Sea Cucumber Aquaculture in the Western Indian Ocean: Challenges for Sustainable Livelihood and Stock Improvement

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Abstract The decline in sea cucumber fisheries that serve the Asian dried seafood market has prompted an increase in global sea cucumber aquaculture. The tropical sandfish (*Holothuria scabra*) has, in this context, been reared and produced with mixed success. In the Western Indian Ocean, villagers often participate in the export fishery for sea cucumbers as a source of income. However, with a growing concern of depleted stocks introduction of hatcheries to farm sandfish as a community livelihood and to replenish wild stocks is being promoted. This review identifies and discusses a number of aspects that constitute constraints or implications with regard to development of sandfish farming in the region. The conclusion is that for sandfish farming to live up to its expectations the possible impacts need to be further studied, and that improved evaluation of ongoing projects is required. In the interim, a precautionary approach toward new enterprise activities is suggested.

Keywords Sandfish · *Holothuria scabra* · Farming · Re-stocking · Environmental impacts · Governance

INTRODUCTION

The stagnating catches from our oceans cannot keep up with the seafood consumption of the world's growing population (Pauly et al. 2002). To some extent this growing demand has been met by the rapid development of the aquaculture sector that now provides half of all fish destined for human consumption (FAO 2010). Besides supplying people with nutritious foods aquaculture also generates jobs and income and its development has benefited from the domestication of new species (Duarte et al. 2009). The farming of sea cucumbers (Echinodermata: Holothuroidea) is an example of a relatively new aquaculture activity in the tropics that

provides high value products to the Asian dried seafood market. This article focuses on the farming of the tropical sea cucumber *Holothuria scabra* (common name: sandfish) in the Western Indian Ocean (WIO) and analyzes how farming fits with the ongoing sea cucumber fishery and in the broader coastal social-ecological setting. The title “sustainable livelihood and stock improvement” was chosen because these are often premises that are used to promote this activity. Consequently, the specific aim is to highlight ecological and social aspects that constitute constraints or implications for development of sandfish farming in the region. These aspects are discussed from a governance and sustainability perspective.

THE SEA CUCUMBER FISHERY

Collecting sea cucumbers for production of “bêche-de-mer” or “trepang” (the dried body wall) for export to the Asian dried seafood market has a long history in the productive waters of the central Indo-Pacific (MacKnight 1976; Preston 1993). This has provided an important source of income to communities in remote areas where alternatives are few (Purcell 2010). With reform of China's foreign trade policy and integration into the world economy during the 1980s, and an increasing demand for a wide range of species predominantly by medium income groups in China (Ferdouse 2004), the bêche-de-mer market grew during the latter part of the twentieth century (Kinch et al. 2008). Consequently, the contemporary bêche-de-mer fishery for Asian markets expanded rapidly and now occurs in all continents and includes both tropical and temperate water fisheries (Anderson et al. 2011). The high demand has put sea cucumber fisheries around the globe under stress and many fisheries have been closed because of overfishing (Purcell 2010).

Commercially valuable sea cucumbers are generally conspicuous in their environment making them easy to find and consequently vulnerable to extensive collection. Sea cucumbers are gonochoric broadcast spawners releasing their gametes into the water column for fertilization, often on an infrequent annual basis (Conand 1993). This reproductive strategy exposes them to the intuitive prediction that dilution of gametes in the water mass will restrict successful fertilization of eggs (Levitan and Petersen 1995). In addition, there is a further reduction in the success of reproduction when there are low densities of breeding adults in the environment (Petersen C. 2001; Bell et al. 2008). This is referred to as depensation, Allee effect or inverse density dependence (Myers et al. 1995). The density threshold, where a population is no longer viable because of heterogeneous distribution is known as the Allee effect threshold (Gascoine and Lipcius 2004). The disproportionate reduction in success of recruitment in diluted populations pinpoints the importance of maintaining a healthy spawning biomass in fisheries (Bell et al. 2008). Unfortunately, recovery of overfished stocks once fishing has ceased may take longer than anticipated, depending on Allee effects but also on variables about which there is limited knowledge (Friedman et al. 2011). Recent closures of productive Melanesian fisheries such as Papua New Guinea and Solomon Islands (Purcell 2010), that in modern times have provided a considerable part of the world catch, will presumably have market effects with increasing fishing effort in less controlled regions and also increased demand for farmed sea cucumbers.

The sea cucumber fishery to produce *bêche-de-mer* is common throughout the WIO (e.g., Comoros, Kenya, Madagascar, Mauritius, Mozambique, Seychelles, Tanzania, and Zanzibar, see Conand 2008), and is an important source of income to many coastal communities (Fig. 1) (Conand and Muthiga 2007; Eriksson et al. 2010; Ochiewo et al. 2010). The fishery in the WIO is multi-species, however, sandfish constitute an important part of the catch (e.g., Ochiewo et al. 2010). The fishery targets habitats in the entire seascape and fishing is carried out by men, women, and children. The demography reflects the method; women and children generally carry out near-shore gleaning, while men are often organized in boats to run breath-hold and scuba diving operations (e.g., Conand and Muthiga 2007; Eriksson et al. 2010). The positive socio-economic impact that the fishery has on communities is believed to be substantial (Marshall et al. 2001; Conand and Muthiga 2007; Ochiewo et al. 2010). For example, this is illustrated by the dependence on the fishery among communities in Zanzibar, where 24% of interviewed fishers said that they would struggle to find an alternative income source (Eriksson et al. 2010).

Many nations in the region are struggling to keep harvests within sustainable levels and there are reports of widespread overfishing and declining catches (e.g., Conand 2008; Eriksson et al. 2010). Current African *bêche-de-mer* production is estimated to have fallen by at least 70% from a peak in 1996 at 7113 tonnes to a stable 1000–2000 tonnes between 2003 and 2008 (Fig. 2) (FAO 2010). The WIO nations listed above have contributed to ca. 75% of the African catch over the past 10 years. Note that the data on exports from this region is unreliable and many countries are not reporting exports.

Recent studies on social and ecological elements of sea cucumber fishery in the WIO (see Conand et al. 2006) suggest that overfishing generally is a result of weak management, knowledge gaps about species ecology from which to formulate sound management, and the generally data poor situation (e.g., Conand and Muthiga 2007). Despite the contemporary fishery being active for nearly half a century, many nations still lack well formed policies or capacity to monitor and control (Muthiga et al. 2010) and many fisheries operate without effective management (Conand and Muthiga 2007; Conand 2008), sometimes in a clandestine manner (Eriksson et al. 2010). It is in the context of depleted fisheries, high export demand and weak governance that the development of sea cucumber aquaculture is gaining momentum in the region.

SEA CUCUMBER AQUACULTURE

Spawning and larval rearing methods for the temperate sea cucumber species *Apostichopus japonicus* were developed in pioneering research during the 1940s and 1950s, initiated in reaction to overexploitation of stocks of these sea cucumbers in Japanese waters (Imai and Inaba 1950). Mass production of viable juveniles has since been applied to coastal restocking and ranching projects in Japan since the 1980s (Ito and Kitamura 1997; Yanagisawa 1998) and this species is now extensively cultured in single species pond cultures in the People's Republic of China (Chang and Yu 2004; Chen 2004). This led to a rapid increase in world production of *A. japonicus* in the twenty-first century (Fig. 3) with current production levels in excess of 90 000 tonnes (FAO 2010).

The methods developed for *A. japonicus* culture are apparently effective with only small adjustments for culture efforts of sandfish and other species (James 1994; Battaglene and Bell 2004; Pitt and Duy 2004; Battaglene et al. 2002; Asha and Muthiah 2005; Agudo 2006; Stenton-Dozey and Heath 2009). Currently, sandfish and *A. japonicus* are the only hatchery-reared sea cucumber species produced at commercial scales (Lovatelli et al. 2004), and currently only a few other species appear suited for

Fig. 1 Images from the sea cucumber fishery in the WIO: **a** diving fishers catch (*Actinopyga miliaris*, *Holothuria fuscogilva*, *H. fuscopunctata*, *Thelenota ananas*, *T. anax*) in Zanzibar, **b** woman

processing catch in Madagascar, **c** boiled sandfish (*H. scabra*) in Zanzibar. Photos **a** and **b** Hampus Eriksson, photo **c** Garth Cripps

large-scale production (e.g., Battaglene et al. 2002; Asha and Muthiah 2005). Sandfish have attributes that appears to be particularly suited to farming as they have a high commercial value, feed low in the food chain and occur naturally in dense populations in many tropical coastal waters (Hamel et al. 2001). Farming sandfish requires lagoon areas for ranching or grow-out in sea pens, which both offer a potential alternative economic activity for coastal communities and may also provide a base for replenishing depleted sandfish stocks (Bell et al. 2008). For example, a community-based farming project using hatchery-reared sandfish is currently in place in Madagascar with the purpose of providing a livelihood alternative

and establishing a trade company centered on sandfish aquaculture (Eeckhaut et al. 2008; Robinson and Pascal 2009). This is currently the only active enterprise in the region. However, many other areas are being assessed for their potential. For example, a project similar to that in Madagascar is also developing in Tanzania.

CONSTRAINTS TO OR IMPLICATIONS OF SANDFISH FARMING

Aquaculture must fit into the broader social-ecological context to avoid jeopardizing ecosystem resilience or

Fig. 2 African production of bêche-de-mer from capture fishing (source FAO 2010, wet weight)

Fig. 3 World aquaculture production of bêche-de-mer from *A. japonicus* (source FAO 2010, wet weight)

compromising community benefits and to ensure optimal chances of success (FAO 2006). Indeed, one of the main challenges for any type of aquaculture is to minimize negative effects on the natural environment—i.e., on natural processes, natural productivity and biodiversity (Troell 2009). In this context, despite the apparent positive ecological predisposition of sandfish to sustainable aquaculture practices, there is a need for improved understanding about many different aspects ranging from biological to broader governance issues (Table 1). These aspects can constitute either constraints or implications, but must be recognized and addressed through research and open dialog so that farming can develop in a sustainable manner.

Genetic Risk

Sandfish populations exhibit restricted ranges of genetic dispersal, suggesting that they develop local metapopulations with a strong genetic integrity (Uthicke and Purcell

2004). Introduction of new animals may compromise that integrity, particularly with large-scale translocations. There are already examples of translocations of sandfish, for example from India to atolls in the Maldives where sandfish was not native (Bruckner 2004). The effect of such relatively large-scale translocations is unknown and there is little genetic baseline information available.

Also related to genetic risk is inbreeding. Hatchery enterprises in areas where stocks are depleted run the risk of using few animals, or offspring, as broodstock because of the difficulty in sourcing sufficient number of mature animals. Hatchery managers should, in those instances, adhere to applicable broodstock protocols that prevent inbreeding and genetic homogenization (e.g., Blankenship and Leber 1995). Although measures to conserve genetic diversity of sandfish stocks were advocated by Battaglene and Bell (2004), in the current situation of overexploited sandfish stocks, where the aim is to restore breeding populations, either through release of hatchery-reared juveniles or by grouping remaining adults into no-take zones (Bell et al. 2008), genetic integrity may be compromised. This unfortunate situation, resulting from overfishing, presents a challenging task to managers and enterprises wanting to improve the circumstances for the fishery. With the current level of knowledge there are no clear directions for how to navigate decision-making to minimize genetic impacts while trying to replenish sandfish stocks that might otherwise remain at low densities because of the Allee effect limiting supply of recruits. Therefore, we argue that new research on these issues is needed, and promote a responsible approach as suggested by Lorenzen et al. (2010), considering the practicalities of the situation.

Pathogens and Disease

Very little is known about pathogens and disease among wild populations of sea cucumbers, including sandfish. Dense populations of farmed sandfish contract diseases at various levels of the life-history (Eeckhaut et al. 2004; Chen 2004; Lavitra et al. 2009) and introduced or translocated animals may bring foreign pathogens with them. In addition, high-density groups and hatchery production of juveniles over extended periods of time significantly increase the likelihood of disease outbreaks, which may have deleterious effects on associated wild populations (as in abalone; Bower 2000). When pathogens appear in hatcheries and grow out ponds, chemotherapeutics such as antibiotics can be used (Agudo 2006), which has effects on people and wild organisms (Cabello 2006). Prevalence of pathogens and diseases in hatchery facilities with sandfish is known to frequently occur (Eeckhaut et al. 2004) and is of particular concern as grow out farming takes place in high densities within the natural

Table 1 Potential constraints/implications and actions needed to improve scope for sustainable sandfish farming

Aspect	Constraints/implications	Actions needed
Genetic risk	Translocation and artificial breeding programmes of animals constitute genetic risk to natural populations	Inform managers, decision makers, and practitioners of the risks Follow developed breeding guidelines (e.g., Blankenship and Leber 1995) Apply a precautionary approach
Pathogens and disease	Transported animals may bring with them pathogens and diseases that can compromise wild stock. Dense populations in nursing or grow out areas may propagate the establishment of deleterious disease	Research on pathogens and parasites (ciliates, blood worms, bacteria) Research on treatment and handling of medicines Apply benchmarking approach against developed standards for other species
Physical habitat alteration	Alteration or destruction of natural environments to accommodate suitable grow out areas for adult sandfish may have negative impacts on ecosystem resilience and productivity	Research on ecological patterns and processes in grow out lagoons Research on sustainable practices in the grow out phase Apply a precautionary approach
Benthic community effects	New dense sandfish populations in lagoons may have negative impacts on the resident benthic community and biodiversity through competition for space and resources	Research on ecological patterns and processes in ranching/grow out lagoons Conduct baseline biodiversity studies Apply a precautionary approach
Effects of intensified production	Intensified production can have potential negative impacts, which means an increased responsibility of enterprises to assure sustainable practices and resource use.	Development of a code of conduct on development of sandfish enterprises LCA of sandfish farming Research on feed and nutrition
Sandfish taxonomic uncertainty	Knowledge gap regarding variation in biological aspects due to vicariance and taxonomic uncertainty	Resolving the taxonomy of the <i>H. scabra</i> species complex
Governance and effect on fishery	A farming enterprise may undermine the ability to manage the fishery, therefore the farming must fit into the context of the fishery and the social-ecological system	Research on governance and management of the sea cucumber fishery and how farming can be used as a tool in the context of managing the fishery If fishery is depleted and governance weak then a management reform is needed before farming is introduced
Community involvement and theft	A major uncertainty in a farming enterprise is the issues of social equity and governance. If the governance of the fishery is weak then it is likely that the farming enterprise will suffer the same fate as the fishery, unless adjusted before/in conjunction with a new farming enterprise	Apply a social-ecological systems approach to research and enterprises Inform communities and other stakeholders Learn from implementations of MPAs Improved governance needed
Big promises	Sandfish farming is currently being promoted with inflated promises potentially leading nations and communities into unnecessary risk that might undermine the activity's credibility	Share experiences and evaluate success of previous enterprises Balance expectations

environment. In the absence of developed protocols for responsible sandfish farming, operators and legislators can benchmark against standards developed for other aquaculture organisms. For example, the requirement of systematic inspection of animals and equipment to detect early signs of pathogens or disease, issuing health certificates and applying quarantine measures for movement of animals, effective procedures to isolate potentially

contaminated animals or equipment, minimizing exposure to disease vectors, and prohibition of antibiotics for prophylactic use, as outlined in the dialogue standards for abalone (WWF 2010) and by the World Organization for Animal Health (www.oie.int). As experience has shown there is every reason to apply precaution to avoid detrimental effects and undesirable boom and bust production (e.g., Primavera 1991; Kautsky et al. 2000).

Physical Habitat Alteration

For animals to reach a marketable size, relatively large and productive lagoon environments are needed for ranching or pens. There are numerous examples from introduction of other aquaculture species resulting in destruction of natural habitat with consequent loss of ecosystem services and productivity (Naylor et al. 2000; Huitric et al. 2002). For sandfish farming, construction of grow out areas have been practiced at various scales from creation of smaller pens to larger lagoon enclosures. Physical alteration of the habitat can be substantial through sediment ploughing and removal of sediment surface layer (Tsiresy et al. 2011). Although potentially beneficial for sandfish growth this type of physical alteration of benthic substrate may have unwanted ecological consequences as seen in seaweed farming (Eklöf et al. 2005). Previous research has shown that stocking density and the carrying capacity of the habitat affect growth rates (e.g., Agudo 2006). Thus, to maintain adequate production levels and long-term use of farming sites these may require sediment re-working, enrichment or fallow periods (Pascal and Robinson 2011). Interestingly, there seems to be a trade-off between the grow-out period and the target harvest size, as farmed animals tend to have thinner body walls, which result in lower yields and reduced profitability (Personal comment, Natacha Agudo, WorldFish Centre, New Caledonia), which highlights that fast growth may actually be undesirable. Therefore, research on the feeding, growth processes, and age at harvest to support production of premium products, and their potential environmental consequences, is required.

Sandfish are suitable for farming in ponds (Pitt and Duy 2004; Agudo 2006), but it is too early in the development of sandfish aquaculture in the WIO to judge whether this will be the way the industry develops. However, considering that the vast majority of commercial culture of temperate sea cucumbers is pond-based (Chen 2004), it cannot be ruled out. Unfortunately, co-culture of sandfish with shrimp in ponds has so far not proven successful (e.g., Bell et al. 2007), however, sandfish are an ideal candidate species for integrated multi-trophic aquaculture (IMTA) (e.g., Troell 2009) or culture in rotational pond systems. If abandoned or unused fish or shrimp ponds initially are used for pilot and small-scale sea cucumber farming the direct environmental damage will be low. However, if successful then demand for land to construct new ponds may increase. In which case there are undoubtedly lessons to be learned from experiences with shrimp farming (e.g., Bryceson 2002).

Benthic Community Effect

Deposit feeding sea cucumbers are major components of tropical coastal ecosystems, where they increase the

structural complexity of the sediment habitat and facilitate benthic nutrient cycling through feeding and digestion of organic material (Uthicke 2001). Recent research has also indicated that the presence of sandfish may be positive for seagrass productivity (Wolkenhauer et al. 2010). However, presence of large-scale grow out enterprises in lagoons may, depending on the level of mechanical substrate alteration, stocking densities and feeding, result in displacement or alteration of benthic community structure, direct competition for habitat and reduced biodiversity.

Predators constitute one of the main risks to be considered for sea cucumber aquaculture using pens (Lavitra et al. 2009). High levels of mortality have been experienced at some farming sites in Madagascar which has led to the development of a range of predator control techniques including pro-actively exterminating crabs before stocking and deploying baited traps around pens (Pascal and Robinson 2011). Such activities, particularly as farming area increases, may potentially impact the benthic faunal structure associated with adjacent seagrass beds. Due to the limited experience from farming so far there are no studies of benthic community effects of sandfish farming available. However, as noted in seaweed farming (e.g., Eklöf et al. 2005), which was initially promoted with minimal environmental concern, some impact is probable with competition for space and resources.

Effects of Intensified Production

In most aquaculture practices the critical inputs to production are natural resources (i.e., feed, seed, etc.) (Kautsky et al. 2001). When farming practices move from extensive to intensive techniques, which is a plausible scenario for sandfish farming in the WIO given the level of interest shown in this activity, the dependence on such resources increases. Under “Physical Habitat Alteration” section, we mentioned that increasing resource input through sediment manipulation may be a beneficial common practice as a tool to improve nutrient uptake in the farming system, the effects of which are unknown. But input resources are also needed in the processing stage of a farm. For example, traditional processing techniques for sea cucumbers require large quantities of firewood to boil the kettles, and to smoke dry the products (Fig. 4). Preston (1993) estimated that 10 tonnes of firewood is needed to produce 1 tonne of *bêche-de-mer*. Intensifying sandfish farming may increase the use of firewood and lead to deforestation and associated erosion, particularly in atoll systems, where firewood is scarce. This is a notable problem in Papua New Guinea (Kinch 2002). This clearly illustrates the need for a broader systems perspective to identify any environmental and social-economic impacts. Recently, life cycle analysis (LCA) has been successfully

Fig. 4 Deforestation is a pressing issue as large quantities of firewood are needed to process the sea cucumbers. **a** Mangrove firewood for sale on the roadside in Daru Island, Papua New Guinea, the mangrove wood is cut from nearby Bristow Island causing notable

deforestation (Photo and personal comment: Jeff Kinch), **b** processor in Zanzibar that uses mangrove wood to boil sea cucumbers (Photo: Hampus Eriksson)

Fig. 5 Photos **a**, **b**, and **c** sandfish from New Caledonia in the South Pacific (Photos: Steve Purcell). Photo **d** sandfish from Mayotte in the WIO, photos **e** and **f** sandfish from Zanzibar also in the WIO (Photos:

Hampus Eriksson). These varieties are probably a species complex under the taxon *Holothuria scabra* (see Massin et al. 2009)

applied to various aquaculture systems (Henriksson et al. 2011) and this methodology may also be appropriate for identifying and quantifying impacts from intensified production of sandfish.

Sandfish Taxonomic Uncertainty

It is uncertain to what extent biological aspects are affected by the range of sandfish varieties or locations. Here, it is

important to note that the nominal taxon *H. scabra* belongs to a species complex (Massin et al. 2009), and like established vicariance in other known sea cucumber species complexes (e.g., Uthicke et al. 2004) the WIO sandfish may require recognition as a separate species. Sandfish in the WIO generally seem thinner in body wall and react differently when handled compared to those in the Pacific; the WIO specimens often elongate and soften rather than contracting or retaining their shape (Fig. 5). The recovery

rate (dry to wet weight ratio) for WIO sandfish has not been studied. This situation may limit the scope for producing premium products from sandfish farmed in the WIO and hence limit profit potential. If this is the case, it can also provide an incentive for translocation or introduction of a more commercially “desirable” variety. Research is urgently needed to resolve the taxonomy of the WIO sandfish species.

Governance and Effect on Fishery

Paradoxically, economic activities that are aimed at relieving pressure on fish stocks can provide profits that are used for further investment in fishing. An example of this is seaweed farming in the central Indo-Pacific (Sievanen et al. 2005). In the WIO the sea cucumber fishery networks appear strongly established and introduction of farming without including participants from those networks seems unlikely. In this sense, sea cucumber fishermen in Zanzibar argue that the lack of capital to invest is a major bottleneck in the performance of the sea cucumber fishery (Eriksson et al. 2010). It therefore seems likely that profits from farming in some cases will contribute to further depletion of an already impoverished fishery. Future research should address how farming can be used as a tool in managing the fishery.

Despite the emergence of new and pragmatic research regarding management of the sea cucumber fishery in the tropics (e.g., Friedman et al. 2008; Purcell 2010) there are few success stories. With the limited capacity to monitor (e.g., Muthiga et al. 2010) and by simple physical observation unequivocally distinguish farmed sandfish from wild (Purcell et al. 2006), an aquaculture export enterprise may undermine a strict management protocol, or even a fisheries closure, as illegal catch may be included in legal aquaculture exports. The Zanzibar fishery for sea cucumbers, for example, provides an accessible legal market for sea cucumbers illegally sourced from mainland Tanzania, rendering the ban in Tanzania ostensibly ineffective to all fishers capable of crossing the Zanzibar channel. This exemplifies that nations with a legal export channel for farmed sandfish products run the risk of undermining efforts of management for long-term sustainability of the wild fishery and would require strong control to prevent such a scenario.

Community Involvement and Theft

Related to governance issues mentioned above (“[Governance and Effect on Fishery](#)” section) is the structure for social equity in an enterprise. In sea cucumber fisheries it is common that agents undertake processing centrally to capture value addition along the chain (Friedman et al.

2008). Given the high cost of producing hatchery-reared juveniles and the need for rigorous quality control during processing, there may be a tendency or need for sea cucumber aquaculture to follow the same route. If the objective of sea cucumber farming is to improve village economies, create income alternatives and relieve pressure on stocks, then every effort should be made to ensure that communities are not marginalized in the enterprise. Communities that are empowered to maintain collective ownership of their coastal resources and have strong governance structures are less likely to lose access to larger interests associated with large-scale intensive aquaculture. In addition, the potential loss of fishing grounds with creation of grow out areas and designated to-take zones in favor of farms within lagoon habitats, may trigger competition for space and user conflicts. Setting aside areas for farms is similar to the practice of creating marine protected areas (MPAs). We argue that the principle lesson to be learned from experience with designing MPAs in the East African region, and to be applied into designing grow out areas, is that an integrated, participatory approach and good governance is likely to build a higher level of support and trust (Francis et al. 2002). Theft of farmed sandfish from ranching areas or pens is, in this context, a pressing concern relating to the governance of the operation and indicates the importance of good governance in partnerships between communities and hatchery operators. However, even if such partnerships are established theft may still be problematic. For example, in Madagascar almost 3000 market-sized sea cucumbers (9% of the total stock) were stolen from enclosures in five villages, despite the formation of village by-laws, creation of reserves and surveillance (Robinson and Pascal 2009). It is probable that if weak governance has led to questionable performance and depletion of the fishery then farming may follow the same route.

Big Promises

Inflated promises when promoting sea cucumber farming have been identified as a major concern by leading sea cucumber scientists having insight into farming (Eriksson 2009), and Pacific Islands fishery agencies are recommended to exercise caution when assessing proposals of sea cucumber farming given a history of dishonest entrepreneurs in the region (SPC 2009). In Vanuatu for example, a community that had protected their sea cucumber stock were led to believe that their lagoons would have to be cleared of all sea cucumber so that hatchery cultured juveniles of “exotic” sandfish, introduced to the lagoon by an overseas company, would grow and provide better profits. The company harvested and exported all the wild stock while the introduced animals were haphazardly

released—most disappearing and leaving the community without profits or sea cucumbers (Personal comment, Kalo Pakoa, Coastal Fisheries Science and Management Section, SPC, New Caledonia). In such situations, where investors present inflated promises, the need for informed and credible governance is critically important.

Promotion of sandfish farming in general is often based on limited biological knowledge of existing stocks, limited habitat/community awareness in areas of proposed development and limited experience of grow-out and production. Issues that prevent farming, at least in the short term, from living up to its potential include those related to governance (e.g., poaching, social equity), hatchery knowledge gaps (e.g., diseases), vulnerability to unforeseen events (e.g., weather, infrastructure problems), and questionable profitability (few animals reaching premium size and quality). If farming is being promoted without acknowledging these issues, it may lead nations and communities into unnecessary risk and undermine the reputation of the activity for the day when it can live up to it.

DISCUSSION

Contextualizing Constraints and Implications

Although hatcheries have been developed and used with various degree of success over the past ca. 20 years (James 1994), it can be argued that the tropical sea cucumber industry is still in the early stages of commercial development. Nonetheless, there is potential to successfully implement sea cucumber farming as a livelihood option in tropical coastal settings. In this context, we find it crucial that local communities and managers are aware of the uncertainties associated with the full production cycle from hatchery to export-ready product, and that running a hatchery is costly and profitability is uncertain (Hair et al. 2011). With this knowledge there is opportunity to form policy, to inform potential stakeholders and thereby prevent inflated promises.

When developing aquaculture it is critical to enforce sound policies to protect coastal areas from environmental degradation, respect expectations and societal requirements, and to protect the rights of coastal communities (FAO 2006). To what extent this is achievable in potential sandfish farming areas remains unclear. For example, the contemporary sea cucumber fishery that has been operating in parts of the WIO for nearly half a century is insufficiently managed and often lacks policy framework (Eriksson et al. 2010; Muthiga et al. 2010). The current review identifies that there is a need for further research, precautionary measures, and appropriate contingency plans regarding the expanding sandfish aquaculture sector in the

WIO. Before improved understanding about population genetics and dispersal is obtained we suggest a complete ban on translocation of animals between countries in the region. In hatchery operations we also see a need to develop sandfish broodstock management protocols and local sourcing regulations to avoid genetic homogenization through repeated use of the same broodstock or inbreeding, although we acknowledge that guidelines are difficult to navigate when stocks are severely depleted. In particular, we emphasize that the lack of research and experience regarding effects on physical habitat, benthic communities, and existing ecosystem services, supports our argument to advocate a responsible approach as outlined in general terms by Lorenzen et al. (2010). In the interim, we suggest that learning from the experiences of other species aquaculture (e.g., Bryceson 2002; Huitric et al. 2002; Eklöf et al. 2005; Henriksson et al. 2011) can support decision-making for future successful sandfish enterprises. For example, we recommend that it be a requirement to operationalize hatchery measures that can be benchmarked from established aquaculture species (e.g., abalone WWF 2010), to prevent disease outbreaks that can potentially spread to wild populations. Finally, we insist on the importance of taxonomic clarity regarding potential *H. scabra* varieties and also call for research that operates in the social-ecological interface and incorporates the already active fishery in the context of farming as a livelihood activity and as a tool for fishery management and stock restoration.

Farming as a Community Activity

The success of fisheries management being reflected in fishers conduct can be attributed to the process of decision-making, where regulative institutions and decisions that take shape rapidly have little scope for success unless hinged on cultural-cognitive institutions (de la Torre-Castro and Lindström 2010). Rather, cooperation and inclusion of social institutions in the decision-making process suggest an increased likelihood of success. Similarly to MPAs, grow out of sandfish in nearshore lagoon areas that are important fishing grounds for communities stands a better chance of success if all resource users/stakeholders are consulted. The inclusion of communities in the development and decision-making is therefore crucial for spreading stake and responsibility ensuring that sound management of grow out areas prevail, thereby minimizing risk of poaching and illegal activity, and ensuring that communities collect revenue from farming. Given that private companies, compared to individual families or communities, are usually better able to cope with and recover from external disturbances or failures in production and macroeconomic changes, untested aquaculture

activities should not be promoted to local people and the risks, at least during livelihood establishment, should be borne by the investors. In addition, perhaps business models where communities are employed should be given consideration, as this may be advantageous for both communities (e.g., no investment, regular salary, social security) and the company (e.g., improved supervision and quality control). Because coastal communities in the WIO region depend heavily on coastal ecosystem services for subsistence and income, it is critical to improve understanding of how introduction of sea cucumber farming will impact on continuous provision of these services. Thus, without this knowledge, introduction of sea cucumber farming as a livelihood activity may, contrary to the objective to improve resilience of coastal communities (e.g., FAO 2006), actually lead to the opposite.

Can Farms Substitute Fishing and Replenish Stocks?

Increased aquaculture production can potentially lower market prices thereby decrease the profitability of fishing and reducing investments in gear and effort (Naylor et al. 2000). In the case of sandfish this is an unlikely scenario because of two main reasons. First, the *bêche-de-mer* market is “unsaturated” (Purcell 2010), with new markets emerging globally where consuming communities reside. With a high demand and over-exploited fisheries, farmed sandfish products are unlikely to flood the market or decrease price of products. Rather, the product may to some extent “fill the gap” of the depleted wild fisheries. Second, most areas where sandfish could be farmed are in less developed countries in the tropics, where poverty is high and alternative sources of income are few (Bell et al. 2008), thus it is unlikely that production of sandfish will rise rapidly as it did for *A. japonicus* in more developed nations. Fishing is therefore likely to continue regardless of increased farming activities.

Modern aquaculture technologies cannot replace good governance in the sea cucumber fishery. For successful re-stocking or restoration of wild stocks, a sound understanding of the fishery and associated management to mitigate the cause of overfishing is a pre-cursor. For sandfish, assigning no-take zones for re-stocking is a plausible scenario for replenishing depleted stocks (Bell et al. 2008). It is however important to note that there is a knowledge gap regarding dispersal from source populations of commercial invertebrates, thresholds for depensation for tropical sea cucumbers (Friedman et al. 2011) and also that research this far has not sufficiently taken into account the effects of farming on genetic integrity. In addition, the lack of capacity for effective management for the wild fishery in many places in the WIO region

(e.g., Eriksson et al. 2010; Muthiga et al. 2010) needs to be addressed before re-stocking or replenishment can be expected. Bearing in mind that there are at least 30 species in the wild fishery it is unreasonable to expect that they can all be produced in hatchery for re-stocking depleted populations, or indeed that it would be economically feasible. Therefore, until these aspects are better researched we predict that farming is unlikely to substitute fishing or alleviate pressure on stocks.

CONCLUSIONS

The potential for sustainable, profitable, and socially equitable sandfish farming in the WIO region is limited by a range of aspects, for which there is currently limited understanding. This article outlines the constraints and implications of these aspects and concludes that they must be acknowledged as currently inhibiting the sustainable development of sandfish farming and therefore prioritized for future research. Until critical evaluation of existing farming enterprises has been conducted we recommend a precautionary approach to sea cucumber aquaculture in the WIO region. If the challenges of governance and ecological knowledge gaps can be overcome through reform and research there is scope for successful farming for both livelihoods and replenishment of wild stocks—as an integrated tool to manage the wild fishery. To meet the challenges there is a need to share experiences across regions and to facilitate learning so that best practices are disseminated and mistakes are not repeated.

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