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Governance structures and sustainability in Indian Ocean sea cucumber fisheries

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ABSTRACT

Good governance is paramount to the sustainability of fisheries, and inclusiveness of stakeholder groups has become the centerpiece in the ethos of managing small-scale fisheries. Understanding the effect of governance network structures on fishery sustainability can help guide governance to achieve desired outcomes. Data on resource users, fishing methods, governance networks and classifications of stock health were compiled for 17 sea cucumber fisheries in the Indian Ocean. The subjective influence of the actors and the complexity of governance networks on the health of wild stocks were analyzed. The fisheries differed widely in their resource users, fishing methods and governance networks. Little correspondence was found between the number of nodes in the governance networks and the health (exploitation status) of wild stocks. Government entities dominated the networks but neither their relative influence in the networks nor their proportionate contribution to the number of entities in the networks greatly affected stock health. These findings do not refute the benefits of inclusive governance, but rather suggest that multiple other factors (e.g. inadequate regulations, weak enforcement, high number of fishers) are also likely to play a role in influencing sea cucumber fishery sustainability. These factors must be tackled in tandem with good governance.

1. Introduction

Natural resource management is a challenge that must straddle the realms of social and natural sciences, thus constituting an extremely complex challenge without simple solutions [1,2]. This awareness is now being echoed increasingly frequently in the interdisciplinary natural resource management literature as an argument for the reorganization of governance to better support inclusive and adaptive management strategies [3,4]. The message is that fisheries management is a complex task with constantly changing circumstances [2], relying largely on the design and dynamics of institutions [5]. The need for research to guide reforms in governance is highly relevant in the context of implementing a broader ecosystem approach to fisheries management (EAFM), which relies on the involvement of multiple stakeholders, their needs and objectives [6,7]. Therefore, it is important to focus the attention of fisheries management research towards the operational and governance context in which rules and regulations are meant to operate and achieve the purposes for which they have been formulated [1,8].

The inclusive management discourse has gained considerable momentum in the small-scale fisheries (SSF) management research agenda. It recognizes past management failures and that SSF management systems are more effective when resource users participate in making and enforcing the rules (e.g. [9]). The approach aims to facilitate reorganization of governance so that relevant stakeholders within the system boundaries participate in shaping institutions, under the premise that these reshaped institutions will more effectively manage the conduct of resource users. Governance is also increasingly replacing management as the focus of SSF research [3]. A functional interpretation for governance in SSF embodies the social interaction for coordinating use.

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Systematic mapping of governance structures through a conceptualized view of networks with participating entities, linked through social interaction, can aid in gauging how knowledge, innovation and decision-making equity are distributed [10]. Governance entities are those organizations or agencies that participate in the development of fishery management institutions. Links between entities in the networks can act as important bridges across levels on the same scale and across scales; for example, linking local governance entities to national policies [11]. Multiple actors and polycentric structures can in this sense equate to diversity in experience and knowledge in a governance system [12]. In practice, however, multiplicity can also introduce inefficiency and conflict because actors may have divergent perspectives on rights and legitimacy over resource management and use [13].

Research on governance in natural resource management aligns well with the holistic ambitions of EAFM. For example, adaptive co-management is an inclusive governance framework [14] that fits the EAFM model [15]. The literature posits that such inclusive strategies provide incentives for compliance through increased understanding and equity [16] and streamline feedbacks for learning and adapting [14]. The evolution of social–ecological processes can be traced through the mechanisms and properties that support governance reforms attuned to system contexts, such as coastal management reform in Chile [17], zoning of the multi-use Great Barrier Reef Marine Park [18] and addressing the multi-faceted impacts by countries bordering the Baltic Sea [19]. These case studies comprise distinct scenarios with different resources, problems and contexts—perhaps therefore also with limited utility for other ecosystems or fisheries settings.

Fisheries governance must fit the fishery context, or the "system-to-be-governed" [20]. An intuitive logic then is that industrialized fisheries with few actors could perform with few participating bodies in the governance structure. In contrast, a fishery with different types of small-scale fishers in different social contexts and some industrialized fishers would need a more complex, polycentric governance structure. This leads to a notion that a greater number and complexity of resource user (i.e. fisher) groups should be matched by a greater complexity in governance structure. However, few studies have assessed this notion among fisheries with comparable resource types or demonstrated the bounds within which such a notion operates successfully. This leads to an important research question for evaluating governance systems in SSFs: is there evidence that certain structures of governance networks (management models) are more successful than others? This question cannot be addressed without also considering the fishery user groups and whether the governance structure matches the diversity of these groups.

In the present study, the fishery context and governance structure of sea cucumber fisheries in the Indian Ocean were evaluated. By focusing on one resource type, the data allow appraisal of the generality of success in SSF with differing operational contexts and governance structures. Sea cucumbers are harvested throughout the world predominantly to produce a dried product, known as "beche-de-mer" or "trepang", which is exported to eastern Asian markets as a luxury seafood [21–23]. They are collected by gleaners, skin divers, compressed-air divers and using bottom trawls. Sea cucumber fisheries contribute towards poverty reduction directly as an export commodity and are an important source of income for millions of men, women and children worldwide [24]. In the Indian Ocean, national sea cucumber fisheries have been in existence for many decades [21] and were recently studied in several countries through regional projects [25–29]. These fisheries are widespread and offer a fitting case study for SSF governance theory.

2. Methods

2.1. Data collection

This study draws on data collected from fishery managers from 17 countries and territories in East Africa and the Indian Ocean corresponding to FAO area 51 (Fig. 1). Zanzibar and Rodrigues were separated from mainland Tanzania and Mauritius, respectively, because their fisheries are managed by different government entities. Countries in this FAO fishery area collectively contribute approximately an estimated 30% of global sea cucumber production [26]. Data were collected at a regional workshop on sea cucumber fisheries management [30] and participants were informed that this information would also be published. The workshop was held for regional fishery managers or senior fishery officers, who had a working understanding of the sea cucumber fishery and were in a position to influence management change within their respective national organizations. Participants also had to be able to provide knowledgeable and constructive contributions to the workshop discussions and outputs. There were 18 participants at the workshop.

Data that were available for analyses differed between locations (Table 1). Participants from Mozambique, Eritrea and Rodrigues could not participate at the meeting and so data derived from workshop exercises were not collected for these countries. In addition, data on resource users were not available for Comoros and Mayotte, where sea cucumber fishing is closed. However, Tanzania, Rodrigues, Egypt and India, which also have closed sea cucumber fisheries but have operated historically, could supply these data.

2.2. Resource user groups and harvesting methods

Prior to the workshop, participants provided data regarding the structure and organization of the sea cucumber fishing activities in their countries. This included information on resource users (men, women, children) and the fishing methods (gleaning, skin diving,

Fig. 1. Study countries and territories. Map of Indian Ocean FAO area 51, showing countries and territories participating at the workshop, and which were included in this study. Prohibition symbols (barred circles) denote those that currently have a moratorium on sea cucumber fishing.

Table 1
Data collected for analyses, by country in alphabetical order. Available data differed between countries because of their varying participation in the workshop process.

Country/ territory	Resource user groups and harvesting methods	Stakeholder identification exercise and governance structure	Stock status evaluation
Comoros[a]		✓	✓
Egypt[a]	✓	✓	✓
Eritrea[b]	✓		
India[a]	✓	✓	✓
Kenya	✓	✓	✓
Madagascar	✓	✓	✓
Maldives	✓	✓	✓
Mauritius	✓	✓	✓
Mayotte[a]		✓	✓
Mozambique[b]	✓		
Oman	✓	✓	✓
Rodrigues[a,b]	✓		
Seychelles	✓	✓	✓
Sri Lanka	✓	✓	✓
Tanzania[a]	✓	✓	✓
Yemen	✓	✓	✓
Zanzibar	✓	✓	✓

[a] Fisheries currently under moratoria.
[b] Provided information on user groups and harvesting methods, but did not participate at the workshop.

compressed-air diving, trawling) that were used in each country. Data were tabulated and illustrated by calculating the Bray–Curtis dissimilarity matrix using the VEGAN package in *R* [31], and non-metric multidimensional scaling (nMDS) ordination was performed on this matrix.

2.3. Stakeholder identification, governance structure and stock status

Network analysis was used to illustrate the participation by multiple sets of actors in the formation of policy and rules in each country. In a stakeholder identification exercise during the workshop, participants listed the stakeholders that participated in influencing policy and rules in that country's sea cucumber fishery. The aim of the exercise was to define governance participation and networks for each country. Once stakeholders were identified, the importance of their participation in shaping policy and rules was ranked from 1 to 3, where: 1 = not important, 2 = important, 3 = very important. As a final task in the exercise, an adjacency matrix was created where the importance of the links between the identified stakeholders were ranked from 1 to 3, following the ranking criteria above. These data were visualized using the network analysis package 'igraph' [32] in *R* [33]. Government influence over the total governance network was calculated as the fraction of scores given to government entities compared to other entities.

Fishery managers categorized the health of their wild stocks according to the five fishery status categories proposed by FAO [34], modified to take other factors into consideration according to sea cucumber-specific fishery status indicators developed by Friedman et al. [35]. The indicators provide binomial "tick or cross" category answers to guide decision-making. However, other features of the fishery could also be taken into account, which may not have been captured in the fishery status indicators. The guiding criteria for decision support about stock health status were as follows:

1. Under-exploited—all ticks; stocks not very affected by fishing historically.
2. Moderately exploited—one or two crosses; but stocks appear healthy.
3. Fully exploited—one to three crosses or question marks; but current exploitation rate is sustainable.
4. Over-exploited—few ticks; fishing is unsustainable; but some breeding populations still exist.
5. Depleted—few or no ticks; fishing is unsustainable; stocks below 10% of unfished abundance.

The influence of number of nodes in governance networks, and the fraction of score assigned to government entities in those networks, on stock status categories was analyzed using an ordered logistic regression model in the MASS package in *R* [33], because the stock status categories are ordinal data. Model output is presented with regression coefficient (β) as a measure of effect size, model confidence intervals (CI) at 95%, and significance level (p). Data were also analyzed to ascertain trends in the influence of governments by correlating the fraction of score assigned to government entities in national networks to the number of resource user groups, and to the number of nodes in networks, using a beta regression model in *R* [33]. Beta regression was chosen because it is a suitable model for response variables in the standard unit interval (0,1) [36]. Beta regression model output is presented as regression coefficient (β), correlation coefficient (r^2), and significance level (p). The relationship between numbers of nodes in networks and fishery number of user groups was investigated using a linear model function in *R* [33]. Model output is presented in the same way as for the beta regression.

3. Results

3.1. Resource user groups and harvesting methods

Indian Ocean sea cucumber fisheries differed greatly in the involvement of different resource users and the methods they employ to collect sea cucumbers (Table 2). Across the region, sea cucumber fishing tended to be a male-dominated activity. Fisheries in Egypt, India, Maldives, Seychelles, Sri Lanka and Tanzania were exclusively operated by men that utilized intensive methods, such as skin diving, scuba or compressor diving. In the Egyptian and Indian fisheries (currently closed), trawl gear operated by men was also used to collect sea cucumbers. In about half of the countries, women also participated in the collection of sea cucumbers. Fisheries in Madagascar, Mozambique, Oman, Yemen and Zanzibar were operated by men, women and children employing multiple collection methods. Results from the ordination showed that resource users and fishing methods were most similar among the fisheries in Mozambique, Yemen and Zanzibar, whereas these differed greatest among the fisheries in Rodrigues, India and Seychelles (Fig. 2).

3.2. Stakeholder identification, governance structure and stock status

The structure of the governance networks differed greatly among countries (Fig. 3). The most contrasting cases were Egypt, with three nodes in the governance network diagram, and Zanzibar with 15 nodes. In Egypt, three government entities influenced policy and rules, whereas governance in Zanzibar comprised six government entities, three market actors, four non-government organizations (NGOs) and two fisher organizations.

Overall, government organizations constituted 50–100% of all entities participating in fishery governance. Across all countries, the average influence rank of government entities was higher (2.25) compared with that of fisher organizations (1.94), private enterprises (1.87) or NGOs (1.44). The fraction of the total score assigned to government entities decreased with increasing number of nodes in the network ($\beta = -0.18$, $r^2 = 0.29$, $p < 0.01$) (Fig. 4). In other words, as governance networks grew in size, a greater proportion of the entities was non-government. The overall trend was influenced by the governance network in India, which had the largest Cook's distance and residual, because government entities dominated the network

Table 2
Methods and resource user groups characterizing Indian Ocean sea cucumber fisheries. Note that fisheries in Comoros and Mayotte were closed and did not have previous information on harvest methods or resource users (so are not included). Countries are ordered alphabetically by increasing number of resource user groups.

Country/territory	Resource users			Harvest methods			
	Men	Women	Children	Gleaning	Skin diving	Scuba or compressor diving	Trawling
Egypt[a]	✓				✓	✓	✓
India[a]	✓				✓		✓
Maldives	✓				✓	✓	
Seychelles	✓					✓	
Sri Lanka	✓				✓	✓	
Tanzania[a]	✓			✓	✓	✓	
Eritrea	✓	✓			✓		
Kenya	✓	✓		✓	✓	✓	
Mauritius	✓	✓		✓	✓	✓	
Rodrigues[a]	✓	✓		✓			
Madagascar	✓	✓	✓	✓		✓	
Mozambique	✓	✓	✓	✓	✓	✓	
Oman	✓	✓	✓	✓	✓		
Yemen	✓	✓	✓	✓	✓	✓	
Zanzibar	✓	✓	✓	✓	✓	✓	

[a] Fisheries currently under moratoria.

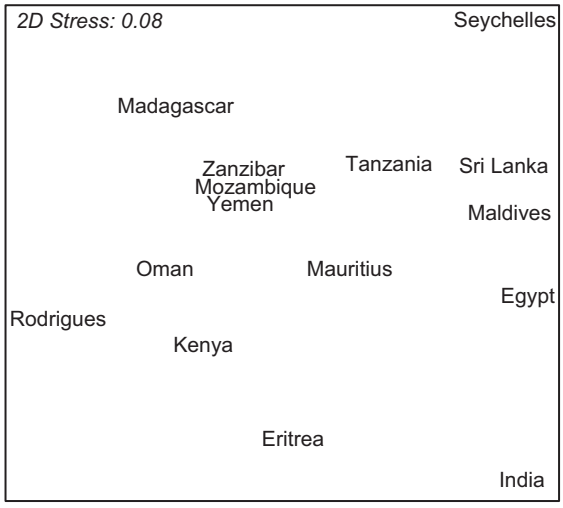

Fig. 2. Indian Ocean sea cucumber fisheries. Ordination plot illustrating the resource users and the fishing methods used in Indian Ocean sea cucumber fisheries. Data were ordinated using the Bray–Curtis dissimilarity matrix.

and were scored high in influence. In contrast Kenya, which also had 14 nodes in the network, had fewer government entities and more influential non-governmental entities, yielding a government influence score half of that in India. Both countries had over-exploited stocks.

Madagascar, Maldives, Mauritius and Tanzania were categorized as depleted. Egypt, India, Kenya, Oman, Sri Lanka and Yemen were over-exploited. Seychelles and Zanzibar were fully exploited, while Mayotte and Comoros were under-exploited (Fig. 4). Neither the number of nodes in the governance networks (β=0.02, CI=−0.22–0.26, p=0.89) nor the government fraction of the total score (β=−2.68, CI=−9.30–3.26, p=0.19) explained the stock status.

The number of user groups (men, women and children) in a country's fishery did not influence the number of nodes in governance networks (β=0.49, r^2=−0.06, p=0.64). However, there was a trend that the fraction of total score assigned to government entities decreased with more user groups (β=−0.94, r^2=0.12, $p<0.01$); i.e., government entities tended to be less influential in fisheries with men, women and children fishers, whereas government entities dominated in fisheries operated by only men. The fraction of scores assigned to government entities in countries with many resource users ranged between 0.48–0.67, compared to 0.62–1 in countries with one user group.

4. Discussion

4.1. Governance structures and sustainability

This study shows that the structure of governance networks does not have a consistent effect on fishery sustainability. Sea cucumber fisheries can be diverse in the manner that they operate, with highly varied governance structures, harvest methods and resource users. Understanding heterogeneity in SSFs is important, because presumably they have different management requirements based on the types of fishers and fishing methods. For example, the Seychelles fishery, comprising licensed scuba divers under limited-entry rules (restricting participation to 25 diving licences), facilitates a comparatively successful monitoring and reporting scheme [37] and this is reflected in the relatively simple structure of the fishery governance network. In other countries, where fishing is more diverse and where there are no limited-entry rules, governance is more complex with a combination of government, NGO and community-level organization influence (e.g. Kenya, Madagascar and Zanzibar).

The relative influence of government entities lessened with more user groups, indicating that more user groups tend to bring about inclusiveness across different types of entities, or at least a dilution in relative government influence. The influence of government entities in more complex networks decreased with multiple participating entities. This could also indicate that where governance is weak, other entities get involved. Across all countries, government organizations constituted at least half of the entities in governance systems, reinforcing the notion that governments play a pivotal role in managing these fisheries, as occurs in Pacific sea cucumber fisheries [38]. In agreement with the literature on adopting context-specific approaches rather than an ideological application of one model to all systems (e.g. [1,39]), our findings underscore that strategies for improvement ought to be distinct to the fishery context of each country. For example, even though Zanzibar and Yemen may have similarities in the resource users and their operations, they are very different in the governance structure—hence, they cannot be assumed to be facing the same governance challenges to improve fisheries status. Neither governance structure in these two countries appears to have been successful in maintaining sustainable levels of catch.

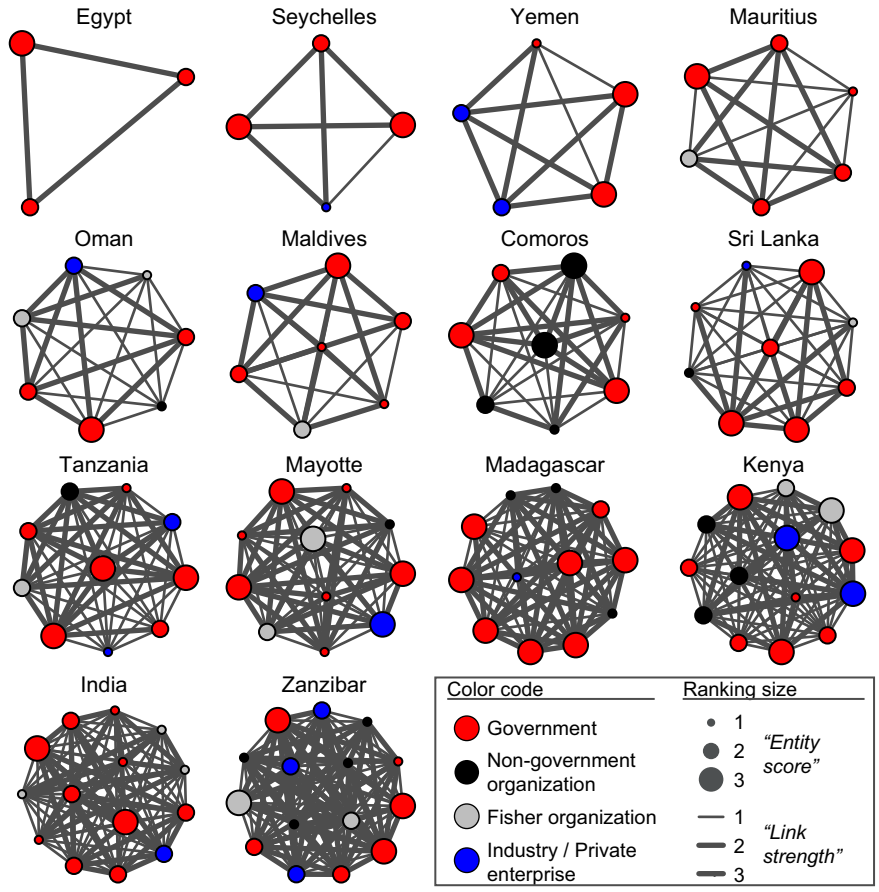

Fig. 3. Governance networks. Network diagrams for governance entities participating in formation of policy and rules of sea cucumber fisheries in the Indian Ocean. The positioning of nodes is random, so inferences should not be drawn from position (e.g. inner or outer position, high or low position).

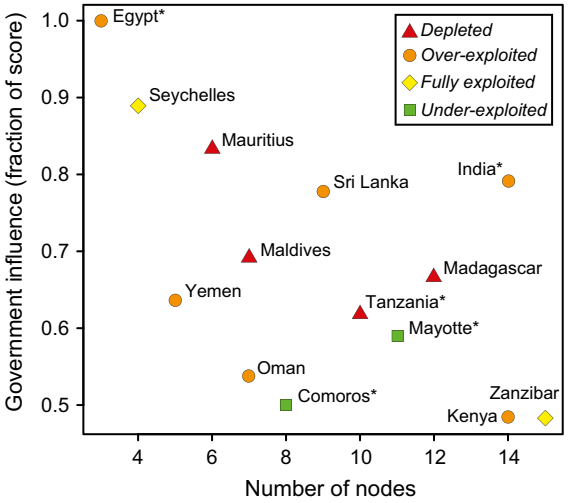

Fig. 4. Governance and sustainability. Bivariate plot of the government influence (as a proportion of the total score of all network entities) versus the number of nodes in the governance network. Symbols distinguish stock status categories chosen from multidisciplinary indicators (see Section 2.3). None of the countries scored as 'moderately exploited'. Asterisks (*) denote fisheries presently in moratorium.

The benefits of network size and representation of various actors and stakeholders in governing fisheries will be context dependent, and multi-stakeholder involvement may not always be a key factor affecting the fate of fishery resources. It might be expected that fisheries with comparatively healthy wild stocks would be those with more inclusive governance structures, given documented positive outcomes from such management models (e.g. [40–42]). However, there was no strong evidence that the number of nodes in the governance network influenced stock status. While this does not refute the importance of the structure of governance network, it indicates that the condition of wild stocks in these fisheries was influenced by other factors.

4.2. Multiple factors influence resource sustainability

Inadequate regulatory measures and enforcement arguably contributed to poor resource status in the fisheries in this study. Weaknesses in implementing regulatory measures are commonplace in sea cucumber fisheries across the Indo-Pacific [24,38]. Fishers in Kenya have indicated an unspoken voluntary rule not to land pieces smaller than the length of the palm of a hand (~20 cm) [43]. However, there have been no legislated minimum size limits on harvests in Kenya and fishers continuously land immature sea cucumbers [44]. Minimum size limits for sea cucumbers are arguably too small in Madagascar [45] and Zanzibar [27]. In Egypt and India, where trawl gears have been permitted to harvest sea cucumbers, those fisheries are over-exploited. Trawl gears should probably be prohibited because they damage habitats and can deplete otherwise inaccessible abundant patches of sea cucumbers that can constitute important spawning stocks for the fishery. Likewise, scuba diving should probably be prohibited in fisheries involving shallow reef species [35,46], but the current study found that harvesting method routinely used in many Indian Ocean fisheries.

Beyond the existence of legislated regulatory measures, enforcement is also weak in many of the fisheries examined, and not

surprising in those where stocks are now over-exploited or depleted. Weak surveillance was part of the downfall of the Egyptian fishery and its lack of recovery [47]. In Kenya, where governance was multi-tiered and complex, "inadequate" enforcement has led to poor compliance of regulations [44]. Monitoring of sea cucumber catches is not done in Zanzibar, which is unfortunate since landing surveys provide an opportunity for enforcement and feedback for adaptive management [48].

Indian Ocean fisheries experience a high level of illegal fishing through roving mobility and clandestine trade with complex cross-jurisdictional movements [28,49–52]. Through mobility, fishers can exploit proximal areas with differing rules, which undermines local management efforts. For example, the fishery closure in Tanzania is evaded by Tanzanian fishers selling their catch in Zanzibar, or by Zanzibari fishers that sail across to poach sea cucumbers in mainland Tanzanian waters. Fishing communities, even those vested with authority for enforcement, have difficulties fending off foreign fishers. Consequently, stocks may become over-exploited despite good local-scale governance. Regional cooperative approaches and national co-management models with strong enforcement may aid in combating the problem of this roving fishery [28].

High fishery participation rates (i.e. number of fishers) will make it hard to govern the fishery sustainably [24], especially when local-level institutions are not vested with management responsibilities. Some of the Indian Ocean sea cucumber fisheries have thousands (e.g. Sri Lanka [53]) or hundreds of thousands of fishers (e.g. India [54]). For fisheries resources vulnerable to high rates of fishing mortality, such as sea cucumbers, overfishing may be a predictable outcome, unless management systems can engage with fishers and restrain fisher numbers and/or fishing effort.

4.3. *Considerations of governance network analysis*

Governance networks can become so complex that it is difficult for managers to make sense of nodes and connections. Systematic mapping of governance structures through a conceptualized view of governance as networks of various entities, linked through social interaction, can help fishery managers to better understand and visualize their governance structures, especially regarding the representation of resource-user groups. Network analyses, such as those used here, provide a tool for visualizing these links and showing where they act as important bridges across levels and scales, e.g. linking local governance entities to national policies [11]. The capacity to adapt to changing conditions, as well as the collective actions of a group, can be reduced in cases where there is very high density of links [55,56]. The lack of correlation between multiple entities in governance networks and resource sustainability in this study could be in part attributed to the fact that fisheries with complex networks may have been unable to easily adapt management measures in the sea cucumber fisheries as stocks declined, due to burdens of consulting, and reaching consensus, with so many stakeholder groups that have a say in their governance. It is also possible that as management challenges increase, more governance entities engage, or are created, without sufficient mechanisms to ensure they work effectively together.

Analyses that also encompass data on attributes of governance function, e.g. leadership or agency, can further aid in gauging how knowledge, innovations and decision-making equity are distributed [10,57]. In this context, some shortcomings in this study are recognized. First, data and classifications of stock status were influenced by the perceptions of resource managers. For example, the fishery status chosen by participants from Zanzibar was less grave than status based on fishery-independent data [27]. Indeed, optimistic bias by fishery managers in fishery diagnoses has been reported elsewhere [38]. There was also subjectivity in the interpretation of influence of entities in governance networks. Moreover, this study is a snapshot perspective on governance structures and has not incorporated deeper insights into network function. Such insight can be discerned through interviews with stakeholders representing participating entities. A better evaluation of node score and the strength of links could be achieved by incorporating multiple actors rather than one government fishery manager. In addition, the methodology adopted in the stakeholder identification exercise constrained the evaluation because all identified entities had to be linked and scored between 1 and 3. That all entities were linked inhibited assessment of polycentric patterns, i.e. asymmetrical networks, which could have been easily done if a zero score was possible. Nevertheless, the graphical network method was more instructive than tabular presentation [38] and useful to evaluate complexity and influence.

5. Conclusions

The generally deteriorated status across Indian Ocean sea cucumber fisheries cannot be systematically attributed to stakeholder representation in management models, but is likely influenced by a range of factors, as well as the individual and interactive attributes between those entities involved in governance. Therefore, it is not the governance network and structure that is the sole challenge to address. The governance structure required to achieve necessary management tasks in each case is unquestionably important to devise equitable mechanisms with desirable attributes (e.g. adaptive and precautionary). However, the challenge to accomplish sustainable SSFs will not be met solely by reforming governance systems—other factors that impact on sustainability must be addressed in unison.

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