Lessons for resource conservation from two contrasting small-scale fisheries

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REPORT

Lessons for resource conservation from two contrasting small-scale fisheries

Hampus Eriksson, Maricela de la Torre-Castro, Steven W. Purcell, Per Olsson

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Abstract Small-scale fisheries present challenges to management due to fishers' dependency on resources and the adaptability of management systems. We compared social-ecological processes in the sea cucumber fisheries of Zanzibar and Mayotte, Western Indian Ocean, to better understand the reasons for resource conservation or collapse. Commercial value of wild stocks was at least 30 times higher in Mayotte than in Zanzibar owing to lower fishing pressure. Zanzibar fishers were financially reliant on the fishery and increased fishing effort as stocks declined. This behavioral response occurred without adaptive management and reinforced an unsustainable fishery. In contrast, resource managers in Mayotte adapted to changing fishing effort and stock abundance by implementing a precautionary fishery closure before crossing critical thresholds. Fishery closure may be a necessary measure in small-scale fisheries to preserve vulnerable resources until reliable management systems are devised. Our comparison highlighted four poignant lessons for managing small-scale fisheries: (1) diagnose the fishery regularly, (2) enable an adaptive management system, (3) constrain exploitation within ecological limits, and (4) share management responsibility.

Keywords Adaptive management · Coral reef · Fisheries · Governance · Invertebrate · Sea cucumber

INTRODUCTION

Amidst increased overfishing globally (FAO 2014), management theory has progressed considerably on the basis of both successes and failures in capture fisheries. Fisheries management systems in general have been rigid and largely unable to cope with uncertainty of ecosystem responses (Kinzig et al. 2003; Hughes et al. 2005). Complex social-ecological systems have also tended to be viewed simply as "fisheries" (Castilla and Defeo 2005). A more modern approach to improving fisheries sustainability has shifted the focus of research onto how human activities are embedded in ecosystems (Folke 2011), and links social processes with natural systems (e.g., Berkes and Folke 1998; Berkes et al. 2003).

Small-scale fisheries (SSFs), especially those in the tropics, make significant contribution to economies and food security in poor and vulnerable communities (Mills et al. 2011). These fisheries are under significant pressure (Kittinger et al. 2013), and too often underperform on their economic and social objectives (Andrew et al. 2007). The urgency to amend the failing management of SSFs is tied to the global commitments to Millennium Development Goals (UN 2013). However, management challenges are substantial due to factors including the dispersed constituency (Andrew et al. 2007), financial dependency (Daw et al. 2012), and difficulty in engaging with stakeholders (Ratner and Allison 2012). SSFs have been under the spotlight of theoretical research and the focus of new models for governing social-ecological systems (e.g., Cinner et al. 2009; Ratner and Allison 2012; Kittinger et al. 2013). Pragmatic frameworks for diagnosis and management of SSFs have been stressing the importance of learning and adaptability of management systems (Andrew et al. 2007). However, many fisheries are yet to adopt the new models and face increasing external pressures to fish unsustainably.

Comparison of fishery development trajectories for similar resources can help identify strategies likely to achieve resource sustainability. Unsuccessful and successful examples in fisheries provide for valuable lessons,

especially in tandem. Here, we highlight lessons from two contrasting sea cucumber fisheries from Zanzibar (Unguja Island) and Mayotte in the Western Indian Ocean (WIO). Tropical sea cucumber fisheries are mostly export-oriented and are thus subject to global market drivers. Although domestic consumption is usually minor, they can be seen as archetypes of SSFs, since they are widespread (>70 countries), provide income to livelihoods of at least 3 million fishers, are multi-species, and generally involve artisanal methods with simple boats and fishing gears (Purcell et al. 2013). Hence, this comparison should offer valuable insights to managing other SSFs.

Fishing sea cucumbers (Holothuroidea) for export to Asian dried seafood markets has a long history in the Indo-Pacific (Conand 1989). Tropical sea cucumber fisheries have proven very difficult to manage and fishery development commonly follows a destructive boom-and-bust pattern (Anderson et al. 2011), even in high-income countries (Eriksson and Byrne 2013). Management principles for sea cucumber fisheries have progressed considerably during the past two decades (Purcell 2010; Purcell et al. 2014). A better understanding of the social-ecological systems dynamics and adaptive management in sea cucumber fisheries would help to prioritise management actions.

We have documented the sea cucumber fishery in Zanzibar in previous studies and concluded that the fishery is deteriorated and insufficiently managed (Eriksson et al. 2010, 2012a). Here, we compare the fishery and management in Zanzibar to that in Mayotte. The comparison delivers insights about the influence of social-ecological context on fishery development and the different strategies used by the government management agencies to address increasing fishing effort and declines in wild stocks.

Analytical framework

A conceptual structure, inspired by the framework for analyzing sea cucumber fisheries by Friedman et al. (2008) and de la Torre-Castro et al. (2007), provides a means to systematically evaluate the fishery development processes. This structure incorporates three broad elements for comparison:

(1) *Status of the natural resource* The commercial value of the resource is assessed as a proxy for the overall condition of stocks.
(2) *Fishery structure and organization* Fishery development and the fishing systems are described.
(3) *Fishery management* The management regimes are compared by analyzing general legislation, fishery-specific regulations, and their enforcement.

MATERIALS AND METHODS

Zanzibar case study

The island of Zanzibar (6°8′S, 39°20′E), also called Unguja Island (Fig. 1a, b), is a semi-autonomous territory of The United Republic of Tanzania with a separate fisheries management authority. During this study, the Department of Fisheries and Marine Resources (DFMR) was responsible for managing the marine resources. Marine management in Zanzibar is highly influenced by external actors and NGOs that, in many cases, sway the agenda for conservation. Around 85 % of Zanzibar's coastal people live on less than US$1 per day (Ruitenbeek et al. 2005). Recent decades have seen the human population rise to ~1 mil in parallel with increased exploitation of marine resources. Artisanal fishing is a dominant economic activity (Jiddawi and Öhman 2002).

Mayotte case study

Mayotte (12°50′S, 45°8′E), located in the Comoros archipelago (Fig. 1a, c), became a semi-autonomous 'overseas collective' (Collectivité Outre-Mer) of France in 1976. This study deals with decisions made before an annexation as a French department in 2011 and will not elaborate on this point. The economic support from France has contributed to a relatively higher living standard and development compared to other WIO countries (Quillard and Pusineri 2008). Owing to French colonialism, Mayotte has long been influenced by Western resource management policy, also accentuated by the European Union Legislation and environmental directives. When the sea cucumber fishery was active (mid 1990s to 2004), the Service des Pêches (SdP) was the agency responsible for fisheries management. The population of Mayotte is estimated at more than 200 000 (Guézel et al. 2009). Similar to Zanzibar, Mayotte's human population has increased dramatically over the past 30 years (Gourbesville and Thomassin 2000). Fishing is an important economic activity and many households subsist from fishing (Guézel et al. 2009).

Status of the natural resource

The manta-board survey technique (English et al. 2003) was used to count sea cucumbers along 300 × 2 m belt transects to estimate stock abundance. This technique is a rapid assessment method appropriate to most of the exploited sea cucumber species (Friedman et al. 2008; Purcell et al. 2009). Sampling stations comprised six replicate transects dispersed randomly in a patchwork of coastal habitats at depths 1–10 m. Transect length and tow speed were monitored using a handheld GPS unit by a

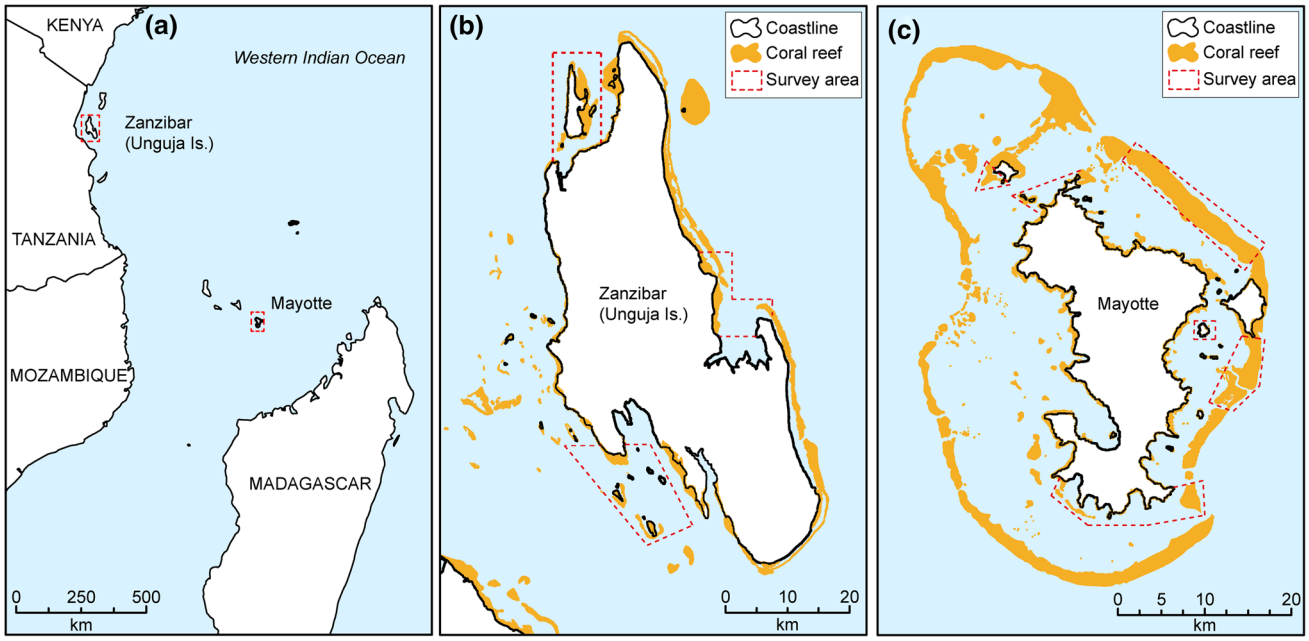

Fig. 1 Map of the study area; **a** the Western Indian Ocean **b** Zanzibar, and **c** Mayotte. The *dotted lines* are outlines of the coastal areas where visual censuses of sea cucumber stocks were performed

second researcher on the boat. The towed observer enumerated sea cucumbers seen within the belt transects and recorded a range of habitat variables estimated visually, including the habitat type and percentage area coverage of broad substrate types (e.g., Purcell et al. 2009; Eriksson et al. 2012b). In Zanzibar, 47 stations were surveyed, while 46 stations were surveyed in Mayotte, constituting approximately 17 ha of assessed benthos around each island. Total coral reef area was estimated using ESRI ArcGIS 10® and the global distribution of coral reefs dataset (UNEP-WCMC et al. 2010) to gauge area of available fishing ground between the two islands.

Because these were commodity fisheries, the fishers' targeted species with higher commercial value first (Friedman et al. 2008; Branch et al. 2013). Therefore, we used the frequency of observations of low-, medium-, and high-value species and the total resource (commercial) value as proxies for the overall condition of the stock. Catches were monitored during approximately 2 weeks at three landing sites during 23 June–23 August 2009 in Zanzibar and the species-specific average values per-piece in USD paid to fishers were calculated (from Eriksson et al. 2010). Each species' value was multiplied by its corresponding abundance at each survey station to estimate the total commercial value. We tested the effect of location (Zanzibar and Mayotte) and habitat variables on the total commercial value per station using a generalized linear model for negative binomial distribution, which was the best fit for the data, using the MASS package in R 2.9.2 as outlined by Logan (2010).

Fishery structure and organization

The fishery situation in Zanzibar has been reviewed (Nilsson 2008; Raymond 2008; Eriksson et al. 2010). These studies conducted interviews from October 19 to December 31, 2007 in eight villages in Zanzibar, including fishers ($n = 72$), middlemen ($n = 15$), and traders ($n = 5$) as well as senior management officials ($n = 8$) and local monitoring agents ($n = 15$). In addition, further interviews with SCUBA diving fishers were carried out in 2010 (Eriksson et al. 2012a). Results from these studies are summarized for the purpose of this comparison. Export statistics from Department of Tourism and Trade Statistics in Zanzibar were compiled.

In Mayotte, historic documentation and fishery reports were consulted for mapping fishing activities for sea cucumbers (e.g., MAD 1916; Pouget 2003, 2004). Interviews were conducted with eight current or former officers of authorities involved in, or responsible for, fisheries management. Interviews were semi-structured with open-ended questions, following Bunce et al. (2000). Interviews were held in English and lasted approx. 1 h. One former fisherman from Mayotte was also interviewed to complement written reports and managers' perceptions of the fishery situation when it was operating. This was an in-depth interview held in French with the assistance of a translator. Other fishers involved in the sea cucumber fishery in Mayotte could not be located. Export statistics were consulted from Pouget (2004).

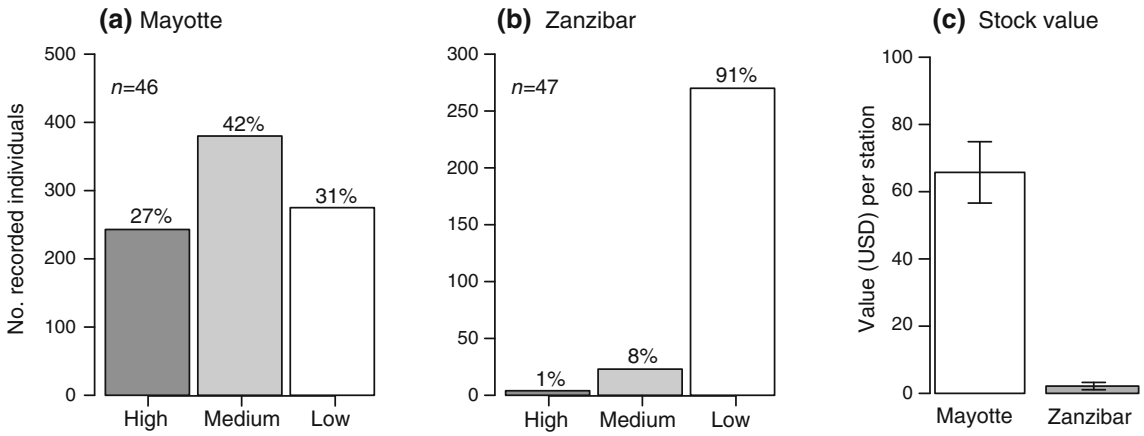

Fig. 2 The distribution of total counted commercial high-, medium-, and low-value species among all sample stations in **a** Mayotte ($n = 46$) and **b** Zanzibar ($n = 47$). **c** The mean value of commercial sea cucumbers per survey station sampled in Mayotte and Zanzibar. Value is the species-specific price per piece that fishers receive in Zanzibar (Eriksson et al. 2010)

The fishery management

The fishery management situation has been documented (Nilsson 2008; Raymond 2008; Eriksson et al. 2010, 2012a). Legislative documentation obtained from DFMR and interviews stated above were consulted for the purpose of this comparison. In Mayotte, the fishery was characterized using published literature, legislative documents, and official reports. Information from interviews conducted with fisheries management officials in Mayotte detailed above was used to describe and understand the management process.

RESULTS

Resource value of stocks

We found a stark difference between locations in the ratios of high- and medium-value species compared to low-value species (Fig. 2a, b). High- and medium-value species constituted 69 % of surveyed sea cucumbers in Mayotte but just 9 % of observed animals in Zanzibar. Concomitantly, the average commercial value of sea cucumbers observed per survey station (3600 m^2) was 65.7 USD at Mayotte compared to 2.2 USD at Zanzibar (Fig. 2c). Location was the most powerful explanatory variable distinguishing differences in resource value among stations ($z = 10.31$, $p < 0.01$) (Table 1). Depth also had a significant, but weaker, explanatory power, with higher-valued species found in deeper locations in Zanzibar. None of the other habitat variables showed any explanatory power. The survey station at Chumbe Coral Park in Zanzibar, a no-take protected area, contained sea cucumbers to a value of 50.5 USD, considerably higher than the Zanzibar-wide average of 2.2 USD. Excluding this small station from the calculation halves the average commercial value in Zanzibar to 1.1 USD per survey station conducted in fishing areas. These findings indicate a significant protection effect on commercial value of sea cucumber stocks, both between the two islands and within Zanzibar.

Table 1 Statistics from the generalized linear model using resource value of sea cucumbers in stations as the response variable

Variable	z value	p value
Location	10.31	<0.01
Relief	−0.97	0.33
Complexity	−0.63	0.53
Oceanic influence	1.21	0.23
Depth	2.57	0.01
% Soft sediment	0.63	0.53
% Rubble	0.82	0.41
% Boulders	0.64	0.52
% Consolidated rubble	1.57	0.12
% Pavement	0.82	0.41
% Live coral	1.23	0.21
% Dead coral	1.12	0.26
% Seagrass	−1.32	0.19

The fishery structure and organization

Fishery history and initiation

The early fishing history is similar between locations (Table 2). In both Zanzibar and Mayotte, fishing of sea cucumbers started around 100 years ago (MAD 1916; Gilbert 2004). The sea cucumber market contracted

Table 2 Comparison of the sea cucumber fishery structure and organization between Zanzibar and Mayotte

Aspect	Zanzibar	Mayotte
Fishery history and initiation		
Historical harvests	Started early 1900s	Started 1916
Contemporary harvests	Re-commenced in 1960s	Re-commenced in mid-1990s
Fishery operation		
Resource users	Men, women, and children	Men only
Number of fishers	>1000	<100
Coral reef area	230 km^2	310 km^2
Collection methods	(1) Intertidal gleaning	(1) Intertidal gleaning
	(2) Breath-hold diving to <10 m	(2) Breath-hold diving to <10 m
	(3) SCUBA diving by highly mobile fishers	
Catch and exports		
Number of harvested species	>30	<6
Value of catch	>90 % low-value or species recently commercialized	100 % High to medium commercial value species
Export volume	319 t (2002–2007)	26.5 t (2000–2004)
	ca. 53 t $year^{-1}$	ca. 5.3 t $year^{-1}$
Export value	167 000 USD (2002–2007)	Not available
	ca. 28 000 USD $year^{-1}$	
	ca. 0.52 USD kg^{-1}	
Import destinations	Multiple global entrepôts	Mainly regional transit markets

globally during the world wars and fishing was likely inactive in the region until China's re-integration into the world economy, as has been described in the South Pacific (Kinch 2008). Chinese traders in Zanzibar apparently initiated more intense harvests during the 1960s (Eriksson et al. 2010). In contrast, fishing in Mayotte appears to have remained inactive until the mid-1990s, when Chinese shark fin traders motivated harvests of sea cucumbers (Pouget 2004). Malagasy fisher immigrants also spurred the recent initiation of the Mayotte fishery (Pouget 2004).

Fishery operation

The scale and *modus operandi* of contemporary harvests differs greatly between locations (Table 2). No records exist of the estimated number of fishers in Zanzibar from the twentieth century, nor do any assessments of sea cucumber populations. In 2010, 1000 fishers were estimated to be actively engaged in the Zanzibar fishery (Eriksson et al. 2010), over an estimated reef area of 230 km^2. These fishers used three collection methods; (i) gleaning on intertidal habitats, (ii) breath-hold diving from boats down to 10 m by men, and (iii) SCUBA diving by young men.

There were approximately 85 sea cucumber fishers in Mayotte with an available reef area of 310 km^2. Teams of male fishers using small fiberglass boats predominantly accessed reef areas to collect sea cucumbers. Sea cucumbers were harvested either by intertidal gleaning or breath-hold diving.

Catch and exports

Similar to the comparison of resource value, catch and exports differed markedly between locations (Table 2). The catch in Zanzibar consisted of more than 30 species. At least 90 % of the catch was low-value species or those recently commercialized. In Mayotte, six species were harvested, predominantly those of high-value, notably *Holothuria nobilis* but also *H. fuscogilva*, and *Thelenota ananas* (Pouget 2004).

According to DMFR records, 53 t of dried sea cucumber was exported from Zanzibar on average p.a. during 2002–2007. Pouget (2004) reported that 5.3 t of dried product was exported from Mayotte during 2002, but export volumes in other years were unreported. This export volume over the last 5 years of operation (2000–2004) would equate to a total of 26.5 t total exports, which is equivalent to 10 % of Zanzibar's total exports over an equivalent period. The export value from Zanzibar was approximately 840 000 TSZ per tonne (535 USD). Unfortunately, export value from Mayotte was not available. However, the smaller volume and the high-value target species illustrate how the Mayotte fishery was more selective for premium species. Zanzibar is a regional trade entrepôt and a substantial part of the exports are sourced

Table 3 Management and governance aspects of the sea cucumber fisheries in Zanzibar and Mayotte

Aspect	Zanzibar	Mayotte
Legislation	Fishing rules are legislated (RGZ 1998, 2010)	Fishing rules are legislated (AFFMAR 2009, Préfecture de Mayotte 2004)
Fishery-specific management regulations	Length restriction (10 cm)	Fishing was unregulated until 2004 when the fishery closed
Enforcement	No enforcement of length restriction	The fishery closure is enforced by the police, gendarmerie, customs, and Affaires Maritime
Monitoring	No monitoring of the fishery or catch. Exports recorded but not to species level	Fishery not monitored but exports were recorded (sometimes to species level)
Information flow	No systematic or informal communication	High participation in dialog with fishers
Human capacity	Highly limited	Education from French systems, strong personal interest in conservation
Adaptive learning mechanisms	No monitoring and no assessment of the fishery	Fishery and resources assessed before closure

from fishing grounds outside of Zanzibar (Eriksson et al. 2012a). This role in trade is also illustrated in the export target markets, considering that Zanzibar directly supplied global market entrepôts (e.g., Singapore, Hong Kong, Los Angeles; Eriksson et al. 2012a). In contrast, exports from Mayotte were mainly destined to regional transit markets (e.g., Tanzania, Madagascar and Mauritius; Pouget 2004) before re-export to Asian markets.

Fishery management

Legislation and management regulations

Both locations have legislated their regulatory measures but the sea cucumber fishery management in Zanzibar is resource limited and weak (Table 3). In Zanzibar, fishery legislation and the organizational structure of DFMR are fairly robust and well-structured (Ruitenbeek et al. 2005; de la Torre-Castro 2006). In addition to broad fisheries policy (RGZ 1998, 2010), Zanzibar has other regulations transcending different fisheries, such as the requirement for annual licenses for fishing boats and exporting marine products. A few villages have informal regulations, not widely known or followed (Eriksson et al. 2010). While DFMR aims to sustain harvests of all marine life (RGZ 2010), no management plans or objectives were specific to the sea cucumber fishery. There was a minimum legal size limit of 10 cm for all species unspecified live or dried product (RGZ 1984) but it was not communicated and, consequently, was rarely known among fishers, actors in the trade, or the interviewed managers (Eriksson et al. 2010). The size regulation was also not large enough to allow the commercial species to reach sexual maturity before being harvested (Conand 1993), illustrating a management inconsistent with ecology. Managers in Zanzibar said that while a need for improved management was unanimous, a lack of resources (i.e., economic and human) hindered its development (Eriksson et al. 2010).

Mayotte's fisheries laws are developed under the same central legislation framework for the utilization of natural resources as in other French overseas territories (AFFMAR 2009). There was no specific policy recognizing sea cucumber fishing, nor fishery-specific regulations, when modern harvesting began in the mid-1990s. With the increase in number of fishers, resource managers stated that SdP decided to monitor the fishery's development, so research was conducted in the early 2000s to assess the fishery. That multi-disciplinary assessment showed: (i) a decline in population abundances in underwater surveys (Pouget 2003), (ii) other nations had failed to manage fisheries in similar circumstances, (iii) the ecological roles of sea cucumbers in reef ecosystems were significant, and (iv) stocks were considered fragile to fishing impacts (Prefecture de Mayotte 2004). The existing technical competency and data were also deficient to manage an operating fishery effectively. Therefore, the fishery was closed in 2004 as a protective conservation measure to safeguard stocks and the ecosystem services that they provide. This law is enforceable by different authorities (e.g., Police, Gendarmerie, Customs, Brigade Lagoon, Affaires Maritime), illustrating a broad sharing of enforcement responsibility.

Monitoring, information, and human capacity

Resource limitations are reflected in the extent of regulations, monitoring, and enforcement between the study cases (Table 3). The DMFR in Zanzibar employs fisheries officers, known as beach recorders or "Bwana dikos", to record fishery data (de la Torre-Castro 2006). However, their heavy workload with other fisheries' tasks prevents them from systematically monitoring the sea cucumber fishery. There had been no population assessments of sea cucumbers in the Zanzibar fishery. Even so, the managers were aware that sea cucumber populations had deteriorated from fishing, as they had broad local knowledge, and received information from fishers and village fishing committees. The absence of systematic monitoring and

insufficient institutions illustrated a management system that lacked mechanisms to receive and process feedback from fishers and ecosystems.

In Mayotte, the staff at SdP was integrated with the State department, DAF, that had formal responsibility for assessing and monitoring terrestrial and marine natural resources. This structure allowed for dialog and information exchange on issues relevant to several units across DAF. Officers at SdP expressed a strong sense of stewardship and responsibility to manage and preserve marine resources—in the context of their professional roles and personal perspectives. Respondents (managers) were keen recreational divers and had constructive interactions with fishers. For example, SdP provided literature on sea cucumber postharvest processing to fishers, allowing them to add value to their catch. The fishers also disclosed fishing grounds, catch and effort to SdP, which guided SdP in conducting the survey and gauging trends in the fishery.

DISCUSSION

Our constructivist approach reveals factors that appear to have strongly influenced resource conservation and depletion. The issues faced by fisheries managers in Zanzibar and Mayotte are not dissimilar to those of sea cucumber fisheries in the Pacific (Purcell et al. 2014) and other coastal SSFs in the Indo-Pacific (Andrew et al. 2007; Cinner et al. 2009; Kittinger et al. 2013). Most notably, (i) fishers were poor and fishing was an important economic part of their livelihoods, (ii) fishery agencies were not well-informed and fishing was initially operating under open access resource rights, (iii) until recently, fishery data were lacking in both cases to understand stock status. However, the management agencies were able to deal with those issues in distinctly different ways, allowing stocks at Mayotte to be conserved at appreciable levels while those at Zanzibar were depleted. The management strategies have likely converged with other factors to influence the trajectories in these two cases. For example, socioeconomic factors are likely to influence fishers' ability to respond to changing conditions in the fishery and how they perceive rules and evaluate strategies (Sumaila et al. 2006; Cinner et al. 2009; Slater et al. 2014). Mayotte's affiliation to France cannot be ignored in this sense, as it may have contributed to a wider range of livelihood options available to fishers than in Zanzibar and to a higher enforcement capacity.

SSFs in low-income tropical countries have seen unprecedented pressures on stocks and livelihoods, resulting in fishery collapse and loss to biodiversity (Worm and Branch 2012; Kittinger et al. 2013). This is exemplified by recent sea cucumber fishery closures in at least 24 tropical nations due to overfishing (Purcell et al. 2013). Fishery collapses have occurred because management has been poorly equipped and structured to mitigate overfishing. New configurations for regulatory measures and governance systems are being devised to move these fisheries toward sustainability (e.g., Purcell 2010). In the meantime, sustainability may be impossible under many of the existing management systems. In this context, fishery closures need not be an endpoint, but rather an intermission, acknowledging the need for a radical change to the status quo. Our study yields four important lessons for managers to avoid the pathway to collapse in similar small-scale fisheries:

(1) *Gain regular feedback from the fishery and appraise the fishery operation through multiple flows of information*. Our case study echoes the importance of diagnosis of fisheries (Andrew et al. 2007). A distinguishing factor that supported management in Mayotte to implement a fishery closure was regular feedback between fishery officers and fishers, and a proactive stock assessment. Assessing the state of stocks does not need to come from fishery-independent surveys (e.g., underwater visual census); i.e., landing ('creel') surveys and sociological surveys will often be more cost-effective (Purcell et al. 2014). This study also highlights the utility of lessons from other fisheries in the diagnoses. Such types of learning mechanisms and information sources are critical for responding to change through adaptive management responses (Berkes and Folke 1998).

In Mayotte, there was a vertical flow of information from managers to fishers, and vice versa, that guided adaptive management responses. An important lesson is therefore to build constructive relationships and communicate with fishers. Such communication between resource users and authorities reinforces trust and generates stewardship incentives (Gutierrez et al. 2011). Conversely, weak communication flows undermine adaptive institutions due to the absence of feedback from monitoring (Berkes and Folke 1998). This weakness exists in Zanzibar because the monitoring agents responsible for data-collection are limited in capacity and influenced by dilemmas (i.e., kinship, loyalty, poverty, and control) in their operation, which interferes with their performance as a whole and undermines management functionality (de la Torre-Castro 2006). Foreign trading agents exploited the weak monitoring protocol in Zanzibar to operate unscrupulously through the unregulated and prospecting SCUBA diving fishery impacting on sustainability and fisher's health (Eriksson et al. 2012a).

(2) *Be adaptive and act swiftly to changes in resources and fishing*. In Zanzibar, adaptive management responses were absent. Catches clearly shifted toward low-value species and the fishers started using SCUBA when shallow water stocks dwindled, but no radically different management was implemented to deal with the changes. In contrast, Mayotte managers took prompt actions to review the fishery when fishing activity increased, and brought in stringent measures to protect sea cucumber populations following the assessment.

Timely changes to management measures are crucial. For example, the lack of early intervention in Galapagos Islands allowed that sea cucumber fishery to expand uncontrolled with fishers acquiring boats on credit (Shepherd et al. 2004). This effectuated a threshold on decision-making, because when conservation measures were later legislated it gave rise to violence and illegal fishing. Responses to changing resource condition by fishers (e.g., expanding operations on credit) can hence constitute reinforcing processes on the fishery trajectory. As also seen in Zanzibar, these processes can be very difficult to break and limit feasible choices for managers. The decision-making process in Mayotte demonstrates that learning mechanisms coupled with adaptability are important to adjust to changing conditions in the fishery—before crossing critical thresholds. The corollary is that management institutions should limit the pace of exploitation if the management system has weak adaptive capacity.

(3) *Constrain fishing effort to match the size of stocks or fishing grounds*. The number of fishers in Zanzibar was not commensurate with the area of the fishing grounds and history of unregulated fishing. Over time, the fishers depleted the resource at a pace outstripping management adaptation, and had to use more intensive methods as they depleted the valuable species and shifted to harvest lower-value species. In contrast, the lower number of fishers in Mayotte per unit area of fishing grounds resulted in slower changes to the resource and catch composition. Those changes were then identified and addressed in a timely way by the management authority. The number of fishers per unit area of reef habitat is closely related to their annual catch and the sustainability of stocks (Purcell et al. 2013). Therefore, managers should take the time to estimate how many fishers the fishing grounds are likely to support and set appropriate limited-entry rules, or alternative measures, to limit fishing effort.

The comparatively lower fishing effort in Mayotte avoided depletion of high-value species, so fishers did not need to target lower-value species to make fishing profitable. In addition, the persistence of sea cucumbers in shallow waters meant that fishers did not need to fish with intensive methods, such as SCUBA diving. These conditions contrast with Zanzibar, where catches became dominated by low-value species and fishing intensified. Importantly, the trend to target new and lower-value species subsidizes the continuous catch of endangered high-value species—forming a "pathway to extinction" (Branch et al. 2013).

(4) *Share management responsibility*. Enforcement capacity is often weak in SSFs such as those for sea cucumbers (Purcell et al. 2013, 2014). In Mayotte, a sharing of responsibility for enforcement among authorities appeared to provide for better surveillance and compliance of regulations. This contrasts with Zanzibar, where enforcement by the fishery management agency was weak and catches were not inspected to verify compliance of minimum size regulations.

Different management approaches must be implemented that are distinct to the social-ecological characteristics of the SSFs (Ratner and Allison 2012). The management system in Zanzibar was not attuned to receive information or process information to make decisions accordingly. In terms of governance, it is unreasonable to expect that villages or communities can fence out the strong market forces that give rise to the mobile and clandestine fishing in Zanzibar. Therefore a governance model that distributes and shares management responsibility between government and community appears advantageous. This must be coupled with high institutional capacity to enforce rules and keep at bay the destructive responses that reinforce the trajectory of the fishery.

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