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Sea cucumber management strategies: challenges and opportunities in a developing country context

Merrill Baker-Médard and Kristina Natalia Ohl

Middlebury College – Environmental Studies, 531 College Street, Franklin Environmental Center at Hillcrest, Middlebury, VT 05753, USA

Subject Review

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Author for correspondence:
Merrill Baker-Médard,
Email: mbakermedard@middlebury.edu

Summary

Sea cucumbers play a critical role in maintaining healthy marine ecosystems. Sea cucumbers are also a key source of income for millions of small-scale fishers worldwide. The lucrative nature of this industry has led to severe reductions in sea cucumber populations in numerous regions globally. A large proportion of sea cucumber fisheries are located in developing countries, which present unique challenges to management, including addressing highly decentralized methods of extraction and processing, limited economic and technological resources for governance and, in many cases, a high dependency on sea cucumbers as a primary source of income for small-scale coastal fishers. In this review, we review the benefits and challenges of seven categories of sea cucumber management strategies used globally in developing countries, including gear restrictions, size and weight limits, effort and catch controls, temporal closures, area closures, value chain licensing and territorial use rights in fisheries. We conclude that sea cucumber management in developing countries could benefit from focusing regulatory solutions on narrowed parts of the value chain, coupling production-based management strategies with processing and export regulations and providing avenues for local fishers to inform policy at the local, regional and national levels.

Introduction

An estimated 3 million people collect sea cucumbers globally (Purcell et al. 2013). Unlike other high-value fisheries, sea cucumber fisheries tend to be decentralized and to rely on both men and women for their extraction, and they are found in almost every marine ecosystem worldwide (Anderson et al. 2011, Fröcklin et al. 2014, Eriksson et al. 2015). Sea cucumbers are deposit feeders critical to maintaining the balance of benthic microenvironments, the foundation of a highly productive and healthy marine ecosystem, including coral reefs (Uthicke 2001, Máñez & Ferse 2010). Sea cucumber overfishing has serious impacts on sediment health, water quality, nutrient recycling, seawater chemistry and energy transfers across the food chains in numerous marine systems globally (Lane & Limbong 2013, Conand 2018).

Developing countries make up the majority of sea cucumber exports globally, and sea cucumber fishing in many of these countries is a primary source of income for small-scale fishers (de la Torre-Castro et al. 2007, Conand 2008, Anderson et al. 2011, Carleton et al. 2013, Pakoa & Bertram 2013, Purcell et al. 2013). While sea cucumbers have been harvested by many cultures for centuries, overfishing became apparent at the end of the twentieth century, when demand for luxury seafood consumption increased in Asian countries (Fabinyi 2012), more people began to participate in sea cucumber fishing across the globe (Máñez & Ferse 2010) and the use of highly efficient technologies such as compressor diving and drag-netting spread (Purcell 2010, Eriksson et al. 2015). The lucrative nature of sea cucumber fishing has led to near depletion or even local extinction of certain species in numerous regions globally; notable cases include areas in Egypt, Indonesia and Malaysia (Anderson et al. 2011). An estimated 38% of the world's sea cucumber fisheries are deemed 'overexploited', 20% 'depleted' and another 14% 'fully exploited' (Purcell et al. 2013). Similarly, the Food and Agriculture Organization of the United Nations (FAO) reported that a total of 81% of sea cucumber fisheries were in decline due to overfishing (Anderson et al. 2011). Concern for the sustainability of this lucrative fishery has led to an increase in information sharing and management efforts globally (Purcell 2010).

An estimated 90% of sea cucumbers harvested worldwide are imported and consumed in Southeast Asia and the Far East (Ferdouse 2004). The main import markets are traditionally China, Hong Kong Special Administrative Region, Singapore and Taiwan; recently, however, demand has been rising in other Southeast Asian countries and in countries with a large Asian diaspora, such as the USA (Purcell 2010). Currently, one of the larger exporters of sea cucumbers is Indonesia, while other leading exporters include Sri Lanka, Madagascar and Mexico. Prior to 2009, additional major exporting countries included Fiji, Papua New

Guinea, Tonga, Tanzania, Philippines and New Caledonia (Anderson et al. 2011). The Central West Pacific region is the main exporter of sea cucumbers, with a mean of 7000 tonnes in dry weight exported yearly (Conand, 2018). Papua New Guinea, Fiji and the Solomon Islands were previously among the largest exporters of this region; however, landings and exports have declined in these countries since the 1990s, possibly due to overexploitation (Govan 2017, Conand 2018). New fisheries in surrounding countries are therefore responsible for high landings in the region. Tracing the exact origin of sea cucumbers within the global trade network is difficult. Globally, reported exports are less than half of reported imports (Anderson et al. 2011). Lack of consistent and reliable export data makes international trade difficult to accurately quantify (Ferdouse 2004). Severe underreporting of fisheries exports is common, but is particularly problematic in developing countries.

Given the array of challenges endemic to this fishery, efforts to better understand and more successfully manage sea cucumbers are proliferating (Toral-Granda et al. 2008, Purcell et al. 2013, Conand 2018). Here, we build on previous reviews that focus on sea cucumber management strategies globally (Friedman et al. 2008a, Purcell 2010) and investigate different wild sea cucumber fisheries management strategies specifically for developing countries. We use 'developing country' here to mean countries with emerging economies with relatively low gross national incomes per capita and low scores on the United Nations Human Development Index, including nations of Africa, Asia and Latin America. In particular, we highlight underexplored opportunities for sea cucumber managers to focus regulatory solutions on narrowed parts of the value chain, serving as monitoring and enforcement leverage points for other nodes of the value chain. Finding ways to improve regulatory efficiency is particularly important in a developing country context, where financial and human resources are often scarce.

While there is some documented success of sea cucumber management strategies working in industrialized countries such as the USA, Canada and in French-governed territories and departments (Uthicke et al. 2004, Hamel & Mercier 2008, Eriksson et al. 2015), evidence of successful sea cucumber management in developing countries is scarcer. Sea cucumber fishery management in developing countries presents unique challenges, including the decentralized nature of the sea cucumber production and processing, limited resources and personnel dedicated to marine resource governance and high economic dependency on this lucrative fishery for small-scale fishers (Eriksson et al. 2015). In this review, we focus on both management and governance. While management primarily involves operational decisions or the means and actions required to achieve specific fisheries and biodiversity conservation objectives, governance refers to the broader processes through which individuals and institutions make management decisions (Armitage et al. 2012, Borrini-Feyerabend & Hill 2015). Some of the governance processes we highlight here include accountability, transparency, representation, inclusiveness, equity, integration and coordination.

Methods

The articles included in this review were identified from September 2017 to November 2018 by three mechanisms: keyword search in Google Scholar, the Pacific Community's (SPC) Beche-de-Mer Information Bulletin archives (http://coastfish.spc.int/en/publications/bulletins/beche-de-mer) and by reviewing the references of the articles identified from these databases. Combinations of the keywords 'sea cucumber' and 'management' were used to identify relevant articles. Only articles written in English were included in the review. No constraints were made for the year of article publication; however, newer articles with updated management strategies concerning a particular nation were prioritized over older articles about the same nation. Similarly, articles including information on nations not included in previous reviews were prioritized. A variety of articles were incorporated, including peer-reviewed articles, governmental documents, nongovernmental documents, FAO reports, news articles and notes written in the 'communication' section of SPC's archive.

Results

A total of 93 documents were identified in the initial review, 37 of which were excluded based on duplicate information or inadequate explanation of sea cucumber management strategies used in a particular country. The remaining 56 articles were read with particular attention to the strategies used specifically to manage sea cucumber stocks.

The review uncovered seven categories of sea cucumber management used in developing countries globally. While these categories are not exhaustive, they capture the general categories of wild sea cucumber management, including: gear restrictions; size and weight limits; effort and catch controls; temporal closures; area closures; value chain licensing; and territorial rights assignment. These categories broadly align with those found in previous reviews (Friedman et al. 2008a, Purcell 2010); however, we de-aggregated territorial use rights in fisheries (TURFs) from other area-based management strategies (e.g., marine protected areas (MPAs)) in order to emphasize the potential for TURFs to align with customary marine tenure regimes. Aquaculture is an increasingly important strategy being used in developing countries and has immense potential to help wild populations recover and maintain production. However, we decided to exclude aquaculture from our review, given that the technical considerations (e.g., habitat suitability, hatchery requirements, finding adequate broodstock) and institutional issues (e.g., land disputes, control and enforcement, technology transfer, marketing) associated with this particular management strategy merit a much deeper analysis than that which we could provide here (see Hair et al. 2012 for a comprehensive overview). Furthermore, the development of strategies for managing wild populations is an important concern independent of sea cucumber aquaculture (Purcell et al. 2013).

Gear

Most countries where sea cucumber fishing exists employ some kind of gear restrictions. The most common gear restrictions include: underwater breathing apparatuses (UBAs; e.g., hookah, SCUBA gear); dredge nets; and the use of lights (flashlights or torches) at night. Banning UBAs is thought to help protect deeper-dwelling sea cucumber populations and generally to reduce the catch per unit effort of collectors. One example in Kenya shows that gear restrictions, when paired with other methods like small area closures, can increase fisher incomes (McClanahan 2010). Monitoring and enforcement of gear restrictions, however, are key challenges in numerous developing countries (Purcell 2010). For gear restrictions to be effective, adequate personnel and funding are needed at a highly localized level. For example, in

Madagascar, Papua New Guinea and Fiji, UBAs are banned for sea cucumber fishing, yet infractions are very common (Maillaud 1999, Kinch et al. 2008, Baker-Médard et al. 2011, Mangubhai et al. 2017a). Additionally, because UBA use is illegal, many divers are not properly trained and UBA-related accidents are common. In north-western Madagascar, a region known for a high level of illegal SCUBA gear use, approximately one sea cucumber diver dies per week (Ruffez 2014). In one village surveyed in north-western Madagascar, approximately one in every ten young men suffers a SCUBA diving-related accident (Baker-Médard et al. 2011). Legalizing SCUBA gear, however, may not improve the rate of injuries and deaths associated with the fishery. In Nicaragua, among the Miskito, where SCUBA gear is permitted while harvesting sea cucumbers, the diver fatality rate is approximately 1 per every 500 people in fishing communities (Barratt & Van Meter 2004); one to three injuries or deaths may be occurring daily (Rogers et al. 2017).

In the Seychelles, SCUBA gear is restricted to licensed harvesters. As a result, illegal use of the equipment and the associated accident rate are lower than in other Indian Ocean countries where sea cucumber diving is prevalent (Aumeeruddy & Conand 2008, Laurence 2017).

Size and weight

Size and weight restrictions in fisheries are based on the understanding that larger and older individuals of a species contribute more to stock productivity and stability compared to younger and smaller individuals. The potential benefit of this management strategy is that it can be fairly simple to enforce at multiple points in the value chain and it can help fishers earn more for each sea cucumber they catch (Purcell 2014, Govan 2017). Lee et al. (2018) demonstrate, for the three species they assessed, that if minimum size limits are adequately enforced, long-term harvest will likely increase by 97% and revenue for fishers could increase by up to 144%.

Size and weight restrictions are popular management strategies for many other types of fisheries, but they pose some problems for sea cucumber management. One issue is that sea cucumbers vary widely in length depending on species. To ensure effective management, species-specific data of size at sexual maturity are required, but such data are difficult to obtain (Purcell 2010). Even if there were species-specific size restrictions, sea cucumbers contract while handled, which makes it difficult for fishermen to effectively measure live-caught sea cucumbers. Weight restriction relates to how sea cucumbers are marketed globally, but sea cucumbers also vary widely in weight across species and can lose wet weight quickly as they expunge excess water while being held. Weight restrictions are similarly complex for 'dried' specimens, where different processing and drying methods influence the dry weight. In some cases, poorly dried product must be further dried or reprocessed before export (Friedman et al. 2008a, Hair et al. 2016). While many countries have official size limits, there is often a lack of communication about these laws with local fishers, as well as a lack of enforcement. In Philippines, not one of the 79 fishers interviewed in 2018 was aware of a 5-cm size limit implemented in 2013 (Jontila et al. 2018). Size-based management is also used in Papua New Guinea, where a suite of species-specific minimum live lengths (ranging from 15 to 45 cm) and dry lengths (ranging from 8 to 15 cm) exist (PNG Government 2016). Previously in Papua New Guinea, this size restriction has had little to no impact on the extraction of undersized sea cucumbers because of a lack of communication with local fishers about size limits and a lack of enforcement efforts (Kinch et al. 2008, Barclay et al. 2016). As of 2016, new species-specific labelling mandates for all sea cucumber exports may facilitate closer monitoring of undersized exports; however, the efficacy of this strategy has yet to be determined (Hair et al. 2016, PNG Government 2016). In Yap (Micronesia), in a management plan developed in 2008 to introduce weight restrictions (Friedman et al. 2008b), sea cucumber species were designated as either 'standard' or 'premium' with species-specific official wet and dry weight restrictions. To enhance the ease of inspections, sea cucumbers had to be in 10-kg single-species packages for export, for which the total number of sea cucumbers was also regulated. Success is yet to be documented, as the process of implementing the management plan has been slow to start; however, researchers are optimistic (Pakoa & Bertram 2013).

Effort and catch restrictions

Management strategies that use quotas, or 'total allowable catch' (TAC), have been fairly successful in large-scale fisheries, but can be both inequitable and difficult to enforce in small-scale fisheries (Pomeroy 2012). For this reason, primarily larger countries with more resources are currently implementing this management strategy. The potential benefits of some TAC-based strategies are that they can alleviate the competitive pressures for fishers to maximize revenue by trying to harvest as much of a resource as possible before others can attain it. Shares of the TAC allocated to individual fishers or boats are therefore often put in place as a way to prevent the 'race to fish' (Emery et al. 2014). Papua New Guinea implemented a species-specific TAC system applied to each province. While initially promising, the success of this management strategy was negligible given gaps in reporting and delays in enforcement at the provincial level (Kinch et al. 2008, Barclay et al. 2017). New legislation in Papua New Guinea maintains a similar province-level approach to reporting TAC; however, it introduced more frequent reporting requirements at more nodes of the value chain (PNG Government 2016). The efficacy of this approach has yet to be determined. Similarly, Cuba has a TAC that applies to the total tonnage collected (320 tons/year dry weight), as well as total number of boats (a related but different form of control focused on capacity) allowed to collect sea cucumbers (Toral-Granda 2008). The impact of Cuba's TAC regulation has been positive on higher-quality (referred to as 'class A') sea cucumbers, and they now make up a larger percentage of total exports (Toral-Granda 2008).

Another difficulty in implementing this management strategy is that it requires ongoing reliable estimates of total stocks and distributions of sea cucumber populations. The significant economic and human resources required for in-water stock assessments make this strategy especially challenging in a developing country context. However, new methods for assessing sea cucumber stocks may help overcome these challenges. For example, Carleton et al. (2013) found that modelling stock and maximum sustainable yield was possible using size and species-specific export data combined with habitat-specific sea cucumber density mapping.

Value chain licensing

Licensing requirements have great potential to help manage sea cucumber stocks in a developing country context; however, multiple challenges exist to successfully implement this strategy. Licensing has been shown to be an effective sea cucumber management strategy in the Seychelles. Individual fishers are eligible for

licences and are required to fill out forms detailing their catch; the renewal of licences is contingent on regular reporting and compliance with the broader set of management rules (Aumeeruddy & Conand 2008). Similarly, sea cucumber processors are required to keep information about purchases in logbooks and random inspections are frequently carried out in processing facilities (Aumeeruddy & Conand 2008). The benefit of this management strategy is that it has built-in incentives to help ensure sustainable fishing practices, given that the renewal of fishing licences is contingent on good fishing practices and proper reporting. In Papua New Guinea, similar reporting requirements are attached to licensing. Previously, individual-level licensing was difficult to adequately monitor and enforce in Papua New Guinea (Kinch et al. 2008); however, in 2016, the country established mandates for more frequent reporting at more nodes of the value chain (PNG Government 2016), the success of which has yet to be determined (Hair et al. 2016). Unlike in the Seychelles, where there is a centralized processing facility, in many developing countries sea cucumber processors are also very decentralized; processing is often done by the fishers themselves or by local middlemen (Mangubhai et al. 2017b). However, licensing requirements for exporters are already present in most developing countries, and greater control over this smaller group of people might be a more feasible approach to licensing. The existence of exporter licences without associated capture licences, or a quota-based system for export, will have little impact on the sustainable management of sea cucumber fisheries as a whole.

Seasonal restrictions and moratoria

Short-term closures of a fishery are often used to protect species during a vulnerable period, such as during the breeding season. For many sea cucumber species, however, this biological reasoning for short-term closures does not apply because there is no specific 'breeding season' (Purcell 2010). Furthermore, the increased harvest pressure that may occur prior to a closure could result in a lower overall breeding biomass, thus being more detrimental to sea cucumber populations than having no closure at all (Purcell 2010). Nonetheless, numerous countries use this strategy to manage their sea cucumber populations. For example, prior to the 2009 moratorium in Papua New Guinea, sea cucumber fishing was closed seasonally from 1 October to 15 January each year, but this had no strong impact on the sustainability of the sea cucumber harvest, likely due to out-of-season extraction, pre-season overfishing of the breeding stock (Kinch et al. 2008) or the inefficiency of seasonal closures as a management strategy (Purcell 2010). As of 2016, Papua New Guinea extended their closed season by 2 months until 31 March (PNG Government 2016); however, it remains to be seen whether this will help better protect sea cucumber stocks.

Over 25 of the countries included in this review have resorted to or regularly rely on long-term closures, or moratoria, to restore depleted stocks (Purcell 2010, Carleton et al. 2013, Purcell & Pomeroy 2015, Purdy et al. 2017). The main benefit of using this all-or-nothing management strategy is that bans are relatively easy to monitor and implement for small-scale fisheries compared to other management types. These are most often only put in place out of necessity, when the stocks have been significantly overexploited and will not return to a healthy size unless all fishing immediately ceases. In one atoll of the Solomon Islands (Ontong Java), during 1972–1994, there is evidence that frequent year-long moratoria, where even years were open and odd years were closed, worked to maintain sea cucumber populations; fisheries production and profit stayed relatively stable during this time (Christensen 2011). Similarly, after conducting detailed studies on the health of sea cucumber stocks in Mayotte (West Indian Ocean), officials concluded that the significant decline in numbers, paired with a lack of knowledge on how to effectively manage the fishery, warranted a long-term closure; closure of the fishery led to rises in stocks and species diversity (Eriksson et al. 2015). After a ban on sea cucumber fishing for 6 years in Torres Strait, similar evidence of adult population rebound exists (Friedman et al. 2008a).

While there is evidence of some successful restoration of sea cucumber populations via moratoria, this extreme measure is not ideal and should only be used as a last resort (Purcell & Pomeroy 2015). Illegal fishing is a common occurrence, undermining the potential efficacy of seasonal bans and moratoria (Toral-Granda 2008, Purcell 2010, Asha et al. 2015, Eriksson et al. 2015, Ram et al. 2016). Additionally, long-term closures of a fishery can have significant negative impacts on those who economically depend on sea cucumber fishing as a primary source of income, ultimately reducing the likelihood of their compliance with the regulation (Asha et al. 2015, Purdy et al. 2017). Furthermore, depending on the relative level of depletion of the population, a single season or even a single year may be insufficient to rebuild a viable sea cucumber fishery. In one case in Chuuk (Micronesia), after 50 years of no sea cucumber fishing (from 1938 to 1988), sea cucumber populations failed to recover (Richmond 1997, Battaglene & Bell 2004, Carleton et al. 2013), which indicates that using moratoria to manage sea cucumber stocks is a risky strategy given the difficulty of estimating when the smallest viable population threshold has been crossed and a population cannot recover. For relatively well-resourced developing countries where strong monitoring mechanisms are in place, year-long or multiyear moratoria might be a viable management option. Moreover, fishers must also have access to alternative livelihoods in order to sustain year-long or multiyear moratoria (Asha et al. 2015, Purdy et al. 2017).

Area closures

Spatially related management strategies are also among some of the easiest to monitor and implement and are therefore a favoured management strategy for under-resourced countries with small-scale sea cucumber fisheries. Like many other strategies, however, they have their challenges and limits in effectiveness. MPAs may be a useful strategy in many developing countries in order to replenish stocks, but they have limitations (De Santo 2013). The benefits of enclosing an area in order to replenish stocks outside of it are contingent on the size and spacing of the enclosures (Gaines et al. 2010), source–sink dynamics in the ecosystem (Palmer et al. 1996), predator–prey dynamics (Baskett et al. 2007) and the relative strength of boundary enforcement (Bergseth et al. 2015). In the Great Barrier Reef, DNA fingerprinting showed that only a few Pacific black teatfish (*Holothuria nobilis*) made a 90-m migration between two study sites in the period of a year (Uthicke et al. 2004). The relatively sedentary nature of sea cucumbers therefore makes them extremely vulnerable to local extinction, and they are unable to effectively recover from intense local fishing pressure (Purcell 2010). The Great Barrier Reef study of *H. nobilis*, which included surveys of populations across 23 reefs corresponding to varying degrees of protection over time, indicates that even under strict monitoring and enforcement, area closures may help stabilize stocks only after several decades (Uthicke et al. 2004). While

enclosure might help populations stabilize by seeding adjacent areas through gamete dispersal, MPAs are unlikely to help increase adjacent fisheries production through density-dependent spillover (Purcell 2010). There is some cursory evidence of sea cucumber populations stabilizing due to the existence of MPAs in New Caledonia (Friedman et al. 2008a). Similarly, in Malaysia, high densities of sea cucumbers exist within a network of 40 MPAs (Comley et al. 2004). However, as has been found in a case study of Egypt, depending on the predator–prey dynamics coupled with the dominant pressure from local fisheries, the abundance of sea cucumbers may actually decrease within an MPA (Ashworth et al. 2004).

Only in some cases may the establishment of MPAs help stabilize or increase sea cucumber populations in the long term (Purcell 2010, Barner et al. 2015). The cases where MPAs have been somewhat successful tend to be in developed or higher-income developing countries (Comley et al. 2004, Friedman et al. 2008a), indicating that where fishers are particularly poor and enforcement capacity is low, relying on MPAs as a management strategy might be risky (Purcell et al. 2013). Additionally, while a long-term payoff might be possible in some cases, waiting for the payoff is in and of itself a barrier to using MPAs as a sea cucumber management strategy. Insufficiency of funding for enforcement and a lack of incentive to avoid fishing in the closed areas are common in developing countries (Barner et al. 2015). One potential solution to this problem is rotational closures. Belize and Vanuatu are among the countries that have attempted this management strategy (Léopold et al. 2015, Rogers et al. 2018). The advantage of rotational area closures is that they allow for shorter-term investment in site-specific monitoring and enforcement where resources are limited.

Assigning property

TURFs are a management strategy that has been used to incentivize fishers to independently and sustainably manage resources (Afflerbach et al. 2014). This management strategy's main benefit is that it grants exclusive rights to a community to use a designated resource or area, meaning that if it is well implemented, it does not rely primarily on a centralized authority for its success, instead relying on local resource users' self-interest to monitor and enforce rules concerning the fishery from which they derive direct benefit. It has been implemented in many areas, but its success is dependent on several factors. Firstly, TURFs are more likely to succeed in managing low-mobility species (Nguyen Thi Quynh et al. 2017), and thus are potentially suitable for sea cucumbers. Secondly, and very importantly, the nation in which the territorial rights will be used must have a legal framework that allows property to be designated to an individual or collective in the ocean (Costello & Kaffine 2010, Afflerbach et al. 2014). While terrestrial property rights are well developed globally, only some nations (notably Indonesia and some Pacific Islands) have clear avenues through which to recognize customary marine tenure and/or designate marine property to communities or individuals (Cinner & Aswani 2007, McCay & Jones 2011, Meo 2012, Cohen & Steenbergen 2015). Thirdly, TURFs are best suited for communities where there is little fisher migration (Nguyen Thi Quynh et al. 2017). For example, in Madagascar, a form of community TURF is being explored through locally managed marine areas (LMMAs) (Rocliffe et al. 2014). One of the key challenges to implementing these TURFs is addressing the seasonal mobility of the fishing population. Ensuring that migrant fishers respect the resource-use rules and rights of local fishers is a perennial challenge (Cripps & Gardner 2016). In smaller and more isolated fishing communities where traditional fishing grounds are already socially and politically embedded, however, this management strategy is feasible (Johannes 2002, Aburto et al. 2013, Cohen & Steenbergen 2015). LMMAs are being used in Fiji to manage sea cucumber fishing within customary fishing grounds (*qoliqoli*) (Meo 2012). Seasonal closures within these LMMAs constitute one of the most commonly used marine management tools. However, while densities were generally higher inside LMMAs, most species had densities below regional reference values, suggesting that area closures alone are insufficient to maintain or restore depleted populations (Mangubhai et al. 2017a). Research from both the Solomon Islands and Indonesia shows the importance of TURFs aligning with pre-existing local governance and social structures (Cohen & Steenbergen 2015). In Indonesia, several fairly successful TURFs that have been established to protect known sea cucumber spawning sites are governed in part with customary rules restricting sea cucumber harvest, called *sasi-teripang* (Cohen & Steenbergen 2015, Samian & Santiago 2018) (Table 1).

Discussion

A fairly wide diversity of sea cucumber management strategies exists globally; however, sea cucumber fishing moratoria remain a dominant strategy across developing countries. Given the challenges of managing a decentralized fishery in a developing country context, where centralized management capacity is often low, it is not surprising that an outright ban is one of the most commonly employed strategies. Bans may be a useful stop-gap measure, but if used repeatedly over time, they ultimately lead to a boom–bust dynamic in the fishery and high rates of illegal fishing (Pakoa & Bertram 2013). It is harder for fishers, processors and exporters to adapt to the highs and lows of no-ban/bans as a management strategy. Additionally, a ban on sea cucumber fishing will not help stocks to be replenished if a minimum viable population threshold is crossed or if monitoring and enforcement is inadequate to stem ongoing illegal extraction (Battaglene & Bell 2004, Purcell et al. 2013). Although it is more logistically and financially challenging for countries at multiple levels of governance, moving towards perennial reliance on a diverse suite of management strategies is likely to be better for livelihood stability, sea cucumber stock stability and long-term capacity building for management.

There is a high degree of reliance on centralized authorities for the inception, implementation and enforcement of sea cucumber management strategies, and this is not often successful. Given the decentralized nature of sea cucumber fishing, evidence from sea cucumber and other fisheries indicates that having local resource users participate in management improves resource-use rule compliance (Ostrom 1990, Johannes 2002, Berkes 2007). A small-scale fishery management model will be strongest if it distributes management responsibility and allows for clear communication exchanges across all stakeholders. Specifically, providing avenues for local fishers to inform sea cucumber management policy at the national level, as well as devolving some management authority to local fishers, will likely improve management outcomes (Eriksson et al. 2015, Jontila et al. 2018, Rogers et al. 2018). Regular feedback between officials and fishers and efforts being made to build strong relationships between governing officials and fishers are essential for trust and compliance.

An analysis of the relationship between national marine legislation and customary marine resource-use rules in the Pacific Islands shows that, despite the recognition of customary fishing

Table 1. Compendium of sea cucumber management strategies organized into the seven dominant categories used in developing countries globally.

Management type	Description	Places implemented	Objectives	Requirements	Challenges	References
Gear restrictions	Fishing tools restricted by type and size. E.g., Madagascar prohibits the use of SCUBA gear for harvesters; Papua New Guinea prohibits the use of flashlights and surface lights for harvesters	Belize, Fiji, Kenya, Madagascar, Papua New Guinea, the Seychelles, Solomon Islands, Vanuatu	To decrease overall catch per unit effort and/or ecological problems associated with the fishing method	Knowledge of the ecological impact of gear used; decentralized monitoring and enforcement	Monitoring and enforcement must operate at a highly localized level given the decentralized nature of most sea cucumber extraction; requires adequate personnel and funding to monitor and enforce	Baker-Médard et al. (2011), Cohen and Steenbergen (2015), Govan (2017), Kinch et al. (2008), Lokani et al. (1996), Manghubhai et al. (2016), Purcell (2010), Ram et al. (2016), Rogers et al. (2018)
Size and weight limits	Minimum individual wet or dry weight and/or minimum length. E.g., Fiji sets a minimum length of 7.62 inches for all commercial sea cucumbers; Costa Rica sets a minimum wet length of 20 cm for all species	Ecuador (Galapagos Islands), Fiji, Madagascar, Papua New Guinea, Philippines, Micronesia, Solomon Islands, Vanuatu, Zanzibar	To protect juveniles and breeding adults and thus stabilize overall population	Species-specific information on size at sexual maturity; monitoring and enforcement where sea cucumbers are landed	Species vary greatly in size and weight at maturity, thus requiring species-specific knowledge; sea cucumbers contract when handled, making wet length difficult to measure; monitoring and enforcement must be where landing occurs if controlling live weight/size	Barclay et al. (2016), Cohen and Steenbergen (2015), Eriksson et al. (2015), Friedman et al. (2008), Hair et al. (2016), Jontila et al. (2018), Lee et al. (2018), Leopold (2016), Lokani et al. (1996), Manghubhai et al. (2016), Purcell (2010), Ram et al. (2016), Toral-Granda (2008)
Effort and catch controls	Effort restrictions established through fleet size. Catch limits set either by species or across all species. TAC set according to stock population, can be assigned individually or to communities. E.g., Cuba established a nationwide TAC of 320 tonnes dry weight/year; Galapagos Islands limits boat length to 18 m maximum	Belize Cuba, Ecuador (Galapagos Islands), Mexico, Papua New Guinea, Vanuatu	Effort restrictions: to indirectly limit catch by limiting the range and length of fishing trips Catch limits: to reach but not exceed maximum sustainable yield	Fleet size restriction: knowledge of fleet size, boat length relative to the rage capacity of vessels and spatial distribution of sea cucumbers TAC: accurate estimates of sea cucumber population and regular monitoring to keep within sustainable yield; yearly readjustments of TAC depending on stock status	Delays in reporting lead to overshooting TAC; assessing sustainable yield is difficult given its reliance on ongoing species-specific stock assessments; restricting fleet size and establishing a quota can lead to inequitable access to the fishery	Barclay et al. (2016), Bennett and Basurto (2018), Carleton et al. (2013), Conand (2008a), Govan (2018), Hair et al. (2016), Hernández-Flores et al. (2018), Kinch et al. (2008), Lee et al. (2018), Leopold (2016), Purcell (2010), Rogers et al. (2018), Toral-Granda (2008), Uthicke et al. (2004)
Temporal closures	Temporary or long-term closures, ranging from daytime/night-time restrictions, to seasonal restrictions, to multiyear moratoria. E.g., Eritrea fishing season restricted to 5 months/year; Venezuela banned sea cucumber fishing since 1996; Vanuatu prohibits night-time fishing	Belize, Costa Rica, Cuba, Ecuador (mainland), Egypt, Eritrea, Fiji, India, Indonesia, Mauritius, Mayotte (France), Mexico, Micronesia, Northern Mariana Islands, Panama, Papua New Guinea, Rodrigues, Samoa, Solomon Islands, Tanzania, Torres Strait (Australia), Tonga, Vanuatu, Venezuela	Short-term closure: to protect species when they are most vulnerable or to limit overall annual fishing effort Moratoria: To allow for stocks to recover after significant overexploitation	Adequate monitoring and enforcement at the level of extraction and export; knowledge of socioeconomic impacts; regular monitoring of stocks to determine when closure/ban should be lifted	Cheating occurs when fishers, processors and/or exporters store their product until the seasonal restriction or moratoria is over; compliance may be difficult to achieve given some fishers' economic dependence on sea cucumbers; limited evidence that short-term closures help stocks recover; if minimum threshold has been passed, a moratorium may be ineffective	Asha et al. (2015), Barclay (2016), Bennett and Basurto (2018), Carleton et al. (2013), Cohen and Steenbergen (2015), Conand (2008a), Eriksson et al. (2015), Friedman et al. (2008), Govan (2017), Hair et al. (2016), Jimmy et al. (2012), Kinch et al. (2008), Leopold et al. (2015), Purcell (2010), Purcell et al. (2013), Purdy et al. (2017), Rogers et al. (2018), Rohe et al. (2019), Toral-Granda (2008)

Table 1. (*Continued*)

Area closures	Area-based management approach that either partially (marine protected area) or fully (reserve) restricts fishing activity. May be permanent, temporary or a rotational closure. E.g., Malaysia has a network of marine protected areas that were established in part to protect invertebrates, including sea cucumbers	Belize, Costa Rica, Ecuador (Galapagos Islands), Egypt, Madagascar, Indonesia, Malaysia, New Caledonia, Samoa, Solomon Islands	To protect habitat and source populations; to supplement sea cucumber fisheries outside the reserve through spill-over of adults, juveniles or larvae	Assessment of the appropriate size; spacing and location of enclosures to maximize protection and flow of propagules between enclosures; discussion with stakeholders to ensure buy-in; site-specific monitoring and enforcement	Loss of fishing zones may prevent buy-in of fishers and lead to illegal harvesting inside the closure; migratory fishers may not know or respect boundaries; it may take several decades for fishers to benefit from reserve spill-over	Ashworth et al. (2004), Battaglene et al. (2004), Barner et al. (2015), Choo (2008), Cohen and Steenbergen (2015), Jimmy et al. (2012), Purcell (2010), Rogers et al. (2018)
Value chain licensing	Licenses enforced at one or more level(s) of the value chain such as harvesting, processing and export. E.g., Solomon Islands requires both processing and export licenses; the Seychelles restricts sea cucumber harvest to 25 boats/year with a maximum of 4 divers per boat	Belize, Cuba, Fiji, Mexico, Micronesia, Papua New Guinea, the Philippines, the Seychelles, Solomon Islands, Vanuatu, Zanzibar	To control the total number of harvesters, processors and/or exporters; to facilitate monitoring other regulations such as size limits, TAC and seasonal closures	Knowledge of the number and location of individuals/companies involved at each level of the value chain; establishing a 'code of conduct' for license renewal; may require information specific to species or 'class' of sea cucumber	Exporters tend to under-report data; informal 'middlemen' are difficult to regulate; requires significant communication and coordination to connect multiple nodes of the value chain	Alfonso et al. (2005), Bennett and Basurto (2018), Conand (2008b), Conand et al. (2006), Eriksson et al. (2015), Jimmy et al. (2012), Jontila et al. (2018), Kinch et al. (2008), Lokani et al. (1996), Purcell (2010), Rogers et al. (2018), Vidal-Hernaández (2019)
Territorial rights (TURFs)	Area-based management where groups or individuals are granted exclusive privileges to fish. Spatial concessions typically located in shallow sea beds. Some LMMAs function as TURFs. E.g., Mexican multispecies TURFs focused on benthic species, including sea cucumbers, provide concessions to cooperatives; Indonesian TURFs are based on customary sea tenure	Belize, Brazil, Chile, Fiji, Indonesia, Madagascar, Mexico, the Philippines, Samoa, Solomon Islands, Vanuatu	To incentivize fishers to sustainably manage resources through the granting of exclusive rights to a designated resource or fishing area. Fishers are frequently then tasked with monitoring and enforcing restrictions within these areas	A legal framework to transfer use rights to community; community buy-in at the local level to cede access rights to a set individual or group; a process to fairly partition the fishing grounds among users	Politically and socially challenging to partition fishing grounds either into small plots (if held by individuals) or regional areas (if held by community); developing a legal framework for transfer of rights takes time and governmental buy-in; migratory fishers may not know or respect boundaries	Afflerbach et al. (2014), Cohen and Steenbergen (2015), Friedman et al. (2008), Mangubhai et al. (2017), Meo (2012), Poon and Bonzon (2013), Purcell (2010), Rocliffe et al. (2014), Rogers et al. (2018), Samian and Santiago (2018)

LMMA = locally managed marine area; TAC = total allowable catch; TURF = territorial use rights in fisheries.

grounds and the involvement of traditional authorities in sea cucumber management, compliance and enforcement in these regions suffer due to a lack of communication and collaboration within the governing structures across multiple scales (Rohe et al. 2019). By increasing communication and integrating regulations across multiple nodes of the value chain, the frequent disconnect between state and non-state actors (e.g., community-based associations, private companies, conservation non-governmental organizations) has a better chance of transitioning from indifference or antagonism to accommodation and mutual support.

Additionally, given the scale at which key ecological processes function for sea cucumbers (e.g., most sea cucumbers are broadcast spawners and depend on adequate regional connectivity of populations for fertilization; Bruckner et al. 2003), some regional coordination of local management strategies is necessary (Cohen et al. 2015). Similarly, networks of actors engaged in illegal sea cucumber harvest also operate at regional and national scales, requiring coordination across multiple locales to help address this problem (Baker-Médard et al. 2011, Rogers et al. 2017). A management strategy that integrates the interests and efforts of local fishers as well as regional governmental and commercial actors would also help maintain a two-way flow of information and likely help coordinate monitoring and enforcement efforts.

In Yucatán (Mexico), local sea cucumber fishers and collectors created a set of local rules that were informed by, but did not readily align with, government policy (Bennet & Basurto 2018). Instead, the local rules were determined primarily by relations of production such as patron–client relationships and the existence or absence of fishing cooperatives. These findings indicate that local modes of production and strategies of market access must be considered alongside broader governmental resource management goals. Ultimately, Bennet and Basurto (2018) argue that regulations should focus on trade and commercialization in addition to resource harvesting, and focusing on trade is less costly and more effective than harvest-level controls. This assertion aligns with what we see as a missed management opportunity in many developing countries.

Licensing, specifically licensing the processing and exportation of sea cucumbers, has immense potential to change overharvest dynamics in the industry (Barclay et al. 2016). Developing countries where processing happens to be more centralized present a management opportunity that is ripe for intervention. For example, in Belize, the majority of sea cucumber processing occurs at plants owned and operated by exporters (Rogers et al. 2018). A narrowing of the value chain to just a handful of exporters located in just a few locations also exists in Papua New Guinea (Barclay et al. 2017).

This narrowing of the value chain from many fishers to just a few exporters provides an opportunity for integrating regulations at multiple nodes of the value chain. Vidal-Hernaández et al. (2019) demonstrated this narrowing of the sea cucumber value chain in Yucatan, where 82% of regional trade flows through a single permit-holder. This highlights an opportunity for managers to focus regulatory solutions on these narrowed parts of the value chain, serving as leverage points to influence regulations at other nodes of the value chain. Finding leverage points within the broader value chain is particularly important when managing sea cucumbers in a developing country context, where financial and human resources are often scarce. Licensing, specifically when coupled with other management strategies, has immense potential to influence harvest practices. Upstream regulations (e.g., TAC, size or weight restrictions) integrated into regulations at the point of export (e.g., purchasing data) are likely to be easier to implement given that fewer individuals and organizations operate as exporters. Furthermore, given that downstream nodes of the value chain have de facto control over upstream nodes, it is likely to be more efficient to manage the industry using integrated cross-scale regulations.

For example, licensing sub-collectors (operating at the regional level) as well as exporters (operating at the national level) could be done in tandem with quota controls, seasonal restrictions, and size/weight restrictions. Recently, Papua New Guinea has taken this approach; provincial-level collectors are restricted from purchasing sea cucumbers once the TAC is met in each province, and similarly, exporters must comply with species-specific minimum lengths, seasonal closures and closures once a provincial TAC has been met (PNG Government 2016). Furthermore, Papua New Guinea has established management advisory committees at multiple levels of governance (local, provincial and national) with liaisons between them in an attempt to cooperatively implement a multilevel integrated management strategy (PNG Government 2016). What Papua New Guinea regulations lack are integrated multilevel controls for monitoring and enforcing no-take zones and gear restrictions. Under a cooperative model where there is an emphasis on local monitoring and enforcement, the vertical integration of harvesting, processing and export may help incentivize adherence to harder-to-monitor regulations such as no-take zones and gear restrictions. Bennet and Basurto (2018) found that the higher market value of sea cucumbers associated with cooperatives helped reinforce the collective action required to maintain the cooperative. If a no-take zone is recognized and valued by a cooperative, then the opportunity costs associated with the restricted zone will likely be offset in the short term by the higher market value, and by spill-over in the long term.

Sustainability certification for wild sea cucumber fisheries is a strategy that remains underutilized in a developing country context. Places like Western Australia and British Columbia are currently pursuing sustainability certification or review as a sea cucumber management strategy (Lindop 2017, Marine Stewardship Council 2018). While the potential for third-party sustainability certification to succeed in a developing country context faces multiple barriers related to expense and efficacy (Purcell et al. 2017, Wakamatsu & Wakamatsu 2017), its feasibility may be enhanced by coupling it with a spatial management strategy such as a TURF or MPA system. Placing a premium on certified sea cucumbers harvested from TURFs or from communities that also manage MPAs could help incentivize compliance with TURF or MPA regulations, while also ensuring that the sea cucumbers extracted from these areas were harvested sustainably.

While demand for sustainably harvested sea cucumbers is not currently high, there is a strong demand for high-quality products in China and other countries importing sea cucumbers for consumption (Fabinyi et al. 2017). It is likely that sustainability certification in and of itself could improve product quality; furthermore, if the certification process was coupled with training and workshops to improve processing methods, fishers would benefit from price premiums for their higher-quality product (Friedman et al. 2008a, Barclay et al. 2017). Additionally, research has shown that going through the process of obtaining sustainability certification in a developing country context helps empower communities, increase communication and learning across multiple sociopolitical scales and generally improve the functioning and efficacy of the regulatory network (Carlson & Palmer 2016). These secondary benefits of sustainability certification are critically important to

sea cucumber management in a developing country context, where capacity constraints limit the ability to develop and effectively implement integrated management strategies across multiple levels of organization (Purcell 2010).

No simple or single solution exists for regulating sea cucumber fishing. There is a need for an increase in long-term, empirical studies documenting the effectiveness of the variety of management strategies being used in developing countries. An exchange of information through published research and international forums is necessary in order for countries to analyse the benefits and drawbacks of each management system, to learn from other case studies and to identify which strategy may be appropriate for each region's particular needs.

Conclusion

Managing sea cucumbers in a developing country context faces multiple challenges, ranging from highly decentralized harvesting and processing to limited financial and human resources dedicated to management. However, unique opportunities also exist in terms of engaging fishing communities in resource management and leveraging regulatory pressures at narrowed parts of the value chain. We argue that improving sea cucumber management in developing countries would benefit from not only focusing on these narrowed nodes of the value chain, but also coupling production-based management strategies with processing and export regulations. Additionally, communities that are highly reliant on the sea cucumber industry for their livelihoods stand to benefit the most from successful sea cucumber management; thus, as Barclay et al. (2016) argue, community interests and development needs should be considered alongside fisheries management objectives.

Author ORCIDs. Merrill Baker-Médard 0000-0002-3724-8320

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