Constraints and solutions for managing Pacific Island sea cucumber fisheries with an ecosystem approach

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The ecosystem approach to fisheries (EAF) is a holistic paradigm that considers stocks of exploitable species, marine ecosystems and stakeholders. Management agencies must strike a balance between their capacity constraints and the requisites of management measures. Most small-scale sea cucumber fisheries of Pacific Islands have been plundered while others are being opened to commercial exploitation. Data from fishery managers and a regional workshop were used to assess the current problems, institutional constraints and solutions to the management of sea cucumber fisheries in 13 Pacific Island countries (PICs). Technical capacity was often strong for some management actions such as developing marine reserves but weak for others, such as enforcement. Using multi-disciplinary indicators, half of the fisheries were diagnosed by their managers as being overfished or depleted, despite evidence of optimistic bias. Fishery governance varied greatly among the PICs, and co-management frameworks were not typical of any cultural region. Management objectives were prioritised differently among managers but most highly ranked was to protect ecological resilience. The fishery managers proposed different sets of regulatory measures and various management actions, such as surveys to collect socio-economic and fishery-dependent data, support for local governance and strong enforcement—all widely under-practised. Pacific sea cucumber fisheries exemplify how the transition to an EAF by management institutions must involve reorganisation of their technical and human-resource capacities among management tasks. Levies on exports need to be internalised to fund improved management. Management agencies should consider a shift in resources from developing marine reserves, conducting underwater surveys and aquaculture-based restocking to strengthening enforcement capacity, stakeholder involvement and communication with fishers. In concert with these actions, short fishing seasons, shortlists of allowable species and tighter enforcement at export points may serve to turn the tide on boom-and-bust exploitation and safeguard biodiversity.

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1. Introduction

Small-scale fisheries have been recently recognised as significant sources of global world catches of seafood and integral parts of coastal livelihoods and employment of millions of fishers worldwide [1–3]. They are vital for food security [4,5] and/or poverty reduction in low-income countries [4,6]. Owing to the broad geographic spread and large numbers of fishers, these fisheries suffer from the global affliction of overfishing and under-management [5,7]. In cases of severe overfishing, management must now turn from profit maximisation to conservation of breeding populations and biodiversity [8]. Unfortunately, institutions that manage small-scale fisheries often suffer from weak technical capacity and limited human resources [1,9,10].

Recent prescriptions for ailing small-scale fisheries involve a more holistic “ecosystem approach” to fisheries management (EAF). EAF can be defined as a blend of ecosystem management to conserve the biophysical components of ecosystems and fisheries management to satisfy societal needs by focusing on fishing activities and the target resource [11]. Integral parts of an EAF are the involvement of stakeholders in the management process and consideration of a broad range of objectives [9,11,12]. This differs somewhat from
ecosystem-based fisheries management (EBFM), which strives to sustain healthy marine ecosystems and the fisheries they support [13].

In harmony with EAF principles [11], many scientists have argued for co-management systems in which governance is shared between government agencies and stakeholders [1,14,15]. Co-management can be seen as a prospective way to implement an ecosystem-based approach but it does not necessarily result in EAF outcomes. Some caution is also warranted, as co-management systems may not be universally ideal, as they demand greater short-term transaction costs, and may lead to conflict among groups, reduce adaptive capacity or contribute to social inequity [15–19]. Nonetheless, co-management has been particularly useful in small-scale fisheries [1,20].

Operationalising an EAF can, however, be arduous for managers in low-income and island countries. The process involves the diagnosis of the fishery, defining and prioritising management objectives, setting of regulatory measures to achieve the objectives and actions by the manager to implement and monitor those measures [11,21]. Ideally, all of these steps should be undertaken jointly with stakeholders in the fishery. A consultative process allows for discussion of key uncertainties, logistic constraints and practicality of implementing various management measures [11,22]. The management solutions must concurrently arise within the technical and human resource capacity of management institutions.

Small-scale coastal fisheries in Pacific Islands contribute to food security, livelihoods and culture [9,23]. While finfish contribute significantly to food security in coastal communities, invertebrate fisheries such as sea cucumbers provide community-level income streams and contribute to national export revenue. Sea cucumbers are a key resource, contributing to poverty alleviation for probably more than three million fishers globally [24]. They are fished, either for subsistence consumption or export, in every Pacific Island Country (PIC) [25] and are a vital marine export commodity for numerous countries elsewhere [24,26,27]. Exportation of the processed product, called beche-de-mer, from Pacific Islands to Asian markets has occurred intermittently for at least 160 years [25]. Sea cucumbers are the third-most economically important marine export from Pacific islands, after tunas and pearls, and are probably worth much more than officially reported [28]. Sea cucumber production from Fiji, Solomon Islands and New Caledonia, when converted to wet weight equivalents, compare to 19–32% of tuna catches in their exclusive economic zones [29].

Globally, sea cucumber fisheries have often lacked comprehensive management plans and enforcement capacity to deal with intense exploitation rates [24]. Soaring market demand, lack of alternative income streams for fishers and ineffective management have led to recent over-exploitation of resources across the Pacific [25,28]. Over-exploitation of wild stocks has prompted national fishery closures in Papua New Guinea, Solomon Islands and Vanuatu within the past 5 years [24]. The closures herald failures in past management systems but, at the same time, give hope to the future as they demonstrate a political will to take drastic measures to protect these resources.

A few fisheries in the Pacific Islands have remained as subsistence fisheries (domestic consumption only) (Fig. 1) but have come under recent pressure to open harvests for export. Reversing the trend of over-exploitation in Pacific sea cucumber fisheries will arguably depend on a change in management strategies and better governance, which in the past have lacked transparency about roles and responsibilities of institutions in co-management [30]. A critical question is: what regulatory measures and actions by the managers are most critical for sustainability and achievable within the constraints of management institutions? Decision-support tools exist to help evaluate stocks and formulate management plans for sea cucumber fisheries [31–33], but never before has their application been appraised and documented.

To understand constraints of Pacific fishery agencies and guide them through the process of revising their management plans and actions for sea cucumber fisheries, a regional workshop was coordinated in Fiji during November 2011 [34]. Participants were fishery managers or senior fishery officers in charge of managing sea cucumber fisheries. Data on current management actions and institutional capacity shed new light on constraints in managing these fisheries and the need for a new management paradigm. As sea cucumber fisheries are also economically valuable in small-scale fisheries in southeast Asia, the Indian Ocean and Latin America, this study should be of value to improving management globally. Our findings are also relevant to other coastal and small-scale fisheries that are managed with similar institutional constraints.

Fig. 1. Management regime of sea cucumber fisheries examined in this study. Closed fisheries comprise those with recovering stock and some with stocks in a depleted condition in 2011. In 2013, the fishery in Vanuatu re-opened. Open fisheries may be fully exploited to depleted but still open to commercial fishing.
2. Materials and methods

2.1. Research approach

The study was based on data and responses from 13 fishery managers before, and during, a technical regional workshop in November 2011 coordinated by a consortium of research and development agencies [34]. It examined sea cucumber fisheries from 13 Western-Central Pacific islands (Fig. 1). The workshop participants from each country were fishery managers from national fishery agencies, who had a deep understanding and involvement in their sea cucumber fishery and were in a position in the agency to influence management changes.

Prior to the workshop, the fishery managers provided data on a series of variables about the human resource capacity, management approach, current management regulations, fishing activities, communication with stakeholders, enforcement and inspections [34]. The managers were informed beforehand that the data would be used for research and subsequently published. The number of replicates (i.e. respondents) was lower than 13 for some questions that did not apply to certain fisheries. A principal component analysis (PCA) using PRIMER v6 software was used to examine the similarity in management capacity (technical and human resources) among fisheries agencies from response data (count and binomial) on eight questions; data were standardised by maximum values then square-root transformed prior to analyses. Based on manuals by FAO [33] and Purcell [32], seminars and plenary discussion sessions served to mentor the fishery managers on the fisheries biology of sea cucumbers, management principles and decision support tools [34].

2.2. Management objectives

The fishery managers collectively listed 10 management objectives considered most important in their fisheries. Each manager then independently ranked the objectives in order of importance, in their opinion, for their country’s sea cucumber fishery. The objective considered most important was ranked 1, the second-most important one was ranked 2, and so on, until the least important objective which was ranked 10. Ties were disallowed.

2.3. Diagnosis of stocks

Six multi-disciplinary indicators of stock health proposed by Friedman et al. [31] guided the fishery managers to score (as ticks for yes, crosses for no, question marks for unsure) the health of their fishery, following the five categories identified by FAO [35]. Responses to the indicators led to a suggested status category. This is a decision-support process; hence other factors were considered that sometimes swayed the diagnoses. The guiding criteria for decision support about stock health status were as follows:

- **Underexploited** \( (U) \) – all ticks; stocks not very affected by fishing historically.
- **Moderately exploited** \( (M) \) – one or two crosses; but stocks appear healthy.
- **Fully exploited** \( (F) \) – one to three crosses or question marks; but current exploitation rate is sustainable.
- **Overexploited** \( (O) \) – few ticks; fishing is unsustainable; but some breeding populations still exist.
- **Depleted** \( (D) \) – few or no ticks; fishing is unsustainable; stocks below 10% of unfished abundance.

2.4. Regulatory measures and management actions

Current management measures and their effectiveness in each of the 13 fisheries were reviewed in workshop sessions. Following recent manuals on an ecosystem approach to managing sea cucumber fisheries [32,33], the managers followed the “roadmap” decision support framework to have initial sets of regulatory measures and management actions based on the stock status, management capacity and scale of fishing in each fishery. From that starting point, the managers could add or remove regulatory measures and management actions depending on idiosyncrasies of the fishery.

2.5. Plenary discussions

A plenary discussion session with fishery managers was used to better understand the current problems with enforcement and inspections in Pacific sea cucumber fisheries. Likewise, plenary sessions unveiled constraints to an EAF and potential solutions by broadening the development and goals of management beyond fishery stocks. Four case study fisheries were examined in closer detail by groups of the fishery managers and workshop facilitators [34].

3. Results

3.1. Governance

Governance structure varied greatly among countries and for various management actions and regulatory measures within countries (Table 1). About half (7 of 13) of the sea cucumber fisheries used co-management frameworks for developing management plans; i.e. both government (national and/or provincial) and local/traditional authorities were afforded responsibility and/or authority. Similarly, 6 out of the 13 fisheries legislate regulations through co-management arrangements.

Some countries, such as Solomon Islands and Cook Islands, have complex governance structures for setting regulatory measures (Table 1). For many countries, there is more than one level of governance over certain regulatory measures but not others. Regulatory measures in Papua New Guinea, New Caledonia, Palau, Kiribati, Tonga and French Polynesia are mostly handled solely by the national or provincial government management authority. Imposing moratoria and the licensing of fishers, processors and exporters tended to be least hierarchical, or “multilayered”, in terms of institution involvement.

3.2. Management capacity

Management capacity varied greatly among the 13 fishery agencies, especially in the number of export inspection officers, number of scientists with skills in stock assessment and patrol boats for inspections at sea (Fig. 2). Micronesian countries have weaker capacity for managing sea cucumber fisheries than most agencies in Melanesia and Polynesia. Concerning the Micronesian countries, none had skilled officers to conduct stock assessment analyses, they had fewer officers who could identify sea cucumber species than in Melanesian and Polynesian countries, none had funding for underwater visual censuses, and none had patrol boats for inspecting sea cucumbers at sea.

Technical capacity in fishery agencies was relatively strong for some management tasks and weak for others. The number of agency scientists with technical skills in stock assessment (e.g. to calculate maximum sustainable yield) varied widely among the 13 fisheries. Half of the countries had no such scientists. Management agencies generally had many officers (average = 6) responsible for planning and
implementing marine reserves. All but two agencies had at least three officers who can identify live sea cucumbers to species level. On the other hand, just 5 of the 13 agencies had more than two officers trained in export inspections and one quarter of countries have no trained inspection officers. More than three quarters (79%) of fishery agencies have human resources and skills for underwater visual census (UVC) but, paradoxically, less than one quarter (21%) has funding for conducting regular UVCs. All but three fishery managers reported difficulty in obtaining monthly information on catch from fishers.

Enforcement and inspection capacity was generally very weak. On average, agencies have less than two boats for inspections at sea and half of them have none. Half of the managers believed that landings of (fresh) sea cucumbers are checked “practically never” in their fishery. Sea cucumber landings were checked one or more times per week in only four fisheries. In most cases, bags of beche-de-mer (dried sea cucumbers) are checked occasionally prior to export, and in four of the export fisheries they are checked “regularly”. In just half of the export fisheries, inspection officers have received training in identifying dried sea cucumbers.

3.3. Management objectives

More than two out of three (71%) government agencies had not established formal management objectives for their sea cucumber fisheries and most (79%) did not have reference points for assessing management performance. During the workshop, the 10 multidisciplinary management objectives were ranked quite differently among the fishery managers (Fig. 3). The objective ranked most important, on average, was to maintain stocks at levels to sustain viable populations and recruitment. At near equal second place in average priority was that fishing was managed to sustain consistent levels of stocks over time (i.e. not a boom-and-bust cycle) and maintained employment in communities. Objectives to sustain stocks and economic value of the fisheries were most highly valued (Fig. 3). The two least important objectives of fishery managers, on average, related to the consumptive use and value of sea cucumbers to stakeholders but the rankings varied greatly.

3.4. Management systems, current regulations and exploitation

Management processes were generally weak. Only two of the countries (Tonga and Papua New Guinea) had management advisory committees, involving stakeholders, for their sea cucumber fisheries. Just one-third of countries had a national management plan for their sea cucumber fishery.

Half of fisheries imposed size limits on fresh and/or dried sea cucumbers. None of the fisheries limit the number of species that can be fished or limit new species from being fished; i.e. no shortlists of allowable species. Eight of the 13 fisheries ban the use of SCUBA and hookah for collecting sea cucumbers. In just one-third of the fisheries, fishers need a permit and must furnish logbooks. A list of all fishers is kept by less than one-quarter of agencies but most of them (82%) have a list of processor/exporters.
Fishery officers visited, on average, just 12% (± 15% s.d.) of sea cucumber fishers in their fisheries in 2011 but this was highly variable among PICs. Four of the 13 fishery agencies did not have any communication activities with sea cucumber fishers in 2011. Only three of the 13 fishery agencies send out newsletters or information leaflets to fishers. All but three (77%) of the managers believed that it was difficult or impossible to license the sea cucumber fishers. Conversely, all but two managers believed it should be easy to license all processors/exporters in the fishery.

In nine (69%) of the fisheries, the managers believed that fishers have increased in numbers in recent years and information was insufficient to ascertain fisher numbers for three countries.

In all but two territories (French Polynesia and New Caledonia), managers believed that fishers are collecting lower-value species more nowadays. Similarly, two-thirds of the managers stated that a wider range of sea cucumber species is exploited nowadays than in the past.

### 3.5. Fishery stock status

None of the three geographic regions (Melanesia, Polynesia, Micronesia) had all fisheries sustainable; i.e. fully fished, moderately fished or under-fished (Table 2). In a broad sense, Melanesia has a higher proportion of fishery stocks in poor condition.

![Fig. 3. Box plot of average ranks of ten management objectives by the 13 fishery managers. Error bars are 5th and 95th percentiles, boxes delineate the 25th and 75th percentiles, vertical lines within boxes are medians and dotted lines are means. Objectives were ranked from 1 to 10 by each manager; 1 being the most important objective and 10 the least. Individual ranks are undisclosed for confidentiality.](image-url)
(overfished or depleted) than Micronesia or Polynesia (Table 2) and three of these five countries had national moratoria in place (Fig. 1). The three fisheries diagnosed as having moderately-exploited stocks are the three fisheries in which exports of sea cucumbers has been banned to preserve subsistence fishing (Fig. 1).

3.6. Regulatory measures

For all but two fisheries, both industrial-scale and small-scale fishers are subject to a common set of regulations. The fishery in Solomon Islands is separated into distinct small-scale and industrial-scale sectors, which would be managed separately according to gears and boats used. In Tuvalu, certain areas are fished by small-scale fishers and others by industrial-scale fishers, and the two area types would be managed separately.

On average, the managers chose seven regulatory measures for future management plans of their fisheries. Widely different suites of regulatory measures were identified and no two managers identified the same suite of measures (Table 3). Measures most commonly perceived as essential for the future were minimum size limits, gear restrictions, licensing of exporters and fishers, no-take marine reserves and shortlists of allowable species.

3.7. Management actions

In a similar fashion to the nomination of regulatory measures, managers generally chose a diverse suite of actions to apply in managing their fisheries (Table 4). On average, they chose nine management actions to apply.

Most of the managers chose to conduct fishery-dependent, fishery-independent and socio-economic surveys to gain information on their fisheries. All but two of the managers set the support of local governance as a priority. Investment in establishing active management advisory committees, legislation of management regulations and enforcement were viewed as priorities in almost all cases. Most (9 of 13) managers decided that education and communication with stakeholders should be an important part of their fisheries management strategy. Only two managers believed that restocking was currently needed in their fishery.

4. Discussion

This study illustrates that financial, technical and human capacity can be severely limited in small-scale fisheries for implementing sophisticated, costly or time-consuming regulatory measures. Similar weak institutional capacity exists in sea cucumber fisheries in East Africa and the Indian Ocean [36]. Pacific Island sea cucumber fisheries are a useful example that fishery-specific management solutions are needed because each has a unique mix of governance structure, technical and human resource capacity, prioritisation of management objectives, and health of stocks. Co-management should be advantageous for sea cucumber fisheries but the weak capacity in management institutions currently limits its application. Embracing an EAF will need a new management paradigm, in which decision makers accept much more conservative rates of exploitation to avoid overfishing and conserve vulnerable species. The new paradigm should also internalise monies from export levies and comprise a reorganisation of skills and human resources among management tasks and new regulatory measures that are adapted at regular intervals in light of re-diagnosis of fishery health from simple performance indicators.

4.1. Governance

A broad, yet inconsistent, use of co-management was revealed across Pacific Island sea cucumber fisheries. The great variation in governance frameworks among the PICs can be attributed to a wide range of historical external factors [37]. Although co-management is considered the dominant approach to management in the small-scale fisheries sector [38], government-directed (national or provincial) management dominated in about half of the sea cucumber fisheries examined. Melanesian countries have typified case studies on small-scale fishery co-management [15,39–41], but the data show relatively infrequent use among management measures in most Melanesian sea cucumber fisheries. Co-management was not typical of any of the three large cultural regions (Melanesia, Micronesia, Polynesia).

Governance structure also varied considerably among various management measures within individual fisheries. This is logical, since certain management measures are best controlled solely by government institutions while others could be handled jointly by local-level institutions [1,16,42]. An important point with export commodities is that some regulations, such as species-specific bans or size limits, need to be controlled and standardised nationally. Community-based management in which communities are vested with all management authority would thus be problematic.

Governance hierarchies in PICs did not correspond neatly with the status of stocks among the fisheries. Fisheries managed solely by the national or provincial government institutions were not systematically over-exploited or depleted. However, of these top-down-governed fisheries with stocks in reasonable conditions, Palau and French Polynesia have had little commercial exploitation until very recently and there are few fishers in New Caledonia compared to the scale of fishing grounds [24]. This suggests that sustainability might occur in the absence of co-management where exploitation has not been prolonged or intense.

Implementation of effective co-management in Pacific Island fisheries is a major challenge due to transaction costs and the limited human resources to organise a large constituency. Additionally, many of these government institutions are undermined by poor conditions, low pay and limited career opportunities for fishery officers [43]. Future research could therefore explore efficient mechanisms for developing co-management of small-scale fisheries in PICs.

4.2. Management capacity

Throughout tropical countries, fisheries management institutions commonly lack skilled scientists and efficient data collection mechanisms needed for complex fisheries science [44]. In addition, the skill sets within management agencies can be critically imbalanced to deal with the variety of tasks required to manage these fisheries effectively and within an EAF. The two lessons are that regulatory measures must be simple and commensurate with available management capacity, and an EAF will require a more even spread of funds and resources among management tasks.

The frequent and strong capacity in PIC management institutions to plan and implement marine reserves mirrors a similar bias in external research and development towards the broad appeal of marine reserves [45]. Many PIC government management institutions also currently invest substantial resources into culture-based restocking as a fishery management tool [46]. Conversely, the often weak capacity for analysing data to assess stocks, identifying processed products in trade, and inspecting dried sea cucumbers destined for export leads to two poor outcomes. Firstly, management agencies may have data on stock abundance and exports but struggle to analyse exploitation trends and, second, export data are not validated rigorously for imposing export levies.
Table 3
Regulatory measures chosen for future implementation by the fishery managers for each of the 13 Pacific island fisheries. SS—small-scale; Ind—industrial-scale. M—moderately exploited; F—fully exploited; O—overfished; D—depleted.

| Country           | Fishery type | Stock status | Size limits | Gear restriction | Limit number of fishers | Limit boat size | Catch quotas | Exporters need licence and submit logbook | Fishers need licence and submit logbook |
|-------------------|--------------|--------------|-------------|------------------|-------------------------|-----------------|-------------|------------------------------------------|----------------------------------------|
| Papua New Guinea  | SS           | O            | ✓           | ✓                | ✓                       | ✓               | ✓           | ✓✓✓✓✓                                  | ✓✓✓✓                                  |
| Solomon Islands   | SS sector    | D            | ✓           | ✓                | ✓                       | ✓               | ✓           | ✓✓✓✓✓                                  | ✓✓✓✓                                  |
|                   | Ind sector   | ✓            |             |                  |                         |                 |             |                                         |                                        |
| Vanuatu           | SS           | F–O          | ✓           | ✓                | ✓                       | ✓               | ✓           | ✓✓✓✓✓                                  | ✓✓✓✓                                  |
| New Caledonia     | SS           | F            | ✓           | ✓                | ✓                       | ✓               | ✓           | ✓✓✓✓✓                                  | ✓✓✓✓                                  |
| Fiji              | Ind/SS       | O            | ✓           | ✓                | ✓                       | ✓               | ✓           | ✓✓✓✓✓                                  | ✓✓✓✓                                  |
| Palau             | SS           | M            | ✓           | ✓                | ✓                       | ✓               | ✓           | ✓✓✓✓✓                                  | ✓✓✓✓                                  |
| Marshall Islands  | SS           | F            | ✓           | ✓                | ✓                       | ✓               | ✓           | ✓✓✓✓✓                                  | ✓✓✓✓                                  |
| Kiribati          | SS           | D            | ✓           | ✓                | ✓                       | ✓               | ✓           | ✓✓✓✓✓                                  | ✓✓✓✓                                  |
| Tuvalu            | SS areas     | O            | ✓           | ✓                | ✓                       | ✓               | ✓           | ✓✓✓✓✓                                  | ✓✓✓✓                                  |
|                   | Ind areas    | ✓            |             |                  |                         |                 |             |                                         |                                        |
| Cook Islands      | SS           | M            | ✓           | ✓                | ✓                       | ✓               | ✓           | ✓✓✓✓✓                                  | ✓✓✓✓                                  |
| Tonga             | SS           | D            | ✓           | ✓                | ✓                       | ✓               | ✓           | ✓✓✓✓✓                                  | ✓✓✓✓                                  |
| Samoa             | SS           | M            | ✓           | ✓                | ✓                       | ✓               | ✓           | ✓✓✓✓✓                                  | ✓✓✓✓                                  |
| French Polynesia  | SS           | F–O          | ✓           | ✓                | ✓                       | ✓               | ✓           | ✓✓✓✓✓                                  | ✓✓✓✓                                  |
| Totals            |              |              |             |                  |                         |                 |             |                                         |                                        |

| Country           | Seasonal or short-term closures | Bans or moratoria | No-take reserves | Rotational harvest closures | Area and user access rights | Set a small list of permissible species | Closure-pulse fishing-closure | Total number |
|-------------------|---------------------------------|-------------------|------------------|------------------------------|-----------------------------|--------------------------------------|-----------------------------|--------------|
| Papua New Guinea  | ✓                               | ✓                 | ✓                | ✓                            | ✓                            | ✓                                   | ✓                           | 11           |
| Solomon Islands   | ✓                               | ✓                 | ✓                | ✓                            | ✓                            | ✓                                   | ✓                           | 8            |
| Vanuatu           |                                  | ✓                 | ✓                | ✓                            | ✓                            | ✓                                   |                             | 8            |
| New Caledonia     |                                  | ✓                 | ✓                | ✓                            | ✓                            | ✓                                   |                             | 9            |
| Fiji              |                                  | ✓                 | ✓                | ✓                            | ✓                            | ✓                                   |                             | 7            |
| Palau             |                                  | ✓                 | ✓                | ✓                            | ✓                            | ✓                                   |                             | 9            |
| Marshall Islands  |                                  | ✓                 | ✓                | ✓                            | ✓                            | ✓                                   |                             | 6            |
| Kiribati          |                                  |                   |                  |                              |                             |                                      |                             | 5            |
| Tuvalu            |                                  |                   |                  |                              |                             |                                      |                             | 4            |
| Cook Islands      |                                  |                   |                  |                              |                             |                                      |                             | 8            |
| Tonga             |                                  |                   |                  |                              |                             |                                      |                             | 7            |
| Samoa             |                                  |                   |                  |                              |                             |                                      |                             | 5            |
| French Polynesia  |                                  |                   |                  |                              |                             |                                      |                             | 10           |
| Totals            |                                  |                   |                  |                              |                             |                                      |                             | 51           |

a Needs to be species-specific quotas.
b Totals count only one for fisheries with split sectors of fishing areas.
Table 4
Management actions chosen by fishery managers for each of the 13 Pacific fisheries (ticks). Question marks denote management actions that the fishery manager will consider further. M = moderately exploited; F = fully exploited; O = overfished; D = depleted.

| Country         | Fishery type | Stock status | Overview of the harvested species | Fishery-independent stock surveys | Fishery-dependent stock surveys | Socio-economic surveys | Price monitoring | Support local-scale management |
|-----------------|--------------|--------------|-----------------------------------|----------------------------------|---------------------------------|------------------------|-----------------|-----------------------------|
| Papua New Guinea| SS           | O            | ✓                                 | ✓                                | ✓                               | ✓                      | ✓               | ✓                           |
| Solomon Islands | SS sector    | D            | ✓                                 | ✓                                | ✓                               | ✓                      | ✓               | ✓                           |
|                 | Ind sector   | ✓            | ✓                                 | ✓                                | ✓                               | ✓                      | ✓               |                             |
| Vanuatu         | SS           | F–O          | ✓                                 | ✓                                | ✓                               | ✓                      | ✓               | ✓                           |
| New Caledonia   | SS           | F            | ✓                                 | ✓                                | ✓                               | ✓                      | ✓               | ✓                           |
| Fiji            | Ind/SS       | O            | ✓                                 | ✓                                | ✓                               | ✓                      | ✓               | ✓                           |
| Palau           | SS           | M            | ✓                                 | ✓                                | ✓                               | ✓                      | ✓               | ✓                           |
| Marshall Islands| SS           | F            | ✓                                 | ✓                                | ✓                               | ✓                      | ✓               | ✓                           |
| Kiribati        | SS           | D            | ✓                                 | ✓                                | ✓                               | ✓                      | ✓               | ✓                           |
| Tuvalu          | SS areas     | O            | ✓                                 | ✓                                | ✓                               | ✓                      | ✓               |                             |
|                 | Ind areas    | O            | ✓                                 | ✓                                | ✓                               | ✓                      | ✓               |                             |
| Cook Islands    | SS           | M            | ✓                                 | ✓                                | ✓                               | ✓                      | ✓               |                             |
| Tonga           | SS           | D            | ✓                                 | ✓                                | ✓                               | ✓                      | ✓               |                             |
| Samoa           | SS           | M            | ✓                                 | ✓                                | ✓                               | ✓                      | ✓               |                             |
| French Polynesia| SS           | F–O          | ✓                                 | ✓                                | ✓                               | ✓                      | ✓               | ✓                           |
| Totals          |              |              |                                   |                                  |                                 |                        |                 |                             |

| Country         | Establish management advisory committees | Legislation of management regulations | Assign accountability | Enforcement | Education and communication with stakeholders | Improve quality of processing through training | Restocking | Supply-chain restrictions and auctioning | Total number |
|-----------------|-------------------------------------------|---------------------------------------|-----------------------|-------------|-----------------------------------------------|-----------------------------------------------|------------|------------------------------------------|--------------|
| Papua New Guinea| ✓                                         | ✓                                     | ✓                     | ✓           | ✓                                             | ✓                                             | ✓          | ✓                                        | 13           |
| Solomon Islands | ✓                                         | ✓                                     | ✓                     | ✓           | ✓                                             | ✓                                             | ✓          | ✓                                        | 7            |
| Vanuatu         | ✓                                         | ✓                                     | ✓                     | ✓           | ✓                                             | ✓                                             | ✓          | ✓                                        | 7            |
| New Caledonia   | ✓                                         | ✓                                     | ✓                     | ✓           | ✓                                             | ✓                                             | ✓          | ✓                                        | 11           |
| Fiji            | ✓                                         | ✓                                     | ✓                     | ✓           | ✓                                             | ✓                                             | ✓          | ✓                                        | 8            |
| Palau           | ✓                                         | ✓                                     | ✓                     | ✓           | ✓                                             | ✓                                             | ✓          | ✓                                        | 8            |
| Marshall Islands| ✓                                         | ✓                                     | ✓                     | ✓           | ✓                                             | ✓                                             | ✓          | ✓                                        | 9            |
| Kiribati        | ✓                                         | ✓                                     | ✓                     | ✓           | ✓                                             | ✓                                             | ✓          | ✓                                        | 7            |
| Tuvalu          | ✓                                         | ✓                                     | ✓                     | ✓           | ✓                                             | ✓                                             | ✓          | ✓                                        | 6            |
| Cook Islands    | ✓                                         | ✓                                     | ✓                     | ✓           | ✓                                             | ✓                                             | ✓          | ✓                                        | 10           |
| Tonga           | ✓                                         | ✓                                     | ✓                     | ✓           | ✓                                             | ✓                                             | ✓          | ✓                                        | 9            |
| Samoa           | ✓                                         | ✓                                     | ✓                     | ✓           | ✓                                             | ✓                                             | ✓          | ✓                                        | 12           |
| French Polynesia| ✓                                         | ✓                                     | ✓                     | ✓           | ✓                                             | ✓                                             | ✓          | ✓                                        | 9            |
| Totals          | 12                                        | 12                                    | 7                     | 11          | 9                                             | 7                                             | 2          | 1                                       |              |

* Totals count only one for fisheries with split sectors of fishing areas. Question marks are not counted.
Financial and human resources of PIC management agencies are very limiting [9] and long-term solutions to fisheries sustainability must arise from those finite resources. Redressing the inequalities in skill sets and weaknesses in management capacity will arguably require re-prioritisation of training needs within the management agencies and reprioritising of resources. In particular, some of the substantial resources often allocated to developing marine reserves and culture-based restocking could be allocated to more active communication with fishers and engaging stakeholders in the management process. Resources could also be shifted from costly inspections at sea and underwater visual censuses to more cost-effective inspections of dried sea cucumbers on land, which would yield valuable data for regular re-diagnosis of stocks.

4.3. Management objectives

The results show that the prioritisation of management objectives is fishery specific and/or manager specific. This is logical because the fisheries differ in the status of stocks and ecosystems, and some fisheries have been reserved for subsistence use. The top ranked objective reveals the perceived high importance of ecological resilience in the fisheries.

Setting objectives is an important step in the management process [11,21] but seldom articulated for small-scale fisheries in the Pacific. Preston [9] found that conflict between development objectives and EAF is the most common challenge for adopting EAF in Pacific Island fisheries. This may imply that management institutions must shift their conceptual focus from maximising profit and employment to a balance among yield, profit and ecosystem benefits while taking into account the needs of stakeholders [47]. The results also indicate that stock sustainability, environmental sustainability and socio-economic benefits are interrelated issues that cannot be easily separated in fisheries, especially in the context of an EAF. Managers should consider the ecosystem benefits of sea cucumbers, as they are known to contribute to nutrient recycling and ecosystem health on coral reefs [reviewed in [24,27]].

That most managers ranked the subsistence-use objective low corresponds with the notion that sea cucumbers are an occasional food source in Pacific Islands [25] and food security does not depend directly on sustainability of sea cucumber fisheries. However, these resources play an important role in fisher incomes and poverty reduction [25,48,49]. This can explain why economic objectives were ranked relatively high by most managers.

4.4. Diagnosis of stock status

Overall, there were few cases in which commercial sea cucumber fisheries were being well managed and the fisheries with relatively healthy stocks were ones with few commercial fishers or have been closed to export-oriented fishing. Many management agencies in PICs severely lack capacity for conventional stock assessments to estimate abundance and density of sea cucumber populations. This situation supports a modern realisation that the diagnosis should recognise opportunities and threats within the fishery using available science [12].

The managers used knowledge of the fishery in addition the six multi-disciplinary indicators to choose a rank of stock health. The fishery managers tended to diagnose their sea cucumber stocks in better health than a recent objective classification [24]. Based on recent population surveys showing sparse, or significantly impacted, stocks in six of the seven fisheries more-optimistically diagnosed fisheries [41,48,50–53], we argue that their diagnoses indicate a degree of optimistic bias. Indeed, such bias is common in other fisheries [54]. Thus, some objective measures of stock health (e.g. ratio of high value species in exports) should be used to moderate the subjectivity of fishery managers.

4.5. Regulatory measures for sustainability

Annual harvests of sea cucumbers have clearly been excessive in PICs using current, conventional, regulatory measures. Arguably, new management measures will be needed to turn the tide on over-exploitation. Simple sets of regulatory measures will be most easily implemented yet need to reduce annual captures and safeguard vulnerable species.

Management solutions need to be tailored to small-scale fisheries in light of diagnoses [12,55]. Fisheries in a depleted state may need some years of fishery moratorium to recover populations to productive levels [31,56,57]. Once stocks have recovered, a suite of regulatory measures will be needed to meet fisheries and conservation objectives [58].

The vast number of fishers [24] and lack of suitable frameworks of sea rights in many PICs [9] make rights-based approaches to fisheries [59–61] intangible in the short term. Rights-based incentives are arguably insufficient in small-scale fisheries where poor fishers have few livelihood alternatives [62]. Exceptions where this could be developed are where customary marine tenure is strong (e.g. Solomon Islands) or where de facto rights over fishing grounds are recognised (e.g. French Polynesia).

Gear restrictions and size limits were among the most commonly chosen regulatory measures and can be considered best practice [31,32] despite certain compliance issues. However, gear restrictions and minimum size limits will only partially reduce annual catches.

Total allowable catch (TAC) quotas are undermined in coastal Pacific fisheries by a number of critical constraints [32]. Further, this study shows that (1) technical capacity is lacking to be able to derive TAC quotas scientifically, and (2) institutional capacity and systems for collecting regular data on catches are lacking in almost all PICs to be able to enforce TAC regulations. Thus, total annual catch volumes could be considered as desirable targets but not as regulatory measures.

The most difficult problem of controlling and reducing fishing effort [54,60] must be tackled in sea cucumber fisheries. Reducing the number of fishers is currently intractable in most PICs owing to the large number of fishers and traditional rights to exploit a common resource. Therefore, PICs need to turn to alternative mechanisms to reduce fishing effort, such as short fishing seasons, e.g. a couple months each year. The short fishing seasons should be best chosen in consultation with fishers and exporters, which embodies EAF principles of stakeholder input [11]. Periodic closures of one or many years, as employed for other reef resources [63], would be problematic for the national trade and export networks in sea cucumber fisheries.

Managers must also safeguard viable breeding populations of all species and conserve species at risk of extirpation. This could be achieved through shortlists of allowable species [24,64]. Such shortlists should exclude a number of sea cucumber species that have recently been assessed as threatened with extinction [65]. This regulatory measure was attractive to many of the fishery managers despite being new and untested in sea cucumber fisheries.

4.6. Realigning management actions

Stakeholder involvement and enforcement in most PIC fisheries are relatively weak. Better integration of stakeholders with the management process should lead to better compliance and ease enforcement [12,66]. Small-scale fishery managers should create forums, such as Management Advisory Committees, where the
views of stakeholders can be represented [11,55]. Embracing an EAF in PICs will certainly require greater investment in engaging with the stakeholders and formally incorporating their views in the management process, from diagnosis to enforcement [11]. A better understanding of fishers’ views can come from interview-based socioeconomic surveys [48,67].

Enforcement of regulations is one of the biggest global challenges to fisheries [68] and often neglected [9,59]. Efforts to engage and empower communities in enforcement are likely to be well rewarded [59,69], especially in remote Pacific islands. Trade of dried sea cucumbers (beche-de-mer) is funnelled through usually less than a couple dozen exporters in each fishery, presenting cost-effective points for collecting fishery-dependent data and “choke-points” for compliance inspections. Although inspection officers are equipped to identify beche-de-mer [70,71], they need training to improve technical capacity in conducting inspections. Regular inspections of products prior to export will provide a means to apply correct export levies. Internalising monies from export levies into the fishery, to fund management, monitoring and enforcement [11,60], will be an important pillar in building a new management paradigm.

Management frameworks in PICs will need to plan for greater adaptability of regulatory measures and management actions. Management cycles in most PICs have been arguably too long for reviewing fishery performance and have not allowed for timely adaptation. Sea cucumber fisheries in many PICs have been heavily swayed by conflicting interests of decision makers. In this regard, reference points to measure the performance of regulations and decision-control rules [11,21] that assign pre-agreed adaptations of the management plan in the review stage could streamline the adaptive management process.

5. Conclusions

Pacific Island management institutions have severe constraints to deal with coastal fisheries. Scientists and development agencies need to support PICs through pragmatic advice on management actions and regulatory measures that are compatible with the institutional resources and capacity. Reconsideration of an EAF by managers in this study engendered a new paradigm, in which institutional resources are spread more evenly among management actions in an EAF and management institutions impose measures that result in more conservative exploitation.

Conventional management approaches and weak enforcement have arguably led to overfishing in half of the Pacific’s sea cucumber fisheries. The most important message for managers is that if radically different outcomes are desired, then radically different management measures are needed. Managers should consider regulatory measures that limit fishing effort and protect species at risk, and adapting these measures periodically in light of management performance. A new management paradigm must also involve new approaches to improve compliance and stakeholder involvement.

Lastly, these recommendations for Pacific Island sea cucumber fisheries are not given as a “miraculous prescription” [7] to remedy overfished stocks. Broader reforms that transcend reef fisheries are needed simultaneously, including improved governance systems [59,60], promotion of leadership and social capital in communities [72], preparedness for climate-change impacts [73], and embedding the fishery management solutions in broader challenges to provide livelihood options to fishers [6,62]. While efforts are made to address these overarching needs, management agencies must urgently tackle the immediate problem of excessive exploitation to safeguard sea cucumber populations for the future.

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