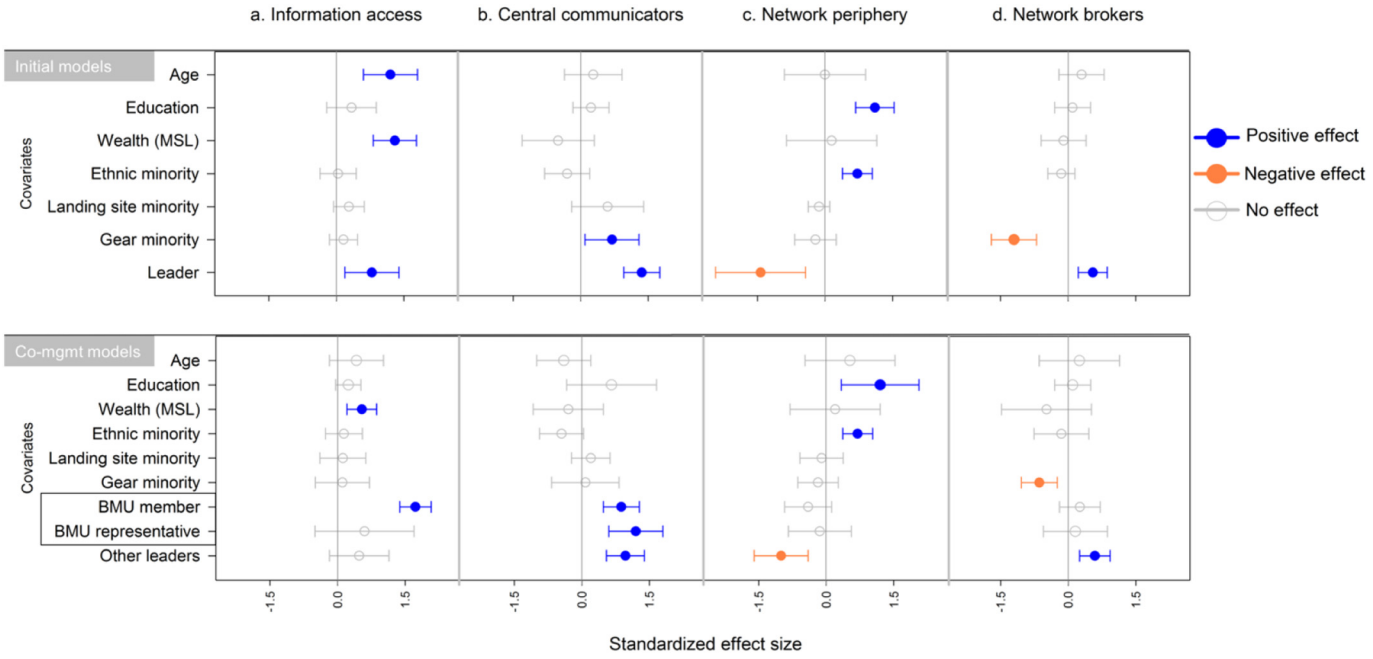

Fig. 3. Influence of social, cultural, and economic factors on information access and knowledge exchange across four Kenyan coral reef fishing communities. Fisher's (n = 616) reported ease of access to fisheries management information (a) was modelled using an ordinal regression. Whether a fisher was a key communicator (b) in the knowledge exchange network (indicated by their normalized outdegree centrality score) was modelled using a linear regression. Whether a fisher fell on the periphery of the network (c) and whether a fisher was identified as a network broker (d) were modelled using binary logistic regressions. Standard errors were bootstrapped in models b–d to account for the non-independent nature of network observations. A random effect was also included for individual fishers to account for a minority of fishers operating across two of our study sites (n = 71 out of a total of 616). Full model results and AIC values are reported in Tables S5 and S6.

4.3. Knowledge exchange networks

The knowledge exchange networks largely exhibited highly centralized structures with most fishers organized into one main cluster (component) and several on the periphery (Fig. 2, Table S2). One exception was community C, where there was an active group of female fishers and the knowledge exchange network was characterized by two obvious network clusters that were primarily associated with gender (Fig. 2; also see Fig. S2, where nodes are colored by gender for this community). Across all four sites, there were 80 individuals who did not report any information and advice ties with others, nor did others report ties with them (i.e., network isolates). Of the remaining 536 individuals, 463 were part of a single, large network component within each community, i.e., a central subnetwork in which it was possible to move between any two nodes using one or several links (see Table S1 for a summary of network statistics).

Further qualitative examination of the knowledge exchange networks indicated that leaders, both internal (fishers who are also leaders, i.e., fisher leaders) and external (e.g., NGO and government representatives, fish traders, etc.), tended to be key sources of fisheries-related knowledge, i.e., they appear highly central, with many outgoing ties (Fig. 2). Our results from the ANOVA confirmed this: fisher leaders (fishers who were also leaders) had significantly higher outdegree centrality than other fishers across all communities studied, and external leaders had significantly higher outdegree centrality scores in two of our four study communities (Table S3).

We did not find clear sub-group structures within the main component of each community's network using the Girvan-Newman community detection method. However, results from our density models of variable homophily show clear and strong tendencies of within landing site ties; i.e., fishers are significantly more likely to exchange information and advice if they use the same landing site (Table S4; Fig. S2). The one exception was community C, where nearly everyone used the same landing site (all but two fishers, Table S1). This community was also the only community studied that had a large, active group of both female and male fishers. Here, we found strong homophilic tendencies along the lines of gear and gender (Table S4), which themselves were strongly correlated, with female fishers primarily using harpoons, and male fishers using traps and line. There were also some significant homophilic tendencies among gear types in community D, but these tendencies for within-group preferences were not as strong as those structured by landing site (Table S4). Interestingly, ethnicity was largely not associated with the formation of within-group preferences for exchanging fisheries-related information and advice (Table S4). These results provided the basis for our definition of brokers: brokers were defined as those that exchanged information and advice across different landing sites within communities A, B, and D; and across genders in community C.

4.4. Factors structuring knowledge exchange

Our results regarding central communicators, those on the network periphery, and network brokers demonstrate that social and cultural factors play an important role in structuring how fishers exchange fisheries-related knowledge (Fig. 3). Yet in contrast to information access, these results were largely insensitive to whether or not we accounted for formal engagement in co-management. Specifically, across both sets of models we found that all types of (fisher) leaders were more likely to act as central communicators, though our models accounting for engagement in co-management demonstrate that BMU members also act as central communicators and thus are important sources of fisheries-related knowledge for others as well (Fig. 3, Tables S5–S6). Whether or not you account for engagement in co-management, those with higher levels of education and ethnic minorities were more likely to be on the network periphery, whereas (fisher) leaders were significantly less likely to be (Fig. 3, Tables S5–S6). Only (fisher) leaders (not including BMU representatives) had a significant tendency to broker fisheries-related knowledge across landing sites (communities A, B, and D) and between male and female fishers (community C). Fishers using less dominant gear were less likely to broker (Fig. 3, Tables

S5–S6). Though engagement in co-management doesn't appear to affect these results, with the exception of the network broker model, comparisons of the AIC values suggest that our models accounting for the co-management process were a better fit (Tables S5–S6).

5. Discussion

Our results demonstrate that key social, cultural, and economic factors are important for structuring information access and knowledge exchange in reef fisheries. In terms of information access, we show that formal engagement in co-management helps to overcome some social and cultural barriers. Yet economic barriers remain important, and those not formally engaged in the co-management process – comprising anywhere from 37 to 70% of fishers in some communities, appear to suffer from information asymmetries. In contrast to information access, our results suggest that the social and cultural factors structuring the knowledge exchange process among fishers are largely insensitive to whether or not formal engagement in the co-management process is accounted for.

5.1. Information access and the role of co-management

Information access is critical in knowledge creation (Ackoff, 1989). In social-ecological settings, access to information related to resource conservation and management can not only govern resource extraction behaviour to align with existing rules, but it also plays a key role in building capacity for collective responses to environmental threats (Ostrom, 2007). In coral reefs, fishers may seek management information about resource dynamics and technologies in order to enhance their fishing capacity and/or adjust their practices in line with existing laws and regulations. Fishers may also seek management information in order to develop and adapt localized conservation and management practices to improve environmental and social outcomes (Young et al., 2016). However, existing research has shown that the information needed to support fisheries conservation and management that is effective despite strong local and global drivers of change may not always be in a format that is directly understood and applicable to the needs of local fishers (Nguyen et al., 2018). These uncertainties and misunderstandings can hinder uptake of fisheries conservation and management knowledge. In addition, critical information developed at higher levels (e.g., by scientists) can fail to reach fishers in a timely manner, particularly where certain actions or decisions need to be made quickly or in a set timeline at the local level (Soomai, 2017). There are also a range of factors that can prevent access to diverse sources of local ecological knowledge which can be just as important, e.g. fishers may have incentives to withhold local ecological knowledge from others given the competitive nature of fishing (Barnes et al., 2017) and factions within communities can drive dominant local knowledge signals (Crona and Bodin, 2010). Co-management arrangements are argued to be an effective way to bridge these information gaps because they involve strong partnerships within communities, and between communities and higher-level institutional actors (Berkes, 2009). These arrangements not only facilitate the flow of information across knowledge and practice, but can work to foster mutual understanding of shared values and priorities among resource users (Adger et al., 2005).

In Kenya, an annual multi-stakeholder fisher's forum has been established as a platform for the transfer of scientific knowledge about fisheries conservation and management (McClanahan et al., 2016). In practice the forum helps to build relationships between scientists, fisheries managers, and local stakeholder groups (particularly fishers), and offers a consistent space where trust, credibility, and legitimacy can be developed and built upon - a critical element for successful knowledge exchange in co-managed arrangements (Young et al., 2013). In addition to this forum, other formal and informal arrangements have been established as a part of the co-management process to foster information sharing among communities and to bring in external knowledge to help address contentious issues surrounding fisheries conservation and management; such as meetings between fishers and government authorities, fishing patrols, fisheries open days, agricultural shows, and other outreach programs (Kawaka et al., 2017). These initiatives help provide access to diverse sources of information by inviting resource users to interact directly with researchers, government authorities, NGO representatives, and other local stakeholders; and our results indicate that they likely help to overcome traditional barriers to information access by involving younger and non-leader BMU members who may have otherwise found it difficult to access fisheries conservation and management information (Fig. 3).

Despite the collaborative and participatory nature of co-management in Kenya, our results highlight key opportunities for improvement. In particular, we show that non-BMU members – comprising up to 70% of the total estimated population of fishers in some communities – are marginalized in terms of information access. This result has clear implications for conservation and management, as the actions of all resource users (despite whether or not they are formal members of the co-management institution) can have a substantial impact on conservation and management outcomes. At the very least, all resource users need access to information concerning any devised rules, such as the location of fishery closures or restrictions on gear use. These findings thus indicate there may a need to increase localized engagements (e.g., meetings at the site level) so that learning and sharing lessons through the participatory processes described above can extend beyond the formal boundaries of the co-management institution and work to develop best practices for conservation across the broader community (Cohen et al., 2012).

Our findings also suggest that there may be a culture of elite capture; i.e., on average, wealthy fishers have significantly easier access to fisheries management information than others (Fig. 3). Participatory reef conservation and management initiatives are now often focused on not only improving ecological conditions, but also the livelihoods of reef dependent people; however, elite capture can sometimes prevent the poorest from benefiting from these initiatives (Clifton, 2013). This is because privileged individuals often dominate decision-making processes, and in doing so, increase their access to collective benefits, which can further marginalize the poor (Platteau, 2004). The issue of elite capture in participatory processes thus brings to light the relationship between knowledge and power. Power can manifest as a 'distribution of knowledge' that operates through both individual and collective action (Foucault and Gordon, 1980), the dynamics of which can influence *who* gets access to *what* information (Fazey et al., 2013). Our findings indeed show that wealthy individuals have significantly easier access to information, indicating that key information regarding fisheries conservation and management is unevenly distributed among the poor and the privileged. Moreover, our results regarding knowledge exchange (discussed further below) show that despite this concentration of information among the wealthy, the wealthy are not more likely than others to share their knowledge widely by acting as central communicators or brokers (Fig. 3). Thus, to some extent, wealthy fishers may be influencing who and what information is included or excluded from the knowledge exchange process underpinning conservation and management decisions. There are clear ethical implications associated with this, yet there are also practical implications for conservation, as the inequitable distribution of costs or benefits associated with conservation and management actions can lead to poor compliance and even conflict (Hauck, 2008). Managers and other institutional actors engaged in the co-management process and seeking to implement conservation actions should thus work to ensure their engagement strategies include actors from a diversity of economic backgrounds. Still, it is important to note that elite capture does not always result in elite control that further disadvantages the poor (Dasgupta and Beard, 2007). Thus, a case might be made for careful engagement with specific elites to facilitate improved reef conservation and management outcomes where amenable [e.g., see Kusumawati and Visser's, 2016

discussion of "capturing the elite"].

5.2. Knowledge exchange for effective environmental decision-making

The knowledge exchange networks studied here exhibited highly centralized structures with formal leaders (both internal and external) acting as primary sources of information and advice, and ethnic minorities and the highly educated largely falling on the periphery. Though external formal leaders consisted to some extent of fish traders and government representatives, the majority were NGO and CBO representatives. Given the increase in scope and magnitude of environmental issues matched by equally complex social settings, conservation and management guidelines are constantly being updated (Hughes et al., 2017), and may not always be framed in a format that can be easily understood by local leaders (Kirchhoff et al., 2013). In such cases, external leaders (i.e., NGO/CBO representatives in this case) can play a key role in breaking the barriers of knowledge exchange between technical actors and scientists with global perspectives, and those that operate within localized arrangements (Nguyen et al., 2017). Our results indeed indicate that partnerships that facilitate knowledge exchange between NGO/CBO actors and communities are likely key for supporting management and conservation of Kenyan reefs. It may be important that these partnerships are maintained over time in order to support co-management efforts to restore or conserve reef ecosystem conditions. This is because people tend to interpret knowledge based on shared social constructs such as beliefs, values, and norms (Nguyen et al., 2017), which are more likely to align through sustained social interaction (Lin, 1999). Moreover, for knowledge to have a substantial impact on people's opinions and actions, it needs to connect with their priorities and practices (Cook et al., 2010). A thorough understanding of people's priorities and practices is no doubt more likely to be realized through the sort of sustained interaction that tends to accompany long-term partnerships.

Communities are known to be comprised of complicated patterns of subgroups often driven by similarities in personal backgrounds or socioeconomic attributes that can play a key role in structuring information access and transmission (Crona and Bodin, 2006; Barnes-Mauthe et al., 2013). Here, we found that among fishers, landing sites act as key arenas for knowledge exchange. In Kenya, BMUs have a minimum group size based on boats, rather than on members – an artefact of the legislation's history stemming from Lake Victoria, where nearly all fishers utilize boats. On the Kenyan coast however, boats are not as prevalent. Thus, to establish BMUs, many landing sites were grouped together (Cinner and McClanahan, 2015). Yet historically, landing sites were often divided along the lines of ethnicity and gear-use, and some had a history of antagonism (Cinner and McClanahan, 2015). Indeed, research on knowledge exchange among fishers in Kenya from over a decade ago showed strong tendencies for gear-based interactions (Crona and Bodin, 2006), and ethnic tensions and inequalities have been shown to affect access to knowledge in other Kenyan social settings (Schech and Alwy, 2004). Yet we found that landing sites independently play a stronger and more consistent role in structuring knowledge exchange than ethnicity or gear-based affiliation (Table S4), indicating that knowledge sharing in reef fisheries is a fluid and dynamic process likely associated with shifts in alliances and power that is changing over time (Cleaver, 1999). Our results regarding landing site homophily also mirror emerging research from other parts of the world (Alexander et al., 2018), suggesting that this spatial pattern may be emerging as a general feature structuring social interaction in reef fishing communities at a larger scale. Conservation practitioners and those engaged in co-management of reefs should therefore aim at strengthening collaboration and cooperation among actors across landing sites that target common fishing grounds to help ensure joint efforts toward the conservation and management of reef fisheries are successful.

The role of social and cultural factors in structuring the knowledge exchange networks was largely insensitive to accounting for the co-management process. However, our second round of models provided evidence that among fishers, BMU members in addition to leaders (including BMU representatives) were more likely to be central communicators in the knowledge exchange networks (Fig. 3). Individuals occupying central network positions such as these can play a key role in shaping knowledge and determining which interpretations become most dominant across a community (Crona and Bodin, 2010). As such, highly central actors in knowledge exchange networks are often referred to as 'knowledge producers' (Weiss et al., 2011). Our results thus indicate that leaders and those formally engaged in the co-management process play key knowledge producer roles, i.e., they are highly pursued by others for fisheries-related information and advice. Leaders also play key broker roles between landing sites and genders (Fig. 3). This is perhaps promising because it indicates that those with external ties and/or directly involved in the co-management process likely have considerable power over the reef conservation and management discourse among the broader community (Cook et al., 1983; Fazey et al., 2013), which can be integral for shaping perceptions and actions, such as compliance with rules (Bergseth et al., 2018). However, the tightly coupled relationship between knowledge and power can also negatively impact on prioritization and the decision-making process. For example, key knowledge producers might withhold certain pieces of information if they do not perceive the information at hand as important, or if it conflicts with their personal interests (Crona and Bodin, 2010). Moreover, when external actors, key leaders, and formal BMU members drive the reef management discourse, some sources of local knowledge and the priorities and preferences of non-BMU members or other fishers may be inadvertently marginalized (Brugnach and Ingram, 2012). Here, we show that ethnic minorities and highly educated fishers constitute peripheral actors that are not embedded in the knowledge exchange process supporting, and being supported by, the co-management institution. For reef conservation and management to be both more effective and inclusive, those involved in setting priorities should seek to engage these peripheral actors and incorporate their knowledge and preferences with those of more dominant groups (Brugnach and Ingram, 2012).

5.3. Future directions

Our results are suggestive that co-management institutions have little effect on knowledge exchange processes but can help to overcome some social and cultural barriers to information access; but they are certainly not conclusive. Future work examining information access and knowledge exchange in communities both before and after co-management institutions are devised would be able to provide causal evidence on how the participatory nature of the co-management process may break down traditional barriers to information flow in reef fishing communities. Such efforts would be highly complemented by in-depth qualitative research on the perceived barriers to information access and knowledge exchange, which could provide additional insight into how the factors identified in this study manifest as the co-management process unfolds and/or relate to other factors that were not studied here, such as time constraints and language barriers (Fazey et al., 2013; Cvitanovic et al., 2015). Future work could also extend our inquiry to include the fisheries-related information and advice seeking behaviour of other types of actors, such as external fish traders and NGO representatives, whom may be important for the overall success of reef conservation and management initiatives.

6. Conclusion

Coral reefs are currently facing a range of threats that are escalating in both scope and scale. It is therefore imperative that those who depend on, and are responsible for conserving and managing coral reef fisheries have access to the information and knowledge needed to

support effective decision making. Here, we present results from a rare effort to examine factors that structure information access and knowledge exchange networks among reef fishers operating over a relatively large spatial scale. Our results suggest that co-management can break down traditional social and cultural – but perhaps not economic – barriers to information access; while social and cultural factors remain important for structuring knowledge exchange. Future work focusing on how these barriers relate to specific conservation outcomes, and solutions to overcome them, would be of major value in achieving a sustainable future for both reefs and the people who depend on them.

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Appendix A. Supplementary data

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